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MORTALITY RATES AND STOCK ASSESSMENT OF *METAPENAEUS MONOCEROS* ALONG THE KAKINADA COAST*

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ABSTRACT

Instantaneous total mortality coefficent (Z) in *Metapenaeus monoceros* has been estimated from the length-frequency distribution estimated to annual catch for the years 1974-1977 for both males and females. The estimates of Z based on Heincke's method, Beverton and Holt method and cohort analysis are closer to each other. The estimates of Z by these methods indicate a gradual increase in the values from 1974 to 1977 corresponding to the increase in fishing effort. The estimates of Z obtained by cumulative catch-curve and catch-curve methods are closer to each other and higher than those obtained by the other three methods. Reasons for these variations are discussed. The estimates of natural mortality coefficient (M) by Cushing's method and Pauly's method are closer to each other. Based on the values of Z obtained by Beverton and Holt method (4.364 for males and 3.664 for females) and the values of M obtained by Cushing's method (2.42 for males and 2.22 for females) fishing mortality coefficient (F) is estimated as 1.944 for males and 1.444 for females during the years 1974-77.

Stock assessment by 'Surplus-yield' model and yield-per-recruit model as well as Baranov's catch equation and cohort analysis indicate that the stock is fished just at the optimum level of exploitation and any further increase in effort will reduce the catch per hour of trawling.

INTRODUCTION

ESTIMATION of mortality rates is a basic requirement for fish stock assessments. It is usually estimated as instantaneous total mortality co-efficient (Z) and includes both natural mortality co-efficient (M) and fishing mortality co-efficient (F). Although estimations of mortality rates have been employed to assess the stocks of finfishes since the beginning of this century, such estimations of mortality for the assessment of penaeid prawn stocks are rather scarce since parameters needed to calculate mortality rates are difficult to obtain.

Most of the earliest attempts to calculate mortality rates were based on tagging experiments (Lindner and Anderson, 1956; Klima, 1964; Kutkuhn, 1966; Costello and Allen, 1968). However, the unreliability of the estimates of mortality based on tagging has led many workers to resort to the analysis of the catch composition for this purpose. Neal (1968),

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Berry (1970), Garcia (1977), Parrack (1981), Pauly, Ingles and Neal (1984) and others have used catch composition to estimate the mortality rates. In India, Banerji and George (1967) were the first to estimate the mortality rates of *M. dobsoni* from the catches at Cochin which was followed by Kurup and Rao (1974), Ramamurthy *et al.* (1975, 1978), Ramamurthy (1980) and Rao (MS 1). All these publications pertain to the prawns of west coast of India. Except for the work of Rao (MS 2) on the prawns of the Visakhapatnam virtually nothing is known regarding this aspect of prawns of the east coast of India. Hence, a study of the mortality of *M. monoceros* at Kakinada along the east coast was undertaken during this investigation.

Very little work has been done on the stock assessment of penaeid prawns in Indian waters, except by Ramamurthy *et al.* (1975, 1978), Ramamurthy (1980), Silas *et al.* (1984) and Rao (1988) who adopted the surplus yield model to assess the stocks of prawns. The present study is the maiden effort on the assessment of the stock of *M. monoceros* in the Indian waters.

Material and Methods

Material for this study was collected from the trawlers operating off Kakinada. As the majority of these boats do not maintain any fishing log, it was necessary to follow the procedure generally adopted for recording indigenous gear catches. Data on catches were collected by eye estimation and by enquiry while data on the number of units operated were obtained by actual counting of all the boats landed. Data on effort in trawling hours of the sampled boats were collected by enquiry from the fishing crew. About 20% of the boats were sampled for these statistics on a given observation day. From these values obtained on observation days, once in a week, monthly estimates were computed depending on the number of fishing days in that month. The mechanised boats operating trawl nets were classified as 'pablos', 'pomfrets' and 'sorrahs' depending on the size of the boat. Catch and effort data collected separately for these boats were used to standardise the effort taking 'pomfret' as a standard boat. Data collected during 1967-1978 were analysed for the purpose of this study.

Random samples of *M. monoceros* were collected on all the observation days for length frequency analysis. In the laboratory, samples were sexed and measured for length and weight. Length frequency distribution was studied by grouping length measurements into 5 mm class intervals, *e.g.* 61-65, 66-70, 71-75, etc. with mid-points at 63, 68, 73, etc. respectively. Wherever length groups are mentioned only mid-points are given for the make of brevity. The actual observed numbers in the length frequency distribution were raised to the total catch of the observation day based on the sample weights taken separately for males and females. The data so obtained for sample days were pooled to obtain the catch in numbers for all the sample days in the month which in turn were raised to the monthly catch.

Data collected for the period January 1974-December 1977 were used for the estimation of mortality rates. The monthly length frequency distributions were pooled into annual length frequency distributions on calendar year basis as the mortality rates were annual instantaneous rates. Annual length distributions scaled down to 100 hours of trawling were used in the estimation of mortality rates by Heincke's, Beverton and Holt, catch curve and cumulative catch-curve methods. For cohort analysis, actual annual length frequency distribution were used.

Growth parameter estimates derived by Rao (1990) and Rao and Krishnamoorthi (1990) were used for mortality estimates and stock assessment. The total mortality coefficient (Z) has been calculated by the following five methods :

1. Heincke's method (1913);
2. Cumulative catch-curve method of Jones and van Zalinge (1981);
3. Beverton and Holt method (1957);
4. Catch-curve method of Pauly (1982); and
5. Cohort analysis of Jones and van Zalinge (1981).

The natural mortality coefficient (M) was calculated on the basis of the following three methods :

1. Widrig's method (1954);
2. Cushing's method (1968); and
3. Pauly's method (1980).

The following four methods were used for stock assessment :

1. Surplus-yield model;
2. Yield-per-recruit model;
3. Baranov's catch equation; and
4. Cohort analysis.

Parameter estimates used in the yield-per-recruit calculations are as follows :

Parameters	*Males*	*Females*
K	1.68	1.62
t_o	0.048	0.066
L_α in mm	178.4	207.3
l_r in mm	76	76
l_c in mm	76	76
W_α in gram	36	68
Z average for 1974-1977	4.86	3.66
F average for 1974-1977	1.96	1.46
M	2.4	2.2

Details as well as merits of relevant methods are furnished while presenting results of different methods.

