Shrimp Mortality Rates Derived from Fishery Statistics[1]

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Abstract

This paper seeks to define probable levels of mortality applicable to pink shrimp *(Penaeus duorarum)* on the Tortugas (Florida) fishing grounds. Analyses based on the size composition of shrimp landed by the commercial fishery suggest that average values of Z lie from 0.07 to 0.12 for females and 0.10 to 0.16 for males, when expressed as weekly rates. Estimates of F for 7-day intervals derived by the swept area method range seasonally from 0.02 to 0.16 and have an annual average of 0.09. These rates are interpreted as approximations rather than exact values because of possible shortcomings in the data used.

INTRODUCTION

THE RAPID GROWTH of shrimp fisheries in recent years has lead to increased research, but several aspects of shrimp population dynamics are still poorly understood. At the present stage of knowledge, there is particular need for more definitive information about rates of mortality. This type of data is required to predict yields when fishing is regulated and, hence, is a basis for management regulations.

Recent literature provides several estimates of mortality for stocks of *Penaeus* that support commercial fishing off the southern coast of the United States. However, reported values include a range so broad that conflicting man-

stock were developed from mark-recapture experiments, whereas the present work is based on the size composition of commercial landings and on assumed relations between fishing intensity and fishing mortality.

MORTALITY ESTIMATES FROM THE LITERATURE

Published estimates of mortality and growth rates derived from marking experiments are summarized in Table 1 for three closely related species of *Penaeus* to provide background information. Mortality is listed in terms of instantaneous rates of fishing (F), natural (M) and total mortality (Z). Some values have been adjusted from those appearing in the original papers so that all pertain to intervals of 1 week. Also, the symbol M is used here rather than X, which some authors used to indicate loss rates resulting from natural mortality and experimental conditions. Growth rates are included because they are pertinent to later discussions. They are listed in terms of the

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instantaneous coefficient of growth (K) from the von Bertalanffy equation (see Ricker, 1958: 194, equation 9.5) where K is the rate at which the maximum length ($l\infty$) of an organism is approached. Full explanations of these terms can be found in Beverton and Holt (1957). The point of particular interest in Table 1 is the wide range in rates of mortality within and between species. There is no simple explanation for this variation, although part of it probably can be attributed to conditions that bias estimates based on mark-recapture experiments.

In addition to the literature cited in Table 1, Neal (1968) reported maximum estimates of the proportion of populations of *P. aztecus* that die each week from fishing mortality. His figures, based on the virtual population technique, range from 0.02 to 0.32 in terms of weekly instantaneous rates (F).

TABLE 1
Weekly Instantaneous Rates of Mortality (F, M, Z) and Growth (K) from Mark-recapture Studies of *Penaeus* off the Southern United States

Genus and species	F	M	Z	K	Reference
Penaeus duorarum	0.96	0.55	0.76,1.51	0.07	Kutkuhn (1966)
do.	0.16-0.23	0.02-0.06	0.22-0.27	0.04-0.06	Berry (1967)
do.	0.03,0.07	0.08,0.11	0.11,0.18	--	Costello & Allen (1968)
Penaeus setiferus	--	--	--	0.07	Lindner & Anderson (1956)
do.	--	--	0.46	0.12	Klima (1964)
do.	0.06-0.19	0.08	0.14-0.27	0.09[1]	Klima & Benigno (1965)
Penaeus aztecus	0.06	0.21	0.27	--	Klima (1964)
do.	--	--	0.99,1.24	0.07	McCoy (1968)

[1]Estimate of K not included in published material.

The implications of mortality rates to the management of shrimp fisheries can be seen in three papers concerning the Tortugas fishery. From yield calculations based on high rates of mortality (Z=1.51), Kutkuhn (1966) concluded that Tortugas shrimp should be harvested as soon as they reach a size acceptable to markets, i.e., about 70 shrimp per pound (with head removed). Similar calculations with lower rates (Z=0.22 to 0.27) caused Lindner (1966) and Berry (1967) to suggest that fishing be postponed until shrimp have grown considerably larger than the minimum commercial size.

