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WILDLIFE RESOURCES DEPARTMENT

MARINE RESOURCES DIVISION
Charleston, South Carolina

FLUCTUATIONS IN ABUNDANCE OF THE BLUE CRAB AND FACTORS AFFECTING MORTALITIES

Technical Report 1

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Michael D. McKenzie

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C O N T E N T S

A B S T R A C T

A review of the blue crab fishery is presented with emphasis on fluctuations as related to natural and economic tensions. Data on the occurrence and abundance of pesticides, parasites and diseases in local crab populations are summarized. DDT, DDD and DDE were detected in 100 percent of the crab samples at average concentrations of .084 ppm. Mirex and Dieldrin were found in 44 and 28 percent of the samples at .09 and .009 ppm, respectively. The "gray crab" disease organism Paramoeba perniciosa was not detected during this survey period and no associated mortalities were reported.

Laboratory studies defined the upper and lower thermal tolerance limits for blue crabs at various test salinities; crabs were less tolerant at low salinities and high temperatures and high salinities at low temperatures. DDT and Toxaphene were more toxic to blue crabs at lowered salinities. Technical Mirex was comparatively non-toxic to adult and sub-adult crabs at all combinations.

DDT and Toxaphene became more toxic as temperatures ranged above and below 15° C within each test salinity; toxicity was slightly higher at lower thermal extremities. Toxicity of technical Mirex was more evident at higher temperatures in all test salinities. Mirex granulated bait exhibited delayed toxic effects on juvenile blue crabs (less than 3" width) exposed to concentrations of .036 g/l. Toxicity of this bait formulation appears to be dependent on availability of the bait to hungry crabs, size of the exposed crabs and season of application or exposure.

Adult blue crabs were slightly more tolerant of acid water than of alkaline water with a positive zone of tolerance between pH units of 4.0-8.5.

I N T R O D U C T I O N

Fluctuations in abundance of the blue crab, Callinectes sapidus Rathbun, have been historical but yet unexplained along the eastern seaboard. Recently, these variations have been pronounced in the South Atlantic states where volumetric declines have been reflected in the economic stability of the crabbing industry. South Carolina's commercial fishermen witnessed a production decline of some 40 percent or 5.6 million pounds over a five-year period (1964-68) with massive blue crab mortalities occurring intermittently during this time.

Knowledge concerning this phenomenon has not been commensurate with its economic significance and inquiries into the inherent qualities of this negative trend have multiplied. Recurrent seasonal mortalities in 1966, 1967 and 1968 assimilated with an acute shortage of marketable blue crabs precipitated a series of biological conferences between the affected states and cooperating federal agencies. These sessions resulted in a cooperative research program between the South Atlantic states, with federal financing at the 100 percent level by the U. S. Department of the Interior, Bureau of Commercial Fisheries.

The basic aim of this study was to establish a reference line of information concerning factors affecting the

abundance of marketable crabs and to define the possible cause(s) of blue crab mortalities relative to environmental variables, parasites, diseases and pesticides. This report presents data obtained in conjunction with South Carolina's contribution to the cooperative study during January 1968 - March 1970.

L I F E H I S T O R Y

Blue crabs seldom survive longer than two or perhaps two and a half years. Under these circumstances no marketable reserves can accumulate and the success of commercial fishing is sensitive to variations in the success of spawning. The life history of the blue crab in South Carolina is illustrated in Figure 1 which was modified from Pearson (1948).

Early development occurs in the ocean between April and October with spawning reaching a peak in July-August. The young progress through a number of larval forms before appearing crab-like. Postlarval crabs migrate into the brackish water areas and hibernate through the winter. In the spring, movements resume and growth rates increase rapidly until the crab is mature in late summer or early fall. Mating takes place in the brackish waters and females migrate toward the ocean while the males remain in low salinity areas. Females are fertilized during their last molt with first spawning usually occurring in the third spring or summer or a year after mating when the crab is approximately 2 years old. Fischler and Walburg

(1962) concluded that blue crabs in South Carolina limit their migrations between the lower estuaries and adjacent coastal waters. Therefore, each estuarine system probably has an indigenous population with little or no intermingling among coastal regions.

REVIEW OF THE FISHERY

Essentially, the blue crab population is composed of immature crabs less than a year old and mature crabs one or two years of age. The new generation of year-class crabs constitutes the bulk of production during the subsequent summer and fall fisheries. Therefore, a reliable measure of this year-class population provides an index to the relative strength of adult stocks.

Relative abundance data, as derived from experimental trawling at regular monthly sampling stations, is presented in Table 1 with other statistical expansions of the fishery. As shown, the natural abundance of mature and immature blue crabs progressively decreased from 33.3 to 7.2 crabs per unit of fishing effort during 1962-68. It is interesting to note that following the lowest year on record, the 1969 abundance increased sharply to a record high. Although these experimental abundance figures generally parallel with the total annual production, there is not a valid relationship since commercial fishing is so economically influenced. As the availability of marketable crabs decreases, the amount of fishing effort increases and, consequently, the over-all fishing effectiveness becomes less.

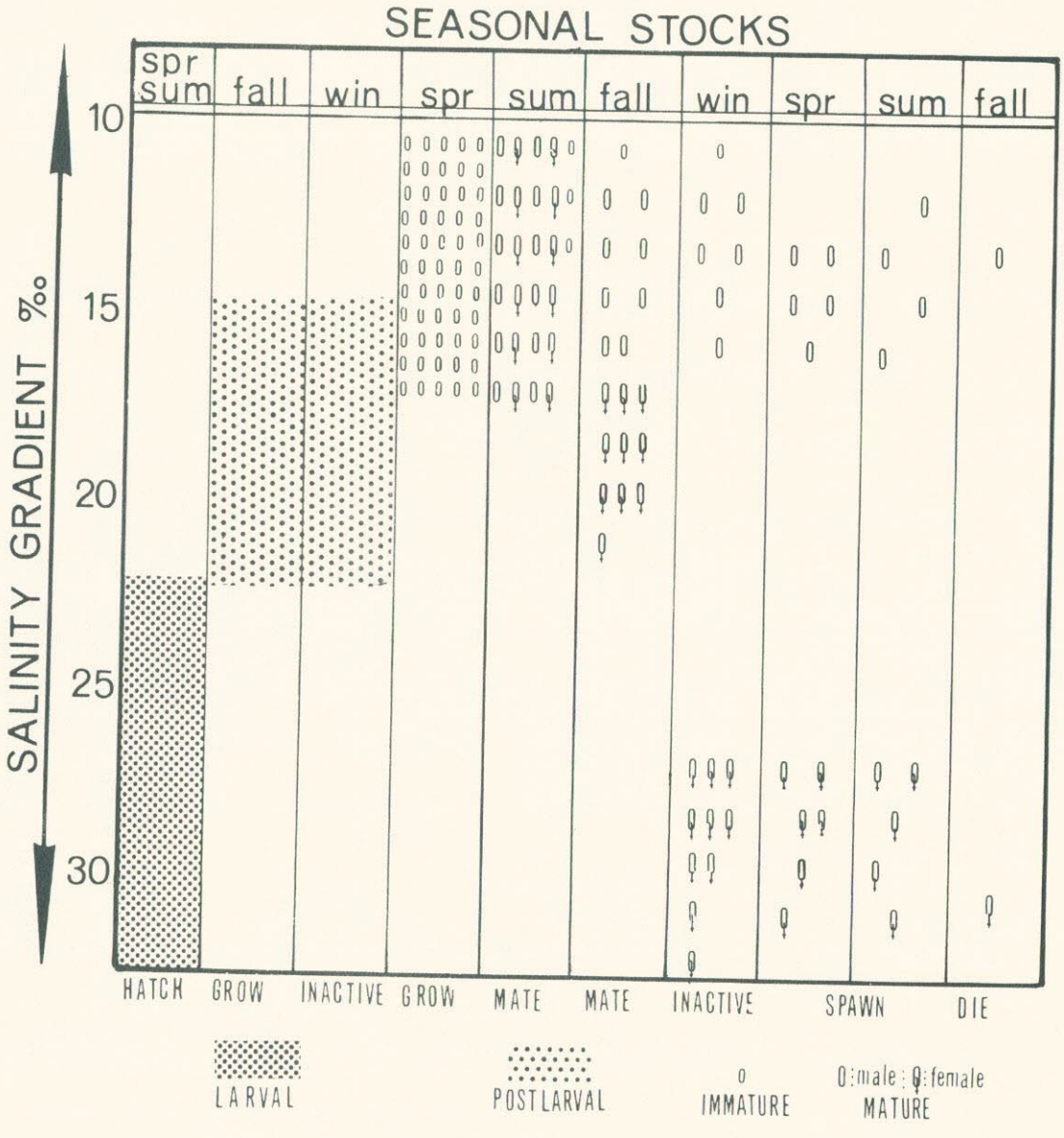

Figure 1.-Life cycle of a Brood of blue crabs in South Carolina coastal waters.

The total number of commercial crabbers decreased by almost 60 percent from 1962 to 1968. The average dockside prices, however, increased from 5 to 10 cents per pound during this same period and, in effect, offered more economic incentive for the deliberate fishermen contrary to the low productivity. Although fluctuations in abundance have occurred at rather alarming rates, the total catch has not been consistently up to its potential due to other alternative fishing opportunities with higher productivity per unit of effort (shrimping, for example).

