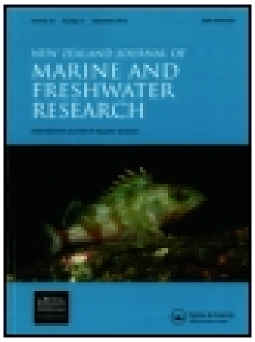

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Mortality estimates for the rock lobster, *Jasus edwardsii*, near Gisborne, New Zealand

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The instantaneous total (Z) and fishing (F) mortality rates were estimated for the New Zealand rock lobster, *Jasus edwardsii* (Hutton), along the east coast of the North Island from the Wairoa River to East Cape. Estimates of Z were made from the seasonal size-frequency distributions (SFDs) of rock lobsters landed from five separate fishing areas for up to five fishing seasons using three different methods. Z and F were also estimated from the rate of return of tagged rock lobsters released in four of the five areas. The best estimates of Z and F for each area were considered to be estimates of F based on tag returns grouped quarterly and taken over an 8 or 9 month fishing season; estimates of Z based on these estimates of F from tag returns, with the addition of an assumed value for the annual instantaneous natural mortality rate of 0.10; and estimates of Z from the SFD analyses. These estimates were more consistent with the estimated lifespans in the fishery than were the estimates of Z derived from tag returns.

Keywords: *Jasus edwardsii*; Crustacea; tagging; size-frequency distributions; mortality estimates; Gisborne, New Zealand.

INTRODUCTION

Knowledge of mortality rates (total, fishing, and natural) is important for an understanding of the dynamics of exploited fish populations. Total and fishing mortality rates are usually estimated from an analysis of the age distribution of the catch or landings, by the analysis of tag return data, or by some combination of the two. The natural mortality rate of an exploited population is more difficult to estimate and usually requires detailed information on catch and effort.

Mortality rates are notoriously difficult to estimate for crustaceans. Crustacea lack structural parts which retain annual marks, so mortality rates cannot be estimated from the age distribution of the catch. However, I have described methods for estimating the total and fishing mortality rates of the New Zealand rock lobster, *Jasus edwardsii* (Hutton), from the rate of tag returns and the total mortality rate from the size-frequency distribution of the landings (Annala 1979). These estimates were derived from data collected during the 1976–77 fishing season in the area between Young Nicks Head and Gable End Foreland near the port of Gisborne.

The purpose of the present investigation is to derive and compare estimates of total and fishing mortality rates for *J. edwardsii* from tag return and size-frequency distribution (SFD) data collected from five fishing areas on the east coast of the North Island between the Wairoa River and East Cape for up to five fishing seasons. These data are being used to analyse the population dynamics of the species, through the use of dynamic pool models, in each of the areas where growth information is available (Annala unpubl. results).

METHODS AND RESULTS

The rock lobster fishery on the east coast of the North Island from the Wairoa River to East Cape has been subdivided into five areas (Fig. 1). This subdivision is based largely on the distinct nature of the fishery in each area as most fishermen usually fish only in one area at any given time. However, there are also biological differences between areas, such as in the size at onset of sexual maturity of females (Annala *et al.* 1980), growth rates (J. L. McKoy, pers. comm.), sex ratios (author's unpubl. data), and size-frequency distributions and mortality rates (this paper).

TAG RETURN DATA

Details of all tagging programmes are shown in Table 1. Rock lobsters were captured either by potting or diving, tagged with the western rock lobster tag (Chittleborough 1974), which permitted their individual identification, and released as quickly as possible to minimise losses due to handling. When possible only undamaged animals were tagged, and

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the most damaged animals returned had no more than two appendages missing. Every effort was made to released tagged animals as close as possible to their site of capture to minimise any displacement effects.

The location and date of release, sex, carapace length (measured to the nearest 0.1 mm from the antennal platform to the posterior margin of the carapace along the dorsal midline), sexual maturity (using external characteristics for females only (Annala *et al.* 1980)), and damage (loss of appendages, puncture wounds, etc.) were recorded for all animals tagged. Fishermen recapturing tagged rock lobsters were asked to give the date, location, method, and depth of capture, as well as to return the entire animal so that the recapture carapace length and state of sexual maturity could be determined.

Total and fishing mortality rates were estimated from the rate of return of tagged rock lobsters from four of the areas (no tagging programme was conducted in the Gisborne North area). All rock lobster pots must be fitted with escape gaps which allow the escapement of undersized animals. However, the SFDs of those recaptured and released were similar, and the return rates about equal, for rock lobsters longer than 79.9 mm initial carapace length, so the returns of animals longer than this were used for the mortality rate estimates.

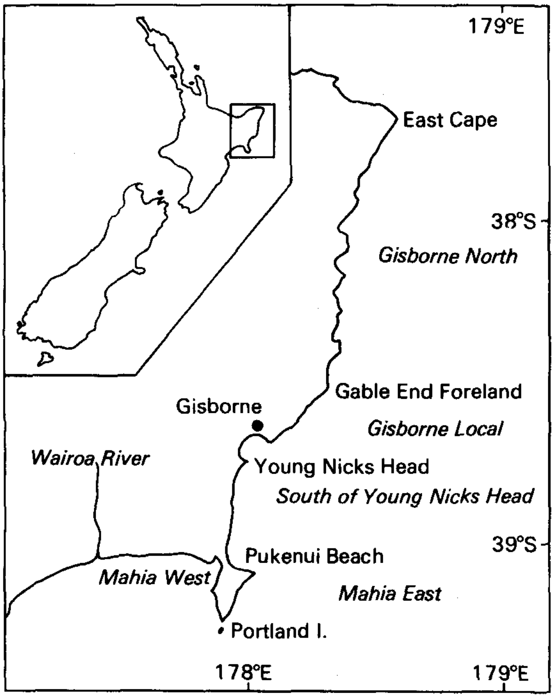

Fig. 1 Locations of the 5 study areas, east coast of North Island. Area names in *italics;* boundaries of areas in roman type (i.e., *Mahia West* extends from mouth of Wairoa R. to Portland I.; *Gisborne Local* from Young Nicks Head to Gable End Foreland).

The instantaneous total mortality rate (*Z*) was estimated by the method of Robson & Chapman (1961) for analysing a segment of the catch curve. The instantaneous fishing mortality rate (*F*) was estimated by a method developed by Paulik (1963) for use with recaptures grouped into time intervals, and a method described by Ricker (1975) when estimates are available for the instantaneous total mortality rate and rate of exploitation. (See Annala (1979) for a description of these methods and their application in the analysis of the July 1976 Gisborne Local data.)

Figs 2, 3, & 4 show the numbers of rock lobsters returned each month after tagging and release for selected taggings in the Gisborne Local, South of Young Nicks Head, Mahia East, and Mahia West areas. Return rates are not shown for taggings when the numbers released were small.

Table 1 Areas and dates of tagging, methods of capture, numbers of rock lobsters (*Jasus edwardsii*) tagged and returned up to 31 May 1979 for tagging programmes on the east coast of North Island. Area boundaries shown in Fig. 1. Methods of capture include potting by Fisheries Research Division staff (FRD pots), diving by Fisheries Research Division staff (FRD divers), and potting by commercial rock lobster fishermen (commercial pots). Number returned does not include those recaptured more than once or with insufficient information to determine date of recapture (m, male; f, female).