TOTAL MORTALITY FROM SIZE COMPOSITION DATA

In view of the inconsistency of estimates available from mark-recapture studies, it is worthwhile to investigate other means for measuring mortality rates. An approach that has been applied to many types of populations relates age composition to the rate of total mortality. This relation is based on the obvious fact that few members of a population reach old age when mortality is high and, conversely, old individuals are relatively abundant when mortality is low. Although the age of individual shrimp cannot be determined, this approach is useful if size is converted to age by means of growth equations.

Size composition data for pink shrimp were gathered as part of a comprehensive study of the Tortugas fishery conducted by the Bureau of Commercial Fisheries for 3 years beginning in September 1963. During this study, biologists obtained length measurements (anterior end of rostrum to the posterior tip of the telson) of shrimp landed by the commercial fleet. From 100 to 300 measurements were made from a landing as shrimp were transferred by conveyor belts from vessels to processing plants. Records also were kept to indicate the size composition determined at processing plants for each sampled landing. These records were in terms of the average number of headless shrimp per pound (15-20, 21-25, ...).

Several steps were required to proceed from the measurements collected to the desired end product—estimates of the average length composition of shrimp on the fishing grounds. First, length measurements were combined for landings that processors had graded into a single size category. This procedure gave frequency distributions describing the length composition of shrimp in a given category (Table 2). Although they are not shown, distributions similar to those in Table 2 were tabulated for each sex. Next, the

TABLE 2
Frequency Distributions Describing the Length Composition of *P. duorarum* in Landings Graded into Single Size Categories

Total length (mm)	Number of shrimp by size category (Headless shrimp per pound)						
	15-20	21-25	26-30	31-40	41-50	51-67	>67
60-69	0	0	0	0	0	2	0
70-79	0	0	0	0	3	18	30
80-89	0	0	0	4	44	307	383
90-99	0	1	15	190	498	1,258	1,563
100-109	1	15	109	958	2,885	3,514	2,883
110-119	4	136	488	3,068	5,482	4,132	2,688
120-129	25	367	1,016	4,517	4,943	2,839	1,303
130-139	154	723	1,224	3,790	3,056	1,410	545
140-149	519	924	1,187	3,021	1,893	857	265
150-159	639	796	875	1,821	1,006	394	116
160-169	488	670	544	1,174	547	264	33
170-179	416	451	352	709	261	153	16
180-189	196	300	157	333	109	55	2
190-199	89	102	43	122	40	16	2
200-209	23	18	10	32	6	1	0
210-219	7	3	4	1	0	1	0
220-229	1	0	1	0	0	0	0
Shrimp measured	2,562	4,506	6,025	19,740	20,773	15,221	9,829
Landings sampled	12	43	49	150	164	110	61

total weight of shrimp landed from the Tortugas grounds in each size category[2] was divided by the weight of measured shrimp in that category. In turn, this ratio was multiplied by the number of shrimp measured in a 10-mm length

[2]*Gulf Coast Shrimp Data* published monthly in the Current Fisheries Statistics series by the U.S. Fish and Wildlife Service.