RESULTS AND DISCUSSION

Estimation of total mortality coefficient (Z)

A basic equation used in fishery biology for expressing the mortality is written as

$$N_t = N_o e^{-Zt}$$

where N_0 and N_t are numbers at time zero and t respectively, and Z the instantaneous rate of total mortality. Of the several methods available (Heincke, 1913; Beverton and Holt, 1957; Chapman, 1961; Robson and Chapman, 1961; Pope, 1972; Ssentongo and Larkin, 1973; Ricker, 1975; Jones and van Zalinge, 1981; Pauly, 1983) to estimate the instantaneous rate of total mortality (Z), five were used in this study.

Heincke's method

Heincke's estimate (Heincke, 1913; Ricker, 1975) of the mortality rate (A) is as follows :

$$A = \frac{N_0}{\Sigma N}$$

The survival rate 'S' is obtained by the formula

$$S = 1 - A$$

and, therefore, the corresponding estimate of survival rate 'S'.

$$S = \frac{\Sigma N - N_o}{\Sigma N}$$

In this method it is adequate to know the number of prawns in the 0-age group and the total number of all age groups (N). Hence, this formula is useful when age determinations of older animals are unreliable. The yearly length compositions for 100 hours of trawling of *M. monoceros* for the years 1974-1977 are used for the estimations. For this purpose males upto 145 mm and females upto 165 mm are considered to represent the 0-age group (Rao and Krishnamoorthi, 1990). The statement of calculation of Z is presented in Table 1. Apart from a slight departure in the Z value of 1976 in both males and females, an increasing trend from 1974 to 1977 was seen for both the sexes. This is also reflected in the decline of the Cph over the period (Rao, MS 1).

TABLE 1. *Estimation of Z by Heincke's method for* M. monoceros

Year	$\sum N$	N_o	$\Sigma N-N_0$	S	Z
		Males			
1974	10971	10725	246	0.00224	3.7977
1975	4664	4651	13	0.00279	5.8826
1976	4289	4277	12	0.00280	5.8810
1977	8603	8593	17	0.00197	6.2275
Average					5.4472
		Females			
1974	10838	9855	983	0.09070	2.4002
1975	7053	6983	70	0.00992	4.6127
1976	3978	3879	99	0.02562	3.6643
1977	8343	8292	51	0.00587	5.1371
Average					3.9511

Beverton and Holt method (1957)

According to Beverton and Holt, if the length at entry into the exploited phase and the average in the catch are l_c and $\bar{l}$ respectively, the expression for 'Z' can be described as

$$Z = K \frac{(L_\infty - \bar{l})}{(\bar{l} - l_c)}$$

where K and L_∞ are the constants of the von Bertalanffy equation.

In the present study 'l_c' is taken as 76 mm since *M. monoceros* below this length is not completely recruited into the sea. This is further corroborated by the observations of its size composition in the backwater catches where 61-65 mm size forms a mode in most of the months. In the trawler catches a mode was observed for both males and females at 76-80 mm size group during the period 1974-76 indicating that the prawn is fully recruited to the inshore fishery at this size. Hence a length of 76 mm is considered as l_c for both the sexes.

The Z values derived thus are tabulated in Table 2. It is seen that the values of Z gradually increased for both males and females from 1974 to 1977 following the trend of fishing effort. Thus it is evident that the increased fishing effort has increased the Z value. This would naturally be reflected in the size of the stock.

TABLE 2. *Estimation of Z by Beverton and Holt method for* M. monoceros

Years	$\bar{a}$	C in mm	A in mm	$\bar{l}$ in mm	
Males : L_∞ = 178.4 mm K = 1.68 l_c = 76 mm					
1974	0.075	5	113	113.38	2.9222
1975	2.112	5	118	107.14	3.7918
1976	2.660	5	88	101.33	5.1197
1977	4.312	5	78	99.56	5.6219
Average					4.3639
Females : L_∞ = 207.3 mm K = 1.62 l_c = 76 mm					
1974	0.884	5	123	127.42	2.5166
1975	3.231	5	138	121.85	3.0192
1976	5.448	5	88	115.44	3.7729
1977	5.707	5	78	106.53	5.3471
Average					3.6640

Cumulative catch-curve method

Jones and van Zalinge (1981) showed that

$$\log_e \sum_L N = \frac{Z}{K} \log_e (L_\infty - L) + \log_e C$$

where N is the accumulated number above certain size L and C is a complex term independent of L. Plotting $\log_e \sum N$ against $\log_e (L_\infty\text{-}L)$ gives a straight line with a slope equal to Z/K, Z being assumed as constant. For *M. monoceros* it was observed that the above relationship is approximately linear over the middle length range, but far from linear for the smallest individuals, represented by the part of the curve A.......B (Fig. 1 and 2) the departure from linearity may be explained by the fact that the smallest individuals are incompletely represented in the catches, so that the numbers in the catches are unlikely to be representative of the numbers in the population. In the case of the oldest individuals, represented by the part of the curve C......D, the curve departs from linearity and the reasons for this could be many. One explanation is that the growth rates of the very large individuals are not likely to be adequately represented since the parameters used are of an average growth curve. In view of these limitations, only the linear part of the curve, from B.......C, could be used for estimating the ratio Z/K.

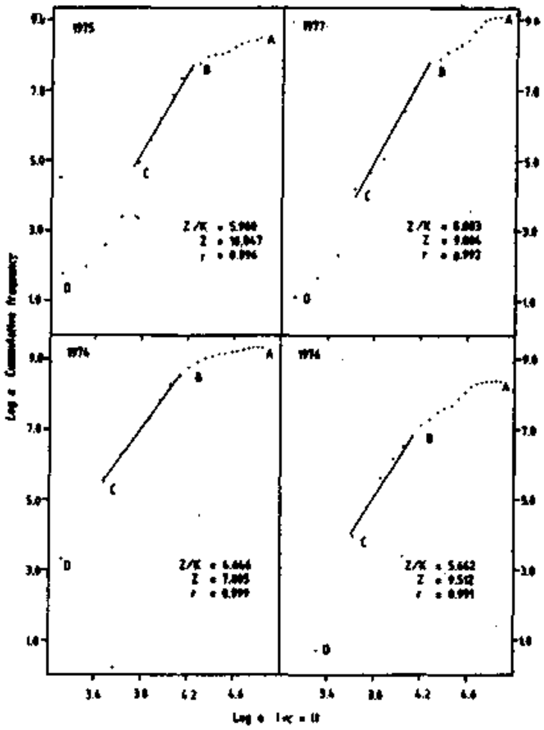

Fig. 1. Estimation of Z/K and Z by cumulative catch-curve for males of *M. monoceros* for 1974-1977.

The estimation of Z by cumulative catch-curve method applied to the annual length composition data (scaled down to 100 hours of trawling) for males of *M. monoceros* is shown in Fig. 1. It is seen that the length range considered varied from year to year and hence, Z values did also vary. Average Z has been calculated at 9.517 which appears to be very much on the higher side when compared to the values arrived at by Heincke's and Beverton and Holt methods.