	Method of capture	No. tagged	No. returned
Gisborne local			
Oct 1975	FRD pots	392 m	197 m
		97 f	25 f
Feb 1976	FRD pots	179 m	96 m
		75 f	17 f
Jul 1976	FRD pots	444 m	273 m
		105 f	27 f
Jul 1977	FRD pots	270 m	156 m
		135 f	26 f
South of Young Nicks Head			
Oct 1975	FRD divers	23 m	6 m
		43 f	1 f
Mar 1977	Commercial pots	560 m	282 m
		28 f	5 f
Jul 1977	Commercial pots	374 m	199 m
		91 f	23 f
Mahia East			
Jul 1976	Commercial pots	51 m	30 m
		32 f	14 f
Oct 1976	Commercial & FRD pots	129 m	58 m
		256 f	114 f
Jul 1977	Commercial & FRD pots	136 m	74 m
		208 f	101 f
Jul 1978	Commercial pots	214 m	103 m
		152 f	65 f
Mahia West			
Oct 1975	FRD divers	75 m	16 m
		107 f	11 f
Oct 1976	Commercial & FRD pots	164 m	78 m
		273 f	94 f

Over 99% of the tags were returned by commercial rock lobster fishermen using pots. However, fishing effort was not constant during the period when tags were returned, so the return rates were adjusted by the effort expended during each month. Although it is recognised that the number of pots fished or the number of pot-lifts are better measures of effort for a pot fishery, because of limited data the best effort measure available for this study was the number of days fished per boat during each month. These data were obtained from the landing records of the fish processing sheds and not from the Ministry of Agriculture and Fisheries fishing return scheme, which did not include effort data.

No data were available on changes in the number of vessels fishing in the Gisborne Local and Mahia West areas, so the average number of days fished per month by selected vessels was the measure of effort chosen for these two areas. The average number of days fished in June 1976 (9.9 days per vessel) was set

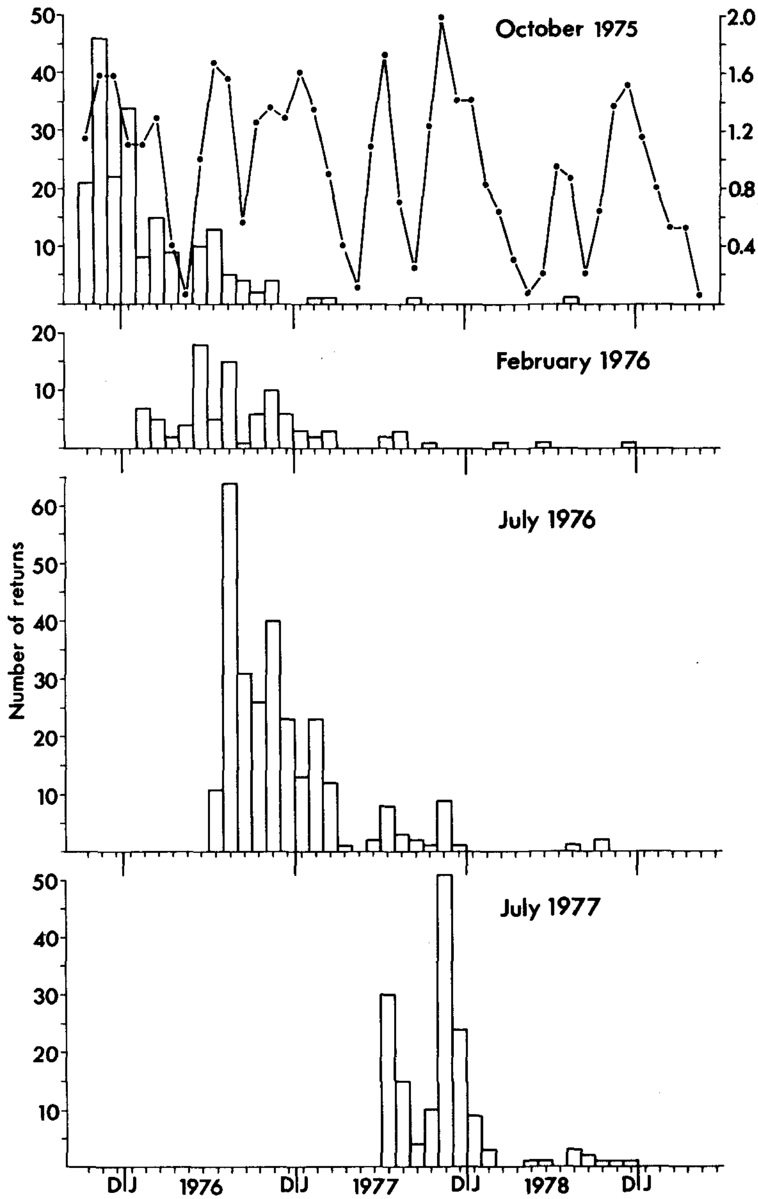

Fig. 2 Number of male rock lobsters returned during each month of those tagged and released in Gisborne Local area, Oct 1975, Feb 1976, Jul 1976, and Jul 1977. Level of relative effort expended during each month in Gisborne Local area shown by filled circles and applies to all four tagging programmes.

equal to 1.00 and used as the basis for estimating relative effort in the Gisborne Local area (Fig. 2), and the average number of days fished in November 1976 (16.3 days per vessel) was used for Mahia West (Fig. 4).

The measure of relative effort for Gisborne Local was also used for the area South of Young Nicks Head (Fig. 3). The use of the Gisborne Local effort data was considered valid, and was necessary, because the considerable interchange of vessels between the two areas made it impossible to separate the effort expended.

The catch and effort data available for Mahia East were complete for most vessels, so the total number of days fished per month by all vessels in the area was chosen as the measure of effort. The total number of vessel days fished in November 1976 (85 days) was used as the basis for determining relative effort (Fig. 4). Relative effort increased steadily during the three seasons as the number of vessels fishing in the area increased.

Mortality rates of females were estimated only for Mahia East and Mahia West. Females constituted only a small proportion of the landings from Gisborne Local and South of Young Nicks Head at the time of tagging, so their mortality rates were not estimated. Returns of berried females were excluded from the mortality rate estimates as they cannot be legally landed by fishermen. However, their numbers were small and their exclusion had little effect on the estimates.

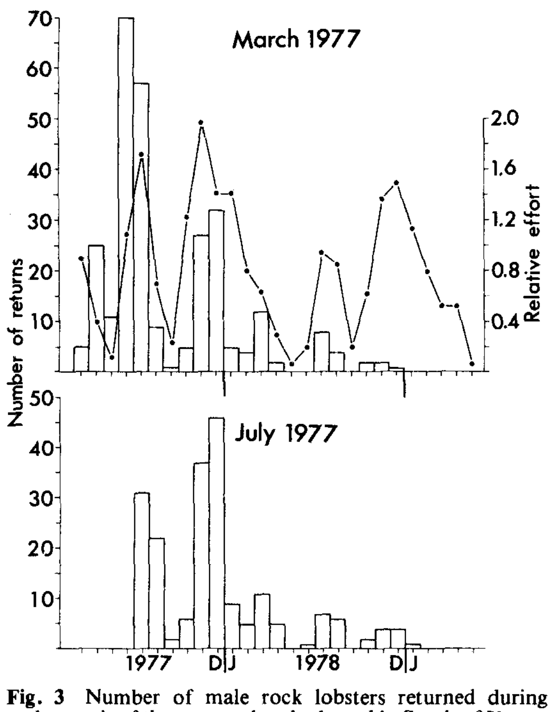

Fig. 3 Number of male rock lobsters returned during each month of those tagged and released in South of Young Nicks Head area, Mar & Jul 1977. Level of relative effort expended during each month in Gisborne Local area shown by filled circles and applies to both tagging programmes.

The return rates of tagged rock lobsters were similar to the levels of fishing effort, i.e., periods of high return rates coincided with periods of high fishing effort, catch, and catch per unit effort in the commercial fishery (Saila *et al.* (1980) and author's unpubl. data). Fishing effort was generally low in all areas in the 3-4 months from March to June; this coincided with a period of low availability of rock lobsters. Therefore, estimates of Z and F were also made for 9-month (monthly and quarterly groupings) and 8-month (bimonthly groupings) fishing seasons in addition to the full 12-month season. The estimates for males (Table 2) and females (Table 3) for any given area generally varied considerably for the different time groupings within a given tagging programme and among the different tagging programmes.

Size-frequency Distributions

The SFDs of the landings were sampled from the 1974-75 to the 1978-79 seasons, each season being defined as extending from 1 June to 31 May of the following year. Samples were taken during one week of each month (or occasionally every second month) from July to February inclusive for each season. An attempt was made to measure all the landings made from all five areas during the week of sampling, but this was not always possible.

