MORTALITY RATES IN POPULATIONS OF PINK SHRIMP, *PENAEUS DUORARUM*, ON THE SANIBEL AND TORTUGAS GROUNDS, FLORIDA[1]

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ABSTRACT

Mark-recovery experiments were made to obtain estimates of fishing and natural mortalities as a portion of studies related to the life history of commercial shrimps in the Gulf of Mexico. In two experiments, groups of pink shrimp were injected with biological stains and released into the Sanibel and Tortugas fisheries off the southwest coast of Florida. Marked shrimp were recaptured by commercial shrimp fishermen.

Mortality estimates were derived from analysis of marked shrimp recoveries during the first 10 and 8 weeks of the Sanibel and Tortugas experiments, respectively. In the Sanibel population, fishing mortality was estimated to have been 6.8 percent for each 2-week period, and all other losses in the population were 14.8 percent; for the Tortugas population, fishing mortality was estimated to have been 13.1 percent for each 2-week period, and all other losses 19.7 percent.

In the past 3 decades, biologists have probed at various aspects of the life histories of commercial shrimps in the Gulf of Mexico. Recently, large-scale, mark-recovery experiments were made to estimate rates of fishing and natural mortalities in shrimp populations. A mark-recovery experiment, in which biological stains were the marking agent, was undertaken on the Tortugas pink shrimp (*Penaeus duorarum*) trawling grounds west of Key West, Fla., in September 1961. Development of an appropriate recovery system brought return of 21.1 percent of the marked shrimp. These shrimp were in commercial catches and returned by fishermen at shrimp landing ports. Analysis of data produced estimates of the rate of fishing and natural mortality in the Tortugas pink shrimp population (Kutkuhn, 1966). Two similar experiments were carried out in south Florida waters in 1962 and 1963. Emphasis was placed on obtaining a complete tabulation of fishing effort and recovering a high percentage of the marked shrimp that were recaptured by commercial gear. One experiment was on the Sanibel grounds south of Sanibel Island, and the other on the Tortugas grounds (fig. 1). These two experiments form the basis of this report.

THE SANIBEL AND TORTUGAS FISHERIES

In both fisheries, trawling gear is similar to that used elsewhere in the Gulf of Mexico (Bullis, 1951). Trawling is at night because pink shrimp usually remain buried during the day. Other species of penaeid shrimp in the catches are of minor commercial importance.

The area known as the Sanibel grounds comprises about 2,000 km.[2] (600 square nautical miles) of trawlable bottom in two sections, south and northwest of Sanibel Island, Fla. Most fishing is on the southern portion of the grounds between the 11- and 18-m. depths. The fishery began in 1954 and has produced about 272,000 kg. (600,000 pounds) (tails) of pink shrimp annually. Peak catches are made from March through May each year when 35 to 90 vessels participate in the

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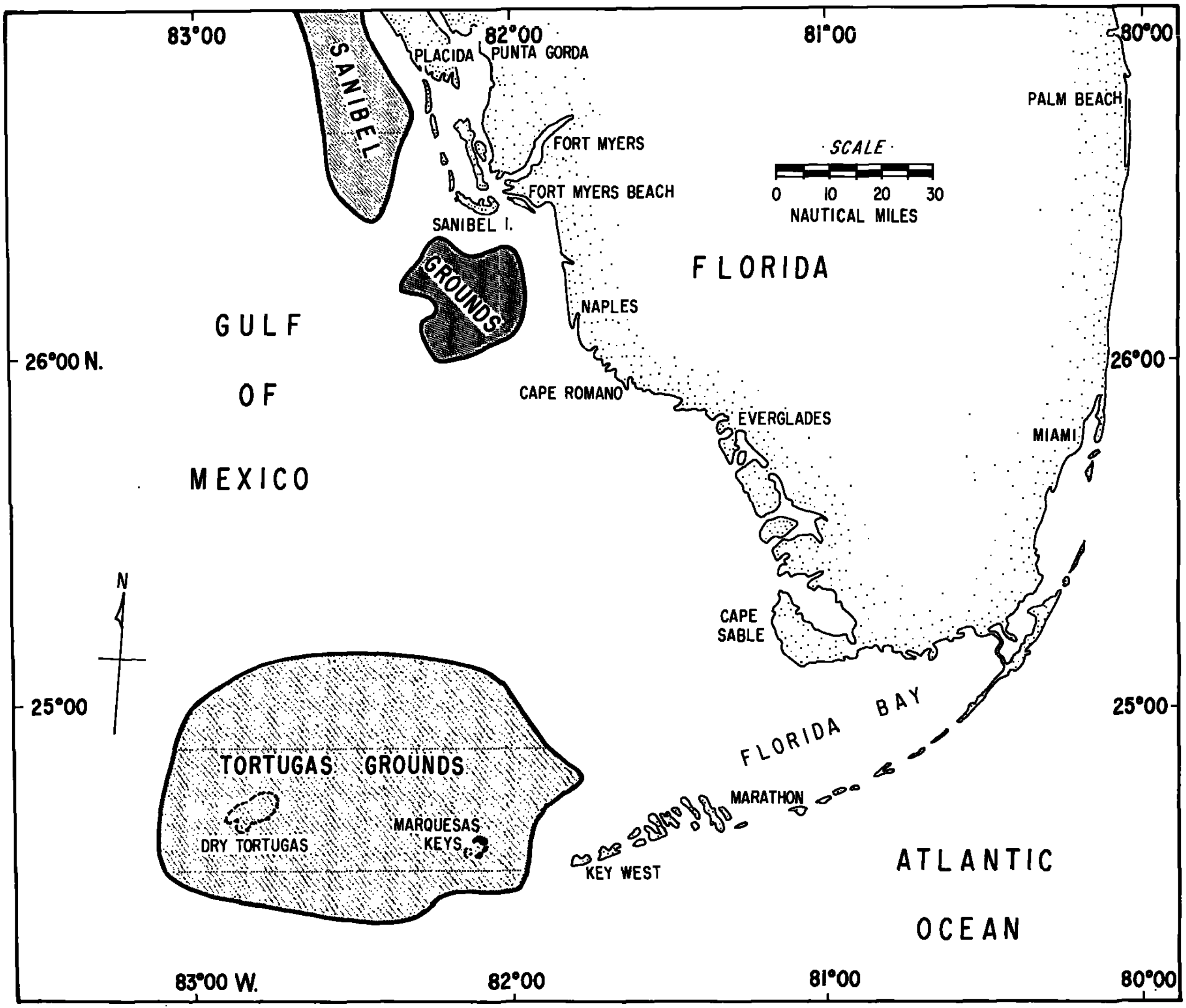

