MORTALITY ESTIMATES FOR THE NEW ZEALAND
ROCK LOBSTER, *JASUS EDWARDSII*

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ABSTRACT

The instantaneous total mortality rate and instantaneous fishing mortality rate were estimated for an exploited population of male New Zealand rock lobster, *Jasus edwardsii*. Instantaneous total mortality rate estimates were made from the seasonal size-frequency distribution of landed rock lobsters using three different methods and ranged from 0.64 to 1.07. Estimates of both mortality rates were also made from the rate of return of tagged rock lobsters over an entire year and by adjusting the rate for an 8- or 9-month fishing season. These estimates of the instantaneous total mortality rate ranged from 1.92 to 3.13 and were considered too high to be representative of the entire exploited population. Instantaneous fishing mortality rate estimates from the tag returns ranged from 1.17 to 1.85, with the lower rates based on an 8- or 9-month fishing season. Using the results from both types of analyses, and the observed lifespan of rock lobsters in the fishery, the best estimates of the instantaneous total mortality rate are between 1.00 and 1.50 and of the instantaneous fishing mortality rate between 0.90 and 1.40, assuming the instantaneous natural mortality rate equals 0.10.

Knowledge of the total mortality rate, and its components of fishing and natural mortality, is essential for an adequate understanding of the population dynamics of an exploited population. Mortality rates are generally estimated from 1) the age composition of the population, with the age composition of the catch serving as the population sample; 2) the results of mark and release experiments; or 3) some relationship between catch and effort.

The purpose of this investigation is to derive and compare estimates of mortality rates for an exploited population of the New Zealand rock lobster, *Jasus edwardsii*. Rock lobsters do not contain any structural parts retaining annual marks, so estimates of mortality rates cannot be made from the age composition of the catch. However, the total mortality rate can be estimated by analysis of the size-frequency distribution of the catch, and three different methods are employed. The results of these analyses are compared with estimates of the total mortality rate derived from a tag-recapture study conducted over the same fishing season and in the same area from which the size-frequency distributions were drawn. The results of the marking experiment are also used to estimate the fishing mortality rate, which is then compared with the estimates of the total mortality rate using a previously derived estimate of the natural mortality rate.

METHODS AND RESULTS

Analyses of Size-Frequency Distributions

The three methods used to estimate the total mortality rate from the size-frequency distribution were: 1) the approximate method of separating a polymodal size-frequency distribution into its component distributions described by Bhattacharya (1967); 2) Method 2 of Van Sickle (1977), where growth and size-frequency data were used to estimate mortality on a size specific basis; and 3) the partitioning of a size-frequency distribution by the average annual growth increment into components approximating age classes (average annual growth increment method) described by Hancock (1965).

Mortality rates were estimated from the size-frequency distribution of male rock lobsters landed from the Gisborne local area during the 1976-77 fishing season. Females constitute only a small proportion of the landings from this area, so their mortality rates were not estimated. Gisborne is a major fishing port located on the east coast of the North Island (Figure 1). The Gisborne local area is defined as encompassing the rock lobster fishing grounds extending from Young Nicks Head in the south to Gable End Foreland in the

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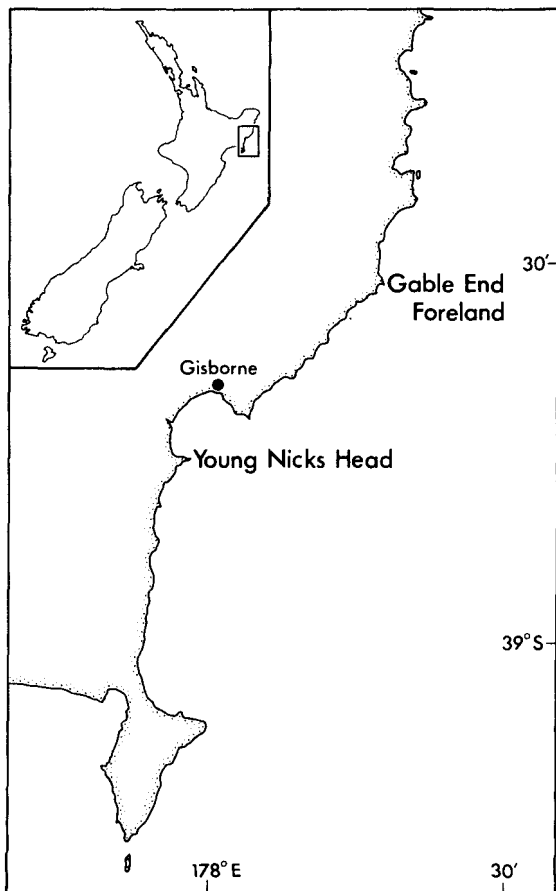
surement used was the carapace length taken from the base of the antennal platform to the dorsal, posterior margin of the carapace along the midline. These individual samples were given equal weights and combined directly to yield a monthly sample. The monthly samples were then weighted by the proportion of the total seasonal landings landed during that month and combined to give a weighted seasonal size-frequency distribution (Table 1, Figure 2). This weighting procedure was applied to average out changes in the size-frequency distributions due to fluctuations in catchability, recruitment, and mortality to permit estimation of the average annual total mortality rate.