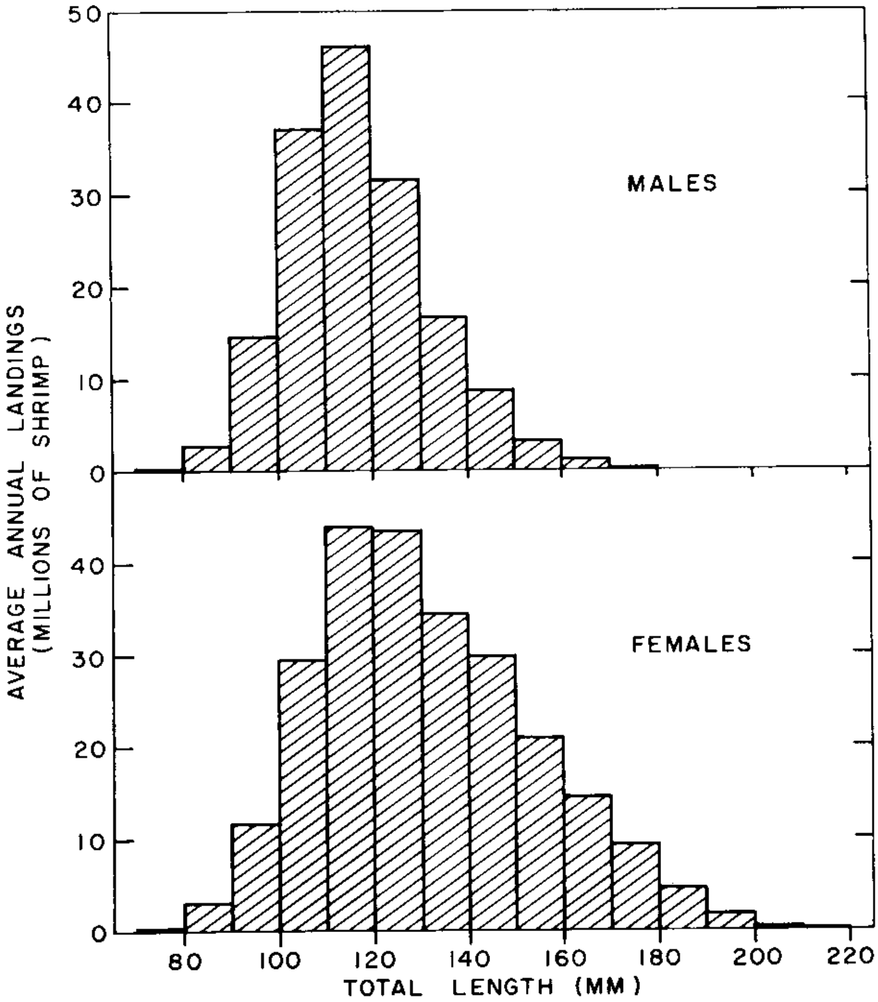

FIG. 1. Calculated average annual length distributions for male and female *P. duorarum* landed from the Tortugas grounds 1956-65.

group to estimate the total number of that size in landings. The average length composition of shrimp landed annually in the 10-year period 1956-65 was calculated in this manner (Fig. 1). Provided that shrimp of all sizes were exposed to equivalent amounts of fishing, this procedure should give a reasonable indication of their relative abundance on the grounds.

Rates of total mortality can be estimated from the decline in abundance of large shrimp (Fig. 1), once length has been converted to age. Shrimp measuring 120 mm or more were considered to be fully recruited to the fishery and accurately represented by sample measurements. The age of shrimp in a

TABLE 3

An Illustration of the Method Used to Calculate the Rate of Total Mortality (Z) for Female Shrimp when $K = 0.08$ and $\ell_\infty = 200$

Length group	Number of shrimp	ℓn N	Age
(Mm)	(Millions)		(Weeks)
120-129	43.648	17.592	12.3
180-189	4.651	15.353	32.4

$$Z = \frac{17.592 - 15.353}{32.4 - 12.3} = 0.11$$

length group was calculated by solving the von Bertalanffy equation for t with each of several sets of values for K and $l\infty$. Table 3 illustrates the method used to compute rates of total mortality (Z) from estimates of abundance and age.

Estimates of Z calculated from the length distributions of Fig. 1 are plotted against K in Fig. 2. This plot provides a convenient means for delimiting probable ranges in Z when growth parameters are not known with certainty. On the basis of the length data shown in Fig. 1, a reasonable value of $l\infty$ is about 175 mm for males and about 205 mm for females. Reference to Fig. 2 indicates that Z values for 7-day intervals calculated for these maximum lengths are from about 0.10 to 0.16 for males and 0.07 to 0.12 for females, when K ranges from 0.04 to 0.07 on a weekly basis.

These estimates of Z are interpreted as average rates that apply over an annual cycle. Higher or lower rates could be expected during a year as fishing intensity changed. In comparing these estimates to those determined from mark-recapture experiments, it should be recognized that marked shrimp are usually released when and where the fishery is most active to ensure that a sufficient number will be recaptured. As a result, rates based on marking experiments tend to be above the average level for a population.