FIGURE 1.—Geographic location of the Sanibel and Tortugas pink shrimp trawling grounds.

fishery. A few vessels trawl in the area throughout the year. Catches are landed at Fort Myers, Fort Myers Beach, Punta Gorda, Placida, or Naples, Fla.

The Tortugas grounds comprise about 10,000 km.[2] (3,000 square nautical miles) of trawlable bottom west of Key West, Fla. Most fishing is between the 18- and 55-m. depths. The fishery began in 1950 and has produced about 5,442,000 kg. (tails) of pink shrimp annually. Peak catches occur from October through March each year, and 300 to 500 vessels participate in the fishery (Iversen and Idyll, 1959). Some trawling occurs on the Tortugas grounds throughout the year. Catches are landed at Key West, Marathon, Everglades, Fort Myers, Fort Myers Beach, or Tampa, Fla.

DATA REQUIREMENTS AND DESIGN OF EXPERIMENTS

To obtain the information required to estimate mortality rates, a group of animals is drawn from the standing crop, marked, and returned to the former environment. We assume that subsequent observations of the marked group are applicable to the population of which the group is believed to be part. Requirements for a successful experiment are that: (1) the experimental animals either are unaffected by the capture-mark-release process, or the effect is accurately measured and considered in the subsequent analyses; (2) accurate records are obtained of the numbers, dates, and locations of recaptures; and (3) a comprehensive tabulation is obtained of fishing effort in the area where the experimental group is available.

Experiments reported by Costello and Allen (1962) and Zein-Eldin and Klima (1965) indicate marking with biological dyes has little effect on the individual shrimp. Experience gained during earlier work (Costello and Allen, 1966) allowed the capture-release phases to be carried out with negligible injury to the live animals.

Personnel stationed at principal landing ports obtained recovery information on marked shrimp from fishermen and packing plant workers. In addition, they interviewed shrimp-boat captains to determine the time, location, and extent of fishing effort. We have a record of fishing effort for all shrimp vessels trawling in the Sanibel area. We have information on 77 percent of the shrimp vessels fishing the Tortugas grounds; and from these data we have estimated the effort that applied to the area containing marked shrimp.

FIELD OPERATIONS

To arouse their interest in the experiments, shrimp fishermen were contacted individually before the release of marked pink shrimp on the Sanibel and Tortugas grounds. A reward of $2.00 was offered for return of each marked shrimp.

In both areas, the Bureau of Commercial Fisheries chartered vessel *Silver Bay* captured shrimp and served as a platform for marking. Shrimp captured on the Sanibel grounds March 19 to 22, 1962, were stain-marked by injection of a 0.5 percent solution of fast green FCF, and 2,496 individuals were released at 26 randomly selected sites in the trawling area (fig. 2). Shrimp captured on the Tortugas grounds December 8 to 15, 1962, were stain-marked with a 0.25 percent solution of Trypan blue, and 2,350 individuals were released at 16 randomly selected sites in an area being fished by most of the fleet at that time (fig. 2).

Size compositions of marked shrimp released in both experiments, as determined from samples of marked shrimp ready for release, are shown in figures 3 and 4.

Adult pink shrimp, usually benthic, are particularly vulnerable to predation in the upper water layers, so an underwater release device described by Costello (1964) was used to lower and release marked shrimp near the bottom.

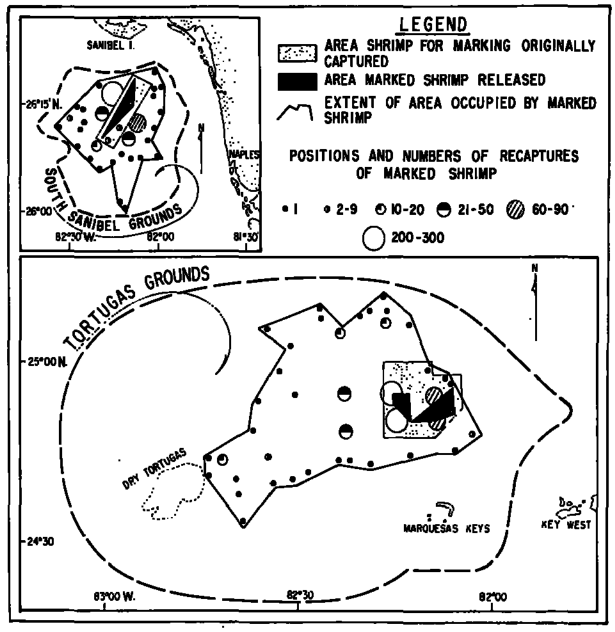

FIGURE 2.—Capture, release, and recapture areas of marked pink shrimp on the south Sanibel and the Tortugas grounds.

On the Sanibel grounds, 563 marked shrimp or 22.5 percent of the experimental population had been recovered by August 30, 1962. On the Tortugas grounds, 784 marked shrimp or 33.3 percent of those released had been recovered by March 29, 1963.