The carapace lengths of all rock lobsters landed on a given day by each vessel sampled were measured to the nearest 1 mm below. The individual samples from a given area were combined to yield a monthly sample for each area. The monthly samples were then weighted by the proportion of the total seasonal landings landed during that month to give a weighted seasonal SFD for each area.

Three methods were used to estimate Z from the SFDs. (1) The approximate method of separating a polymodal SFD into its component distributions described by Bhattacharya (1967); (2) Method 2 of Van Sickle (1977), in which growth and size-frequency data were used to estimate mortality on a size specific basis; and (3) the partitioning of the SFD by the average annual growth increment into components approximating age classes (average annual growth increment method) described by Hancock (1965). (See Annala (1979) for a description of these methods and their application in the analysis of the 1976-77 Gisborne Local data.)

The growth rates used in these analyses were preliminary estimates of annual growth derived from recaptured tagged rock lobsters (J. L. McKoy, pers. comm.). Difficulties in obtaining larger animals for

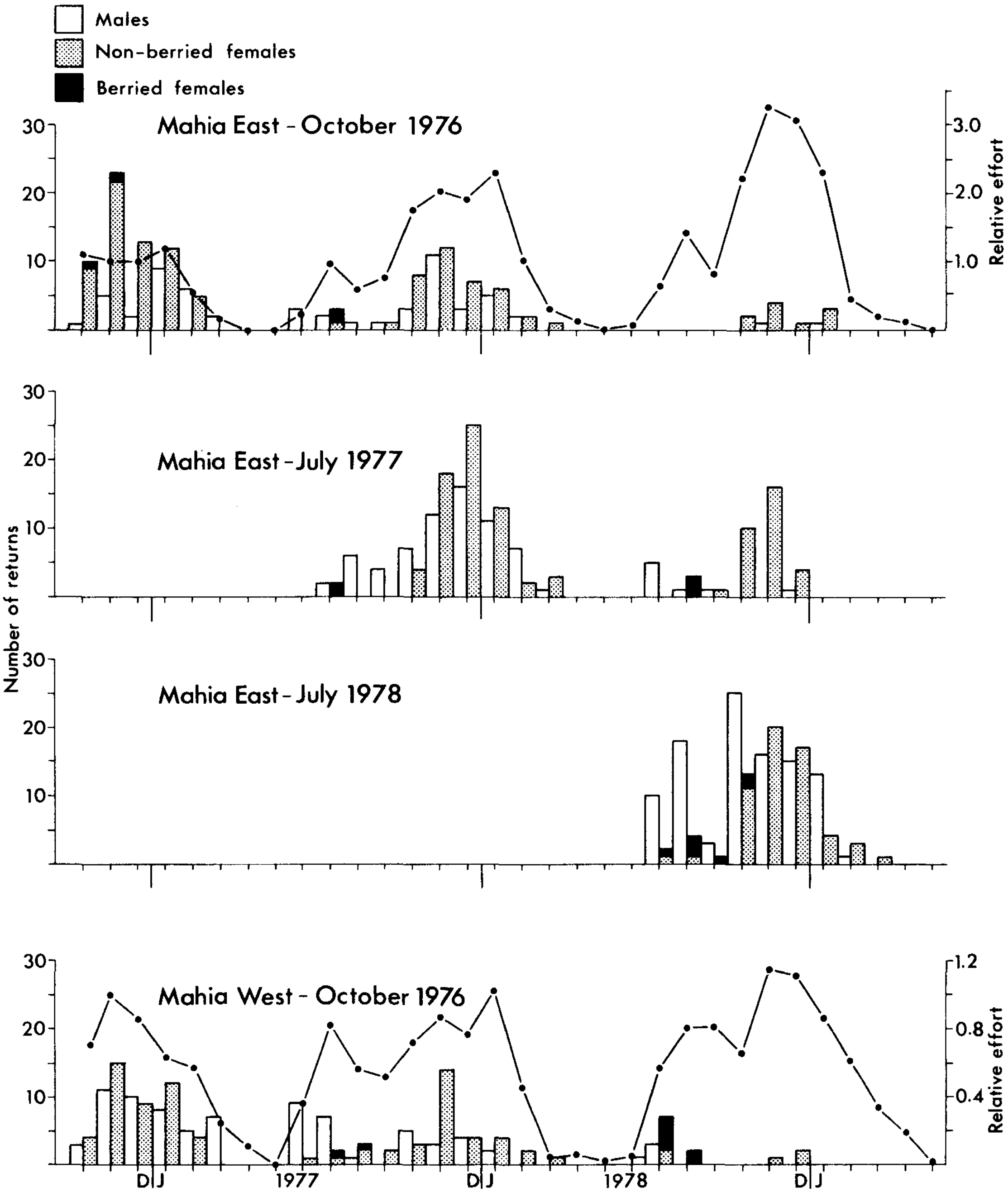

Fig. 4 Number of male and female rock lobsters returned during each month of those tagged and released in Mahia East and Mahia West areas, Oct 1976, Jul 1977, and Jul 1978. Level of relative effort expended during each month for Mahia East shown by filled circles in figure for Oct 1976 tagging and applies to all three tagging programmes. Level of relative effort for Mahia West shown by filled circles in figure for that area.

tagging limited annual growth estimates to males between 90 and 99 mm and females between 80 and 99 mm initial carapace length. However, the limited growth information available for animals over 99 mm carapace length suggests that a relatively constant growth increment may be reasonably assumed for larger animals.

The annual growth estimates based on carapace length for males were Gisborne Local, 5.9 mm; South of Young Nicks Head, 7.9 mm; and Mahia East, 12.2 mm. Annual growth was not estimated for Mahia West males because of insufficient data. The annual growth estimates for mature females from Mahia East and Mahia West were both 2.9 mm. Immature females made up a small proportion of the landings from these two areas (<5%). The annual growth of immature females appears to be greater than that of mature females (J. L. McKoy, pers. comm.), so data on their annual growth increments were not included in these analyses. Annual growth was not estimated for females from Gisborne Local or South of Young Nicks Head because of insufficient data.

The annual growth estimates were rounded to the nearest whole millimetre when using the methods of Van Sickle (1977) and Hancock (1965). The SFDs were partitioned into 6, 8, and 12 mm size classes when using the annual growth estimates for males from Gisborne Local, South of Young Nicks Head, and Mahia East respectively, and into 3 mm size classes when using the annual growth estimates for females from Mahia East and Mahia West.

Table 2 Estimates of annual instantaneous total (*Z*) and fishing (*F*) mortality rates derived from tag returns of male rock lobsters tagged and released on the east coast of the North Island. Estimates based on a fishing season extending over (a) 12