The approximate method of separating the component distributions of a polymodal size-frequency distribution described by Bhattacharya (1967) involves a cubic approximation of density within a size class and a quadratic approximation to the logarithm of the frequency of each class. It was assumed that the frequency distribution is composed of Gaussian component distributions that are adequately separated so that each component has a sufficiently broad region where the effects of

TABLE 1.—Weighted seasonal size-frequency distribution of male New Zealand rock lobsters from the Gisborne local area during the 1976-77 season. Observed frequency values are weighted frequencies × 10^3.

Class midpoint (mm)	Observed frequency (y)	$\log_e y$	$\Delta\log_e y$
94.5	17	2.8332	0.4990
95.5	28	3.3322	0.3814
96.5	41	3.7136	0.5059
97.5	68	4.2195	0.1872
98.5	82	4.4067	−0.1300
99.5	72	4.2767	0.5108
100.5	120	4.7875	−0.1335
101.5	105	4.6540	−0.1107
102.5	94	4.5433	−0.2126
103.5	76	4.3307	−0.3989
104.5	51	3.9318	−0.0198
105.5	50	3.9120	−0.2484
106.5	39	3.6636	−0.1979
107.5	32	3.4657	−0.3302
108.5	23	3.1355	−0.8329
109.5	10	2.3026	0.4700
110.5	16	2.7726	−0.2877
111.5	12	2.4849	−0.2877
112.5	9	2.1972	0.2007
113.5	11	2.3979	−1.0116
114.5	4	1.3863	0.2231
115.5	5	1.6094	−0.2231
116.5	4	1.3863	0.0000
117.5	4	1.3863	0.2231
118.5	5	1.6094	−0.9163
119.5	2	0.6931	0.0000
120.5	2	0.6931	0.0000
121.5	2	0.6931	0.0000
122.5	2	0.6931	0.0000
123.5	2	0.6931	−0.6931
124.5	1	0.0000	0.0000
125.5	1	0.0000	0.0000
126.5	1	0.0000	

FIGURE 1.—Location of the study area between Young Nicks Head and Gable End Foreland on the east coast of the North Island, New Zealand.

north (Figure 1). The landings from this area were chosen for analysis because it has been the site for a series of tag-recapture studies, which were also used to estimate mortality rates. The results reported here are part of an extensive study of the biology of *J. edwardsii* in the Gisborne area.

Size-frequency distributions in the landings were determined on a monthly basis from July 1976 to February 1977, with the exceptions of August and January, during the 1976-77 season. The fishing season is defined as extending from 1 June to 31 May of the following year. There is a natural break between seasons due to a period of low catchability and resulting low effort expenditure during April and May. During each month the landings were chosen on a nonrandom basis for sampling, and the entire landing on a given day for an individual boat was measured. The mea-
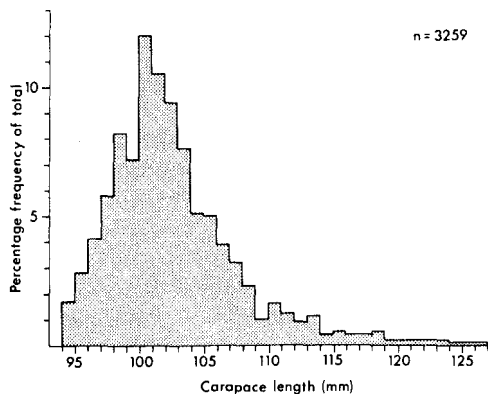
FIGURE 2.—Weighted seasonal size-frequency distribution of male New Zealand rock lobsters from the Gisborne local area landed during the 1976-77 season.

all other components are negligible. Moreover, the class range should be small, and the sample should be of a sufficient size so that the class frequencies are not small in the area of the distribution where the components are being separated.

If the class intervals are assumed to be constant, direct graphical procedures can be used, as simple differencing reduces the quadratic to a straight line. The midpoints of the size classes were plotted on the abscissa and the logarithmic difference in the frequency between successive classes on the ordinate. Each of the regions on the graph containing straight lines with negative slope corresponds to the separate components of the distribution.