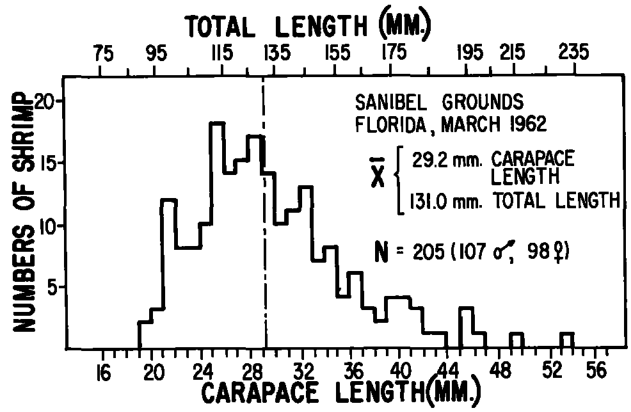

FIGURE 3.—Size composition of a random sample from the marked pink shrimp released on the south Sanibel grounds.

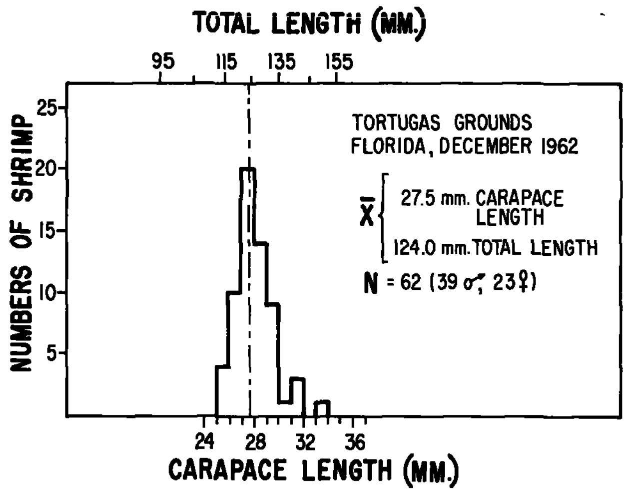

FIGURE 4.—Size composition of a random sample from the marked pink shrimp released on the Tortugas grounds.

DISPERSION OF THE MARKED SHRIMP

On both fishing grounds, plots of the positions of release and recapture of marked shrimp showed that: (1) some marked shrimp dispersed following release and (2) others remained within the immediate area of release for at least 10 weeks.

We used the release and recapture positions in both experiments to define the areas containing the marked shrimp. The outermost positions where marked shrimp were released were plotted and joined to enclose the original areas occupied; as recoveries were received, the outermost recapture positions were joined to delineate the expanding areas occupied. Definitions of the successive areas occupied were obtained with accumulation of several days' recoveries. The location of fishing effort was best established within an area from information compiled for 2-week intervals. For this reason, we selected 2-week intervals as most satisfactory.

Dispersion of marked shrimp from the original release areas proceeded at varying rates (figs. 5 and 6). Movements of the experimental group at Sanibel were generally toward the west and southwest. At Tortugas, dispersion was to the west and northwest. The outlined areas achieved midway between the first and last day of each succeeding 2-week period were selected as best descriptive of the average situation in the periods. At Tortugas, for example, the area occupied by marked shrimp at the midpoint of the first 2-week period after re-

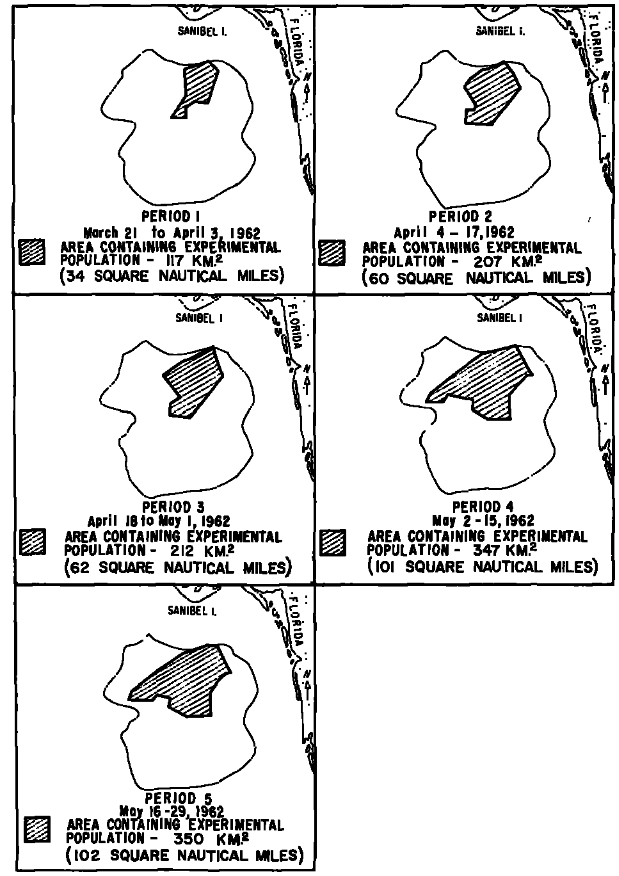

FIGURE 5.—South Sanibel grounds. Area occupied by the population of marked pink shrimp in successive 2-week periods, as determined from recapture locations.

lease was 961 km.² (280 square nautical miles). The area occupied by marked shrimp any day of that 2-week period was considered, therefore, to be 961 km.² (fig. 6). The outlines shown (figs. 5 and 6) and information from interviews on the location of fishing vessels enabled us to separate fishing effort expended in the area containing the experimental group of marked shrimp from total fishing effort on the grounds. During Period 1, in the Sanibel experiment, for example, the total effort expended on the grounds on March 31, 1962, was 16 boat-nights; the effort applicable to the experimental population was 6 boat-nights (table 1).