For females, the graphic representations are presented in Fig. 2. Here also, it is seen that the length range corresponding to the linear part of the curve varied considerably from year to year. Average Z has been calculated as 7.595 which again appears to be very much on the higher side.

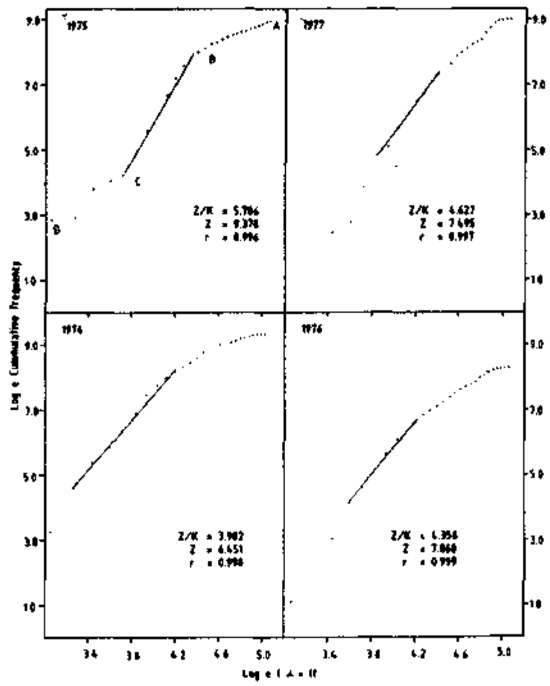

Fig. 2. Estimation of Z/K and Z by cumulative catch-curve for females of *M. monoceros* for 1974-1977.

It is seen from Fig. 1 and 2 that in each case, a greater part of the curve is eliminated for Z estimation since it does not fall in the linear part of the curve. Hence, the calculated Z represents only a fraction of the fishable length range of the species. The higher Z values could be due to this reason and thus an artifact.

Catch-curve method

Edsor (1908) estimated Z based on catch-curves in conjunction with length-frequency. Baranov (1918) on the other hand applied catch-curve method employing age groups. In the equation of Baranov (1918)

$$\log_e N = a + bt$$

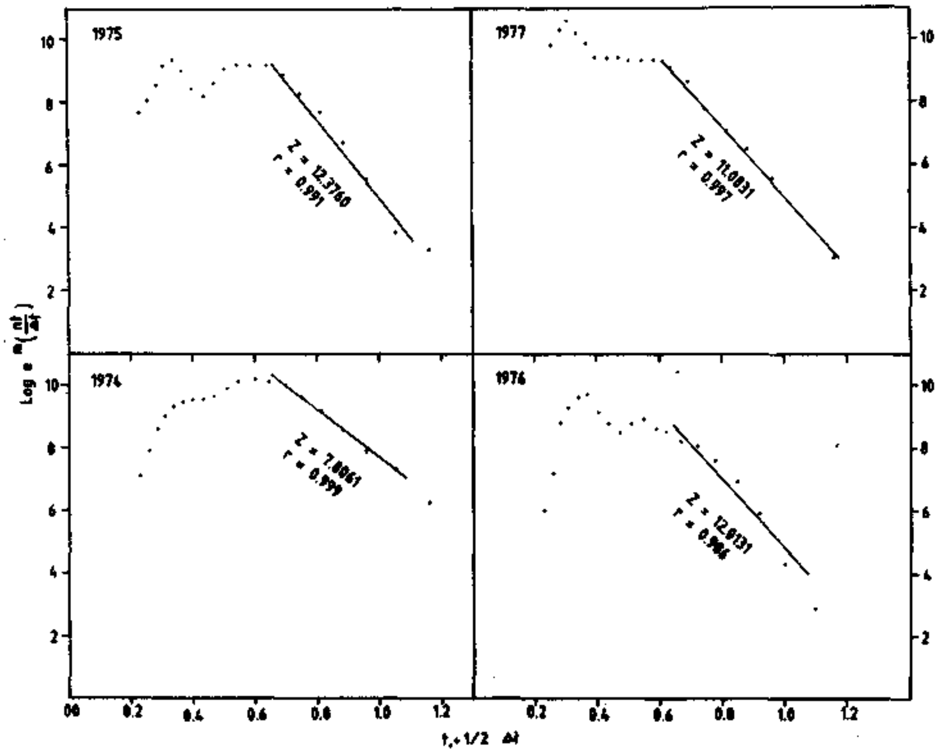

Fig. 3. Estimation of Z by catch-curve for females of *M. monoceros* for 1974-1977.

where (N) is the number of fully recruited and vulnerable animals of a given age (t) and — B = Z, the exponential rate of total mortality (Robson and Chapman, 1961; Ricker, 1975).

When animals cannot be aged individually, as in prawn one could conceive of replacing N by the number of animals in a given length class, and t by the relative age (t') of the animals at mid-length of that class Lt_1 where t' is obtained by solving the von Bertalanffy growth equation

$$t' = \frac{\log_e (1 - l t' / L_\infty)}{-K}$$

This method was applied to prawns by Berry (1970). But the method is liable to considerable bias because large prawns need a longer time to grow through a length class than small prawns, this being due to the fact that prawn growth in length is not linear. Thus, large older prawns 'pile up' in the larger size groups whereby Z is under estimated. A correction for this situation was proposed by Pauly (1982) where each value of N is divided by the time needed to grow through a length class (Δ t) computed as

$$t = \log_e \frac{(L_\infty - L_1) / (L_{\infty} - L_2)}{K}$$

Where L_1 and L_2 are the lower and upper limits of the length class respectively. Thus a length-converted-catch-curve should have the form

$$\log_e (N / \Delta t) = a + bt'$$

The linear portion of the descending limb of the curve should be considered for the estimation of Z as Z is constant over this portion of the legnth range. Also it assumes that Z is constant over the length range in the linear part of the ascending left limb provided there is no mesh selection.

Annual length-frequency data scaled down to 100 hours of trawling for the period 1974-1977 have been subjected to this analysis. The catch-curves are shown in Fig. 3 and 4 for males and females respectively. The results of this analysis can be summarised as follows :

Year	Males Length range (mm) considered	Z	Females Length range (mm) considered	Z
1974	121-155	7.806	145-185	6.605
1975	115-155	12.376	131-180	10.429
1976	115-155	12.013	151-185	8.082
1977	111-155	11.083	135-175	8.647

It was observed that the length range considered for males in the calculation varied from 121-155 mm to 111-155 mm in 1974 and 1977 respectively. Similarly Z also varied from 7.806 in 1974 to 12.376 in 1975. In females also the length range considered for Z calculation varied considerably from year to year. Z varied from 6.605 in 1974 to 10.429 in 1975.