The natural logarithms of the abundance of each of the 1 mm size classes and the logarithmic differences between successive size classes are also shown in Table 1. The logarithmic differences plotted against the midpoints of the size classes are shown in Figure 3, as well as the lines fitted by eye through adjacent points. This procedure involved fitting a straight line with a negative slope through successive points and required a certain amount of subjectivity when choosing the positions of the lines. However, the line-fitting was aided by using the average annual growth increment as a guide in determining the positions of the lines and by fitting the lines more closely to the points with the larger than the smaller frequencies.

Using Bhattacharya's (1967) terminology, the revelant parameters from Table 1 and Figure 3 are:

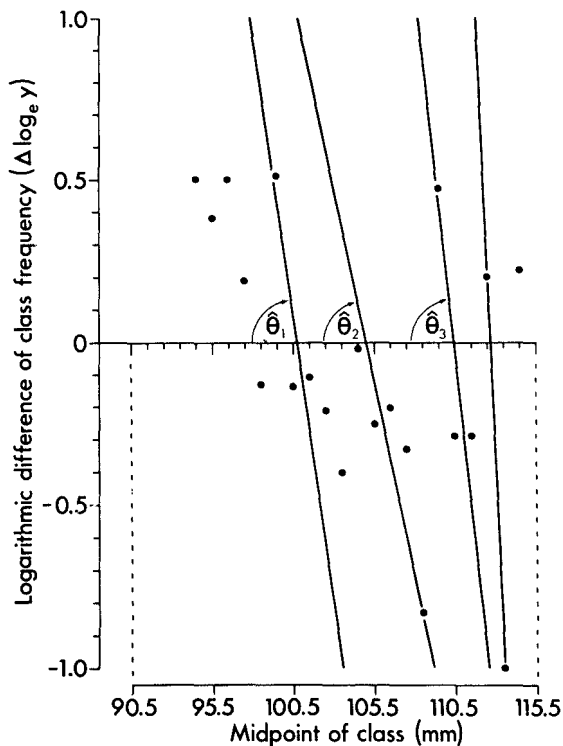$$h = \text{the class interval} = 1 \text{ mm}$$

FIGURE 3.—Logarithmic difference in abundance plotted against the midpoints of successive millimeter size classes from the weighted seasonal size-frequency distribution of male New Zealand rock lobsters landed from the Gisborne local area during the 1976-77 season.

b = the scale of x = 1
d = the scale of y = 20
$\hat{\lambda}_r$ = the x-intercept of the rth line
$\hat{\lambda}_1$ = 100.7 $\hat{\lambda}_2$ = 105.0 $\hat{\lambda}_3$ = 110.5
$\hat{\theta}_r$ = the angle the rth line makes with the negative direction of the x-axis
$\hat{\theta}_1$ = 82.0° $\hat{\theta}_2$ = 78.5° $\hat{\theta}_3$ = 79.5°
$\hat{\mu}_r$ (the mean of the rth component)
  = $\hat{\lambda}_r + h/2$
$\hat{\mu}_1$ = 101.2 $\hat{\mu}_2$ = 105.5 $\hat{\mu}_3$ = 111.0
$\hat{\sigma}_r$ (the SD of the rth component)
  = $\sqrt{(dh \cot \theta_r / b) - (h^2/12)}$
$\hat{\sigma}_1$ = 1.6513 $\hat{\sigma}_2$ = 1.9967 $\hat{\sigma}_3$ = 1.9033.

Using Method iv, and following the steps outlined in table 8, of Bhattacharya (1967), the number of individuals (N_i) in each of the first three fully recruited components of the seasonal size-frequency distribution from the Gisborne local area was estimated as shown in Table 2. Male rock lobsters less than the carapace length size class from 100.0 to 100.9 mm were not fully recruited

TABLE 2.—Estimation of the number in each component (N_i) and the annual instantaneous total mortality rate (T) from the 1976-77 weighted seasonal size-frequency distribution of male New Zealand rock lobsters from the Gisborne local area using Method iv of Bhattacharya (1967).

Component	n	$\dot{o}_i$	$Z = 2n(\dot{o}_i^2 + h^2/12)$	$\dfrac{\Sigma \log_e y}{n}$	$\dfrac{\Sigma(x - \mu_i)^2}{Z}$	$\dfrac{h^2}{24\dot{o}_i^2}$	$\log_e \dfrac{N_i}{\dot{o}_i}$	$\dfrac{N_i}{\dot{o}_i}$	N_i	T
1	5	1.6513	28.1000	4.5184	0.3719	0.0153	5.3047	201.28	332	
										0.36
2	5	1.9967	20.8000	3.6217	0.7217	0.0105	4.7530	115.93	231	
										1.75
3	5	1.9033	22.2360	2.5200	0.1237	0.0115	3.0543	21.20	40	
									Average	1.06

into the fishery, so these smaller size classes were not included in the analysis. Moreover, only the first three components were used because the small number of individuals of larger sizes in the sample made it difficult to accurately distinguish any further components. Assuming that each component approximates an individual year class, the annual instantaneous total mortality rate between components 1 and 3 is 1.06.