ESTIMATES OF FISHING MORTALITY FROM EFFORT DATA

The annual levels of mortality discussed in the preceding section serve as a useful check on other estimates, but have limited value from the viewpoint of management planning. Realistic calculations of yield require information about short-term variations in mortality because the average fishable life span of Tortugas shrimp is brief—probably less than 3 months, although a few shrimp may survive for 18 months or more. Provided that certain types of information are available, insight into changes in mortality rates over short intervals can be gained from records of commercial fishing operations.

Detailed data on the activities of the Tortugas shrimp fleet were collected by an intensive interview survey conducted for 3 years (1963-1966) at Key West, and intermittently at Marathon and Ft. Myers, Florida. During an interview, inquiries were made about the size categories and weight of shrimp

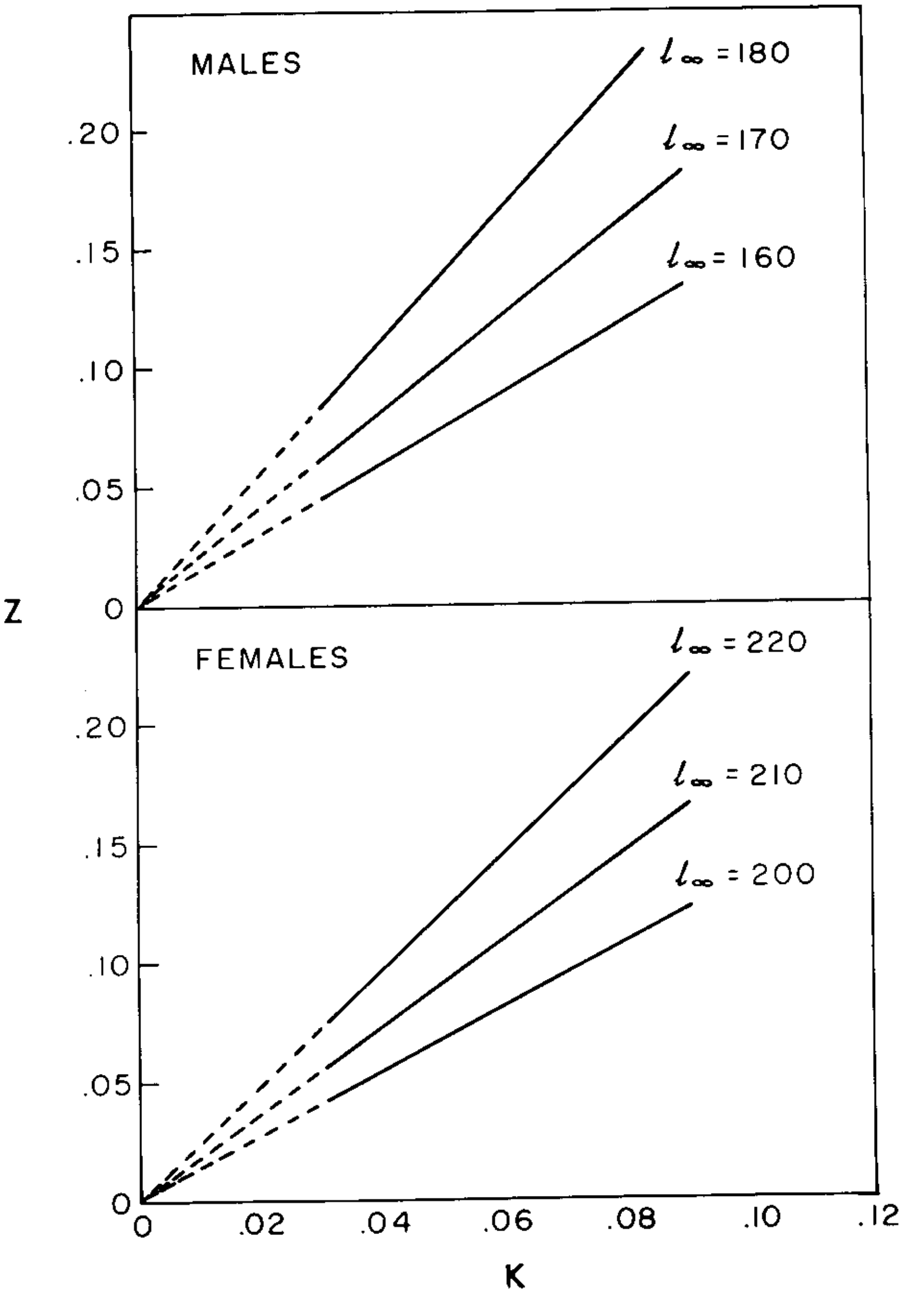

FIG. 2. The relation between K and Z (7-day intervals) for various values of l_∞ for male and female *P. duorarum*. Z was determined from the data represented in FIG. 1.