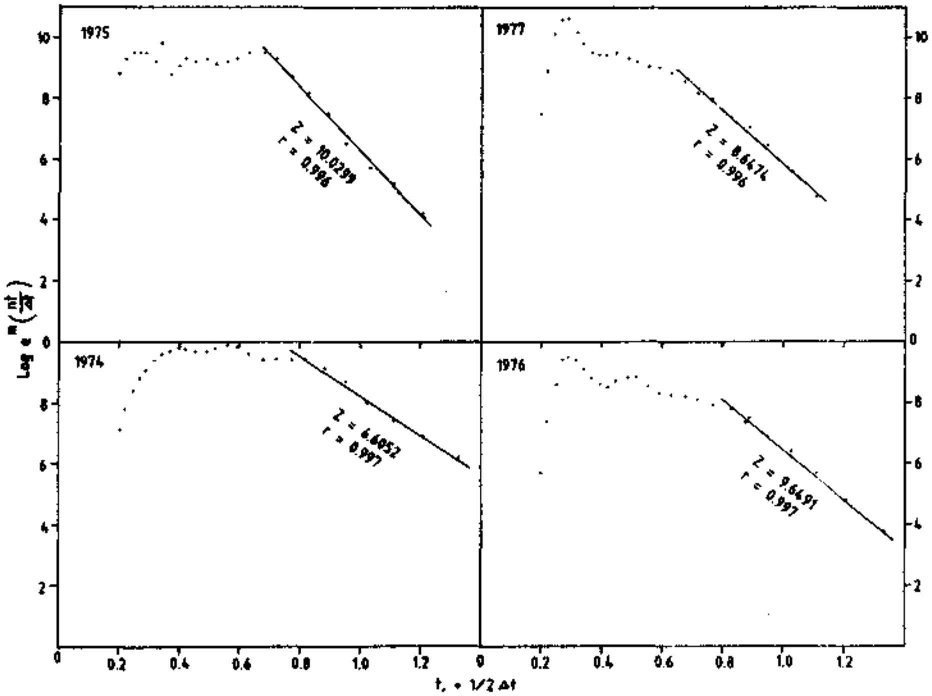

Fig. 4. Estimation of Z by catch-curve for females of *M. monoceros* for 1974-1977.

Cohort analysis

Pope (1972) proposed a simplified Cohort analysis method which was later modified by

TABLE 3. *Cohort analysis of* M. monoceros *males based on the catch of 1974 at Kakinada*
Input parameters : L_∞ = 178.4 M = 2.4 M/2K = 0.71

Length groups in mm	X	C '000's	N '000's	Cumulative landings '000's	F/Z	F	Z	Average No. in the sea '000's	Population biomass in kg
50-60	1.059	63	57868	19246	0.010	0.024	2.404	2632	2930
60-70	1.065	412	51540	19183	0.064	0.163	2.543	2551	4643
70-80	1.071	1107	45053	18771	0.162	0.460	2.840	2398	6662
80-90	1.079	1433	38245	17664	0.213	0.644	3.024	2225	8945
90-100	1.089	1840	31520	16231	0.278	0.916	3.296	2012	11231
100-110	1.102	3335	24890	14391	0.449	1.939	4.319	1718	12885
110-120	1.119	4346	17469	11056	0.587	3.383	5.763	1284	12596
120-130	1.143	4168	10067	6710	0.694	5.398	7.778	772	9685
130-140	1.179	1640	4058	2542	0.648	4.381	6.761	374	5888
140-150	1.239	677	1528	902	0.628	4.018	6.398	168	3266
≥ 150		225	449	225	0.500				
Average						2.133	4.513	Total	78731

TABLE 4. *Cohort analysis of* M. monoceros *males based on the catch at Kakinada for the years 1975-1977*

Length group in mm	1975				1976				1977			
	C in thousands	F	Average Biomass No. in sea in thousands	Biomass in kg	C in thous-ands	F	Average No. in sea in thousands	Biomass in kg	C in thous-ands	F	Average No. in sea in thousands	Biomass in kg
50-60	204	0.213	954	1062	25	0.024	979	1090	913	0.321	2842	3163
60-70	465	0.518	913	1662	563	0.599	940	1711	7182	2.805	2561	4661
70-80	1291	1.567	823	2287	2122	2.578	822	2284	8252	4.070	2028	5633
80-90	905	1.248	725	2913	2340	3.555	658	2645	3348	2.085	1607	6459
90-100	573	0.899	645	3598	684	1.293	529	2953	3704	2.851	1300	7257
100-110	1673	3.181	526	3944	1372	3.235	425	3188	3195	3.260	980	7350
110-120	1837	5.322	345	3384	1194	4.105	291	2855	4700	8.105	580	5692
120-130	1338	8.105	165	2070	988	6.060	164	2057	1803	7.923	228	2854
130-140	448	9.287	48	761	497	7.879	62	976	372	4.343	86	1349
140-150	41	4.035	10	200	115	8.488	14	272	235	7.140	33	641
≥ 150	13				5				20			
Average/total		3.434		21881		3.781		20031		4.290		45059

TABLE 5. *Cohort analysis of* M. monoceros *females based on the catch of 1974 at Kakinada*
Input parameters : L_∞ = 207.3 mm M = 2.20 M/2K = 0.679

Length group in mm	X	C '000's	N '000's	Cumulative landings '000's	F/Z	F	Z	Average No. in the sea '000's	Population biomass in kg
50-60	1.046	62	59049	19016	0.012	0.027	2.227	2308	2839
60-70	1.049	287	53910	18954	0.055	0.128	2.328	2230	4059
70-80	1.053	708	48718	18667	0.130	0.329	2.529	2156	6123
80-90	1.057	1258	43265	17959	0.220	0.621	2.821	2032	8555
90-100	1.062	1536	37534	16701	0.269	0.810	3.010	1894	11269
100-110	1.069	2119	31833	15165	0.360	1.216	3.416	1744	14214
110-120	1.076	1904	25874	13046	0.360	1.238	3.438	1540	16694
120-130	1.086	2694	20579	11142	0.480	2.031	4.231	1326	18657
130-140	1.099	2128	14968	8448	0.472	1.967	4.967	1083	19397
140-150	1.115	2186	10456	6320	0.546	2.646	4.846	827	18533
150-160	1.139	2410	6450	4134	0.671	4.487	6.687	537	14837
160-170	1.175	1107	2856	1724	0.640	3.911	6.111	283	9514
170-180	1.236	417	1126	617	0.596	3.246	5.446	133	5379
≥ 180		200	400	200	0.500				
Average						1.743	3.943	Total	150070