Description of the expanding area occupied by the marked shrimp permitted a refinement of the original data. For each 2-week period, a factor based on the relative size of the original area and the expanded area was computed. This factor

TABLE 1.—*Fishing effort and recoveries of stain-marked shrimp, south Sanibel grounds, March 21 to May 29, 1962*

Date	Total effort	Effort applicable to experimental population	Area containing experimental population	Factor	Fishing intensity [effort per unit area, i.e., boat-nights per 117 $km.^2$ (34 square nautical miles)]	Recoveries
Period 1	*Boat-nights*	*Boat-nights*	$Km.^2$			*Number*
March 21	4	4	117	1.00	4.00	1
22	2	2	117	1.00	2.00	1
23	1	0	117	1.00	.00	0
24	0	0	117	1.00	.00	0
25	0	0	117	1.00	.00	0
26	0	0	117	1.00	.00	0
27	1	1	117	1.00	1.00	11
28	5	4	117	1.00	4.00	20
29	16	6	117	1.00	6.00	29
30	17	8	117	1.00	8.00	29
31	16	6	117	1.00	6.00	13
April 1	16	6	117	1.00	6.00	31
2	6	3	117	1.00	3.00	0
3	8	4	117	1.00	4.00	0
Period 2						
April 4	8	6	207	0.567	3.40	4
5	7	5	207	.567	2.84	3
6	5	3	207	.567	1.70	0
7	6	3	207	.567	1.70	2
8	12	9	207	.567	5.10	37
9	13	9	207	.567	5.10	43
10	17	11	207	.567	6.24	16
11	16	10	207	.567	5.67	29
12	13	9	207	.567	5.10	27
13	10	7	207	.567	3.97	0
14	2	1	207	.567	.57	2
15	3	2	207	.567	1.13	2
16	0	0	207	.567	.00	0
17	0	0	207	.567	.00	0
Period 3						
April 18	3	2	212	0.548	1.10	3
19	2	1	212	.548	.55	0
20	0	0	212	.548	.00	0
21	0	0	212	.548	.00	0
22	1	0	212	.548	.00	0
23	6	4	212	.548	2.19	0
24	6	4	212	.548	2.19	5
25	15	11	212	.548	6.03	14
26	17	13	212	.548	7.12	21
27	19	10	212	.548	5.48	5
28	15	9	212	.548	4.93	8
29	16	9	212	.548	4.93	1
30	17	9	212	.548	4.93	5
May 1	12	8	212	.548	4.38	5
Period 4						
May 2	13	8	347	0.337	2.70	3
3	7	4	347	.337	1.35	3
4	11	8	347	.337	2.70	4
5	12	11	347	.337	3.71	13
6	14	11	347	.337	3.71	9
7	13	13	347	.337	4.38	10
8	16	15	347	.337	5.06	5
9	19	19	347	.337	6.40	5
10	17	17	347	.337	5.73	11
11	17	18	347	.337	6.07	6
12	16	16	347	.337	5.39	6
13	16	16	347	.337	5.39	4
14	7	7	347	.337	2.36	3
15	1	1	347	.337	.33	0
Period 5						
May 16	1	1	350	0.333	0.33	0
17	1	1	350	.333	.33	0
18	1	1	350	.333	.33	0
19	4	4	350	.333	1.33	0
20	6	6	350	.333	2.00	0
21	10	10	350	.333	3.33	1
22	12	12	350	.333	4.00	16
23	21	11	350	.333	3.66	15
24	11	11	350	.333	3.66	2
25	10	11	350	.333	3.66	7
26	12	12	350	.333	4.00	2
27	15	15	350	.333	5.00	11
28	16	14	350	.333	4.66	4
29	20	19	350	.333	6.33	8

allowed measures of fishing effort to be converted to fishing intensity, i.e., fishing effort per unit area, the form required for subsequent analyses (tables 1 and 2).

ASSUMPTIONS AND JUSTIFICATIONS IN THE ESTIMATION OF MORTALITY

Any analytical approach to estimate mortality from mark-recapture data requires certain assumptions. Those we made are listed below followed by the evidence available to justify each.

Assumption 1:

Negligible losses of marked shrimp due to marking, handling at release, or to loss of marks after release.

Justification:

Experiments on survival of shrimp reported by Costello and Allen (1962) indicate that stain-marked shrimp have almost the same mortality as unmarked shrimp even in the presence of predators. Evidence of the longevity of stain marks (Dawson, 1957) excludes the likelihood that the marks fade or are lost over the period of the present experiments. Shrimp were examined individually before release to be certain that marks were distinct.

TABLE 2.—*Fishing effort and recoveries of stain-marked shrimp, Tortugas grounds, December 14, 1962 to February 7, 1963*

Date	Total effort	Effort applicable to experimental population	Area containing experimental population	Factor	Fishing intensity [effort per unit area, i.e., hours per 961 $km.^2$ (280 square nautical miles)]	Recoveries
Period 1	*Hours*	*Hours*	$Km.^2$			*Number*
December 14	1,466	542	961	1.00	542	8
15	3,025	1,376	961	1.00	1,376	27
16	3,607	1,499	961	1.00	1,499	15
17	3,615	1,346	961	1.00	1,346	33
18	3,221	1,153	961	1.00	1,153	51
19	2,914	725	961	1.00	725	93
20	2,380	522	961	1.00	522	32
21	1,822	619	961	1.00	619	20
22	1,021	493	961	1.00	493	5
23	868	538	961	1.00	538	0
24	891	566	961	1.00	566	0
25	1,160	704	961	1.00	704	2
26	1,592	786	961	1.00	786	5
27	1,958	931	961	1.00	931	11
Period 2						
December 28	2,550	1,492	1,772	0.543	810	20
29	2,556	1,496	1,772	.543	812	17
30	1,360	830	1,772	.543	451	3
31	1,196	689	1,772	.543	374	0
January 1	1,175	713	1,772	.543	387	4
2	1,620	1,130	1,772	.543	613	11
3	2,158	1,502	1,772	.543	815	10
4	2,095	1,332	1,772	.543	723	11
5	2,607	1,787	1,772	.543	970	39
6	2,792	1,628	1,772	.543	884	43
7	1,044	545	1,772	.543	296	8
8	923	627	1,772	.543	340	4
9	1,809	1,397	1,772	.543	758	25
10	2,808	2,215	1,772	.543	1,202	18