landed, time spent trawling, areas fished, and details of the vessel, gear and crew employed. Particular attention was given to determining where a vessel trawled so that data could be assigned to specific parts of the fishing area. For this purpose, a grid was imposed on a map of the grounds, dividing the fishing area into squares that encompassed 25 square nautical miles (Fig. 3). Interviews obtained during the survey represented more than 75% of landings at Key West and about half of the total landings from the grounds.

Beverton and Holt (1956) provide a discussion of the theoretical basis for relating fishing mortality to fishing intensity by the swept area method. In essence, the fishing mortality (F) that results when a shrimp vessel makes a trawl haul is equal to the fraction of the population that is caught. If the stock is distributed evenly and the gear catches all shrimp in its path, the ratio of the area traversed to the total area of the grounds is an estimate of F. Similarly, the fishing mortality generated by the entire fleet during a time interval is the sum of the area trawled by all vessels divided by the total area. To apply these principles to the Tortugas fishery, it is necessary to estimate (1) the total area of the grounds, (2) the area covered by trawling, (3) the proportion of shrimp retained by the gear and (4) the distribution of shrimp on the grounds.

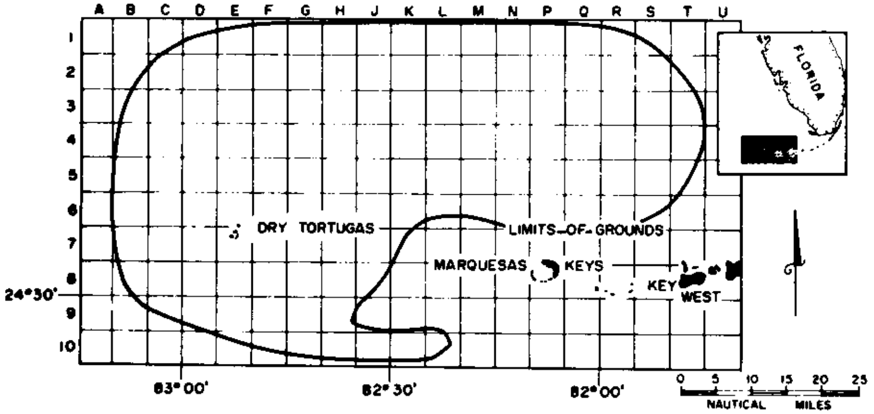

FIG. 3. Grid system used to designate fishing locations on the Tortugas grounds.

An element of subjective judgment is required to estimate the total area of the fishing grounds because the spatial distribution of the fleet changes seasonally in response to catch rates, weather, number of vessels, etc. The best available information is from the interview survey, wherein fishing locations were recorded by grid zones. The outer boundary of the fishery that is indicated in Fig. 3 was established by noting the subareas where fishing occurred at least once in the 3-year period. It encloses about 3,000 square nautical miles, some of which was fished infrequently and, therefore, should not be considered in the present context. A more reasonable estimate, and the one used in later calculations, is the maximum area fished in a month (2,400 square nautical miles), as indicated by the number of squares in which trawling was reported.