Estimates of the annual instantaneous total mortality rate were also derived from the six monthly samples (see Table 5). These estimates ranged from 0.00 to 1.15, with a weighted mean (weighted by the proportion of the seasonal landings taken during the month) of 0.49 and 95% confidence limits of 0.06 and 0.92.

The model used by Van Sickle (1977) describes the exact shape of the size distribution of a stationary or steady state population, with the shape expressed as a function of size-specific mortality and growth rates. His Method 2 requires comprehensive growth and size-frequency data to estimate mortality on a size-specific basis. However, it does not require the explicit determination of the age distribution nor a fitted growth curve, which is advantageous for this species.

The size distribution was divided into size classes (indexed by j), and it was assumed that the mortality rate (μ_j) was the same for all individuals in size class j. The size classes can be of any width, but the growth rate and number density must be known at the boundaries of each class.

Using the terminology of Van Sickle (1977), let j stand for the size interval (z_j, z_{j+1}). If the growth rates $g(z_j), g(z_{j+1})$ and the number densities $N_s(z_j)$, $N_s(z_{j+1})$ at the boundaries plus N_j*, the total number or proportion of organisms in class j are known, then μ_j is calculated from his equation 8:

$$\mu_j = \frac{1}{N_j*}\left[g(z_j)N_s(z_j) - g(z_{j+1})N_s(z_{j+1}) \right] .$$

Estimates of the annual instantaneous total mortality rate applying Method 2 of Van Sickle (1977) to the seasonal size distribution of Table 1 are shown in Table 3. The growth rate of 4.8 mm used at the boundaries is an initial estimate of the average annual growth increment of males in the Gisborne local area, and was based on the molt increment of 204 tagged rock lobsters recaptured during 1976-77. The tagged individuals were all in the size range 80-106 mm, due to difficulties experienced in obtaining larger animals for tagging, so growth estimates were not available for the upper part of the size distribution. However, initial growth information from other areas indicates it is not unreasonable to assume a constant molt increment for males between 80 and 115 mm carapace length.

Some difficulty was experienced in determining the 100% retention length for rock lobsters using a carapace measure because the minimum legal size is based on a tail length measure (Annala 1977). The carapace length class from 100.0 to 100.9 mm had the highest proportion of any single millimeter class in the size-frequency distribution (Table 1, Figure 2) and was therefore chosen as the smallest size class fully represented in the landings. The size-frequency distribution was then partitioned into 4 mm and 5 mm size groups, beginning with the 100 mm size class, to bracket the average annual growth increment of 4.8 mm. The

TABLE 3.—Estimation of the annual instantaneous total mortality rate (μ_j) from the 1976-77 weighted seasonal size-frequency distribution of male New Zealand rock lobsters from the Gisborne local area using Method 2 of Van Sickle (1977).

Size grouping	(z_j, z_{j+1})	N_j*	$(g(z_j), g(z_{j+1}))$	$\mu_j(yr^{-1})$
4 mm	(100, 103)	395	(4.8, 4.8)	0.53
	(104, 107)	172	(4.8, 4.8)	0.53
	(108, 111)	61	(4.8, 4.8)	0.86
			Average	0.64
5 mm	(100, 104)	446	(4.8, 4.8)	0.74
	(105, 109)	154	(4.8, 4.8)	1.24
	(110, 114)	52	(4.8, 4.8)	1.11
			Average	1.03

estimates of the annual instantaneous total mortality rate were 0.64 and 1.03 for the smaller and larger groupings, respectively.

Estimates of the annual instantaneous total mortality rate from the monthly samples (see Table 5) using the 4 mm grouping ranged from 0.46 to 1.00, with a weighted mean of 0.69 and 95% confidence limits of 0.50 and 0.88. The monthly estimates using the 5 mm grouping ranged from 0.90 to 1.18, with a weighted mean of 0.99 and 95% confidence limits of 0.89 and 1.09.

Hancock (1965) estimated the total mortality rate of *Cancer pagurus* in the Norfolk (England) fishery by partitioning the size distribution into approximate year classes based on the average annual growth increment. If the natural logarithms of numbers are plotted against size, a line whose slope is proportional to the total mortality rate is obtained over the size range where growth is constant. Annala (1977) also used this method for estimating the total mortality rate of *J. edwardsii* in the Otago fishery of New Zealand.

The average annual growth increment of 4.8 mm was rounded to the nearest millimeter, and the seasonal size-frequency distribution of Table 1 and Figure 2 partitioned into 5 mm size classes. The results are shown in Table 4, with the annual instantaneous total mortality rate estimated to be 1.07. The estimates from the monthly samples (Table 5) ranged from 0.78 to 1.25, with a weighted mean of 1.11 and 95% confidence limits of 0.97 and 1.25.