TABLE 2.—*Fishing effort and recoveries of stain-marked shrimp, Tortugas grounds, December 14, 1962 to February 7, 1963*—Continued

Date	Total effort	Effort applicable to experimental population	Area containing experimental population	Factor	Fishing intensity [effort per unit area, i.e., hours per 961 km.² (280 square nautical miles)]	Recoveries
Period 3	*Hours*	*Hours*	*Km.²*			*Number*
January 11	3,209	2,432	2,162	0.444	1,080	19
12	3,202	2,414	2,162	.444	1,072	20
13	2,955	2,120	2,162	.444	941	11
14	1,709	983	2,162	.444	436	8
15	1,729	1,135	2,162	.444	504	7
16	1,561	1,205	2,162	.444	535	6
17	2,542	1,694	2,162	.444	752	10
18	3,039	1,887	2,162	.444	838	17
19	3,143	2,126	2,162	.444	944	23
20	3,085	1,976	2,162	.444	877	10
21	844	415	2,162	.444	184	1
22	663	345	2,162	.444	153	0
23	1,882	1,268	2,162	.444	563	4
24	749	483	2,162	.444	214	1
Period 4						
January 25	1,093	897	2,637 (768)	0.365	327	1
26	2,698	2,292	2,637	.365	837	23
27	2,973	2,390	2,637	.365	872	9
28	1,835	1,377	2,637	.365	503	5
29	1,617	921	2,637	.365	336	1
30	2,782	2,116	2,637	.365	772	3
31	3,118	2,630	2,637	.365	960	10
February 1	3,289	2,743	2,637	.365	1,000	4
2	3,185	2,461	2,637	.365	898	5
3	1,843	1,291	2,637	.365	471	4
4	580	236	2,637	.365	86	1
5	488	238	2,637	.365	87	0
6	773	319	2,637	.365	116	0
7	1,095	621	2,637	.365	227	1

Assumption 2:

No losses due to predation during release.

Justification:

The experimental groups, as noted earlier, were returned to the bottom in a release box designed to avoid predation. The effectiveness of this release device had been demonstrated previously by underwater observations (Rounsefell, 1963).

Assumption 3:

Negligible loss of recaptured marked shrimp because of failure to detect them in the commercial catch or failure to report them.

Justification:

Assurance that a high percentage of recaptures were recognized and returned (recovered) was given by the following evidence:

a. Just before these experiments, most fishermen and processing-plant personnel in the area were shown samples of stain-marked shrimp.

b. Eight experiments with stain-marking had been performed recently in these areas, and most fishermen and processing-plant personnel in the Sanibel and Tortugas areas were familiar with stain-marked shrimp.

c. A reward was paid for each recovery when vessels arrived in port or as soon as marked shrimp were found in a processing plant.

d. During both experiments, marked shrimp had many chances to be recognized and returned because all shrimp were "headed" by hand. All Sanibel shrimp were headed at sea, but some Tortugas catches were headed ashore. Ordinarily, a single fisherman may remove heads from 8,000 or more shrimp in a single night. During the Sanibel experiment, fishermen, two to a boat, removed the heads from an average of only about 4,000 shrimp each night (table 3). When they handled less than their capacity, fishermen had time to examine each shrimp and recognize the marked animals. Considerably more shrimp were handled per night by Tortugas fishermen than by Sanibel fishermen. Crew members from many boats told us, however, that they spread catches of shrimp on the deck before heading so that marked shrimp might be easily noticed. Most of the total recoveries (93 percent) were recognized by fishermen at sea and removed from the catch before the return to port (Allen and Costello, 1966). Ashore, Bureau personnel daily reminded workers in processing plants to watch for marked shrimp that passed unnoticed by fishermen at sea.

e. "Planting" experiments indicated a high ratio of recoveries to recaptures. During the time marked shrimp occurred in commercial catches from the Tortugas grounds, small numbers were placed secretly in catches of whole shrimp being unloaded at shore processing plants. These shrimp were of identical size and were

TABLE 3.—*Fishing effort and pink shrimp catch (individuals), south Sanibel grounds, March to May 1962* [1]

Period	Fishing effort	Total shrimp catch [2]	Number of shrimp caught per boat-night [2]
	Boat-nights	*Number*	*Average*
3/21–27	8	24,000	3,000
3/28–4/3	84	403,000	5,000
4/4–10	68	345,000	5,000
4/11–17	44	212,000	5,000
4/18–24	18	45,000	3,000
4/25–5/1	111	434,000	4,000
5/2–8	86	358,000	4,000
5/9–15	93	341,000	4,000
5/16–22	35	105,000	3,000
5/23–29	105	300,000	3,000
Mean catch per boat per night			4,000

[1] Based on 171 interviews of boats landing shrimp at Fort Myers and Fort Myers Beach. Compiled by Bureau of Commercial Fisheries Branch of Statistics.
[2] Rounded to the nearest thousand.