Similar estimates of fishing area were made for each month of the study

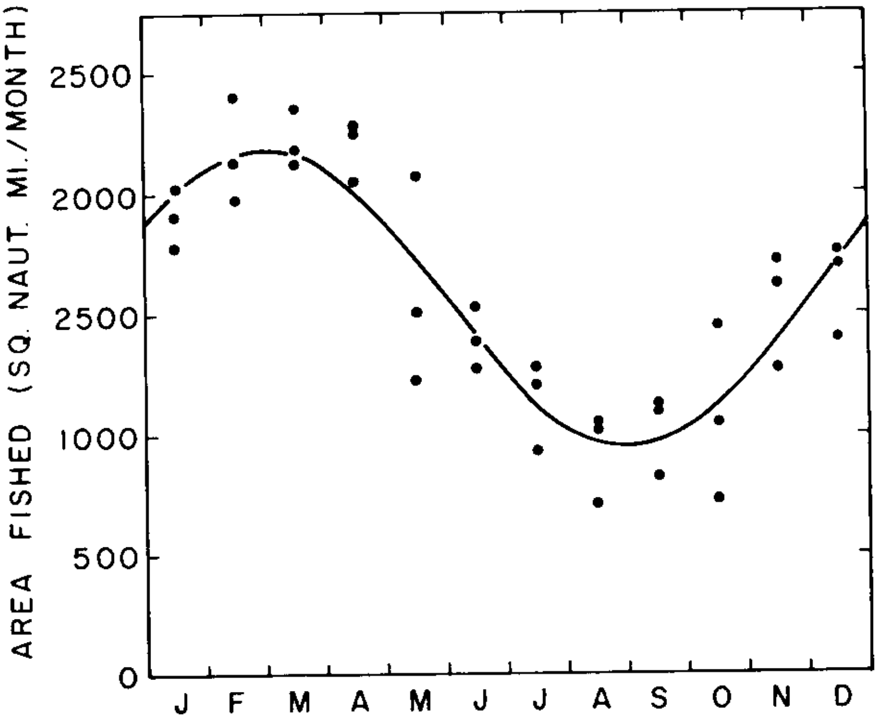

FIG. 4. Seasonal variations in the size of the area fished on the Tortugas grounds, October 1963-September 1966. (A sine curve was fitted to the data to make the annual cycle more obvious.)

period and are used in Fig. 4 to illustrate seasonal changes in the scope of operations. The annual cycle shown in this figure corresponds closely to the pattern of increases and decreases in fishing effort, suggesting that changes in the size of the area fished are a direct result of the amount of fishing (Fig. 5). Presumably, high fishing intensities lead to reduced catch rates and competition for fishing space which, in turn, cause some fishermen to move to the outer portions of the grounds.

The second type of information required—the area trawled by all vessels—can be computed as the product of fishing time and area covered per unit time. The ratio of total landings, as indicated by published reports (Footnote 2), to average catch rates from interview data provides an estimate of total fishing time by months, but less information is available for establishing the area covered during trawl hauls. A survey of nets in use on the Tortugas grounds between January and March 1965 indicated that all vessels towed twin trawls and that their combined width averaged 92 feet (Table 4). The effective mouth opening of a trawl, however, is considerably smaller than its total width, due to the effects of water pressure during towing. Limited experiments by Berry and Hervey (1965) imply that the reduction amounts to about 30% of the total width. On this basis, the average width of the path covered by Tortugas vessels is estimated to have been 65 feet. The length of this path depends on towing speed, and no firm data about average speeds are available in the literature. Conversations with fishermen and others associated with the fishery have indicated that 2.5 knots is a reasonable figure. Employing these estimates, the bottom area swept in 1 hour by a vessel's trawls was slightly less than 1 million square feet or 0.027 square nautical miles.

In the absence of detailed information, it is necessary to assume that all shrimp in the path of a trawl are caught. This assumption is probably close to the fact, although a small fraction may remain burrowed in the sediment, escape under the net, or pass through the net's meshes. Evidence from comparative catches by regular and electrical trawls suggests that few Tortugas shrimp are burrowed at night, the time when most trawling is done (Seidel, 1969). Likewise, the probability of escapement through trawl meshes is considered small in view of preliminary data presented by Berry and Hervey (1965).