Analyses of Tag Return Data

Mortality rates were also estimated from the rate of return of tagged male rock lobsters released in the Gisborne local area in July 1976 and recaptured during the following 12 mo. The instantaneous total mortality rate was estimated using the method derived by Robson and Chapman (1961) for analyzing a segment of the catch curve. The

TABLE 4.—Estimation of the annual instantaneous total mortality rate (Z) from the 1976-77 weighted seasonal size-frequency distribution of male New Zealand rock lobsters from the Gisborne local area using the average annual growth increment method of Hancock (1965).

Size class (mm)	N_i	Z
100.0-104.9	446	
		1.06
105.0-109.9	154	
		1.09
110.0-114.9	52	
	Average	1.07

TABLE 5.—Estimates of the annual instantaneous total mortality rate from the monthly size-frequency distributions of male New Zealand rock lobsters landed from the Gisborne local area during the 1976-77 season. The methods used were Method iv of Bhattacharya (1967), Method 2 of Van Sickle (1977), and the average annual growth increment method of Hancock (1965). N = sample size.

Month (N)	Bhattacharya	Van Sickle (4 mm grouping)	Van Sickle (5 mm grouping)	Hancock
July (325)	0.00	0.63	1.14	1.25
Sept. (399)	0.45	1.00	1.18	0.78
Oct. (1,155)	0.54	0.95	0.90	1.09
Nov. (506)	1.03	0.45	0.96	0.92
Dec. (247)	0.32	0.82	0.94	1.18
Feb. (627)	1.15	0.46	0.91	1.04
Weighted mean mortality rate	0.49	0.69	0.99	1.11
95% confidence limits of the weighted mean	0.06, 0.92	0.50, 0.88	0.89, 1.09	0.97, 1.25

instantaneous fishing mortality rate was estimated by 1) a method developed by Paulik (1963) for use with recaptures grouped into time intervals, and 2) a method described by Ricker (1975) where estimates are available for the instantaneous total mortality rate and rate of exploitation.

A total of 444 male rock lobsters were caught by pots, tagged using the western rock lobster tag (Chittleborough 1974), and released on the fishing grounds. All of the returned rock lobsters were taken in pots by commercial fishermen. Fishing effort was not constant throughout the 1976-77 season, so the rate of return of tags was adjusted by the effort expended in each month. The best measure of effort available was the average number of days fished per month per boat for 12 selected boats in the Gisborne local area.

The average number of days fished in June 1976 (9.9 days/boat) was used as the basis for determining relative effort. The number of recaptures for July 1976 was not included in the analysis because tags were not returned over the entire month. The number of males recaptured, the relative effort, and the number of recaptures per unit of relative effort for each month are shown in Table 6.

The method of Robson and Chapman (1961) used for estimating the total mortality rate depends on determining a mean coded age, $\bar{x}$ according to the terminology of Jones (1976), where $\bar{x} = X/\Sigma y_i$. The total coded age (X) was calculated from $X = \Sigma(i = 1)y_i$ for $i = 1, 2, \ldots J$, where J = the number of samples, and y_i = the number of recaptures per sample.

Using the number of monthly recaptures per unit relative effort from August 1976 through April 1977 is shown in Table 6 as an example,

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TABLE 6.—Recaptures of male New Zealand rock lobsters tagged and released in the Gisborne local area in July 1976, effort expenditure during 1976-77, and the number of recaptures per unit relative effort (y_i).

Year and month	No. of recaptures	Average no. of days fished/boat	Relative effort	y
1976:				
Aug.	64	15.4	1.56	41.03
Sept.	31	5.5	0.56	55.36
Oct.	26	12.5	1.26	20.63
Nov.	40	13.5	1.36	29.41
Dec.	23	12.8	1.29	17.83
1977:				
Jan.	13	15.8	1.60	8.13
Feb.	23	13.3	1.34	17.16
Mar.	12	8.9	0.90	13.33
Apr.	1	4.0	0.40	2.50
May	0	1.0	0.11	0.00
June	2	10.8	1.09	1.83
July	8	17.0	1.72	4.65

$$
\begin{aligned}
\Sigma(i - 1)y_i &= 41.03(1 - 1) + 55.36(2 - 1) \\
&\quad + 20.63(3 - 1) + 29.41(4 - 1) \\
&\quad + 17.83(5 - 1) + 8.13(6 - 1) \\
&\quad + 17.16(7 - 1) + 13.33(8 - 1) \\
&\quad + 2.50(9 - 1) = 513.09
\end{aligned}
$$

$$
\begin{aligned}
\Sigma y_i &= (41.03 + 55.36 + 20.63 + 29.41 \\
&\quad + 17.83 + 8.13 + 17.16 + 13.33 \\
&\quad + 2.50) = 205.38.
\end{aligned}
$$

Thus, the mean coded age $(\bar{x}) = 513.09/205.38 = 2.4982$.