TABLE 6. *Cohort analysis of* M. monoceros *females based on the catch at Kakinada for the years 1975-1977*

Length group in mm	1975				1976				1977			
	C in thousands	F	Average No. in sea in thousands	Biomass in kg	C in thousands	F	Average No. in sea in thousands	Biomass in kg	C in thousands	F	Average No. in sea in thousands	Biomass in kg
50-60	404	0.326	1240	1525	19	0.022	844	1038	117	0.049	2380	2927
60-70	1066	0.912	1170	2129	503	0.624	807	1469	3640	1.633	2228	4055
70-80	1350	1.238	1091	3098	1504	2.023	744	2113	8009	4.177	1916	5441
80-90	687	0.683	1004	4227	1277	1.959	651	2741	4777	3.099	1542	6492
90-100	805	0.864	931	5539	722	1.248	578	3439	2727	2.097	1300	7735
100-110	1413	1.667	848	6911	736	1.407	523	4262	3013	2.722	1107	9022
110-120	1231	1.694	727	7881	1063	2.393	444	4813	3221	3.730	863	9355
120-130	1336	2.182	612	8611	834	2.403	354	4981	2465	3.877	636	8949
130-140	2486	5.714	435	7791	869	3.101	286	5122	2169	5.060	429	7683
140-150	1674	7.449	225	5042	646	3.286	197	4415	1386	5.629	246	5513
150-160	566	5.742	99	2735	605	5.037	120	3316	675	5.334	127	3509
160-170	164	3.499	47	1580	262	4.507	58	1950	435	8.911	49	1647
170-180	77	3.192	24	971	133	5.978	22	890	63	8.637	7	283
≥ 180	33				17				1			
Average/Total		2.705		58040		4.807		40549		4.227		72611

Jones (1974) to enable direct application to catch data by size classes (annual catch by size class). Jones and van Zalinge (1981) used this method to calculate mortality rates and population size of *P. semisulcatus* in the Kuwait waters. Population biomass can be obtained by simple multiplications of the average weight of the animals in the size group with the number of individuals in the size group.

In the present study, length composition of the catches was grouped into 10 mm intervals as 51-60, 61-70, 71-80 mm, etc. Data for 1974-1977 for males and females were analysed separately to discern the fluctuations in the population during these years. In the present study 'M' values for males and females as obtained in the subsequent section are used in this analysis. Stepwise computational details are presented in Tables 3 and 5 for males and females respectively for the year 1974. Results for the years 1975 to 1977 are given in Tables 4 and 6.

The values of F/Z for a length of 100 mm or more for different years for males and females are given below :

Year	1974	1975	1976	1977
Male	0.51	0.59	0.58	0.65
Female	0.44	0.53	0.51	0.61

Values increased from 0.51 to 0.65 for males and 0.44 to 0.61 for females, through 1974 to 1977 indicating an increase in the overall exploitation.

The sex-wise average F for different years is given below :

Year	1974	1975	1976	1977
Male	2.133	3.434	3.781	4.290
Female	1.743	2.705	2.614	4.227

For males F gradually increased from 1974 to 1977; for females it increased from 1974 to 1977 with a slight drop in 1976. Similar trend was observed in the catch and the CPH as well. The trend in Z values was similar to that of F values since M was taken as constant throughout the period.

Comparison of mortality estimates obtained by different methods

It is seen that there is a gradation in the values of Z obtained by different methods. The lowest values were obtained by Beverton and Holt method followed by Heincke's method, cohort analysis, cumulative catch-curve and catch-curve methods. The first three methods gave more or less similar but lower estimations, whereas both cumulaitve catch-curve and catch-curve methods gave closer but higher estimates. This is to be expected because the first three methods take into consideration the entire population for the estimation of Z, whereas, the catch-curve methods consider only a fraction of the population for this purpose. As such the Z values obtained by catch-curve methods are applicable only to those size ranges considered for calculation of Z.

In the catch-curve method it was assumed that the ascending part of the curve also will have the same Z value as that of the descending part. But many of the size groups formed an 'irregular dome' in the catch-curves constructed in the present study. There is no provision in the catch-curve method to infer any value of Z for these size groups. Further, it was observed that majority of the size groups (62% in 1974) fall in this 'irregular dome' category (91-150 mm length range). It is also not out of place to mention that as per the catch-curve method they are considered as incompletely recruited to the fishery. This assumption cannot be valid for *M. monoceros* in the fishery of which these size groups form more than 60% by numbers in the catch.

Pauly *et al.* (1984) tried to interpret, by the catch-curve method, the data collected by

Ramamurthy (1967) for *M. kutchensis*. It is pertinent to state here that during the periods mentioned prawn harvesting was limited to indigenous gear operations which were ineffective in catching prawns. Hence, fishing pressure on the stocks was negligible (Rao, MS 1). Even in this situation Pauly (1980) calculates Z varying from 3.55 to 6.49 and F varying from 1.36 to 4.67. These figures appear to be very much on the higher side. Firstly, the length frequency data were defective as the sexes were combined. Secondly, the fishery during the period was harvesting only a fringe of the *M. kutchensis* population of the area. Thirdly, growth parameters calculated from these are not realistic. For example, the L_∞ was calculated at 140 mm when males upto 155 mm and females upto 185 mm were observed off Veraval during 1979-1983 (Rao, MS 1). Hence, it is difficult to comprehend that such high rates of Z could be generated by these fisheries.

Rothschild and Brunenmeister (1984) are of the opinion that the higher mortalities reported so far for penaeid species are most likely in error. Their observation is based on the expression derived by Holt (1965) for the average age in a population

$$\bar{T} = \frac{t_1 - t_2 e^{-Z(t_2 - t_1)}}{1 - e^{-Z(t_2 - t_1)}} + 1/Z$$

where t_1 is recruitment age and t_2 is cohort age. If a typical 'high' value of Z, say Z = 10, is substituted in the above expression, the increase in the average age of the population at each month that was past recruitment would be 0.04, 0.06, 0.08, 0.09, 0.10 years respectively. In other words, if Z = 10, the average age, in the population converges to only t + 0.1 year or about 5 weeks beyond recruitment, hence, such a population would indeed be composed of quite small prawns. They are of the opinion that the Z values reported for the Gulf of Mexico species based on tagging data were also higher. They estimated the ranges of Z values for 'brown shrimp' as 1.71 - 4.38 and for 'white shrimp' as 2.58 - 4.97 basing on CPUE numbers and mean length. These values agree with those of Parrack (1981) based on tagging experiments.