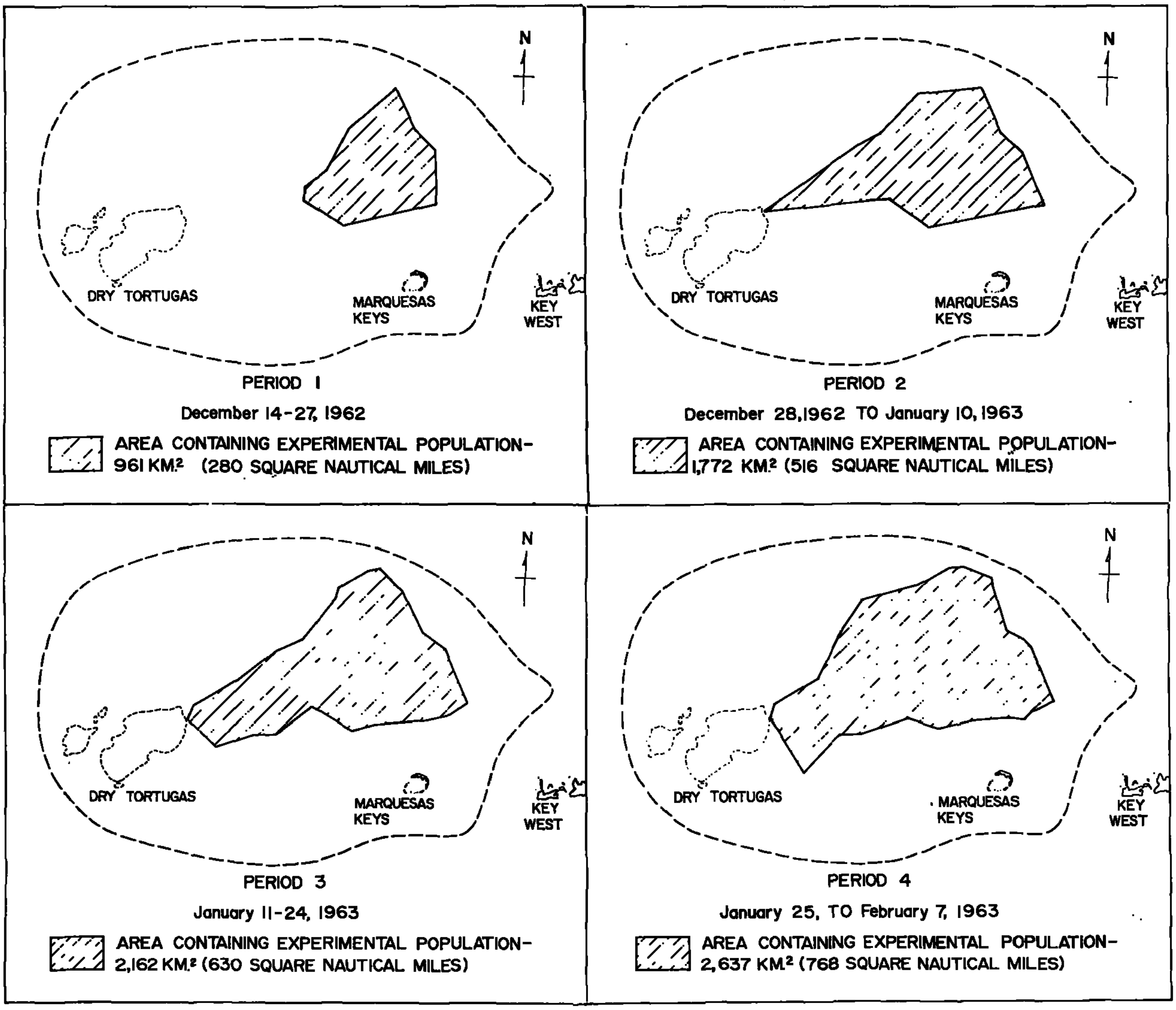

FIGURE 6.—Tortugas grounds. Area occupied by the population of marked pink shrimp in successive 2-week periods as determined from recapture locations.

stained similarly to those released on the fishing grounds. A second mark, not visible to processing plant personnel, was placed on these "planted" specimens so that we could distinguish them from genuine recoveries. Results of these and of later similar experiments indicated that 75 to 89 percent of marked shrimp which enter the shore processing plants are recovered.

We have no direct measure of the percentage of marked shrimp recovered from those headed at sea. In similar mark-recovery experiments in the northern Gulf of Mexico, however, Klima and Benigno (1965) estimated that 83 percent of recaptured marked shrimp were recovered on shrimp boats and 14 percent were recovered in processing plants. They concluded, therefore, that only 3 percent were entirely overlooked.

Assumption 4:

If losses did occur, the ratio of undetected recaptures to recoveries did not change during the periods used in analyses.

Justification:

Field personnel concluded, from daily interviews, that interest in recovering marked shrimp aboard shrimp boats and in processing plants remained constant for at least the first 10 weeks of both experiments. Marked shrimp were recovered over extended periods of time, but recovery and fishing-effort information collected only within the first 10 weeks following release of the marked animals was used for estimating mortality rates for the Sanibel and Tortugas experiments. The period was so restricted because recoveries of marked shrimp reflect their relative abundance in the commercial catch only as long as the interest in recovering them remains constant. The reward is a prime inducement for the return of marked shrimp. Reasonably, when the number of marked shrimp in catches drops markedly, interest wanes and an increasing percentage of recaptures may pass through the fishery unnoticed.

THEORETICAL AND BIOLOGICAL CONSIDERATIONS

Fundamental tenets in computation of mortality estimates are that the decline in numbers in an animal population follows an exponential trend, and that a constant instantaneous mortality coefficient is operative. The latter concept has been applied to many animal populations. Presumably, it may be applied to shrimp. Paulik (1963) noted the acceptability of this concept in short-term experiments, as are being considered here.

Mortality estimates are derived from mark-recovery experiments by measuring density changes in an experimental population. In this application, otter trawls used by the commercial shrimp fleet serve as sampling gear, and decreases in density are reflected in decreased catches of marked shrimp per unit fishing intensity. The average rate of loss is computed and expressed numerically as the instantaneous total mortality coefficient.

At this point, it is pertinent to offer possible explanations for the fluctuations in recoveries of marked shrimp per unit fishing intensity on the Sanibel grounds (table 4), but not on the Tortugas grounds (table 5). It appears, superficially, that decreases in the abundance of the marked shrimp from one time period to the next should be consistently reflected in decreased recaptures per unit fishing intensity. Increased recaptures of marked shrimp at a later time period appear to violate a basic premise upon which the estimate of mortality is based.

The reasons for this apparent anomaly are not entirely clear. Possible sources of bias in the interpretation of mark-recovery data may be introduced by: (1) nonuniform distribution of marked animals over the bottom and (2) inaccurate estimation of fishing effort in relation to the spatial distribution of marked animals. Such difficulties in interpretation of marking experiments were discussed by Ricker (1958).