The proportion of tagged individuals remaining free after the last monthly sampling period was too large to be neglected, so the estimate of mean coded age was equivalent to

$$
\bar{x} = \sum_{i=1}^{J-1} is^i \bigg/ \sum_{i=0}^{J-1} s^i .
$$

Estimates of the survival rate (S) that will satisfy a given value of $\bar{x}$ for any given J were determined from table 3 of Robson and Chapman (1961). In this example $\bar{x} = 2.4982$ and $J = 9$, so the value of S which satisfied was 0.786. This was a monthly value for S, so an estimate of S for the entire year, assuming total mortality acts uniformly over the 12-mo period, was $S_{\text{annual}} = (S_{\text{monthly}})^{12} = (0.786)^{12} = 0.0556$. Thus, the annual instantaneous total mortality rate (Z) measured over the 12-mo period $= 2.89$. However, with fishing effort concentrated in the 9-mo period from mid-June to mid-March and with a low initial estimate of instantaneous natural mortality rate (M) of approximately 0.10 (Annala 1977), it was assumed that mortality acted primarily during the 9-mo fishing season. An estimate of annual total mortality based on this 9-mo period was $S_{\text{annual}} = (S_{\text{monthly}})^9 = (0.786)^9 = 0.1145$, with $Z = 2.17$.

The results of this analysis, as well as the results of grouping the tag returns bimonthly and quarterly are shown in Table 7.

Estimates of the instantaneous fishing mortality rate (F) were made using equation 26 of Paulik (1963) for grouped observations, where $\hat{F} = -\hat{\mu}\ln \hat{S}/(1 - \hat{S}^J)$, and $\hat{\mu} = n./N$, where $n.$ = the total number recaptured over the period of observation, and N = the total number of tags released.

In the example cited above, where tag returns were grouped on a monthly basis from August 1976 to April 1977, $\hat{\mu} = 223/433 = 0.5381$, where the number recaptured in July (11) was subtracted from the number released (444) to estimate the number still at large at the beginning of August (433). Using the monthly value of $\hat{S} = 0.786$, the monthly value of $\hat{F} = -0.5381 \times -0.2408/[1 - (0.786)^9] = 0.1464$. On a 12-mo basis, the annual estimate of $\hat{F} = 1.76$. However, based on a 9-mo fishing season, the annual estimate of $\hat{F} = 1.32$ (Table 7).

The value of F was also estimated from the equation $F = uZ/A$, which was derived from equation (1.13) of Ricker (1975), where u = rate of exploitation, Z = instantaneous total mortality rate, and A = actual total mortality rate.

The value of u was estimated on an annual basis from the equation $u = R/M$, where R = number of recaptures during first year after release and M = number of tags released.

For the July 1976 tagging, $u = 251/444 = 0.5653$. Thus, for the tag returns grouped on a monthly basis, the annual estimate of $F = uZ/A = 0.5653 \times 2.89/0.9444 = 1.73$ over a 12-mo period.

TABLE 7.—Estimates of the annual instantaneous total (Z) and fishing (F) mortality rates of male New Zealand rock lobsters from the Gisborne local area derived from tag returns of those tagged and released in July 1976.

Method	(Z) Robson and Chapman (1961)	(F) Paulik (1963)	(F) Ricker (1975)
Returned tags grouped:			
Monthly, Aug. 1976-Apr. 1977	[1]2.89(2.17)	1.76(1.32)	1.73(1.30)
Bimonthly, Aug. 1976-July 1977	3.13(2.09)	1.84(1.22)	1.85(1.35)
Quarterly, Aug. 1976-July 1977	2.56(1.92)	1.56(1.17)	1.57(1.27)

[1]The figures in parentheses are estimates of Z and F taken over 9 mo for the monthly and quarterly groupings and 8 mo for the bimonthly grouping.

On the basis of a 9-mo fishing season, the annual estimate of $F = 1.30$ (Table 7).

DISCUSSION

The weighting procedure used to derive the seasonal size-frequency distribution was designed to average out changes in the monthly distributions due to fluctuations in catchability, recruitment, and mortality, which affect the estimates of total mortality rate. The estimates derived from the seasonal size-frequency distribution using the methods of Hancock (1965) and Van Sickle (1977) were similar to the means of the respective monthly estimates (Table 5). The estimates from the monthly samples using the method of Bhattacharya (1967) were highly variable, probably due to the small sample sizes, and the mean of the monthly estimates was considerably less than the estimate from the seasonal distribution.