Among the 5 analyses conducted in the present study, Beverton and Holt and Cohort analysis gave closer values of Z as compared to the other three methods. These values of Z appear to be reasonable and nearer to the truth since the entire fully recruited segment of the population is considered for the estimation of Z, and not any specific segment of the fully recruited population as in the catch-curve methods. Parrack (1981) also arrived at similar conclusions.

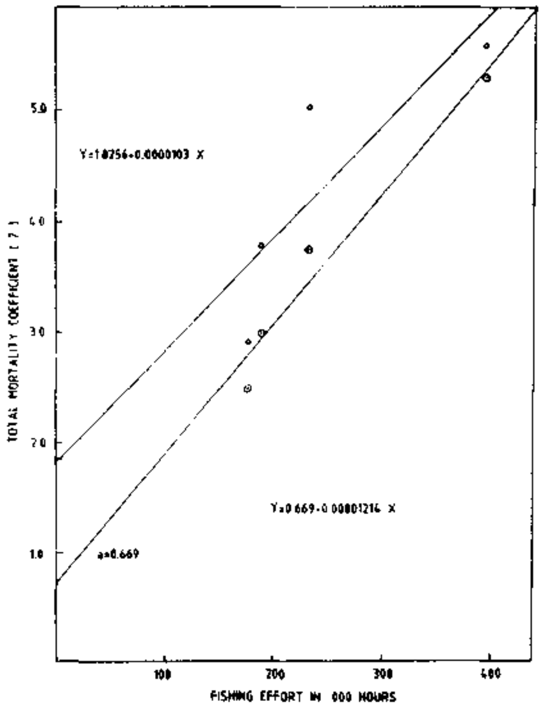

Fig. 5. Determination of M for *M. monoceros* by Wildrig's method.

In the present study the Z values obtained are higher for males than for females in all the years and by all methods. Kurup and Rao (1974) for *M. dobsoni*, *P. stylifera* and *P.*

indicus at Ambalapuzha, Ramamurthy *et al.* (1975) for *M. affinis* from Mangalore and Ramamurthy (1980) for *P. stylifera* from Mangalore from Indian waters and Berry (1970) for *P. duorarum* from Florida waters and Pauly *et al.* (1984) for various species also recorded similar observations.

Estimation of instantaneous annual natural mortality coefficient (M)

In the present study M has been estimated by three methods : Widrig (1954), Cushing (1968) and Pauly (1980).

Widrig's method

One of the important methods for estimating M is to relate the variations in Z with that of effort, f. If the relation is linear, indicating an increase in Z with f, Widrig (1954) proposed the following equation

$$Z = M + qf$$

where, the Y-axis intercept is natural mortality coefficient (M) and the slope is the catchability coefficient (q). Since q represents fishing mortality coefficient generated by one unit of effort, q times annual effort (f) would give F = qf.

In the present study by applying this method to the Z obtained by Beverton and Holt method, M was calculated at 1.826 for males and 0.669 for females with catchability coefficients of 0.0000103 and 0.00001214 respectively (Fig. 5).

Although good correlations exist between Z and f of males (0.83) and females (0.96), there is a wide difference in M values between sexes. One possible reason for it can be that apportioning of effort for *M. monoceros* is difficult in a multispecies trawl fishery. Hall and Penn (1979) tried to apportion the effort to *P. latisulcatus* and *P. esculentus* in the prawn fishery of Shark Bay, Western Australia with no success. Garcia and Le Reste (1981) reviewed various problems associated with collection of effort data in the prawn fisheries and concluded that such apportioning of effort among various species is impracticable. This type of analysis could not be adopted with the Z values derived by other methods as Z did not increase with the effort.

Cushing's method

Cushing (1968) proposed a method by which M can be calculated based on longevity as follows :

$$M = \log_e 100/t_{max}$$

where t_{max} is the age at L_{max}. Assuming that 99% of the animals in a population die by the time they attain L_{max}. L_{max} being the maximum size of the species observed in the virgin fishery.

In the present study males upto 165 mm and females upto 190 mm were encountered in the catches. However, during 1966 and 1967 when the trawlers started fishing the virgin stocks of *M. monoceros*. Males upto 171 mm and females upto 200 mm were observed in the catches. Taking the latter values as L_{max}, t_{max} was calculated, at 1.90 and 2.07 years for males and females respectively. From these values, M was calculated at 2.42 and 2.22 respectively.

Pauly's method based on temperature

Pauly (1980) demonstrated that mean sea surface temperature has a direct relationship with natural mortality. On the basis of 175 independent data sets, he could establish for fishes the relationship.

$\text{Log } M = 0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T$ where L_∞ is expressed in cm (total length), K is put on an annual basis and T is expressed in °C. This relationship which can be used to predict reasonable values of M in any species of fish can be expected to generate equally reasonable estimates of M in prawns for the reasons that prawns and fish generally share the same habitats, predators, etc. and that therefore, are not likely to differ widely in their vital parameters (Pauly *et al.*, 1984). Pauly (1980) also proposed a correction factor for schooling species. Thus, it might be appropriate to reduce the estimate of M by multiplying it by 0.8.

The mean sea surface temperature of the Kakinada region was 27° C. In the present study M values of 2.85 and 2.67 were obtained for males and females respectively by applying Pauly's method. Since these values are higher than the Z values obtained for the year 1974, the M values obtained were multiplied by 0.8. The revised values thus calculated are 2.28 and 2.14 for males and females respectively. These values compare well with the values obtained by Cushing's method.

The M values obtained by Widrig's method cannot be taken into consideration because of the reasons already stated. The estimates of M by Pauly's method are close to those obtained by Cushing's method. However, it is open to question whether sea surface temperature would have a direct influence on the life and mortality of a bottom living animal like *M. monoceros,* for that matter any penaeid prawn. The estimates by Cushing's method, 2.41 for males and 2.22 for females, are close to those assumed for *M. monoceros* from Madagascar waters by Marcille (1978). Hence, these values are considered representing the natural mortality of the species.

Estimates of M for penaeids for different workers varied widely depending on the methods adopted. Nevertheless, the large majority of 'M' values reported in the literature fall between 1.20 and 5.4. The estimates of M obtained in the present study compare well with those of Garcia (1977) for *P. duorarum* (2.52), Parrack (1981) for *P. aztecus* from Texas waters (1.80 to 2.76), Rothschild and Brunenmeister (1984) for *P. aztecus* (1.7) and *P. setiferus* (2.6) in the Gulf of Mexico.