Tagging date	Returned tags grouped	*Z* Robson & Chapman (1961) (a)	(b)	*F* Paulik (1963) (a)	(b)	*F* Ricker (1975) (a)	(b)
		Gisborne Local					
Oct 1975							
Monthly:	Nov 75 to	2.16	1.62	1.14	0.86	1.16	0.96
	Jul 76	(1.40–2.98)	(1.05–2.24)	(0.85–1.43)	(0.64–1.08)	(0.89–1.50)	(0.77–1.20)
Bimonthly:	Nov 75 to	2.47	1.65	1.19	0.80	1.29	0.97
	Feb 77	(1.98–2.00)	(1.32–2.99)	(0.94–1.45)	(0.62–0.97)	(1.10–1.50)	(0.86–1.10)
Quarterly:	Nov 75 to	2.82	2.12	1.33	1.00	1.43	1.15
	Apr 77	(2.34–3.37)	(1.75–2.53)	(1.04–1.63)	(0.78–1.22)	(1.24–1.66)	(1.01–1.31)
Feb 1976							
Monthly:	Mar 76 to	1.94	1.45	0.97	0.73	1.05	0.88
	Nov 76	(0.79–3.21)	(0.59–2.41)	(0.57–1.37)	(0.43–1.03)	(0.67–1.55)	(0.61–1.23)
Bimonthly:	Mar 76 to	1.62	1.09	0.88	0.59	0.94	0.76
	Aug 77	(1.07–2.23)	(0.71–1.49)	(0.61–1.15)	(0.40–0.77)	(0.76–1.16)	(0.65–0.89)
Quarterly:	Mar 76 to	1.50	1.13	0.79	0.59	0.90	0.77
	May 78	(1.09–1.95)	(0.82–1.46)	(0.56–1.01)	(0.42–0.76)	(0.76–1.05)	(0.68–0.88)
Jul 1976							
Monthly:	Aug 76 to	2.89	2.17	1.76	1.32	1.73	1.38
	Apr 77	(2.23–3.59)	(1.67–2.69)	(1.43–2.09)	(1.07–1.57)	(1.41–2.09)	(1.16–1.63)
Bimonthly:	Aug 76 to	2.74	1.84	1.67	1.11	1.66	1.24
	Jan 78	(2.35–3.16)	(1.57–2.11)	(1.43–1.91)	(0.95–1.27)	(1.47–1.87)	(1.12–1.36)
Quarterly:	Aug 76 to	2.38	1.79	1.45	1.09	1.48	1.21
	Oct 78	(2.07–2.72)	(1.56–2.04)	(1.23–1.67)	(0.92–1.25)	(1.34–1.65)	(1.12–1.33)
Jul 1977							
Monthly:	Aug 77 to	2.01	1.51	1.41	1.05	1.27	1.06
	Feb 78	(0.91–3.22)	(0.68–2.41)	(0.96–1.86)	(0.72–1.39)	(0.83–1.84)	(0.76–1.45)
Bimonthly:	Aug 77 to	2.61	1.75	1.40	0.93	1.54	1.16
	Jan 79	(2.07–3.21)	(1.38–2.14)	(1.07–1.72)	(0.72–1.15)	(1.30–1.83)	(1.01–1.33)
Quarterly:	Aug 77 to	2.30	1.73	1.25	0.94	1.40	1.15
	Jan 79	(1.80–2.89)	(1.35–2.17)	(0.93–1.57)	(0.70–1.18)	(1.18–1.68)	(1.00–1.34)
		South of Young Nicks Head					
Mar 1977							
Monthly:	Apr 77 to	3.60	2.70	1.65	1.24	1.73	1.35
	Dec 77	(2.90–4.33)	(2.18–3.25)	(1.33–1.96)	(1.00–1.47)	(1.44–2.05)	(1.15–1.58)
Bimonthly:	Apr 77 to	2.47	1.66	1.24	0.83	1.26	0.96
	Sep 78	(2.11–2.86)	(1.41–1.91)	(1.04–1.44)	(0.69–0.96)	(1.12–1.42)	(0.87–1.05)
Quarterly:	Apr 77 to	2.50	1.88	1.26	0.95	1.27	1.04
	Dec 78	(2.16–2.87)	(1.62–2.15)	(1.06–1.47)	(0.79–1.10)	(1.14–1.42)	(0.94–1.14)

(continued)

The annual growth estimate of 5.9 mm for Gisborne Local males contrasts with the estimate of 4.8 mm used by Annala (1979). The present estimate includes data gathered since the earlier figure was derived and is confined to a narrower range of initial sizes (90–99 mm *vs* 80–106 mm).

MALES. The SFDs of male rock lobsters landed from Gisborne Local, South of Young Nicks Head, Mahia East, Mahia West, and Gisborne North are shown in Figs 5, 6, & 7. The estimates of *Z* from the SFDs for any given area varied among the three methods for any given season and among the different seasons (Table 4).

The length at which rock lobsters were fully recruited was difficult to determine for the 1978–79 SFD for South of Young Nicks Head, so two values were chosen for use with the methods of Van Sickle (1977) and Hancock (1965). The first estimate in Table 4 was made using a recruitment length of 101 mm and the second using a length of 103 mm.

The landings from Mahia East and Mahia West were not separated before 1977–78, so the samples from 1974–75 to 1976–77 were combined. The annual growth estimate for Mahia East was used to analyse the combined SFDs for Mahia East and Mahia West and the SFDs for Mahia East. An annual growth estimate was not available for Mahia West. However, an estimate of the single moult increment for males between 90 and 99 mm is 6.6 mm, which falls between the single moult increment estimates for males between 90 and 99 mm from South of Young

months for all groupings and (b) 9 months for the monthly and quarterly groupings or 8 months for the bimonthly groupings. 95% confidence limits of estimates in parentheses (n.d., no data because of insufficient timespan for returns).

Tagging date Returned tags grouped		Method *Z* Robson & Chapman (1961) (a)	(b)	*F* Paulik (1963) (a)	(b)	*F* Ricker (1975) (a)	(b)
Jul 1977							
Monthly:	Aug 77 to	0.51	0.39	0.67	0.50	0.61	0.57
	Apr 78	(<0.00–1.32)	(<0.00–0.99)	(0.46–0.88)	(0.35–0.66)	(<0.00–0.86)	(<0.00–0.75)
Bimonthly:	Aug 77 to	1.33	0.89	0.75	0.50	0.86	0.72
	Jan 79	(0.95–1.74)	(0.63–1.16)	(0.58–0.93)	(0.39–0.62)	(0.74–1.00)	(0.64–0.80)
Quarterly:	Aug 77 to	1.41	1.06	0.78	0.59	0.89	0.77
	Jan 79	(1.03–1.83)	(0.77–1.38)	(0.59–0.98)	(0.44–0.74)	(0.76–1.04)	(0.68–0.88)
				Mahia East			
Oct 1976							
Monthly:	Nov 76 to	0.32	0.24	0.51	0.38	0.30	0.29
	Jul 77	(<0.00–2.18)	(<0.00–1.64)	(0.21–0.80)	(0.16–0.60)	(<0.00–0.63)	(<0.00–0.52)
Bimonthly:	Nov 76 to	1.01	0.68	0.59	0.39	0.41	0.35
	Feb 78	(0.31–1.80)	(0.21–1.20)	(0.32–0.85)	(0.21–0.57)	(0.30–0.55)	(0.23–0.44)
Quarterly:	Nov 76 to	1.68	1.26	0.77	0.57	0.53	0.45
	Jan 79	(1.16–2.28)	(0.87–1.71)	(0.49–1.04)	(0.37–0.78)	(0.43–0.65)	(0.38–0.53)
Jul 1977							
Monthly:	Aug 77 to	0.79	0.59	0.92	0.69	0.72	0.66
	Mar 78	(<0.00–2.19)	(<0.00–1.64)	(0.50–1.34)	(0.38–1.01)	(<0.00–1.23)	(<0.00–1.02)
Bimonthly:	Aug 77 to	1.58	1.06	0.93	0.62	0.99	0.81
	Jan 79	(0.98–2.24)	(0.65–1.49)	(0.62–1.25)	(0.41–0.83)	(0.78–1.25)	(0.68–0.96)
Quarterly:	Aug 77 to	1.73	1.30	1.00	0.75	1.05	0.89
	Jan 79	(1.13–2.43)	(0.85–1.83)	(0.65–1.36)	(0.49–1.02)	(0.83–1.33)	(0.74–1.09)
Jul 1978							
Monthly:	Aug 78 to	2.25	1.69	1.40	1.05	1.34	1.11
	Feb 79	(1.02–3.62)	(0.76–2.72)	(0.90–1.91)	(0.67–1.43)	(0.85–1.99)	(0.76–1.56)
Bimonthly:	Aug 78 to	3.83	2.57	1.89	1.26	2.09	1.49
	Mar 79	(2.65–5.30)	(1.78–3.55)	(1.20–2.59)	(0.80–1.74)	(1.52–2.85)	(1.14–2.95)
Quarterly:		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
				Mahia West			
Oct 1976							
Monthly:	Nov 76 to	0.06	0.04	0.49	0.37	0.40	0.40
	Jul 77	(<0.00–1.33)	(<0.00–1.00)	(0.23–0.75)	(0.18–0.56)	(<0.00–0.71)	(<0.00–0.62)
Bimonthly:	Nov 76 to	1.26	0.84	0.69	0.46	0.69	0.58
	Feb 78	(0.63–1.96)	(0.42–1.31)	(0.43–0.95)	(0.29–0.64)	(0.53–0.89)	(0.48–0.70)
Quarterly:	Nov 76 to	1.50	1.12	0.75	0.56	0.75	0.65
	Jul 78	(0.99–2.08)	(0.74–1.56)	(0.49–1.01)	(0.37–0.76)	(0.61–0.93)	(0.55–0.77)

Nicks Head (5.5 mm) and Mahia East (8.0 mm) (J. L. McKoy, pers. comm.). Therefore, the annual growth increment for Mahia West is likely to fall between the annual growth estimates for South of Young Nicks Head and Mahia East, and these two estimates were used to analyse the Mahia West data. The annual growth estimate for South of Young Nicks Head was also used to analyse the combined samples.