Table 1.-Comparative Statistics of South Carolina's Blue Crab Fishery During 1960-1969

Year	CPUE Data[2]	Total Catch 000#	Pot Catch 000#	% Pot Catch	Annual Catch per man 00 lbs.	Avg. cents per lb.[3]	Total No. Crabbers
1969	36.9	8,300	7,885	95	31.8	10.2	261
1968	7.2	3,870	3,557	92	27.3	10.2	142
1967	11.6	5,247	4,825	92	28.4	6.4	185
1966	11.7	5,724	5,516	96	24.0	5.8	238
1965	16.9	7,420	5,771	77	28.2	6.1	263
1964	26.1	9,436	4,353	46	36.4	5.7	259
1963	28.5	8,839	6,333	72	27.6	5.4	320
1962	33.3	6,338	3,790	60	18.8	5.0	338
1961	23.4	4,672	2,586	55	15.5	5.0	301
1960	32.7	7,121	3,682	52	22.0	5.0	324

1 The data for 1969 was preliminary and figures are estimated.
2 Catch Per Unit of Effort data for mature and immature crabs at 18 regular monthly survey stations.
3 Prices computed from records of largest South Carolina dealer.

The impact of the crabbing industry on the local economy is best explained through cash inputs of the state's largest dealer-processor. This business had an annual input of approximately $1,000,000 during 1965 in the economy of Beaufort, Jasper and Colleton Counties. Today, this business has an input potential of over $2,000,000 in the local communities.

On a per-man basis the average earnings have scaled from a meager $110 to about $3200. The average work week varies by man, gear and yields and in general crabbing is a part-time activity with about 2-3 man days per week. This factor in addition to the fact that a number of people enter into and leave the fishery within a few months brings the average earnings down considerably. The full-time crabbers, who own their vessels and employ extra man-power, enjoy a profitable year-round income.

Methods of harvesting blue crabs in South Carolina have evolved from the traditional trot-line and trawl to the conventional and more efficient crab pot. Crab pot landings account for over 90 percent during the peak year of 1964. This change in technique is a positive factor in attracting more fishermen into crabbing because it has year-round production capabilities whereas trot-lining and trawling were seasonal.

M O R T A L I T Y S T U D I E S

A project was designed for a multiphased approach to establish background information relative to environmental factors, diseases, parasites and residual pesticides associated with blue crab mortalities. Five study areas were

located to represent the various ecosystems in South Carolina. Criteria for choosing these sampling stations were: (1) the station had to be in a commercial crabbing zone; (2) preferably in an area where previous mortalities had occurred; and (3) the station could not be significantly influenced by external factors such as industrial wastes, etc. Figure 2 shows the general location of each station. The stations are numbered and described as follows:

Station 1. Harbor River, a narrow channel winding through marshland, is located about 4.5 miles south of McClellanville and is tributary to the intracoastal waterway opening into Bulls Bay. This system is a lower distributary of the Santee River Delta with a mean annual salinity of approximately 25 ppt. Sampling depths ranged from 4 to 35 feet.

Station 2. Wando River is a main branch of Charleston Harbor and runs northeasterly from its mouth at the Cooper River for about 17.5 miles. The mean annual salinity is around 16 ppt and sampling depths ranged from 15 to 33 feet.

Station 3. Point of Pines is located along the western shores of North Edisto River about 3 miles from the ocean. This estuary is an important nursery area for immature blue crabs. The mean annual salinity is around 32 ppt and sampling depths were 15 to 27 feet.

Station 4. Folly River is an estuary intersecting Charleston Harbor at the northern end and Stono River at the south. The river proper is about 3.5 miles in length and terminates in a narrow sound filled with marsh islands and a network of winding creeks. Mean annual salinities

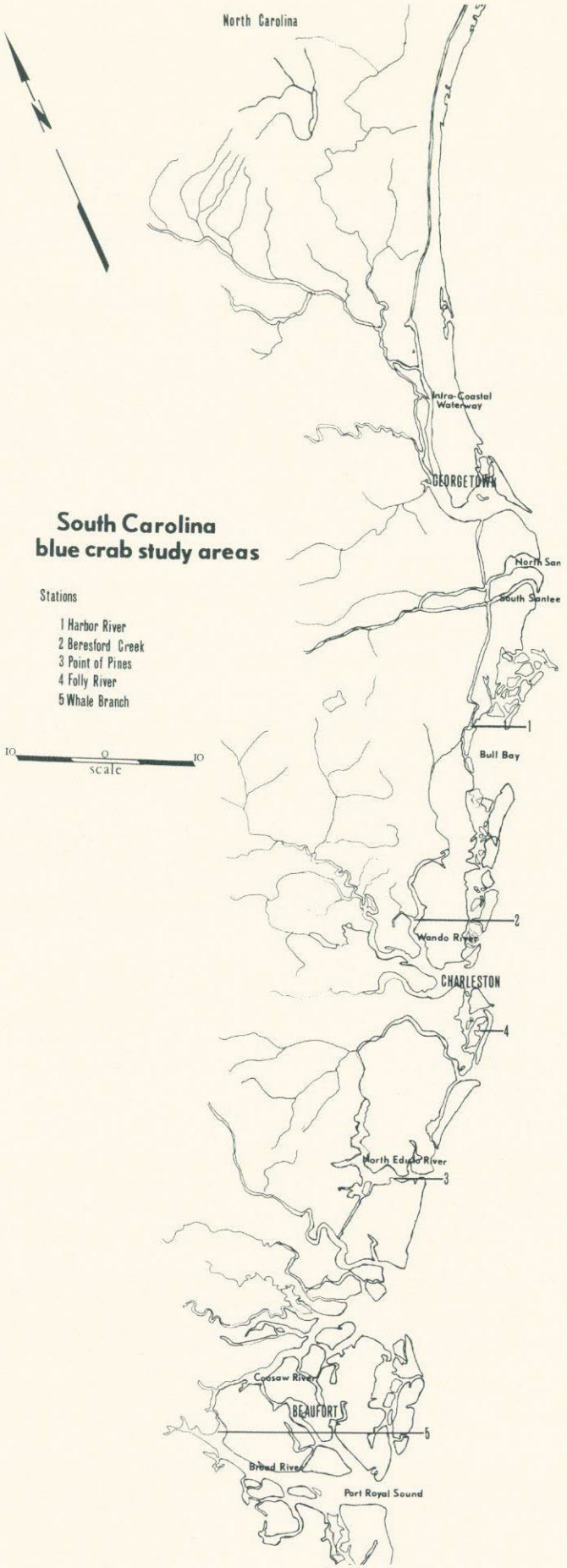

Figure 2.-Blue Crab sampling stations for the collection of hydrological, pesticidal and histopathological data.

run around 26 ppt and sampling depths were 4 to 15 feet.

Station 5. Whale Branch is a natural connection between Coosaw and Broad Rivers near Beaufort. It is approximately 1/3 of a mile wide and 7 to 20 feet deep at low water. The tidal amplitude runs nearly 8 feet and exceeds 9 feet on spring tides. This station is 17 miles from the ocean and salinities are around 20 ppt.

Relation of Hydrological Factors to Crab Mortalities

Selected parameters, as tabulated in Appendix A, were monitored monthly at each sampling station to determine hydrological variations relative to changes in local crab populations. Mortalities in the past have been attributed to extreme variations in the environment.

Carpenter and Cargo (1957) reported that dissolved oxygen (D.O.) concentrations less than 0.6 ml/l and water temperature 28°C were indicative of blue crab mortalities in commercial fishing gear in Chesapeake Bay. Local crab mortalities related to D. O. occurred during the summer of 1968 in tributaries of Charleston Harbor. In two reported cases, fishermen had set crab pots in the deeper waters with characteristic muddy bottoms. Also in both cases, the crabs had been in the pots 48 hours or more. Observations in the immediate area following mortality showed D. O. values as low as 2 ml/l in creek waters. Further evidence suggested that a vertical oxygen profile existed with D. O. values varying in the stratified layers.

Lunz (1968) stated that zones of degradation existed in Charleston Harbor near the mortality areas. These sludge

zones, composed of mixed organic matter, resulted from industrial waste discharges and were deficient of D. O. In fact, the mean Theoretical Oxygen Demand exceeded that in other non-septic zones by a ratio of 50:1. (Charleston Harbor water quality study, 1966). These factors must be considered significant in blue crab mortalities occurring in the Charleston Harbor system and other such estuaries where physical factors affect the vertical flux of D. O. Current information suggests that rapid D. O. fluctuations, in both time and space, could have a high degree of significance on survival of diseased crabs under crowded environmental conditions. Such may have been the case in the mortality of June 1966 in Cooper and Wando Rivers where crabs infected with "gray crab sickness" (Sprague and Beckett, 1966) were found dying.

An interesting factor in this kill was that only Callinectes sapidus fell victim. Other species such as C. ornatus, C. danae and even susceptible finfish did not appear in mortality samples. This would indicate that D. O. was not the sole factor but must have been in combination with other environmental and/or pathological stresses.