Estimation of fishing mortality coefficient (F)

Based on the M values computed by Cushing's method (1968) and Z values by Beverton and Holt's (1957), F values are derived for different years as follows :

	1974	1975	1976	1977
Males	0.50	1.37	2.70	3.20
Females	0.30	0.80	1.55	3.13

It is observed that F steeply increases from 1974 to 1977. Furthermore, it is seen that F for males in 1976 and 1977 and for females in 1977 is far higher than M, indicating that the stocks of *M. monoceros* are being heavily exploited.

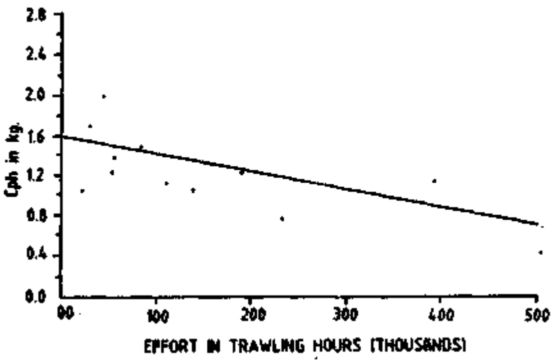

Fig. 6. Relationship between CPH and effort of *M. monoceros* landings at Kakinada (Surplus yield model).

Surplus yield model

The surplus yield model proposed by Schaefer (1954) and elaborated by Ricker (1975) considers the stock as an entity, the abundance of which depends on the amount of fishing. The relation between the total catch (equal to the surplus production) and the effort is a parabolic curve which passes through a maximum at an intermediate abundance level. The plot of effort on Cph gives a straight line. The regression constants 'a' and 'b' describing the line give MSY and optimum effort (F_{MSY}) by the following formulae :

$$MSY = a^2/4b \text{ and } F_{MSY} = a/2b$$

Data on effort and CPH for the period 1967-1978 are presented in Fig. 6. The regression constants 'a' and 'b' are calculated as 1.62 and 0.0018 respectively. Based on these values the MSY and the corresponding optimum effort (F_{MSY}) were calculated at 361 *t* and 446035 trawling hours. The catches in 1974 and 1977 exceeded the MSY even though the effort during these years was lesser than the optimum effort (F_{MSY}). Possibly, this was reflected in the length composition of the catches and the Cph in succeeding years (Rao, 1993).

Yield-per-recruit model

Beverton and Holt (1957) and Ricker (1975) provide comprehensive discussions of methods for estimating yield and their theoretical bases.

The two characteristics of the fishery are the amount of fishing, conveniently expressed as the ratio of fishing to natural mortality (F/M), or the exploitation ratio, E (= F/F + M), and the relative size at first capture, conveniently expressed as $c = l_c/L_\infty = (1 - \exp[-K(t_c - t_0)])$. Hence it can be written as

$$\exp[-K(t_c - t_0)] = 1 - c$$

and

$$\exp[-M(t_c - t_r)] = \exp[-M(t_0 - t_r)]\,(1-c)^{M/K}$$

The final equation can be re-written as

$$Y_w/R = E.\,W_\infty\, e^{-M\,(t_0 - t_r)}\,(1-c)^{M/K}\, \frac{U_n(1-C)^n}{F + M + nK}$$

where Y_w/R = Yield-per-recruit in grams

l_c = length at first capture

l_r = length at recruitment

$U_n = 1$ when $n = 0$, $U_n = -3$ when $n = 1$, $U_n = 3$ when $n = 2$, and $U_n = -1$ when $n = 3$

Only two coefficients in the model can be influenced by man in actual situations. These are fishing intensity, represented in the model by exploitation ratio (E) and the length at first capture (l_c). The latter can be altered by regulating the mesh size of trawls or in some situations, by prohibiting fishing in areas or seasons when small prawns are abundant. Solutions of yield equations with various values of E and l_c give an indication of the results that can be expected from restricted regulations.

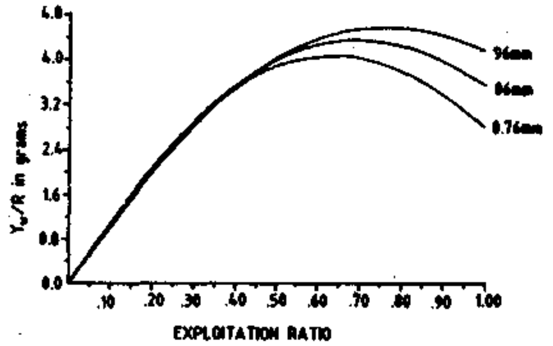

Fig. 7. Yield per-recruit for males of *M. monoceros* at different levels of F when lc is 76 mm, 86 mm and 96 mm.

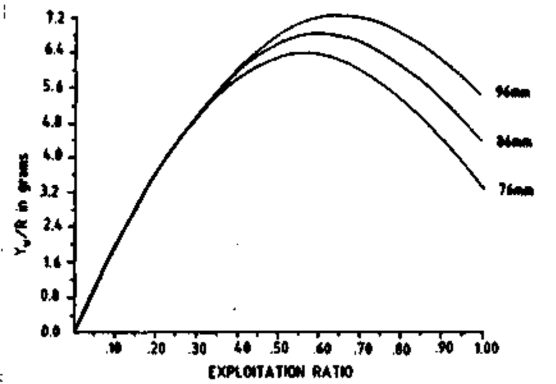

Fig. 8. Yield per-recruit for females of *M. monoceros* at different levels of F when l_c is 76 mm, 86 mm and 96 mm.

In the present study, changes in yields per recruit that would result if l_c is varied (76, 86 and 96 mm) by means of mesh regulations are given in Fig. 7 and 8 for males and females respectively.

In the case of males at the present lc (76 mm) maximum weight per recruit (Yw/R = 4.028) is derived at a 'E' of 0.60. If lc is increased to 86 and 96 mm the yield-per-recruit shows maximum at E = 0.70 and 0.75 respectively. At present (average for the years 1974-1977) the E is 0.45. Hence, it can be stated that at the present pattern of fishing, E can be increased upto 0.60 without any bad effects on the stock. Furthermore, if lc is increased to 86 mm even at E = 0.70 the stocks will not be affected.

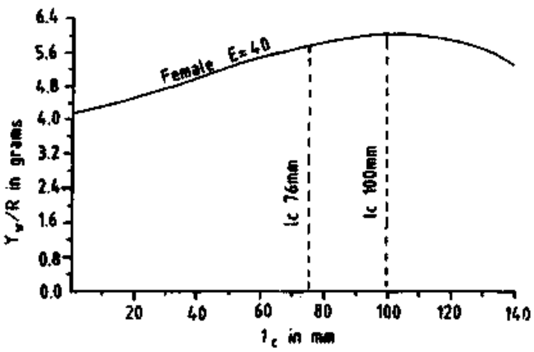

Fig. 9. Yield per-recruit at different levels lc at the present level of exploitation (E = 0.45) for males of *M. monoceros*.