There was no tagging programme in the Gisborne North area, so annual growth estimates from Gisborne Local, South of Young Nicks Head, and Mahia East were used for comparison. The estimates of *Z* from the methods of Van Sickle (1977) and Hancock (1965) varied widely, and were greater for the larger annual growth increments. Accurate estimates of *Z* from these two methods thus depend on an accurate estimate of annual growth, which was not available for this area.

FEMALES. The SFDs of female rock lobsters landed from Mahia East and Mahia West from the 1975–76 to the 1978–79 seasons are shown in Fig. 8. The landings from the two areas were not separated before 1977–78, so data from the first two seasons are from combined samples. The estimates of *Z* varied among the three methods for any given season and among the different seasons (Table 5). Too few females were landed from the other areas to provide adequate samples for estimation of *Z* from SFDs.

DISCUSSION

ESTIMATES OF *Z* AND *F* FROM TAGGING

Annala (1979) discussed the various factors that may affect estimates of *Z* from the rate of tag returns. These included (1) greater susceptibility of tagged rock lobsters to capture by pots; (2) changes in catchability during the moulting period; (3) tag loss; (4) higher mortality of tagged rock lobsters; and (5) emigration of tagged rock lobsters out of the fishing area. These factors would result in over-estimates of *Z*.

Table 3 Estimates of annual instantaneous total (*Z*) and fishing (*F*) mortality rates derived from tag returns of female rock lobsters tagged and released in the Mahia East and Mahia West areas. Estimates based on a fishing season extending over (a) 12 months for all groupings and (b) 9 months for the monthly and quarterly groupings or 8 months for the bimonthly groupings. 95% confidence limits of estimates in parentheses. (n.d., no data because of insufficient timespan for returns.)

Tagging date	Returned tags grouped	Method *Z* Robson & Chapman (1961) (a)	(b)	*F* Paulik (1963) (a)	(b)	*F* Ricker (1975) (a)	(b)
Mahia East							
Oct 1976							
Monthly:	Nov 76 to Feb 77	3.78 (1.01–7.36)	2.84 (0.76–5.52)	1.12 (0.02–2.21)	0.84 (0.01–1.66)	0.98 (0.40–1.87)	0.77 (0.36–1.41)
Bimonthly:	Nov 76 to Apr 78	1.65 (1.11–2.25)	1.11 (0.74–1.51)	0.66 (0.44–0.88)	0.44 (0.30–0.59)	0.52 (0.42–0.64)	0.42 (0.36–0.49)
Quarterly:	Nov 76 to Jan 79	1.75 (1.34–2.20)	1.31 (1.01–1.65)	0.72 (0.52–0.93)	0.54 (0.39–0.70)	0.54 (0.46–0.63)	0.46 (0.40–0.52)
Jul 1977							
Monthly:	Aug 77 to Mar 78	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00
Bimonthly:	Aug 77 to Jan 79	0.79 (0.32–1.30)	0.53 (0.21–0.87)	0.53 (0.35–0.71)	0.35 (0.24–0.47)	0.45 (0.36–0.56)	0.40 (0.35–0.47)
Quarterly:	Aug 77 to Jan 79	0.66 (0.20–1.19)	0.50 (0.15–0.89)	0.49 (0.30–0.68)	0.37 (0.23–0.51)	0.43 (0.34–0.53)	0.40 (0.34–0.47)
Jul 1978							
Monthly:	Oct 78 to Mar 79	0.19 (<0.00–2.24)	0.10 (<0.00–1.68)	0.82 (0.32–1.32)	0.62 (0.24–0.99)	0.42 (<0.00–0.96)	0.40 (<0.00–0.79)
Bimonthly:	Aug 78 to Mar 79	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00
Quarterly:		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Mahia West							
Oct 1976							
Monthly:	Nov 76 to Jul 77	4.81 (3.04–6.87)	3.60 (2.29–5.15)	0.77 (0.18–1.36)	0.58 (0.14–1.02)	0.89 (0.58–1.26)	0.68 (0.47–0.95)
Bimonthly:	Nov 76 to Apr 78	0.61 (0.08–1.19)	0.41 (0.06–0.80)	0.28 (0.15–0.41)	0.19 (0.10–0.28)	0.24 (0.19–0.31)	0.22 (0.19–0.27)
Quarterly:	Nov 76 to Jan 79	0.90 (0.54–1.31)	0.68 (0.40–0.98)	0.31 (0.19–0.43)	0.23 (0.14–0.32)	0.28 (0.24–0.33)	0.25 (0.22–0.29)

The first four factors may have affected estimates of *Z* in all four areas where tagging programmes were conducted. Results from laboratory and field experiments suggest that the rates of initial tag loss and mortality due to tagging are small (about 6%). However, rock lobsters are most susceptible to tag loss and mortality due to the presence of the tag while moulting, and results from laboratory experiments suggest that the combination of tag loss and tag mortality rates may be about 30% during the first year after tagging (author's unpubl. data). If this rate is approached in the field, then the estimates of *Z* from the tag returns will be considerably greater than the true rate.

The fifth factor, emigration out of the fishing areas, does not appear to have been important as few tagged rock lobsters were recaptured outside their release areas (author's unpubl. data).

Annala (1979) also discussed factors that may affect the estimates of *F*. These included the death of tagged rock lobsters due to the presence of the tag, or the loss of their tags, shortly after marking, and incomplete reporting of tags by fishermen. Neither of these factors appeared important. However, the methods of Paulik (1963) and Ricker (1975) used to estimate *F* from the rate of tag returns are both dependent on estimates of *Z*, so that any bias in the estimates of *Z* may also affect the estimates of *F*.

The relative effort data for Mahia East were based on the total number of days fished by the entire fleet and probably reflected any increase in effective effort due to an increase in the number of vessels fishing in the area. However, the relative effort data for Gisborne Local, South of Young Nicks Head, and Mahia West were based only on the average number of days fished per vessel per month for a selected number of vessels and did not take into account changes in fleet size. The number of registered vessels in these three areas also increased during the period of the tagging programmes. If this increase resulted in an increase in effective effort (which could not be determined), then the estimates of *Z* for these areas would be lower than the true rates. Moreover, the relative effort measures used for all areas did not take into account any changes in the numbers of pots fished, which may have affected the level of effective effort.

The time of year when tagging was done also affected the estimates of *Z* and *F*. For example, these estimates were much higher for Mahia East females tagged in October 1976 than those tagged in July 1977 and 1978 (Table 3). Most of the females tagged in October were non-berried, and the return rate of females was high in the months immediately after tagging (Fig. 4). However, most of the females tagged in the two July taggings were berried, and the return rates were low in the months immediately after tagging, perhaps because fishermen returned berried females to the sea. The high initial return rate for the October tagging may have been the main factor behind the high mortality rate estimates.