Historical records over a ten year period (1960-1969) were reviewed and evaluated in an effort to correlate the relative abundance of immature and mature male and female crabs with annual variances of temperature and salinity. Indices of abundance were calculated from systematic experimental trawling data and expressed as catch per unit of fishing effort. An analysis of the data (using the coefficient of multiple correlation) showed non-linear correlation between the variables at each of three

major blue crab nursery areas (Point of Pines, Pelican Bank and South Edisto River). However, there was linear correlation showing salinity preference in each area. (See Appendix B)

Sandoz and Rogers (1944) have shown the influences of variable salinity on survival rates of larval blue crabs and hatching success of crab eggs. They determined that optimum salinities for hatching lay between 23 and 30 ppt. It was further noted that optimum salinities for metamorphosis during the first three larval stages ranged from 21 to 28 ppt. Costlow (1967) further emphasized that survival and rate of development are extremely variable with combinations of temperature and salinity. He stated that survival of the megalops stage never exceeded 50 percent at 15°C but was similar (80%) at 20°, 25° and 35°C in sea water of 20 to 35 ppt.

Relating this work to characteristic blue crab nursery areas in South Carolina, it is postulated that larval crab survival and development are directly proportional with time of hatching, stage of metamorphosis in relation to seasonal shifts of water temperatures and salinities of the water during early stages of development. Blue crab larvae are more abundant in South Carolina coastal waters during May through September when water temperatures are favorable. Although bottom salinities may be optimum for normal development, crab larvae probably remain in surface waters for several weeks since they are phototropic. Consequently, these larvae probably suffer substantial losses due to abrupt changes in temperature with widely fluctuating salinities. A review of climatological data over a 20 year span shows the average

monthly precipitation at stations near a major South Carolina crab nursery area (Point of Pines) to be greater during the past 10 years than in prior years. During this time the relative abundance of crabs in this same area declined from 123.8 to 51 units.

Occurrence and Abundance of Pesticides, Diseases and Parasites

Monthly samples consisting of 10 blue crabs each were collected individually from the five established stations. Electron capture gas chromatography was used for qualitative determination of the pesticide residues. Chlorinated hydrocarbon pesticides were detected in all of the blue crab samples collected during the study period. Summary tabulations for each pesticide according to sampling station by month are presented in Appendix C. Table 2 shows that DDD, DDE and DDT were found in all 50 samples ranging from .009 to .149 ppm, .011 to .180 ppm, and .012 to .247 ppm, respectively. Mirex was found in 22 of the 50 samples at concentrations in the range of .005 to .209. Dieldrin was detected in 14 of the samples at a range of .002 to .019.

Table 2.-Chlorinated Pesticide Residues in Blue Crab Samples

Pesticide	No. of Samples Examined	Positive	Residue in parts per million Mean	Low	High
DDD	50	50	.078	.009	.149
DDE	50	50	.081	.011	.180
DDT	50	50	.091	.012	.247
Total DDT[1]	50	50	.084	.070	.820
Mirex	50	22	.090	.005	.209
Dieldrin	50	14	.009	.002	.019

1 Total DDT comprised of DDT, DDD and DDE.

Monthly variations in the occurrence of the chlorinated pesticides showed peak total DDT levels in crabs during early

spring, summer and fall. Mirex and Dieldrin residues reached a peak during May. Although this data is too weak in magnitude for predicting seasonal variations, it does lend itself to some degree of interpretation. The mean monthly differences of total DDT and Dieldrin can be associated with increased agricultural activities during the spring. Summer and fall peaks probably coincide generally with the maximum fresh water run-off. The presence of Mirex can be directly associated with fire ant control operations.

Since the parent compound DDT was generally present in higher quantities than its metabolites DDD and DDE, it is apparent that the crabs were directly exposed to pollution run-off. There is also an indication of residue buildup from transmission through the food web since the metabolites were present in all samples (Keil & Priester, 1969).

A monthly sample, consisting of 30 blue crabs, was collected from one station per month for histopathological data. Hemolymph smears and tissue sections of hepatopancreas, gills, gonads, muscle and eye stalks for each crab were collected and forwarded to the U.S. Bureau of Commercial Fisheries Biological Laboratory at Oxford, Maryland for diagnostic services.

The occurrence of the "gray crab disease" (Sprague and Beckett 1966) in wild populations of blue crabs was associated with massive crab mortalities in South Carolina during 1966, 1967 and 1968. Therefore, this disease organism (Paramoeba perniciosa) was the target for histological investigations. The etiology of this pathogen has not been established. However, Sprague and Beckett (1968) reported that a free-living

amoeba very similar to the "gray crab cells" had been found in a Berlin aquarium and a new specific name (Paramoeba eilhardi) had been created. Microscopic examination of P. perniciosa revealed that this amoeboid cell had a pair of dissimilar nucleus like bodies (Figures 3 - 5). One body is vesicular with very little chromatin and a conspicuous central endosome. The other elongated body is compact and usually granular in appearance; this body is strongly basophilic and rich in DNA material.

Hemolymph smears from blue crabs collected in South Carolina were found free of Paramoeba during March-December of 1969. However, a total of twelve male specimens exhibiting an unusual and pathogenic exoskeletal disease were collected at various stations. The nature of this disease was similar to that described by Rosen (1966). Routine examinations of these crabs, which were held alive in fiber glass tanks at relatively constant temperatures (20°C ± 2°C) and salinities (26°/00), showed the infection to manifest from a superficial necrosis. Eight of the specimens showed signs of the syndrome on the ventral side with numerous punctiform corrosive marks. Necrotic lesions also occurred on the dorsal carapaces of all specimens. (Figures 6 & 7) One crab had an advanced case which eventually resulted in death; this animal's distal section of the lateral spine was detached to such an extent that the gill filaments were visible. The causative agent involved was unknown; however, a review of the literature (Hess, 1937) implies that chitinoclastic bacteria is a possible agent. Zobell (1946) relates this bacteria as a common commensal on marine crustaceans. According to Rosen (1966) this disease or a similar syndrome was found more frequently in crabs under crowded conditions for long periods.

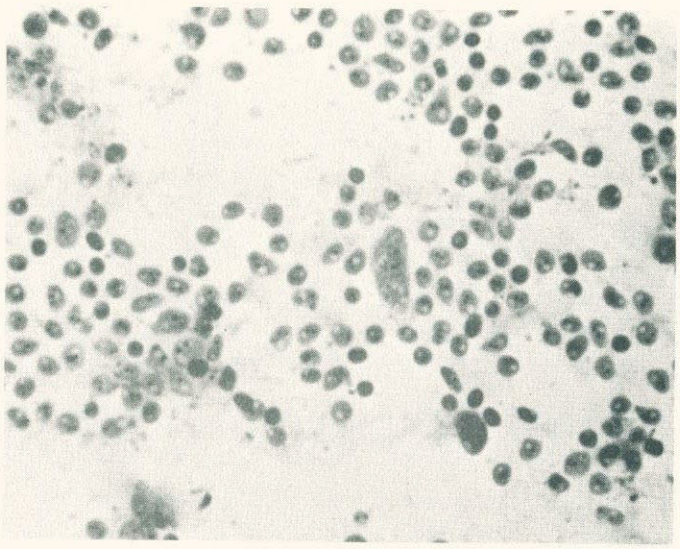

Figure 3.- Blue crab hemolymph infected with Paramoeba perniciosa X600.

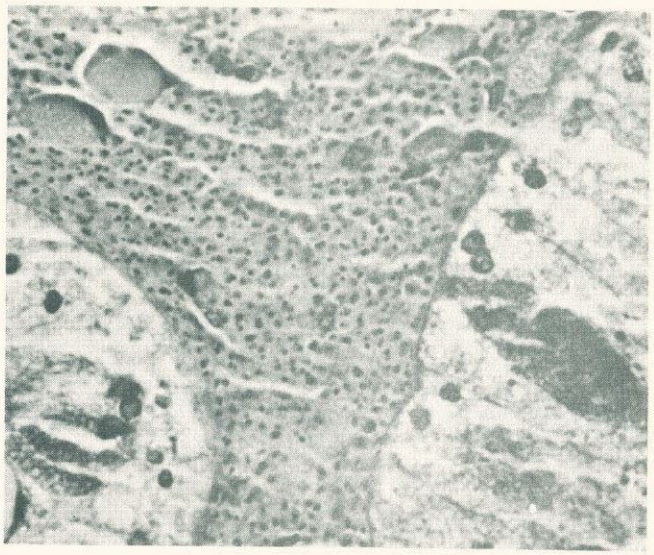

Figure 4.- Infected hepatopancreas section X600.