These sources of bias, however, may not be the only causes of fluctuations in recovery of shrimp per unit fishing intensity. Allen, Delacy, and Gotshall (1960), Konstantinov (1964), Parrish, Blaxter, and Hall (1964), and others recognized that biological activities may affect the catchability of aquatic animals. Wathne (1963) and Fuss and Ogren (1966) noted variable burrowing habits of pink shrimp which may explain variations in shrimp availability to the trawl. Additionally, although pink shrimp are ordinarily benthic, we have frequently observed them in dense schools at or near the surface at night. Similar observations were reported by Burkenroad (1949), Higman (1952), Tabb, Dubrow, and Jones (1962), Iversen and Van Meter (1964), and Joyce (1965). Obviously, vertical movements of

TABLE 4.—*Fishing intensity and numbers of marked shrimp recovered, south Sanibel grounds, March 1962 to May 1962*

[N_o=2,496]

Recovery interval	Marked shrimp recovered	Applicable fishing effort	Area occupied by experimental population	Factor based on area occupied	Fishing intensity (effort per unit area)	Recoveries [1]	Natural logs of recoveries [1]
	Number	*Boat-nights*	*Km.*[2]			*Number*	
3/21–4/3	135	44	117	1.00	44.0	139.9	4.94092
4/4–4/17	165	75	207	.567	42.5	177.0	5.17615
4/18–5/1	67	80	212	.548	43.8	69.8	4.24563
5/2–5/15	82	164	347	.337	55.3	67.6	4.21361
5/16–5/29	66	128	350	.333	42.6	70.6	4.25703
5/30–8/30 [2]	47	----------	----------	----------	----------	----------	----------

[1] Per (mean) 45.6 boat-nights fishing intensity.
[2] Recoveries during this final period were not used in analysis.

TABLE 5.—*Fishing intensity and numbers of marked shrimp recovered, Tortugas grounds, December 1962 to February 1963*

[N=2,350 [1]]

Recovery interval	Marked shrimp recovery	Applicable fishing effort	Area occupied by experimental population	Factor based on area occupied	Fishing intensity (effort per unit area)	Recoveries [2]	Natural logs of recoveries [2]
	Number	*Thousand hours*	*Km.*^{2}			*Number*	
12/14–12/27	302	11.8	961	1.00	11.8	241.8	5.4881
12/28–1/10	213	17.4	1,772	0.543	9.4	214.1	5.3665
1/11–1/24	137	20.5	2,162	.444	9.1	142.2	4.9572
1/25–2/7	67	20.5	2,637	.365	7.5	84.4	4.4356
2/8–3/29 [3]	29	----------	----------	----------	----------	----------	----------

[1] In analysis, this number adjusted to 2,314 for the mean release date of 12/14/62.
[2] Per (mean) 9,450 hours of fishing intensity.
[3] Recoveries during this final period were not used in analysis.

shrimp in the water mass will affect their availability to a trawl fishing on or near the bottom.

Over short periods of time then, we may normally expect considerable variability in catches of pink shrimp (unmarked or marked) which is independent of the decrease in a population with time.

DEFINITIONS OF NOTATIONS

Notations and symbols suggested by Beverton and Holt (1957) and Holt (1960) are used in our analysis and summary. Definitions follow:

Z=Instantaneous total-mortality coefficient

F=Instantaneous coefficient of mortality caused by fishing

M=Instantaneous coefficient of mortality by (natural) causes other than fishing

X=Instantaneous coefficient of other loss in marking theory, i.e., losses in the experimental population due to all causes except recapture (true natural mortality plus losses of individuals which for any reason become unavailable for recapture)[2]

f=Fishing intensity (fishing effort per unit area)

N_0=Initial size of the experimental population (number in batch of marked shrimp liberated at time zero)

n=Number of marked shrimp recaptured in a given period, e.g.,

n_1=Number in first period, n_2=Number in second period, etc.

ANALYSIS

Variations in catch per unit fishing intensity described previously do not nullify the value of this information in deriving mortality estimates. Population decreases with time during the experimental period are reflected well by these data. An analytical technique designed to yield mean instantaneous mortality coefficients, accordingly, was chosen.

The numbers of marked shrimp recaptured each 2-week period varied considerably in both experiments in response to fluctuating fishing intensity. As suggested by Kutkuhn (1966), the numbers of recoveries that accumulate each period may be corrected to unit fishing intensity and analytical methods given by Beverton and Holt (1957, pp. 185–191) applied. A factor of 45.6, the average number of boat-nights [3] of fishing intensity per 2-week period, was applied to Sanibel recoveries to convert them to a unit basis (table 4); a factor of 9,450, the average number of hours of fishing intensity per 2-week period, was used to convert the Tortugas recoveries (table 5). We recognize, however, that this method of analysis is better suited to the Tortugas experiment than to the Sanibel experiment where fishing intensity fluctuated considerably from period to period.

Lines fitted to the natural logarithms of adjusted recoveries (figs. 7 and 8) indicate that the decline in numbers of both experimental groups followed a linear trend. Regression lines have a slope equal to minus (F+X) or Z. For Z, the instantaneous total mortality coefficient, the regression equations yielded values of 0.233 for Sanibel and 0.357 for Tortugas. Values of 153.4 and 121.5 (designated n_1 and n_2) were obtained by substituting appropriate units of time in the regression equation for Sanibel. These figures are

[2] As defined by Beverton and Holt (1957). Holt (1960) gave a varied meaning.

[3] Sanibel fishing effort was reported to us in boat-nights rather than in hours. No valid conversion factor was available to convert boat-nights to hours; therefore, Sanibel effort was used in the form of boat-nights as originally reported.