The number of months over which the tag returns were grouped also affected the mortality rate estimates, there being considerable variation among

Table 4 Estimates of annual instantaneous total mortality rate (*Z*) from weighted seasonal size-frequency distributions of male rock lobsters landed from Gisborne Local, South of Young Nicks Head, Mahia East, Mahia West, and Gisborne North areas. Estimates derived using annual growth estimate for area where size-frequency distributions were taken, except where otherwise specified. (G, estimates derived using annual growth estimate of 5.9 mm for Gisborne Local males; S, estimates derived using annual growth estimate of 7.9 mm for South of Young Nicks Head males; M, estimates derived using annual growth estimate of 12.2 mm for Mahia East males; -, not calculated).

	Method		
Season	Bhattacharya (1967)	Van Sickle (1977)	Hancock (1965)
	Gisborne Local		
1974–75	0.86	0.38	1.28
1975–76	1.17	0.67	1.37
1976–77	1.06	1.02	1.30
1977–78	0.93	0.96	0.98
1978–79	1.36	1.21	1.28
	South of Young Nicks Head		
1977–78	-	1.10	1.42
1978–79	1.24	1.03[(a)]	1.77[(a)]
		1.51[(b)]	1.77[(b)]
	Mahia East and Mahia West combined		
1974–75	0.39	0.72 (S)	0.90 (S)
		1.40 (M)	1.13 (M)
1975–76	0.78	0.79 (S)	0.98 (S)
		0.99 (M)	1.27 (M)
1976–77	0.72	0.64 (S)	0.82 (S)
		1.14 (M)	1.20 (M)
	Mahia East		
1977–78	0.70	0.62	0.86
1978–79	-	0.72	0.84
	Mahia West		
1977–78	-	0.79 (S)	0.83 (S)
		1.43 (M)	1.20 (M)
1978–79	0.70	1.01 (S)	1.02 (S)
		1.50 (M)	1.56 (M)
	Gisborne North		
1975–76	0.64	1.61 (G)	0.88 (G)
		0.94 (S)	1.14 (S)
		1.41 (M)	1.79 (M)
1976–77	0.42	0.58 (G)	0.78 (G)
		0.91 (S)	1.08 (S)
		1.31 (M)	1.53 (M)
1977–78	1.09	0.80 (G)	1.02 (G)
		1.25 (S)	1.38 (S)
		1.54 (M)	1.95 (M)
1978–79	1.05	0.85 (G)	1.30 (G)
		1.31 (S)	1.71 (S)
		1.43 (M)	2.49 (M)

(a) 100% recruitment length of 101 mm used.
(b) 100% recruitment length of 103 mm used.

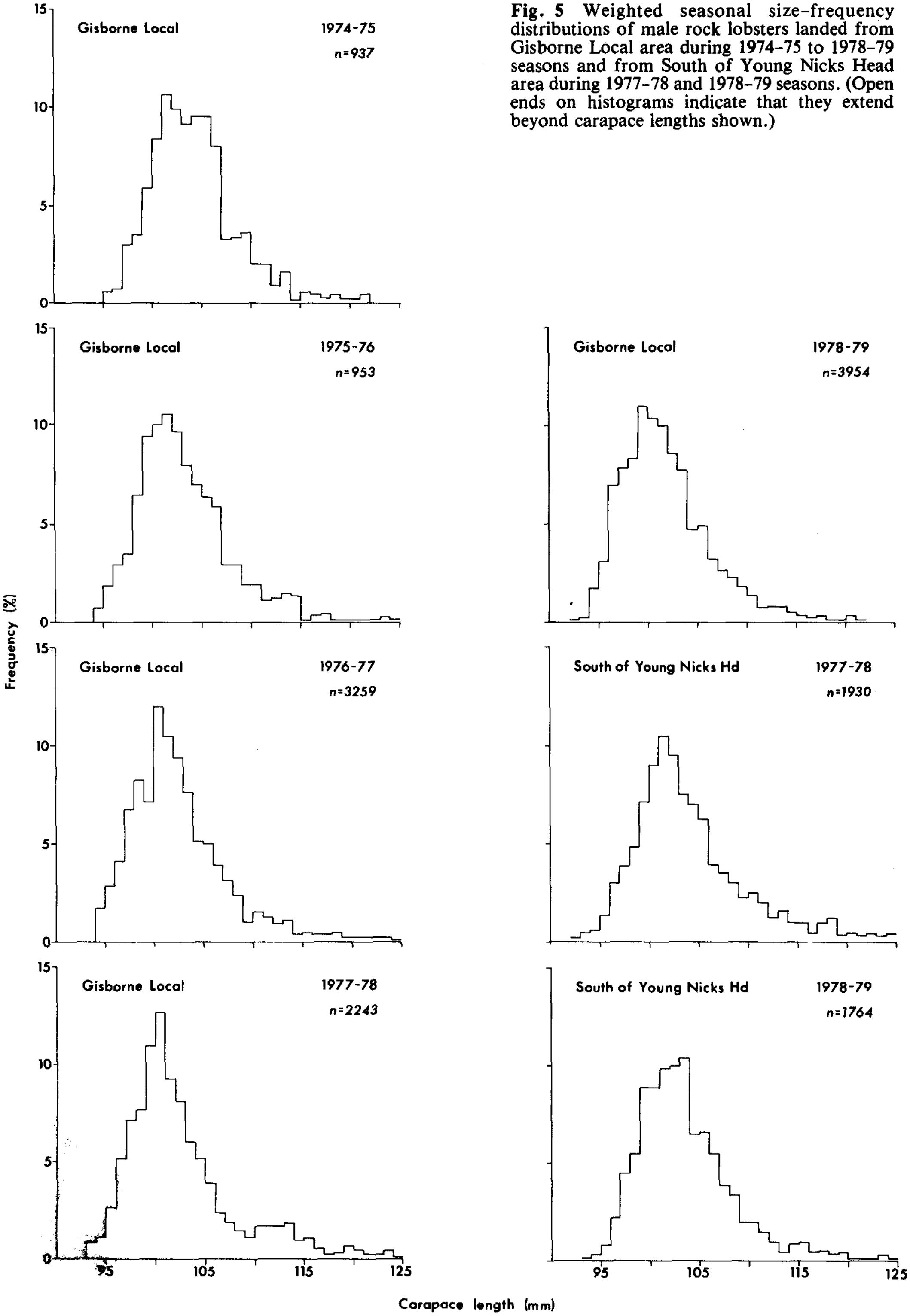

Fig. 5 Weighted seasonal size-frequency distributions of male rock lobsters landed from Gisborne Local area during 1974–75 to 1978–79 seasons and from South of Young Nicks Head area during 1977–78 and 1978–79 seasons. (Open ends on histograms indicate that they extend beyond carapace lengths shown.)

the three groupings for most taggings. The quarterly groupings encompass the longest time-span for returns and probably dampen the effects of any short-term fluctuations in return rates due to changes in catchability associated with moulting and reproductive behaviour. Therefore, mortality rates derived from quarterly groupings are probably better estimates of the true rates than those derived from the monthly or bimonthly groupings.

ESTIMATES OF *Z* FROM SFD ANALYSES

Annala (1979) discussed the various factors which may affect estimates of *Z* from SFD analyses. All three methods require an accurate description of the SFD. The methods of Van Sickle (1977) and Hancock (1965) require information on growth rates, and although Bhattacharya's (1967) method does not require growth data, knowledge of the annual growth increment does aid the analysis of the SFD.