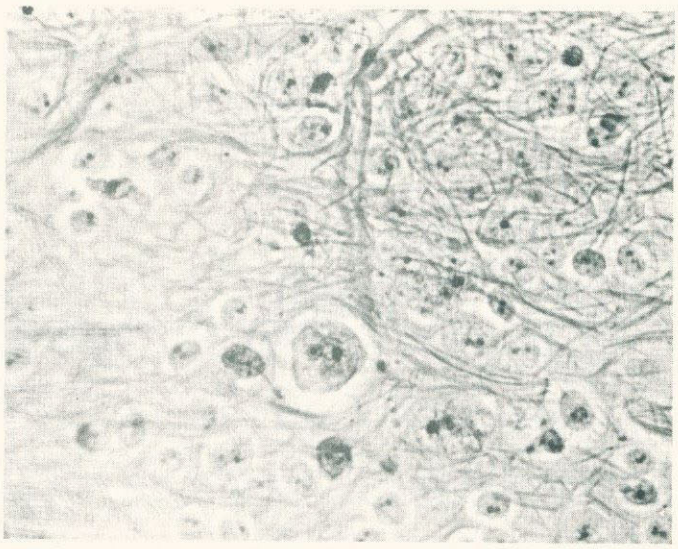

Figure 5.- Tissue smear of infected muscle X600.
(Photomicrographs courtesy of U.S.B.C.F. Biological Lab, Oxford, Maryland)

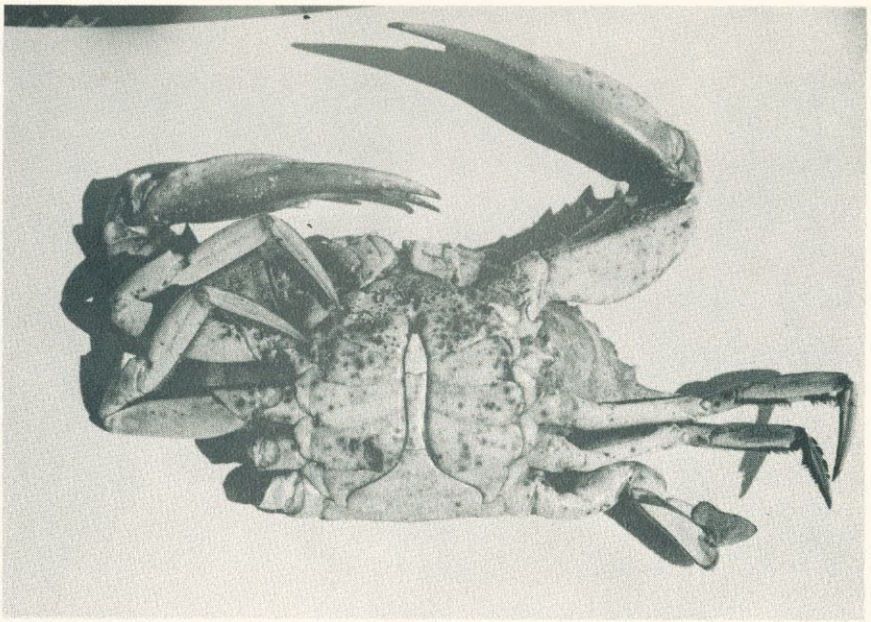

Figure 6.- The ventral side of a blue crab specimen exhibiting the exoskeletal disease.

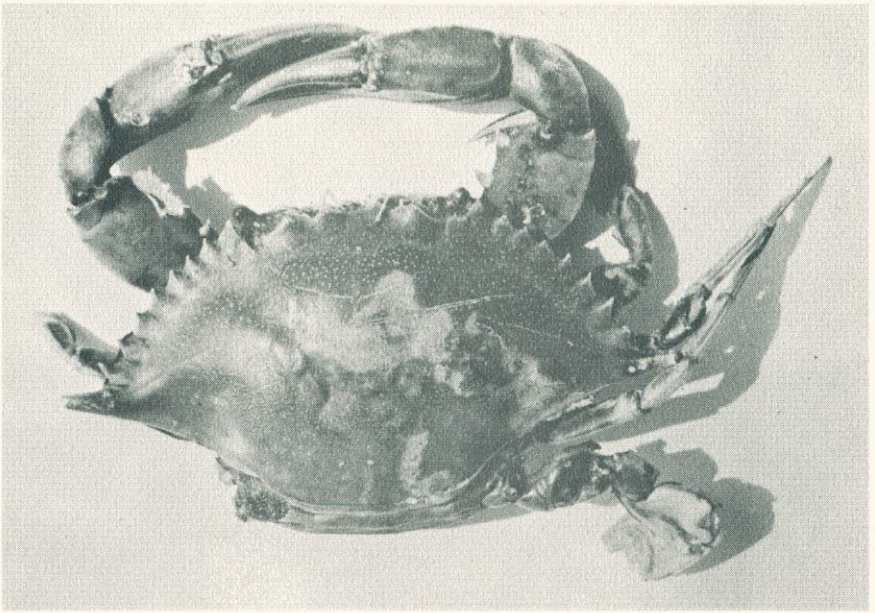

Figure 7.- The dorsal side of diseased specimen. Note the large lesion on right side near the gill area.

Laboratory Studies of Factors Affecting Crab Mortalities

Investigations were conducted to determine effects of selected Hydrological factors, diseases, parasites and pesticides on crab mortalities under controlled laboratory conditions. Since there was an absence of massive crab mortalities and no occurrence of Paramoeba, laboratory experiments were focused on the effects of certain residual pesticides on blue crabs. Pesticides were considered for bioassay in accordance with regional frequency distributions and in the final selection, DDT, Toxaphene and Mirex were specified as the problem compounds.

Experimental crabs

Bioassay specimens were collected from Wadmalaw Sound and stocked in reserve holding tanks prior to acclimation in the laboratory. Crabs that had just moulted or those designated as red-line peelers were segregated from the test groups. Only adult crabs with a carapace width of 5 inches or more were used in the preliminary screening tests. Juvenile crabs less than 3 inches in carapace width were used in certain delineative screening tests. All crabs were fed cut bait during the holding period. However, feeding was stopped during controlled acclimation due to possible problems of pollution.

During the collection periods, water temperatures ranged from 24 to 33°C. Crabs to be used in low temperature experiments were collected during the colder months and conversely those for high temperature tests were taken during the summer.

Salinities in the collection area ranged from 20 to 26 parts per thousand.

Bioassay Methods

Static bioassays were conducted over 96-hour exposure periods as described in Standard Methods, APHA (1965). Blue Crabs exposed to hydrological extremes were considered dead when no movement could be detected upon close observation. When exposed to lethal or near lethal concentrations of pesticides, the crabs would remain in a moribund condition for hours without regaining stability. Therefore, the crabs in these tests were considered dead upon a loss of equilibrium or "over-turning". All results were expressed as median tolerance limits (TLm) which is that concentration causing a 50 percent mortality within 96 hours. A total of five concentrations in logarithmically increased quantities plus a control without pesticide additive was tested in each series of bioassays. Six crabs were placed in each concentration and control. Prior to each test experimental crabs were briefly acclimated for 24 hours at constant temperatures and salinities which were gradually increased or decreased by 2 unit intervals per day until the desired testing conditions were established.

Since the pesticides were insoluble in sea water, Acetone was used as a solvent in preparing stock solutions of each pesticide. The stock solutions were titrated into the test medium at desired concentrations. Acetone in volumes equivalent to the largest in a dosage series for all pesticides was always used in control tanks.

The delineative pesticide screening data were statistically analyzed according to the methods of Litchfield and Wilcoxon (1949) to determine TLm values, variations, slope functions and 95 percent confidence intervals.

Temperature and Salinity Tolerances

A total of 66 combinations of temperature and salinity tests was conducted to determine the effects of abrupt changes of these variables on blue crabs.

Table 3.- Reactions of Adult Blue Crabs to Temperatures and Salinity Combinations expressed as Percent Survival over 96 hours.

	8.6°/oo	13.4°/oo	19.3°/oo	24.2°/oo	30.1°/oo	36.0°/oo
°C Temp.	% Sur.	% Sur.	% Sur.	% Sur.	% Sur.	% Sur.
0	0	0	0	0	0	0
5	80	60	40	20	0	0
10	100	100	100	100	40	20
15	100	100	100	100	100	40
18	100	100	100	100	100	40
21	80	80	100	100	100	80
24	20	80	100	100	100	100
27	0	40	100	100	100	100
30	0	40	80	100	100	100
33	0	0	0	100	100	100
36	0	0	0	0	40	80

As shown in Table 3, crab mortalities due to chilling occurred at all combinations of salinity at 0°C. At 5°C crab survival was higher at the lower salinity range of 8.6 to 13.4 ppt. However, as temperatures increased to the upper extremes (30 to 36°C), crab survival became higher at the maximum salinities. Generally, crabs were less tolerant at low salinities and high temperatures and high salinities at low temperatures. The TLm

values were estimated from the experimental data by straight-line graphical interpolation (Litchfield and Wilcoxon, 1949). Table 4 lists these values as upper and lower tolerances at various salinities.

Table 4. - Estimated 96-hour TLm values for Adult Blue Crabs at various Salinities.

Sal. °/oo	Acclimation temp. °C	TLm Values	
		Upper	Lower
8.6	20	22.0	3.2
13.4	20	26.1	3.8
19.3	20	30.6	5.6
24.2	20	34.2	6.5
30.1	20	35.2	10.7
36.0	20	35.2	18.5

Plotting these data graphically on temperature and salinity coordinates as in Figure 8, a linear relationship illustrating the zone of thermal tolerance is established.

On the lower end of the correlation, the minimum thermal tolerance limits decrease as salinities increase. The upper tolerance limits show a reverse pattern with a maximum tolerance at 35.2°C and a downward trend corresponding with decreasing salinities.