The final point to establish is that shrimp are distributed uniformly over the fishing grounds or, stated differently, that a unit of fishing effort produces the same catch at any location. Most people familiar with shrimp fishing are aware that shrimp often are not evenly distributed at a given time, but this premise is not unreasonable when one considers average conditions over in-

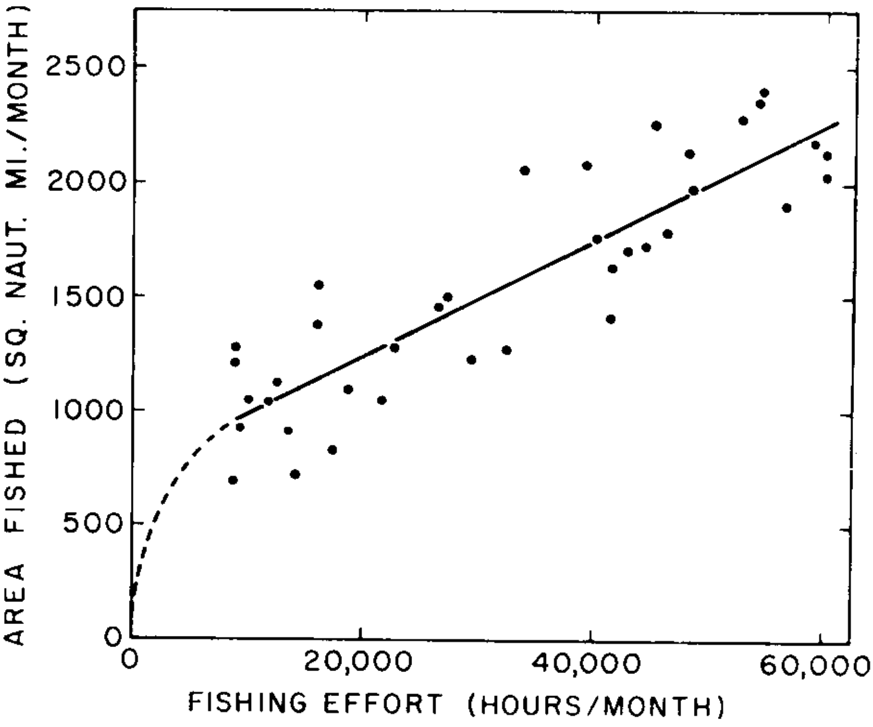

FIG. 5. Relation between the size of the area fished and the amount of fishing by months, September 1963-September 1966. (Fishing effort was adjusted to correspond to a 30-day month for this plot.)

TABLE 4
Size Frequency Distribution of Trawls Used by Tortugas Fishermen, January-March 1965
(Figures represent the combined width of twin trawls, measured along meshes of the head-rope.)

Width (ft)	Number
60-69	1
70-79	23
80-89	104
90-99	73
100-109	28
110-119	8
120-129	6
130-139	2
140-149	2

tervals of a month. The major factors influencing catch rates are the movement of young shrimp onto the grounds and the spatial distribution of fishing activities. Of the two, the effect of fishing is probably more significant on relatively small and heavily fished grounds because fishermen move quickly to locations where they can improve their catches. Previous analyses (Berry, 1967) demonstrated that Tortugas fishermen are alert to changes in shrimp abundance and operate in a manner that effectively levels earning opportunities (value of shrimp caught per hour). Likewise, their activities tend to smooth differences in catch rates within the fished part of the grounds.

The density of shrimp in unfished parts of the grounds is unknown and can only be inferred from catches made on the margins of the fished area. To distinguish marginal fishing on a consistent basis, the assumption was made that 10% of the total fishing effort in any month represented search activities, i. e., fishermen who were seeking better catch rates than those available in heavily fished locations. The search area for a given month was determined by summing effort data from the largest possible number of grid zones (Fig. 3) that included 10% of the fishing effort recorded from interviews. The validity of the search designation is indicated by the fact that, over the 37-month study period, the size of the search area in each month was almost equivalent to the area supporting 90% of fishing (Table 5).

Assuming that catch rates in the search areas were indicative of shrimp densities in unfished waters, it follows that, under average conditions during a month, a unit of effort anywhere on the grounds produced a similar weight of shrimp. Although the number rather than the weight of shrimp caught per unit of effort is the statistic of interest, the bias introduced by using weight is not considered serious in view of other possible sources of error in the present treatment.