The results from the methods of Van Sickle and Hancock were both greatly influenced by the estimates of annual growth. Annala (1979) used an average annual growth increment of 4.8 mm to estimate *Z* for Gisborne Local males landed in 1976–77. The results from Van Sickle's method were 0.64 and 1.03 for the 4 mm and 5 mm groupings respectively, and 1.07 from Hancock's method. The corresponding estimates in this paper, using an

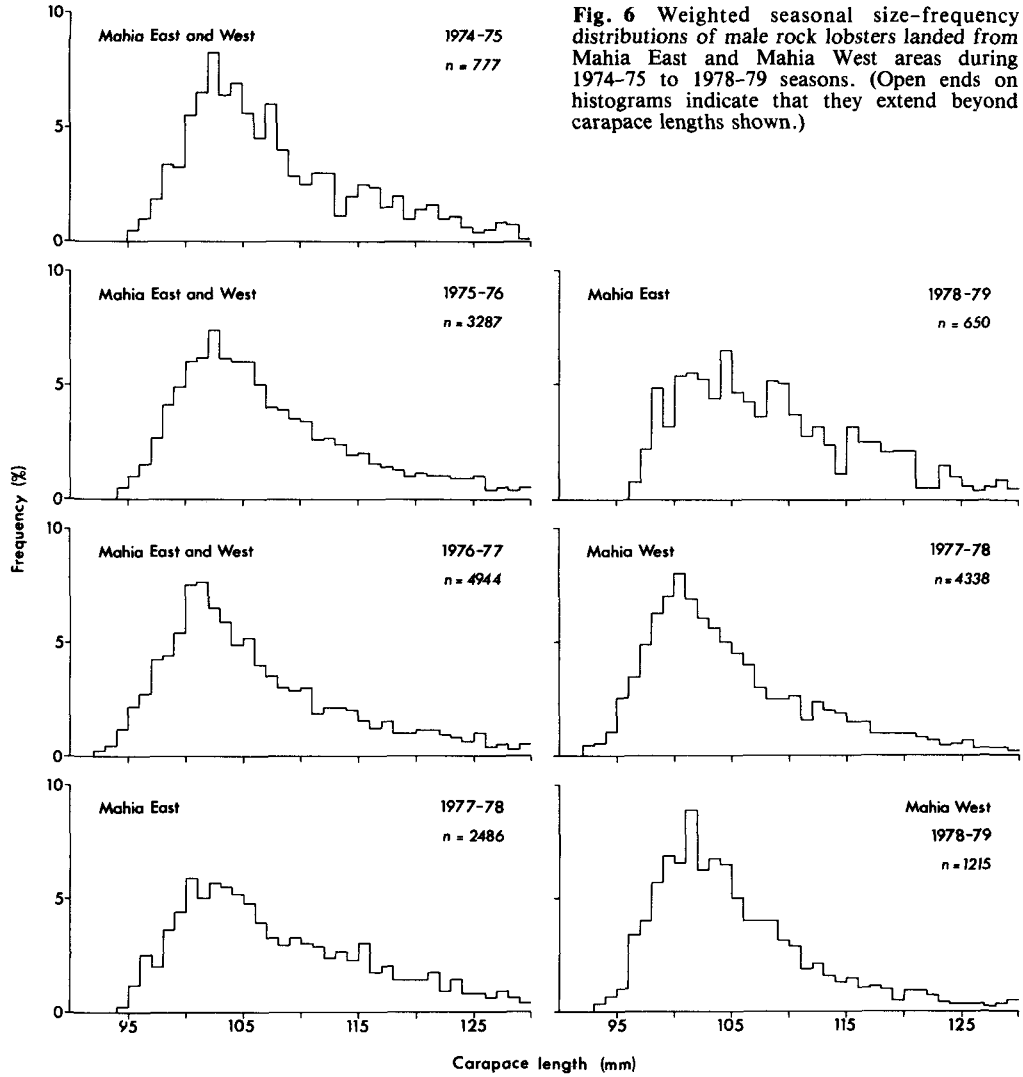

Fig. 6 Weighted seasonal size-frequency distributions of male rock lobsters landed from Mahia East and Mahia West areas during 1974-75 to 1978-79 seasons. (Open ends on histograms indicate that they extend beyond carapace lengths shown.)

average annual growth increment of 5.9 mm, were 1.02 and 1.30 for Van Sickle's and Hancock's methods respectively.

In areas where no annual growth estimates were available (e.g., for Mahia West and Gisborne North males) the estimates of Z varied widely, depending on the growth increments used. These examples emphasise the necessity for accurate estimates of growth rates for use with these methods.

Best Estimates of Z and F

The estimates of Z from the tag return rates and those from the SFD analyses showed considerable variation, the former estimates usually being greater than the latter for any given area. As stated by Annala (1979) and discussed above, the estimates of Z for the entire exploited population from the rate of tag returns taken over both a 12 month and an 8 or 9 month season using the method of Robson & Chapman (1961), and the estimates of F for a 12 month season using the methods of Paulik (1963) and Ricker (1975), were generally considered too high.

The best estimates of Z and F (Table 6) are considered to be estimates of F based on tag returns grouped quarterly and taken over an 8 or 9 month fishing season; estimates of Z based on these estimates of F from tag returns, with the addition of an assumed value for the annual instantaneous natural mortality rate (M) of 0.10 (Annala 1979); and estimates of Z from the SFD analyses. These estimates are more consistent with the estimated lifespans in the fishery of 4–5 years for males and 6–8 years for females (J. L. McKoy, pers. comm.) than are the higher estimates of Z derived from tag returns.

CONCLUSIONS

The best estimates of Z and F for any given area and sex generally varied over a wide range (Table 6). Because of this variation, the best approach is to describe the range of the estimates rather than calculate single, point values for each area based on some measure of central tendency.

The best estimates of Z and F for Mahia East and Mahia West females were generally less than the estimates for males from all the areas, although some overlap occurred. Since female rock lobsters carrying eggs cannot be legally landed, females are largely unavailable during the main egg-bearing period (May–September), which constitutes about half the fishing season, and lower mortality rates for this sex are expected.

The estimates in this study are generally consistent with previous estimates for *J. edwardsii*. Annala (1977) found that F was 1.06 for both males and

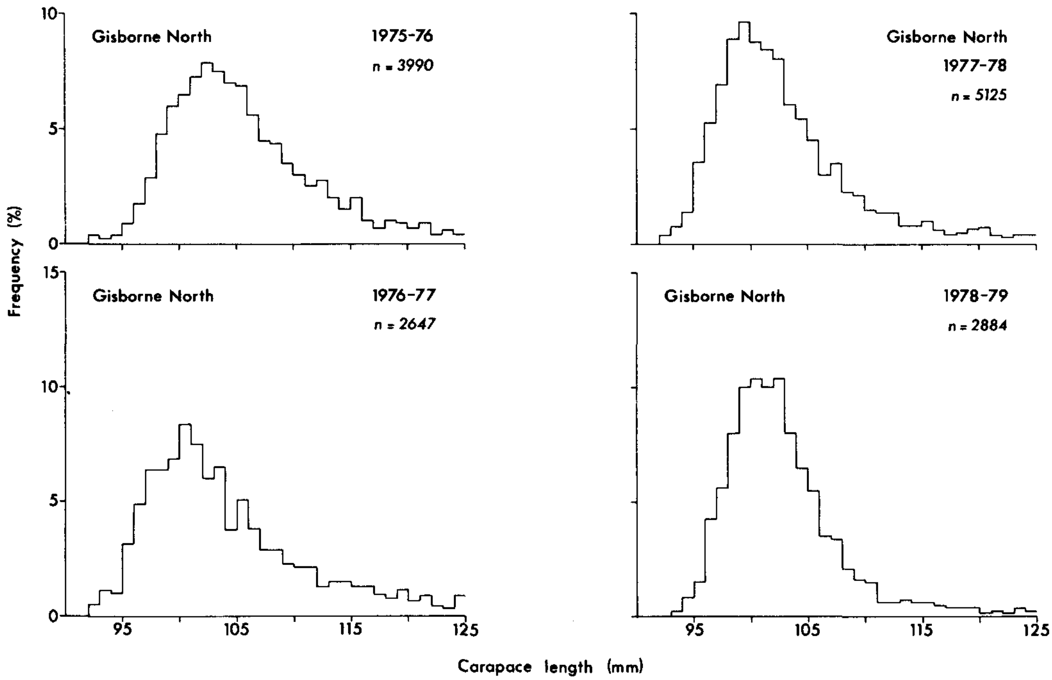

Fig. 7 Weighted seasonal size-frequency distributions of male rock lobsters landed from Gisborne North area during 1975–76 to 1978–79 seasons. (Open ends on histograms indicate that they extend beyond carapace lengths shown.)

females along the Otago coast. Furthermore, he estimated that Z for this area was 1.08 and 1.12 for males and 1.24 and 1.23 for females during two sampling periods, respectively. Annala (1979) also found best estimates of Z between 1.0 and 1.5 and of F between 0.9 and 1.4 for Gisborne Local males during the 1976-77 season.