By connecting the upper and lower thermal tolerance limits, the range of all tolerable temperatures is shown at each salinity. Tagatz (1969) diagramed the upper and lower thermal 48-hour TLm against acclimation temperatures. His results showed that at both high and low salinities the upper and lower TLm values increased with increases in acclimation temperatures.

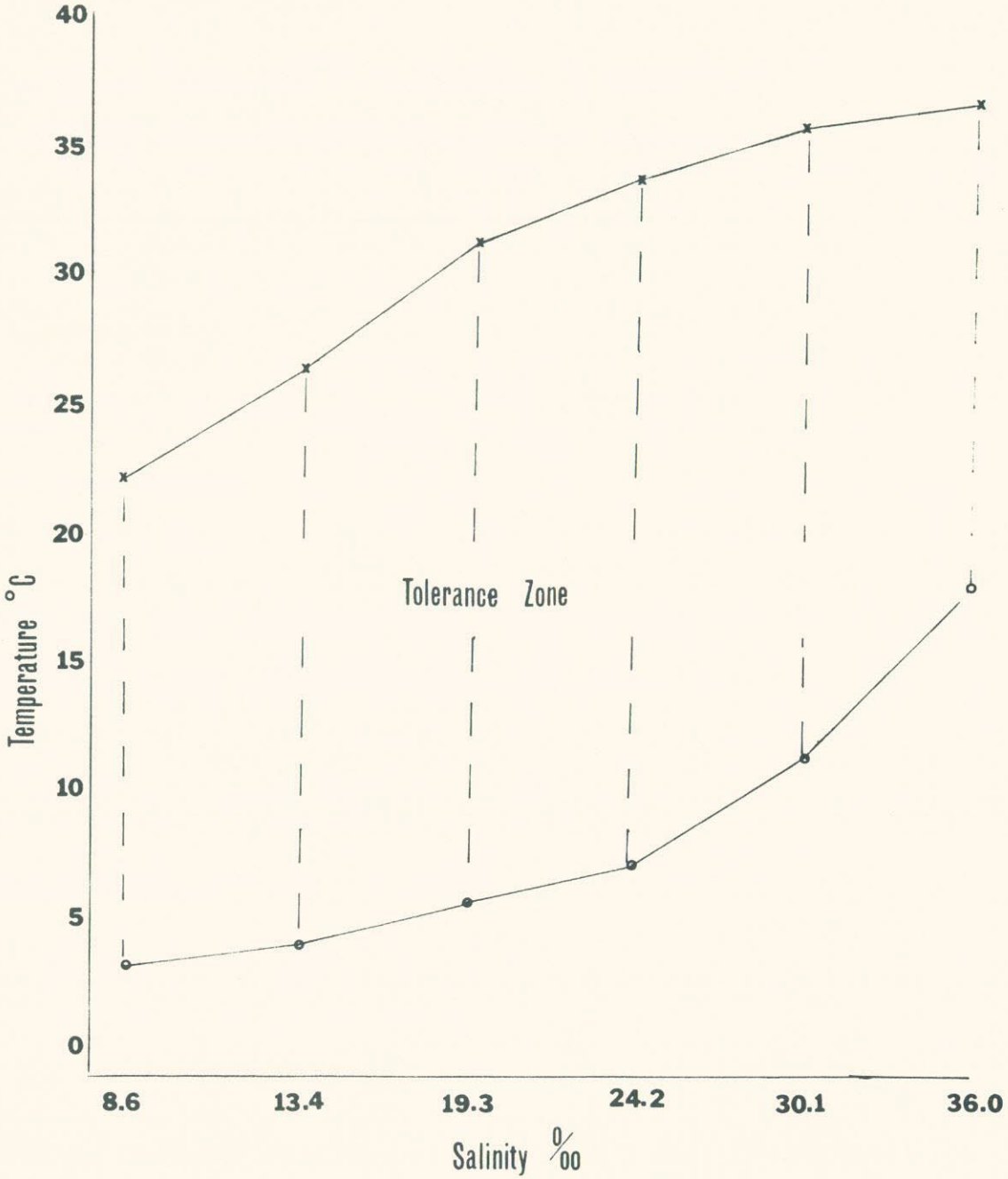

Figure 8.- Upper and lower thermal tolerance levels for adult crabs without acclimation.

These data generally agree with results of this study. However, acclimation time and temperature was an obvious factor in the final results of the two studies. The percentage of adult crab survival apparently becomes greater as the difference between acclimation and test temperatures decreases.

There appears to be an important physiological ecological relationship between the tolerance limits at various temperatures and salinities. The metabolic rate of crustaceans is generally temperature oriented with higher metabolism corresponding with temperature increases (Waterman, 1960). King (1964) also showed that lower salinities had marked increase on blue crab metabolism. This indicates that at low salinities and high temperatures the strain of osmoregulation would add to the stress of metabolism and thus decrease the upper TLm values at such combinations.

In a reverse situation, low temperatures may reduce metabolic activity to such a degree that it would be difficult for crabs in high salinities to maintain a favorable gradient between external and internal salinities. Rees (1966) stated that blue crabs in full strength sea water ($35^{o}/oo$) maintained a blood concentration slightly below that of the seawater regardless of temperature between 10 and $30^{o}C$. However, Tan and Van Engel (1966) showed that blood osmoconcentrations of adult blue crabs were hypertonic at $10^{o}/oo$, $20^{o}/oo$ and $30^{o}/oo$ salinities at $20^{o}C$. Rees (1966) further emphasized that in most cases higher blood concentrations were maintained with temperature decreases. This would indicate that blue crabs can successfully regulate their internal environments near the lower

end of their thermal tolerances. Rees (1966) also stated that adult female blue crabs showed less regulatory abilities than adult males in the lower salinities. This differential ability to regulate sodium in the blood may well explain why sexually mature females prefer higher salinity waters.

Effects of Cholorinated Pesticides

Preliminary Screening

Initial tests with DDT and Toxaphene indicated a rather high level of toxicity in adult blue crabs; technical Mirex in solution was relatively non-toxic to adult and sub-adult crabs. However, the Mirex granulated bait formulation was toxic to juvenile crabs. In concentrations of 1 ppm DDT, all test crabs succumbed after 24 hours continuous exposure. Toxaphene killed 100 percent of the test crabs after 72 hours exposure at 10 ppm. Technical Mirex in suspension had measurable effects only at the end of 72 hours exposure in concentrations exceeding 500 ppm. Mirex granulated bait (85% corncob grit; 15% soybean oil and 0.3% Mirex) showed delayed toxicity to juvenile crabs at equivalent rates of 1.25 pounds per acre.

The responses of blue crabs to the more toxic cholorinated compounds were noticeable within a few hours after exposure. They displayed marked irritability, being extremely sensitive to external movements and sounds. Early reactions included an increased metabolism and swimming in a wild fashion. Later there was a loss of equilibrium with apparent muscle spasms and convulsions.

Delineative Screening

Results from testing combinations of temperatures and salinity against varying pesticide concentrations are recorded as TLm values in Table 2. As shown, DDT was more toxic than Toxaphene and Mirex at all combinations. A comparative relationship is illustrated in Figure 9.

All three compounds were more toxic with decreasing salinity. At each salinity, however, the defined tolerance limits were higher at 15°C. Above and below this mid-point, the TLm values decreased with toxicity being more pronounced at the lower extremities for DDT and Toxaphene. Mirex exhibited a higher toxicity at higher temperatures within each salinity bracket.

Lethal levels of DDT were established within relatively narrow confidence intervals, indicating consistent toxic effects with little range between concentrations causing survival and death. The calculated slope functions were low (ranging from 1.3 to 3.1) and the regression was steep, indicating that toxicity was accurately defined at low levels. In sharp contrast, Marking (1966) found the slope function p p' - DDT for goldfish to be 6.02. This was indicative of a flat curve with wide confidence intervals and, consequently, the toxicity was difficult to define accurately.

The confidence limits for the TLm values of Toxaphene were somewhat wider than those of DDT and the calculated slope functions larger. This indicates that increased concentrations in the survival and mortality range produced less affect within the 96-hour bioassay.