Once the foregoing conditions have been satisfied within acceptable limits,

TABLE 5

Catch Rates in Areas of the Tortugas Grounds that Supported Intensive Fishing and Search Activities, September 1963–September 1966. Fishing Time of all Vessels and the Time Recorded During Interviews Are Included to Indicate the Reliability of Estimates

Month and year	Catch Rates		Area Fished		Fishing Time	
	Intensive fishing	Search activities	Intensive fishing	Search activities	Total	Interview
	Pounds per hour		Square nautical miles		Thousands of hours	
1963						
September	17	21	525	375	13.5	4.5
October	53	43	600	450	22.3	9.4
November	40	35	675	600	32.6	11.9
December	31	32	850	550	42.9	15.8
1964						
January	27	30	1100	800	58.5	18.2
February	22	21	1300	1100	52.7	25.6
March	20	23	1175	1175	56.0	31.4
April	28	20	1025	1025	33.9	18.1
May	23	22	600	625	30.5	9.6
June	23	27	775	500	22.8	7.1
July	26	25	650	275	9.8	3.5
August	47	37	425	275	9.0	2.6
September	44	43	450	375	17.5	6.1
October	50	47	450	275	14.6	5.3
November	41	34	925	800	44.6	17.2
December	31	27	900	850	41.4	13.2

Month and year	Catch Rates		Area Fished		Fishing Time	
	Intensive fishing	Search activities	Intensive fishing	Search activities	Total	Interview
1965						
January	24	22	1100	925	62.0	28.7
February	20	20	1050	925	45.3	28.0
March	26	22	950	1175	49.6	34.6
April	16	16	975	1300	52.6	36.8
May	15	13	800	700	28.3	22.7
June	15	14	950	600	16.1	11.7
July	19	20	650	550	9.2	6.5
August	30	23	575	475	10.5	8.1
September	53	35	575	550	12.5	8.5
October	70	63	575	875	27.4	18.2
November	51	46	725	900	41.4	22.5
December	37	34	775	925	44.3	17.6
1966						
January	31	35	825	950	47.8	22.4
February	29	29	1100	1025	56.0	23.9
March	23	18	1175	1000	61.0	29.4
April	19	15	1250	1000	45.2	26.8
May	16	15	975	1100	40.6	28.9
June	20	18	750	625	16.0	11.9
July	26	17	700	575	9.2	5.1
August	35	33	575	450	12.0	7.4
September	33	29	525	575	18.9	11.0

TABLE 6

Weekly Rates of Fishing Mortality (F) on the Tortugas Grounds by Months from September 1963 through September 1966

Month	1963	1964	1965	1966	Average
January	--	0.15	0.16	0.12	0.14
February	--	0.14	0.13	0.16	0.14
March	--	0.14	0.13	0.15	0.14
April	--	0.09	0.14	0.12	0.12
May	--	0.08	0.07	0.10	0.08
June	--	0.06	0.04	0.04	0.05
July	--	0.03	0.02	0.02	0.02
August	--	0.02	0.03	0.03	0.03
September	0.04	0.05	0.03	0.05	0.04
October	0.06	0.04	0.07	--	0.06
November	0.09	0.12	0.11	--	0.11
December	0.11	0.10	0.11	--	0.11
Average	--	0.09	0.09	--	0.09

-- No Data

calculations of fishing mortality rates are straightforward. If the bottom area swept in an hour of trawling is 0.027 square nautical miles and the total area of the fishing grounds is 2,400 square nautical miles, then

$$F=\frac{0.027}{2,400}(\text{total fishing time in hours})$$

Taking the total fishing time listed in Table 5 for February 1965 as an example, the instantaneous rate of fishing mortality for the month is 0.51. Dividing this figure by 4 gives a weekly rate of 0.13. Estimates of F derived in this manner appear in Table 6 for each month of the study period.

There obviously are several ways in which these estimates could be in error and they should not be interpreted as exact values. They are useful, however, as in indication of the probable magnitude of fishing mortality and its seasonal variation.

The remaining type of mortality—that resulting from natural causes (M)—can be approximated by deducting F from Z. Subtracting the average annual level of F listed in Table 6 (0.09) from the average values of Z derived from size composition data (roughly, 0.10-0.12 when both sexes are considered), suggests that natural mortality has a relatively small value. Provided that they are reasonably accurate, these levels of M lead to the conclusion that there is merit to management procedures designed to protect small shrimp, as suggested by Lindner (1966) and Berry (1967).

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