The factor having the greatest potential effect on the estimates of mortality derived from the size-frequency distributions is probably the influx of new recruits into the fishery by growth over the minimum legal size. Male rock lobsters in the Gisborne local area exhibit marked periodicity in the molt cycle, with most molting between October and December. However, the monthly estimates using the methods of Hancock (1965) and Van Sickle (1977) do not indicate any changes in mortality rate associated with this molting period. Therefore, estimation of the total mortality rate from the weighted seasonal size-frequency distribution is considered valid in this example.

The estimates of total mortality rate from the weighted seasonal size-frequency distribution using the three methods gave similar results. The method of Bhattacharya (1967) is considered adequate when the sample size is large and an estimate of growth rate is available to aid in fitting the lines. However, when used in analyzing size-frequency distributions whose sample sizes were small, such as those from other areas (my unpubl. data) and the monthly samples in this example (Table 5), the results varied widely. Moreover, when used with data without definite modes, the abundance of the first component often appears to be underestimated, perhaps due to the difficulty of determining the 100% retention length, and greater consistency is obtained if the first three components are included for analysis.

Method 2 of Van Sickle (1977) also requires comprehensive size-frequency and growth data.

One of Van Sickle's key assumptions is that the method be applied to a stationary or steady state population, which he defines (after Seber 1973) as one having age and size structures that are cyclic, with a period usually of 1 yr. Thus, size distributions observed at yearly intervals will appear identical. However, he argues that the method can be applied to annual "average" size distributions rather than a distribution at one point in time (Van Sickle 1977, quoting Van Sickle 1975). Growth and mortality rates should not vary with time, and seasonal and year-to-year changes in recruitment and growth should be "averaged out" of the data used.

Estimates derived using the smaller of the millimeter size groupings bracketing the annual growth increment for this example (Tables 3, 5) and for samples from other areas (my unpubl. data) were usually lower than those derived using the larger millimeter size grouping. These lower estimates may be due to the violation of one or more of the above assumptions. Van Sickle's method is very dependent on accurate estimates of growth rates and densities at the boundaries of each size class, and even minor fluctuations in recruitment and for samples from other areas (my unpubl. data) were usually lower than those derived using the larger millimeter size grouping. These lower estimates may be due to the violation of one or more of the above assumptions. Van Sickle's method is very dependent on accurate estimates of growth rates and densities at the boundaries of each size class, and even minor fluctuations in recruitment could affect the estimates of the numbers in the boundary size groups.

The success of the average annual growth increment method of Hancock (1965) is also dependent on the assumptions of constant recruitment and growth rate over the size range considered. However, this method is probably not as susceptible to fluctuations in recruitment as that of Van Sickle (1977), because the use of broad size classes based on average annual growth increments should smooth out any small fluctuations. The accuracy of both these methods may be improved by combining size-frequency distributions obtained over a number of years to reduce the effects of changes in recruitment and growth rates. Continuous monitoring of size-frequency distributions in the Gisborne fishery should result in improved estimates in the future.

In summary, the analyses of the size-frequency distributions using the three methods gave gener-

ally consistent results. The method of Van Sickle (1977) requires the most detailed information on the size distribution and growth rates, and the results are susceptible to the size groupings chosen. Hancock's (1965) method requires less detailed information on growth, as average annual growth increments can be used, but still requires an accurate description of the size-frequency distribution. Bhattacharya's (1967) method does not require information on growth, although knowledge of the annual growth increment does aid in analysis of the data, but again requires an accurate description of the size-frequency distribution.

The instantaneous total mortality rate can also be estimated from length composition data using the expression derived in Appendix B of Beverton and Holt (1956) based on the von Bertalanffy (1938) growth parameters. This method is most accurate when there is a rapid increase in length with age over the important size range and a minimum of overlap between the length distributions of adjacent age groups. Saila et al. (in press) found that growth of male rock lobsters from the Gisborne area during the first few years after recruitment to the fishery (the important size range in this study) is slow relative to earlier years as described by an empirical growth curve. This curve was considered to be a more realistic description of growth than the von Bertalanffy curve at this stage of the species' life history. Moreover, the great variability found in the individual growth increments probably results in a high degree of overlap between the lengths of adjacent age classes. Thus, the conditions for the best use of the Beverton and Holt method do not appear to be met, and it was not applied to this species.

Polymodal frequency distributions may also be separated into their component groups using computer techniques such as ENORMSEP (Extended Normal Separator Program) (Yong and Skillman 1975). An important advantage of this technique over the method of Bhattacharya (1967) is that the goodness of fit of the estimated component distributions to the original polymodal distribution can be determined. However, the accuracy of both techniques is reduced when the modes of the size-frequency distribution are not well separated. The size-frequency distributions analyzed in this example do not exhibit any well-defined modes, so ENORMSEP was not used as it is considered that this technique would not improve the accuracy of the estimates.