Saila *et al.* (1979) developed yield-per-recruit models for the rock lobster fishery in the Gisborne area from preliminary estimates of growth and mortality rates. The growth rates were derived from tag-recapture studies, which for males were conducted in the Gisborne Local, South of Young Nicks Head, Mahia East, and Mahia West areas and for females in the Mahia East and Mahia West areas. The growth estimates used in this paper incorporate most of the data from Saila *et al.* (1979) plus new data (J. L. McKoy, pers. comm.). The estimates of F used in the yield-per-recruit models in Saila *et al.* (1979) were derived from the 1976-77 Gisborne Local data for males (Annala 1979).

It is now evident that growth rates vary between sexes and areas (J. L. McKoy, pers. comm.), as do mortality rates (this paper), and that yield-per-recruit

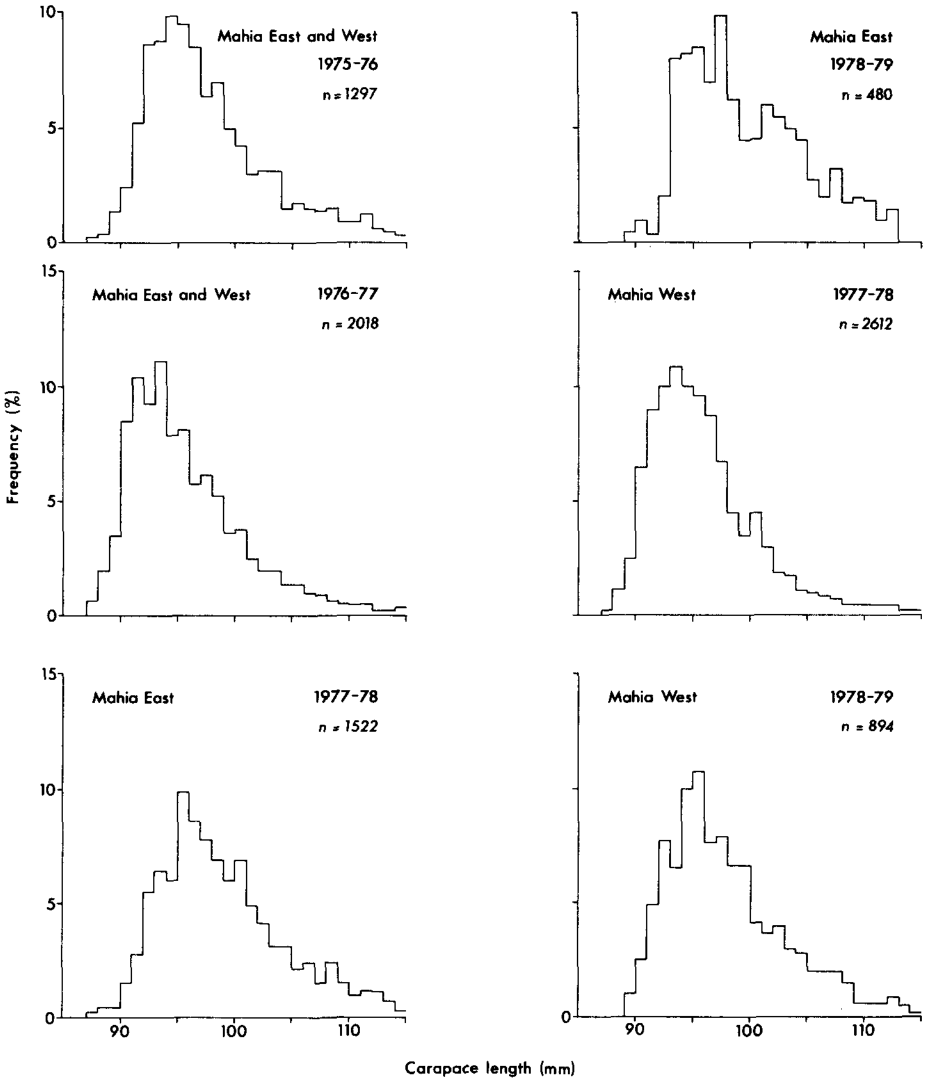

Fig. 8 Weighted seasonal size-frequency distributions of female rock lobsters landed from Mahia East and Mahia West areas during 1975-76 to 1978-79 seasons. (Open ends on histograms indicate that they extend beyond the carapace lengths shown.)

models should be developed for each area. The models should then be compared to determine if these differences in growth and mortality rates have significant effects on the results. Yield-per-recruit models for the areas where growth information is available are being developed (author's unpubl. results).

The instantaneous natural mortality rate (M) is difficult to measure in any fishery. In this paper and others (Annala 1977, 1979, Saila *et al.* 1979), it was assumed that $M = 0.10$. Saila *et al.* (1979) chose values of M one-half and twice as great (0.05–0.20) as being the expected range of the true value of M for their yield-per-recruit calculations. However, M may vary in some compensatory way with F (i.e., being high when F is low, and decreasing as F increases). Thus, the assumption that $M = 0.10$ for each of the fishery areas and for both sexes may not hold true, but because the expected range of M is small (0.05–0.20), any variation from the assumed value of 0.10 would probably have no significant effect on the estimates of Z and F.

Table 5 Estimates of annual instantaneous total mortality rate (Z) from weighted seasonal size-frequency distributions of female rock lobsters landed from Mahia East and Mahia West areas (-, not calculated).

Season	Method Bhattacharya (1967)	Van Sickle (1977)	Hancock (1965)
	Mahia East and West combined		
1975–76	0.71	0.33	0.46
1976–77	0.41	0.25	0.53
	Mahia East		
1977–78	0.58	0.22	0.40
1978–79	-	0.44	0.34
	Mahia West		
1977–78	1.53	0.30	0.62
1978–79	0.88	0.33	0.47

In summary, the mortality rate estimates for each sex from the rate of tag returns varied widely for most tagging programmes for any given area, and depended on the time of tagging and the time-span chosen for grouping the returns. The estimates of Z for each sex from the SFD analyses for a given area in any one season also varied considerably among the three methods for some samples, and were dependent on accurate estimates of the annual growth increment. Because of these variations, mortality rates should be estimated from both the rate of tag returns and SFD analyses. These results should then be compared to derive the best estimates of the rates, which, for this study, were considered to be the estimates of F based on tag returns grouped quarterly and taken over an 8 or 9 month fishing season; estimates of Z based on these estimates of F from tag returns, with the addition of $M = 0.10$; and estimates of Z from the SFD analyses. Mortality rates varied between the sexes and among the areas for each sex, and it is therefore important that mortality rates are estimated separately for each sex and for specific areas, and not generalised from samples taken over a wide area.

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Table 6 Best estimates of annual instantaneous total (Z) and fishing (F) mortality rates derived from tag return data and size-frequency distribution analyses for each of the study areas (-, not calculated).

Area	F (a)	Z (b)	Z (c)
Males			
Gisborne Local	0.59–1.21	0.69–1.31	0.38–1.37
South of Young Nicks Head	0.59–1.04	0.69–1.14	1.03–1.77
Mahia East	0.45–0.89	0.55–0.99	0.62–0.86
Mahia West	0.56–0.65	0.66–0.75	0.70–1.56
Mahia East and Mahia West combined	-	-	0.39–1.40
Gisborne North	-	-	0.42–2.49
Females			
Mahia East	0.37–0.54	0.47–0.64	0.22–0.58
Mahia West	0.23–0.25	0.33–0.35	0.30–1.53
Mahia East and Mahia West combined	-	-	0.25–0.71

(a) Based on tag returns grouped quarterly and taken over an 8 or 9 month fishing season.
(b) Based on estimates of F from column 1, with addition of an assumed value for annual instantaneous natural mortality rate (M) of 0.10.
(c) Based on size-frequency distribution analyses.

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