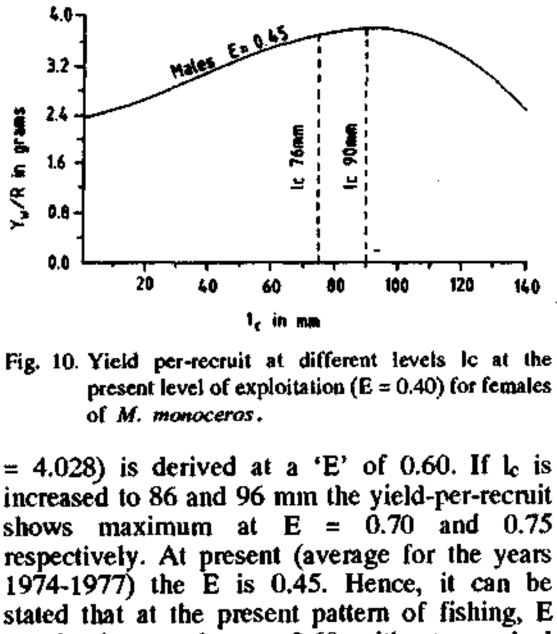

Fig. 10. Yield per-recruit at different levels lc at the present level of exploitation (E = 0.40) for females of *M. monoceros*.

In the case of females, if lc is held constant at 76 mm, maximum yield-per-recruit (6.32 g) will be obtained at E = 0.55. The present exploitation rate for females is 0.40 (average for the years 1974-1977). The stock of females are, therefore, not affected due to fishing. If the exploitation rate is increased to 0.55, the stock may provide a higher yield-per-recruit of 6.33 g instead of the present 5.76 g. In fact, an increase in the lc to 86 mm may yield higher Yw/R even at an exploitation rate of 0.60 (Fig. 8). Although the above averages for the four-year period 1974-1977 show an optimistic trend in the yields, the 1977 values do cause some anxiety. This is because of a significant rise in the effort and concomittant F. In 1977 E (= 0.57) for males is just below the optimum level of 0.60 while for females it is 0.59, a value beyond the optimum level of 0.55. In other words, in 1977 yield-per-recruit for females shows a decline and any further increase in E may result in a corresponding decline in the yield-per-recruit.

It is examined as to how the stock reacts if the exploitation rate is held constant at the present level (average for the four year period of 1974-1977) and l_c is varied. With the present level of E = 0.45 and at varied levels of l_c, the Yw/R will be of the order shown in Fig 9 for males. Yw/R increases with an increase in lc upto 90 mm (instead of the present 76 mm). The yield can be maximised at the present E = 0.45. In females, if lc is increased to 100 mm (instead of the present 76 mm), the yield can be maximised at the present E = 0.40 (Fig. 10).

Stock estimated by Baranov's catch equation

Widrig (1954) proposed a method to calculate population size based on Baranov's (1918) catch equation. The general principle of the method is that the population size depends on the births and deaths in a population and if all other factors are assumed constant, fishing mortality determines the size of the population. In other words, the exploitation rate, 'U' gives the magnitude of the stock, provided the annual catch removed from the stock is known. Exploitation rate 'U' can be obtained by the relationship :

$$U = F/Z\ (1 - e^{-Z})$$

where F and Z are instantaneous rates of fishing and total mortality.

Average annual standing stock (AASS) and average standing stock (ASS) can be obtained by the formulae :

$$AASS = C/U \qquad ASS = C/F$$

where, C is the average annual catch.

Average annual landings of males and females for the period 1974-1977 were 121.6 and 205.5 tonnes respectively. Average Z based on Beverton and Holt's method were 4.364 and 3.664 for males and females; while the M estimates based on Cushing's method were 2.42 and 2.22 for males and females respectively giving respective F values of 1.944 and 1.444. Based on these mortality rates, exploitation rate 'U' was calculated as 0.44 and 0.39 for males and females. From these values of F and U, average annual standing stock (AASS) and average standing stock (ASS) for males were calculated as 276 and 62 tonnes respectively. For females AASS and ASS were calculated as 529 and 141 tonnes respectively. It is generally believed that 50% of AASS can be removed as catch from the population without any bad effect on the population (Gulland, 1968). Based on that assumption, 135 tonnes of males and 265 tonnes of females an be harvested annually from the stock of *M. monoceros* off Kakinada. These estimates are closer to the MSY derived by surplus yield model. It is thus evident that this limit was exceeded in 1977, indicating that the fishery has gone beyond the optimum by this year and any further increase may result in the depletion of the stock.

Estimation of population size from cohort analysis

Estimation of population size can be made from cohort analysis (Jones and van Zalinge 1981). Estimates of population size (N) average numbers in the sea and the population biomass are provided in Tables 3 - 6 for males and females for the period 1974-1977. Population biomass (in kg) estimates for different years is given below :

	1974	1975	1976	1977
Males	78,731	21,881	20,031	45,059
Females	150,070	58,040	40,549	72,611

It is evident that the stocks of males and females gradually declined from 1974 to 1976 and revived considerably in 1977, although not to the level of 1974. A similar trend was observed in the landings as well (Rao, 1993).

General Remarks

The results of the surplus-yield model show that whenever the landings exceeded MSY (*e.g.* 1974 and 1977) the catches in the succeeding years declined. This warrants that the catch should be maintained at MSY for a healthy harvest of the species in subsequent years. The yield-per-recruit analysis indicates that at l_c of 76 mm optimum E is 0.60 and 0.55 for males and females respectively. In 1977, E is just below the optimum for males and it crossed the optimum level for females. It is shown that the fishery can withstand higher exploitation rate if l_c is increased from the present 76 mm to 86 mm or even 96 mm. Baranov's catch function indicates that 135 t of males and 265 t of females can be harvested annually from the stock which limit was exceeded in 1977.

All the four types of stock assessments made on males and females of *M. monoceros* sex-wise and combined, indicate that the stock was fished below the optimum level during 1974-1976 period. In 1977, the stock was fished beyond the optimum level as shown by the results of all the four methods. This may lead to overfishing if the trend in the increase of effort goes unabated. Efforts should, therefore, be directed to stabilize the fishery at the optimum level in respect of MSY, Y_w/R, average annual standing stock and average standing stock for the optimum utilisation of the resource and a healthy management of the fishery.

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