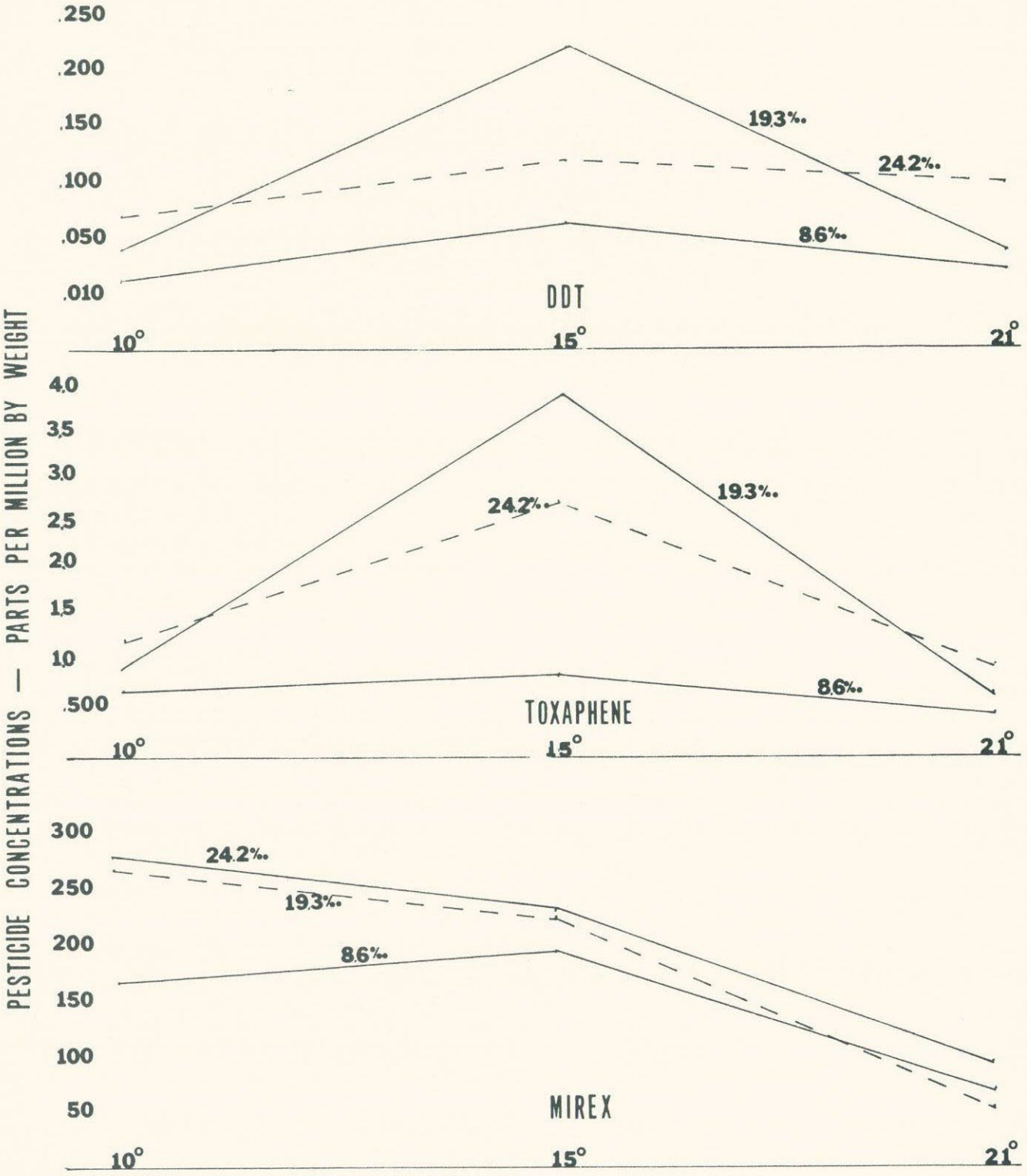

Figure 9.- Toxicity of DDT, Toxaphene and Mirex at various combinations of temperatures and salinity.

TABLE 5. - TOXICITY OF PESTICIDES ON ADULT BLUE CRABS AT VARIOUS TEMPERATURES AND SALINITIES

Salinity	Temp.	TLm (PPM) with 95 percent Confidence Intervals and Slope Functions					
		DDT		Toxaphene		Mirex	
°/oo	°C	TLm	SF	TLm	SF	TLm	SF
	10	.019 (.009 - .036)	1.5	.580 (.460 - .920)	2.1	159 (83 - 302)	3.0
8.6	15	.054 (.030 - .084)	2.5	.900 (.470 - 1.70)	3.0	180 (128 - 250)	1.8
	21	.035 (.021 - .057)	1.9	.370 (.180 - .700)	3.2	72 (48 - 108)	2.1
	10	.043 (.025 - .078)	3.1	.960 (.590 - 1.50)	2.7	260 (173 - 390)	2.0
19.3	15	.213 (.160 - .280)	1.7	3.80 (.270 - 5.20)	1.8	220 (137 - 352)	2.6
	21	.045 (.030 - .067)	1.8	.770 (.570 - 1.0)	1.7	56 (40 - 78)	1.7
	10	.080 (.070 - .110)	1.5	1.20 (.910 - 1.50)	1.8	265 (188 - 371)	1.8
24.2	15	.120 (.100 - .140)	1.3	2.70 (1.3 - 5.9)	3.4	220 (152 - 275)	2.0
	21	.114 (.073 - .180)	2.6	1.00 (.570 - 1.75)	3.2	105 (75 - 147)	1.3

The toxic effects of DDT, and Toxaphene on blue crabs have been thoroughly documented. Butler (1963) presented data on the effective concentration (EC_{50}) of both these compounds on juvenile blue crabs. The 48-hour EC_{50} for DDT and Toxaphene was .01 and .33, respectively. Comparing these results with those obtained from this study, the adult crabs tested under similar conditions (24°/oo and 21°C) are approximately 10 times more tolerant to DDT and 3.4 times more resistent to toxaphene. This study gave evidence that decreased temperature was a definite factor affecting the toxicity of DDT and Toxaphene. Bridges et al. (1963) also found that toxicity of DDT increased with temperature decrease.

The toxicity of Mirex in acetone solution was difficult to define accurately as evidenced by the high TLm values and wide confidence intervals. This compound remained in solution only a short time before precipitating out. Mirex granulated bait 4X was bioassayed with adult and juvenile blue crabs. Adult (5" or more), and sub-adult (3" - 5") crabs were not outwardly affected by the bait material even in equivalent doses of 10 times the standard application rate of 1.25 lbs. per acre. However, juvenile crabs (less than 3") exhibited extreme sensitivity to the bait. At concentrations of .036 g/l (equivalent in wt./surface area to 1.25 lbs./acre) juvenile crabs showed signs of delayed toxicity at various temperature-salinity combinations. Table 6. gives a summary of the experiments with juvenile crabs.

Table 6. - Average Survival Data from Replicate tests on Juvenile Blue Crabs Exposed to Mirex Granulated Bait - 4X[1].

Exposure Time Hours	.036 g/l					.5 g/l	1 g/l
	22 ppt.			30 ppt.	10 ppt.	22 ppt.	22 ppt.
	10°C	20°C	27°C	15°C	20°C	22°C	20°C
0	10	16	10	16	8	16	16
24	10	16	10	16	8	16	16
48	10	16	8	16	6	16	15
72	10	13	5	16	5	12	15
96	10	10	2	16	3	8	11
120	10	4	1	12	3	5	7
144	10	2	0	8	3	3	4
168	10	2	0	8	2	1	2
192	10	0	0	7	0	0	1

1. Controls averaged 90 percent survival

As shown in the preceeding table, there were delayed toxic effects at all combinations except 10°C. An increase in dosage from .036 g/l to 1 g/l did not substantially alter the survival times. Follow up experiments with high concentrations indicated a threshold reaction time; a stage was reached when further increases in concentrations did not shorten survival time. Extensive observation showed the juvenile test crabs ingesting particles of the bait. These crabs were transferred to non-contaminated aquaria and monitored. After 96 hours in the clean water, the crabs showed acute irritation which resulted in spasmotic muscle contractions, a loss of equilibrium and finally death at the end of 192 hours. These data suggest that Mirex bait acts as a stomach poison and, if ingested by juvenile crabs, is a

definite mortality factor.

Figure 10 illustrates the relationship of temperature on relative toxicity of the bait. As depicted, the toxicity rate appears to be temperature dependent. At 10°C there was no mortality recorded but as temperatures increased from 20 to 27°C the survival times and rates decreased. This would indicate that toxicity might be defined as a function of metabolism. A partial relationship between salinity and toxicity of bait material is evident. However, temperatures appeared to be the major factor of influence. Further experimentation showed that small crabs which had ingested Mirex bait at 27°C could survive for an extended time at 10°C. However, as the temperatures were gradually increased there was concurrent mortality. Interpretation of this data indicates that juvenile crabs ingesting the bait during winter months could possibly survive throughout the colder months, but as seasonal temperatures increased mortality would occur.

These data are purely suggestive but from preliminary evaluations, it would appear that acute toxicity of the Mirex bait depends on (1) availability of the bait to hungry crabs; (2) size and age of the exposed crabs, and (3) the season of exposure.

Butler (1963) listed Mirex in solution as a relatively non-toxic pesticide to juvenile blue crabs as compared to other chlorinated hydrocarbons. The 48-hour EC_{20} was 2 ppm. Later studies by McKenzie (1969) and Lowe (1969) suggested that the bait formulation was a stomach poison to juvenile blue crabs.