The estimates of total mortality rate from the rate of tag returns using the method of Robson and Chapman (1961) are much higher (even when adjusted for an 8- or 9-mo fishing season) than the estimates derived from the size-frequency distributions. Morgan (1974a) suggested that the western rock lobster, *Panulirus cygnus*, caught by pots have a higher probability of recapture by pots than rock lobsters initially captured and released by diving. He further suggests that rock lobsters previously caught by pots, marked, and released, have a greater probability of recapture by pots than the probability of capture by pots of the total population. All of the rock lobsters tagged and released in this study were caught by pots, so they may have been more vulnerable to capture by commercial pot fishermen than the untagged individuals in the population. Moreover, due to the nature of the fishing grounds, the tag and release procedure was not conducted in a strictly random manner, and the resulting distribution of tags in the fishery may have led to a greater susceptibility to capture for the tagged rock lobsters.

The estimates of total mortality rate from the tag returns also may be affected by changes in the catchability of the rock lobsters. Laboratory experiments indicate feeding activity is lowest for individual *J. edwardsii* immediately prior to and after molting (my unpubl. results). Morgan (1974b) found a significant negative correlation between premolt stage D1 animals and catchability for the western rock lobster. Fluctuations in the number of recaptures per unit relative effort between August and April (Table 6) indicate that catchability may vary considerably. Any decrease in catchability during the molting period would act to increase the estimate of the total mortality rate.

Other factors affecting estimates of the total mortality rate (Type B errors, Ricker 1975) include: 1) tag loss, 2) extra mortality of tagged rock lobsters, and 3) emigration of tagged rock lobsters from the fishing area, with all three acting at a steady, instantaneous rate throughout the experiment. These factors all result in an overestimate of the total mortality rate.

Preliminary laboratory and field experiments on the rates of initial tag loss and mortality due to tagging indicate these effects are minimal (my unpubl. data). However, rock lobsters are most susceptible to tag loss and mortality due to the presence of the tag while molting. Laboratory experiments are being conducted to determine the long-term rates of tag loss and mortality.

The third factor, emigration out of the area, does not appear to be important. None of the males tagged in July 1976 had been recaptured outside the Gisborne local area. The inshore fishing grounds outside the Gisborne local area are all heavily fished, so the movement of significant numbers of tagged animals would probably be detected, unless they were migrating to deeper, unfished areas.

The methods of Paulik (1963) and Ricker (1975) used to estimate the fishing mortality rate from the tag returns (Table 7) are both dependent on estimates of the total mortality rate. Any bias in the estimates of total mortality rate will affect the estimates of fishing mortality rate. If the tagged rock lobsters were more susceptible to capture then the untagged individuals, then the estimates of fishing mortality rate may be overestimates.

Other factors affecting estimates of fishing mortality rate (Type A errors, Ricker 1975) include: 1) the death of tagged rock lobsters due to the presence of the tag, or the loss of their tags, shortly after marking; and 2) incomplete reporting of tags recaptured by fishermen. As mentioned previously, preliminary experiments indicate the effects of the first factor are minimal. However, predation by fish on the newly released animals may be important and warrants further investigation. It is known that some of the recaptured tags went unreported by fishermen, although the numbers were not large. This would result in an underestimate of the fishing mortality rate.

The estimates of fishing mortality rate adjusted for an 8- or 9-mo fishing season (1.17-1.35) are considerably lower than the unadjusted estimates (1.56-1.85). If the estimate of $M = 0.10$ (Annala 1977) applies to the Gisborne fishery, then $Z = 1.27$ to 1.45 based on the estimates of F for an 8- or 9-mo season. These estimates of Z are more comparable to those derived from the analyses of the size-frequency distributions (0.64-1.07) than to the estimates derived using the method of Robson and Chapman (1961) (1.92-3.13). Moreover, these lower estimates are more consistent with the estimated lifespan in the fishery than are the higher estimates. Based on the average annual growth increment of 4.8 mm and the seasonal size-frequency distribution in Table 1 and Figure 2, rock lobsters appear to survive for about 4 or 5 yr in the fishery. The preliminary empirical growth model developed by Saila et al. (in press) also indicates that male rock lobsters from the Gisborne

local area remain in the exploited phase for a minimum of 4 to 5 yr.

In summary, the estimates of total mortality rate for the entire exploited population from the rate of tag returns are considered too high. The estimates of total mortality rate from the size-frequency distribution analyses, and those based on the estimates of F over an 8- or 9-mo fishing season with the addition of $M = 0.10$, are more consistent with the observed lifespan in the fishery. Thus, the best estimates of Z are between 1.00 and 1.50, and of F are 0.90 and 1.40, assuming $M = 0.10$.

ACKNOWLEDGMENTS

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