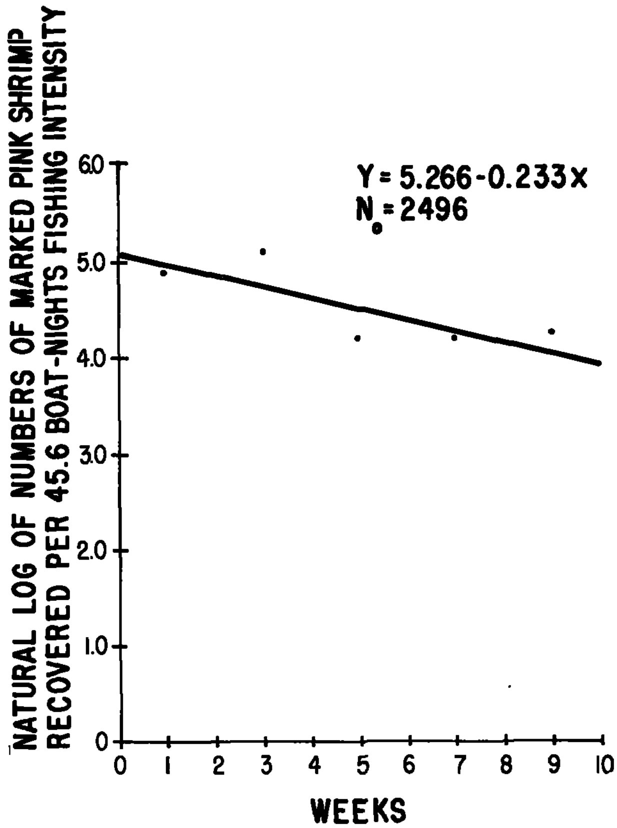

FIGURE 7.—Mortality of marked pink shrimp, south Sanibel grounds, March 21 to May 29, 1962.

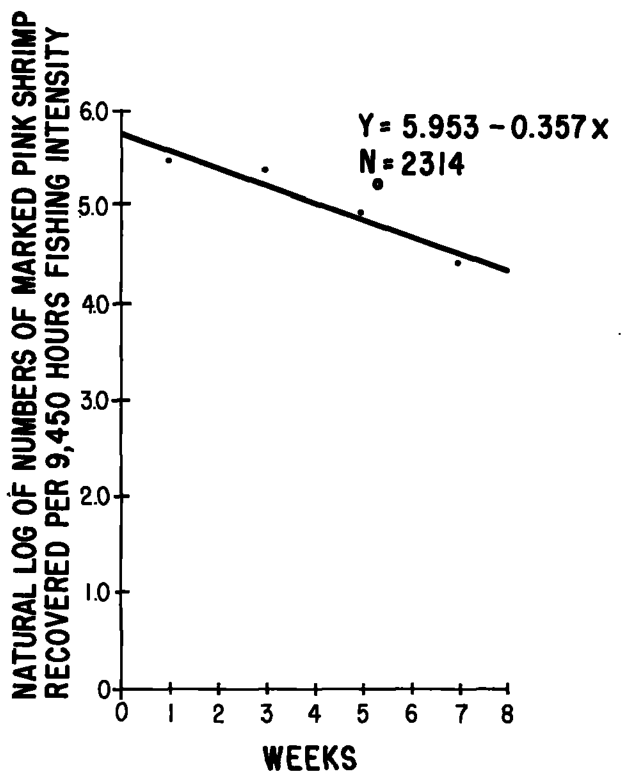

FIGURE 8.—Mortality of marked pink shrimp, Tortugas grounds, December 14, 1962, to February 7, 1963.

the theoretical numbers of recoveries of marked shrimp that would have occurred in the first and second 2-week periods following release of the experimental population with fishing intensity constant at 45.6 boat-nights per 2-week period. For the Tortugas fishery, on the basis of 9,450 hours of fishing intensity per 2-week period, a like procedure gave values of 269.3 and 188.5 for n_1 and n_2. With these numerical values for n_1 and n_2, and the N_0 figures given in tables 4 and 5, we may enter the following expressions from Beverton and Holt (1957, p. 190).

$$F=\frac{\frac{n_1}{\tau}\log_e\left(\frac{n_1}{n_2}\right)}{N_o\left(1-\frac{n_2}{n_1}\right)}$$

$$X=\frac{1}{\tau}\left\{\log_e\left(\frac{n_1}{n_2}\right)\right\}\left\{1-\frac{n_1}{N_o\left(1-\frac{n_2}{n_1}\right)}\right\}$$

By application of these expressions, we divide the Z values given above into fishing mortality (F) and "other losses" components (X).

These calculations gave the following estimates:

	Mortality	Instantaneous rates	Rates (percent) per 2-week period
Sanibel	Fishing	0.0689	6.8
	Other	.1644	14.8
Tortugas	Fishing	.1385	13.1
	Other	.2185	19.7

SUMMARY

Mortality estimates for the Sanibel population have not been previously reported. For the Tortugas population, estimates derived here indicate mortality higher than was reported by Iversen (1962), but considerably lower than was calculated by Kutkuhn (1966).

In either the Sanibel or Tortugas experiment the values obtained for X (coefficient of other loss) cannot be readily accepted as estimates of

M (coefficient of true natural mortality). By definition, X includes M, together with losses from all other causes except fishing. Losses due to migration from the area of fishing, and mortality attributable to marking, handling, or the release procedure can contribute a considerable loss to the experimental group of animals. This fact must be given consideration in the use of X as an estimate of M.

Consideration of possible management implications calls for recognition that operation of trawls may have complex effects upon a resident shrimp population (Lindner, 1936). Also, cessation of trawling affects the population. The mortality estimates we have given were calculated from data assembled while a sizable fishery was in progress. The coefficient of true natural mortality may shift considerably when a regulatory measure, e.g., closure of the fishery, is applied.

F, as a function of fishing effort, fluctuates over short periods of time. The value of M also changes in response to such factors as varying predation by migratory schools of fish. The values derived here, however, for shrimp of the sizes in the experiment, may establish the approximate levels for offshore pink shrimp fisheries. These parameters, together with supplementary information and recommendations by Lindner (1966), may be used as a basis for management of the valuable Sanibel and Tortugas resources.

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