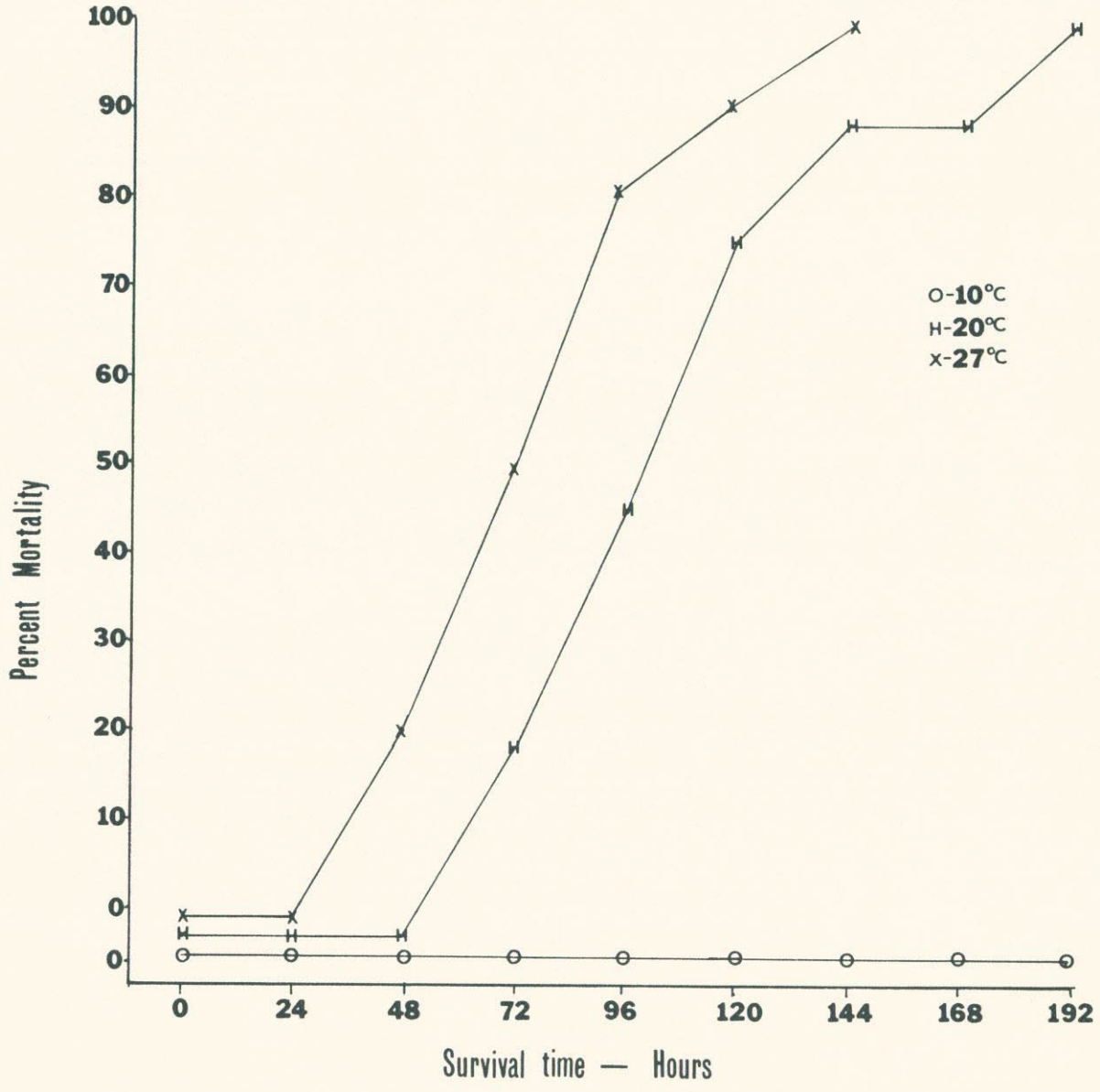

Figure 10.- Survival Curves for Juvenile Crabs exposed to Equivalents of 1.25 lbs./acre Mirex bait (salinity 22°/oo)

The toxic effects, however, were delayed and once the bait material was ingested moribundity was evident after several days. Field studies conducted by Bears Bluff Laboratories showed that at the standard application rate of 1.25 pounds per acre the bait material had no observable effects on adult and juvenile crabs in a major estuarine drainage zone. Further studies indicated that active Mirex could be accumulated in adult crab stomachs at levels as high as 8,860 ppm without resulting mortality. Evidence thus far would indicate that this pesticide is not acutely toxic to crabs outside the year-class group. However, the chronic effects on spawning stocks and corresponding progeny are not known.

PH Tolerance Limits

Highly acid and alkaline effluents are becoming quite problematical along certain estuaries of the South Atlantic region where industrial pollution has been recognized. In an effort to obtain background information regarding the presence of blue crabs in such affected areas, experiments were conducted to ascertain the upper and lower pH tolerances for adult blue crabs.

Bioassays were conducted with acid and alkaline waters to measure reaction times and mortalities against varying pH units. Acid water was made from solutions of hydrochloric acid since it is highly dissociated and the chloride ion was less toxic than several other anions. Sodium hydroxide was used for the high pH adjustments. Crabs tested in acid waters were acclimated for 48 hours at a pH of 6. Those specimens for alkalinity tests were acclimated during this period at a

pH of 7.5. Reaction was measured as negative against time when acclimated crabs sought escape from the test solutions to normal sea water.

The crabs appeared indifferent to sea water of pH 4.0 to 8.5. At 3.5 a somewhat negative reaction was observed with 25 percent mortality occurring after 96 hours. Below this value the reaction time dropped sharply with 100 percent mortality being recorded at a pH of 2.5 within 2.5 hours exposure. (Figure 11). On the alkaline side, water of 7.5 to 8.5 appeared to elicite no response. However, above 8.5 there was a definite negative reaction trend with 100 percent mortality being recorded at 9.5 within 24 hours. Blue crabs appeared to be slightly more tolerant of acid water than of alkaline water.

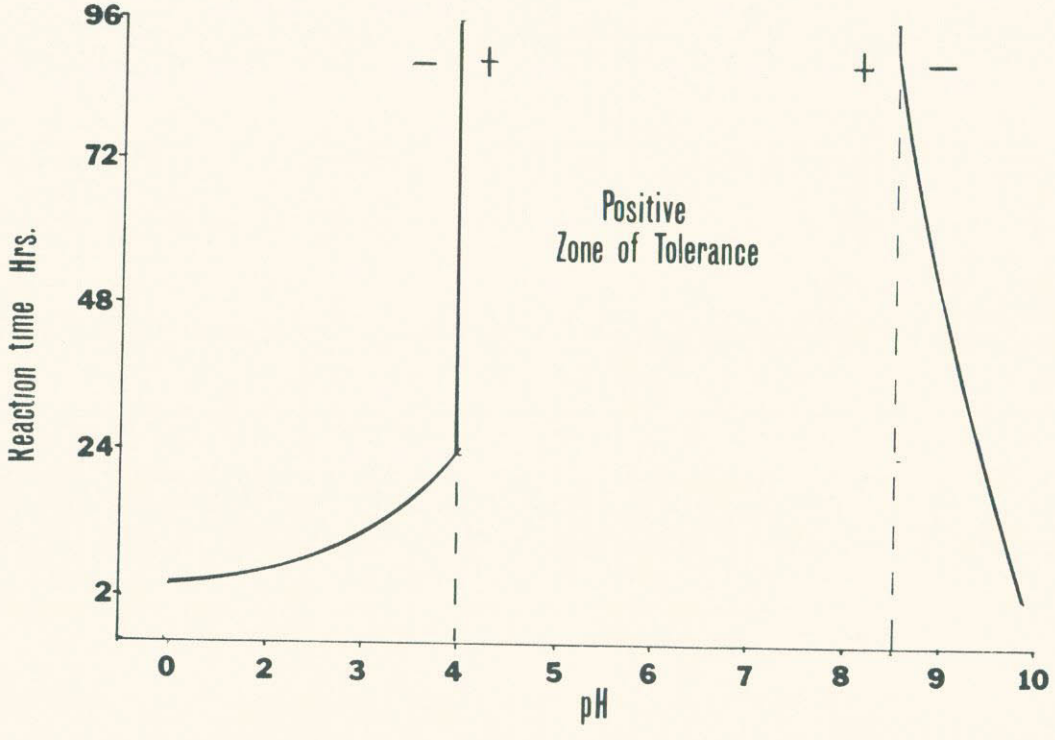

Figure 11. - The recation of adult blue crabs to acid and alkaline water. Six crabs were used for each reaction time determination. Water of 18°C and 24°/oo.

SUMMARY AND CONCLUSIONS

1. Natural abundance of mature and immature crabs declined during 1962-68 and then ascended to an all-time high in 1969. This abundance factor resulted in lower production due to an increase in the amount of fishing effort required for profit sharers. The over-all fishing intensity by man-power dropped by approximately 60 percent. Production has not measured up to its potential because of economic tensions which are largely influenced by productivity per unit of fishing effort.

2. Environmental extremes in combination with diseases, parasites and pollution probably accounted for massive blue crab mortalities in 1966, '67, and '68. Although the "gray crab" disease organism Paramoeba perniciosa was prevalent in the mortality samples for two successive years, it failed to show up in samples collected during the study period.

3. Availability of marketable blue crabs is sensitive to survival rates of post-larvae and can be measured by using year-class populations as indices to the relative strength of adult stocks.

4. DDT and its metabolites were found in 100 percent of the crab samples collected from 5 stations. Average concentrations for total DDT were .084 ppm. Mirex and Dieldrin were detected in 44 and 28 percent of the samples at .09 and .009 ppm., respectively.

5. A degenerative exoskeletal disease was found in twelve male specimens. Extended observations on live specimens indicated this to be a pathogenic disease but the causative agent is unknown. Preliminary data suggests that it is asso-

ciated with chitinoclastic bacteria and crowded environmental conditions.

6. Blue crabs are less tolerant to low salinities at high temperatures and high salinities at low temperatures. The upper thermal tolerance limit in sea water was 35.2°C and the lower extremity at 8.6 ppt was 3.2°C.

7. DDT and Toxaphene are more toxic to adult blue crabs at lower salinities and lower temperatures. The TLm value at 8.6°/oo and 10°C was .019 ppm for DDT and .580 ppm for Toxaphene. Mirex was most toxic at 19.3°/oo and 21°C with a TLm value of 56 ppm. Mirex granulated bait is relatively non-toxic to adult blue crabs but has delayed toxicity on juveniles at concentrations of .036 g/l.

8. A positive zone of tolerance for adult blue crabs exposed to alkaline and acid waters was found between pH values of 4.0 and 8.5.

RECOMMENDATIONS

It is recommended that applied research be continued in an effort to manage the blue crab resource for maximum sustained yields. Techniques can be devised to predict the supply of marketable crabs more accurately through expansion of the existing fisheries inventory program. The relationship between size of spawning stocks and the subsequent number of marketable crabs should be determined for more effective management. Attempts to apply methods of economic analysis to specific problems within the fishery and industry should be made. A refined system of statistics will be necessary for the establishment of successful management. Specifically,

more complete and accurate figures on total production are needed. Additional data on location of catch, type of gear and the amount of effort are required for modern fisheries statistics.

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Appendix A.: Summary of Observed Hydrology at Each Station During the Sampling Period of March 1969 - January 1970.

	Bot. H_2O Temp. ^oC			Sal. %			Turb. cm.			Diss. O_2 ppm			PH[1]
Sta. #	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Avg.
1	8.7	30.8	20.9	2.7	32.3	25.3	10	56	28.1	3.0	8.0	6.3	8.0
2	10.0	29.0	22.1	10.7	22.0	16.2	10	145	42.3	5.0	9.0	6.1	8.0
3	10.0	31.0	22.0	23.0	32.3	29.0	15	85	40.8	5.0	8.0	6.8	8.0
4	8.7	30.3	21.5	17.0	32.0	25.0	16	14.7	48.9	4.0	8.0	6.2	8.0
5	10.0	29.5	21.6	14.0	26.9	21.0	15	120	35.7	5.0	9.0	6.2	8.0

[1]PH remained constant within ± 0.5 units of measurements.

Appendix B. Historical Records from Productive blue crab nursery areas in S. C.: A summary of relative abundance and hydrology at Point of Pines.

Year	Avg. CPUE Mature	Avg. CPUE Immature	Temp. °C Min.	Temp. °C Max.	Temp. °C Mean	Sal. °/oo Min.	Sal. °/oo Max.	Sal. °/oo Mean	Total CPUE
1960	39.2	31.8	11	27.5	19.1	19.2	31.7	28.8	71.0
1961	23.7	31.4	9	29	17.5	25.4	33.8	30.1	55.0
1962	18.3	21.5	8	30	19.8	25.2	33.4	29.9	39.9
1963	24	38.4	8	28.5	20.2	27.6	34.7	25.8	62.4
1964	47	16.9	10	29	18.8	20.2	33.6	27.7	63.9
1965	16.5	35.9	12	29.2	19.3	25.2	34	29.4	52.4
1966	22.7	28.2	5.6	27.5	20.7	27.2	34.5	33.2	50.9
1967	12.2	6.3	9.2	28.4	19.4	26.6	34.1	31	18.5
1968	23.4	15.8	8.6	24.5	14.8	27.9	34	31.9	39.2
1969	24.9	28.9	9	30	17.6	26.2	32.9	29.6	49.3

Appendix B. Historical Records from Productive Blue Crab Nursery Areas in S. C. (Con't):

A Summary of Relative Abundance and Hydrology at South Edisto River.

Year	Avg. CPUE Mature	Avg. CPUE Immature	Temp. °C Min.	Temp. °C Max.	Temp. °C Mean	Sal. °/oo Min.	Sal. °/oo Max.	Sal. °/oo Mean	Total CPUE
1960	6.7	11.0	10	27.5	18.3	2.2	30.8	13.4	17.7
1961	4.5	15.4	7	29.5	18.7	6.2	28.3	14.6	19.9
1962	4.4	9.5	8	29.5	19.1	1.7	29.3	14.8	13.9
1963	3.8	24.2	9	30.5	20.5	9.4	30.0	17.4	28.0
1964	2.5	9.9	7	29.6	20.3	1.6	18.4	9.7	12.4
1965	4.1	15.4	9.5	29.8	19.7	0.0	27.8	13.7	19.5
1966	1.8	8.2	5.6	28.5	19.4	1.2	32.2	18.2	10.0
1967	8.6	10.0	10.2	29.5	19.9	7.6	29.4	19.9	18.6
1968	7.5	3.6	10.1	28.9	19.5	11.4	28.9	22.3	11.1
1969	2.9	22.2	9	30.0	18.4	0	27.6	14.7	25.1

Appendix B. Historical Records from Productive Blue Crab Nursery Areas in S. C. (Con't):

A Summary of Relative Abundance and Hydrology at Pelican Bank.

	Avg. CPUE		Temp. °C			Sal. °/oo			Total
Year	Mature	Immature	Min.	Max.	Mean	Min.	Max.	Mean	CPUE
1960	10.9	2.9	8	26.5	19.0	21.3	32.2	27.0	13.8
1961	18.6	5.2	11	30	19.7	23.5	34.3	28.1	23.8
1962	9.1	13.3	9	30	20.2	25.0	32.0	28.1	24.2
1963	42.8	2.0	8	29	20.2	24.8	34.2	29.6	45.1
1964	22.0	18.2	7.2	29	19.8	19.4	30.9	26.3	40.2
1965	6.6	14.5	10	28.8	19.5	17.8	33.2	26.5	21.1
1966	1.8	.16	6.6	29.0	18.7	23	33.3	29.6	1.9
1967	3.9	.25	10.4	28.4	18.8	22.1	33.1	29.2	4.1
1968	.75	.30	8.6	30.0	19.8	29	34.5	31.4	1.0
1969	1.3	.66	8.3	30.6	20.3	21.5	30.0	26.6	2.0

Appendix C. : Summary of Blue Crab Analyses:

Pesticide Residues (Parts per Million) in Whole Body Crab Samples

Month	Station	Lab No.	DDE	DDD	DDT	DIELDRIN	MIREX OTHER
March	1	C-16	.095	.107	.247	-	.112
	2	C-15	.134	.085	.110	-	.089
	3	C-13	.096	.149	.172	-	.074
	4	C-14	.086	.126	.162	-	-
	5	C-12	.153	.117	.247	.005	-
April	1	C-85	.113	.134	.120	-	.140
	2	C-87	.115	.114	.126	-	.100
	3	C-88	.120	.072	.063	-	.120
	4	C-94	.083	.072	.088	.014	-
	5	C-86	.134	.095	.095	-	-
May	1	C-91	.059	.048	.074	.020	.125
	2	C-93	.165	.101	.087	.020	.209
	3	C-94	.083	.072	.088	.014	-
	4	C-88	.120	.072	.063	-	.179
	5	C-90	.050	.031	.029	-	-
June	1	C-97	.082	.107	.128	.014	-
	2	C-96	.050	.129	.106	-	-
	3	C-92	.096	.025	.071	.071	-
	4	C-99	.043	.076	.104	-	-
	5	C-98	.057	.107	.126	-	-
July	1	C-101	.072	.114	.151	-	-
	2	C-102	.108	.160	.166	-	-
	3	C-117	.085	.102	.130	-	.086
	4	C-62	.123	.058	.100	-	-
	5	C-100	.061	.126	.130	-	-

Appendix C. : Summary of Blue Crab Analyses (Cont'd)

Pesticide Residues (Parts per Million) in Whole Body Crab Samples

Month	Station	Lab No.	DDE	DDD	DDT	DIELDRIN	MIREX OTHER
August	1	C-63	.092	.051	.065	.004	.150
	2	C-66	.108	.072	.083	-	.075
	3	C-65	.180	.116	.099	-	.085
	4	C-64	.163	.076	.123	-	-
	5	C-61	.117	.087	.106	-	-
September	1	C-121	.126	.114	.120	-	-
	2	C-119	.140	.104	.130	-	.080
	3	C-118	.095	.110	.105	-	.106
	4	C-120	.104	.101	.135	-	-
	5	C-116	.115	.130	.162	-	-
October	1	C-141	.020	.029	.033	-	-
	2	C-138	.048	.096	.108	-	-
	3	C-139	.030	.040	.051	-	-
	4	C-140	.050	.064	.068	-	-
	5	C-142	.068	.060	.046	-	.030
November	1	C-193	.022	.015	.015	.002	.038
	2	192	.025	.016	.027	.002	-
	3	190	.017	.010	.015	-	-
	4	191	.011	.009	.018	-	-
	5	185	.030	.022	.016	.004	.010
December	1	187	.012	.010	.012	.005	.010
	2	188	.028	.017	.018	-	.052
	3	186	.030	.010	.014	.002	-
	4	189	.015	.011	.019	.005	.005
	5	194	.030	.025	.023	-	.067