Fisheries Research Bulletin No. 14

Variations in Growth, Mortality, and Population Density of Snapper, *Chrysophrys auratus* (Forster), in the Hauraki Gulf, New Zealand

by
C. M. Vooren and R. F. Coombs

Fisheries Research Division
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Frontispiece: The research vessel *Ikatere*, which carried out the trawl survey described in this bulletin.

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FOREWORD

THIS bulletin by Carel Vooren and Roger Coombs deals with one part of an overall study of the Auckland snapper fishery which is being conducted by Fisheries Research Division. The fish in the general area of the Hauraki Gulf are heavily exploited by a variety of methods, but this account deals only with trawling, the vulnerability of stocks to fishing, and variations in populations, growth, and age of the species.

It is also shown that the annual total mortality among the older fish was quite low, at least until 1971. This may be explained, in part, by their migratory behaviour, which prevents their being subjected to continuous fishing pressure.

Growth rate is fairly low and generally similar in all parts of the Gulf, but there are considerable differences in population density.

Effective use of the snapper fishery will undoubtedly require the exercise of controls, and this work, which contributes substantially to our understanding of the fish and their behaviour, provides an additional basis for rational management.

G. DUNCAN WAUGH,
Director, Fisheries Research Division

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INTRODUCTION

Commercial trawling and Danish seining are prohibited in the Firth of Thames, a shallow bay on the south-eastern side of the Hauraki Gulf, and the population of snapper, *Chrysophrys auratus*, there is not intensively fished by other methods. From data collected by Paul (1976) it was therefore suspected that the population density of the snapper in this area might be so high that the growth rate of old fish was being adversely affected by overcrowding.

This problem was investigated by a comparative survey of the snapper population in the Firth of Thames and on the traditional trawling and Danish seining grounds in the Hauraki Gulf, and this bulletin sets out the results obtained from measuring growth rates, age compositions, and catch rates.

METHODS

The Hauraki Gulf was surveyed in October and November 1971 by the research vessel *Ikatere*, a trawler of 19.2 m overall length, 42.8 gross tons, and 152 bhp. A wing trawl with a ground-rope of 21 m, bridles of 56 m, and a cod-end liner with 3.8-cm stretched mesh was used. Depths fished ranged from 5 m in the Firth of Thames to 49 m in the outer Hauraki Gulf. The towing speed varied between 3.0 and 3.7 knots, and the duration of the tows ranged from 30 to 180 minutes.

For the purpose of the survey the Hauraki Gulf was divided into four areas: outer Gulf (area 1), central Gulf (area 2), outer Firth (area 3), and inner Firth (area 4) (Fig. 1). The last two areas together constitute the Firth of Thames. The first three areas were covered by 12 trawl shots between 4 and 13 October 1971, and 3 trawl shots were made in the inner Firth on 3 November 1971 (Table 1). The shots in the inner Firth were not strictly part of the planned survey and no subsamples for age determination were taken, but since the same gear was used, the additional data on length-frequency distributions and catch rates are included here.

The body lengths of a random sample of up to 800 fish in each catch were measured to the tail fork and rounded down to the nearest whole centimetre below the actual length. The true average lengths are therefore 0.5 cm greater than those given in this bulletin. Samples for age, gutted weight (to the nearest 10 g), and sex were collected from seven catches (Table 1). The samples were random and stratified by length: stratum 1, up to 14 cm; stratum 2, from 15 to 19 cm; stratum 3, from 20 to 24 cm; stratum 4, from 25 cm onwards. Twenty fish were allocated to each of strata

TABLE 1: List of trawl stations

Station No.	Date	Position Start	Position Finish	Time (NZST) Start	Time (NZST) Finish	Avg. depth (m)	No. of snapper caught	Number measured	No. of legal size*	Number sampled
K324	4/10/1971	36° 36′ S, 174° 58′ E	36° 29′ S, 175° 00′ E	1400	1600	42	632	629	135	190
K325	5/10/1971	36° 21′ S, 174° 54′ E	36° 13′ S, 175° 01′ E	0815	1115	49	30	30	12	0
K326	5/10/1971	36° 13′ S, 174° 56′ E	36° 21′ S, 174° 52′ E	1705	2005	49	159	159	89	151
K327	6/10/1971	36° 29′ S, 175° 05′ E	36° 37′ S, 175° 05′ E	0915	1145	43	423	423	141	199
K328	6/10/1971	36° 35′ S, 175° 16′ E	36° 28′ S, 175° 17′ E	1815	2015	43	598	594	58	121
K329	7/10/1971	36° 16′ S, 175° 24′ E	36° 16′ S, 175° 11′ E	0500	0800	37	1578	789	308	206
K330	7/10/1971	36° 27′ S, 175° 25′ E	36° 19′ S, 175° 20′ E	1730	2000	48	381	381	94	0
K331	11/10/1971	36° 53′ S, 175° 14′ E	36° 49′ S, 175° 17′ E	1420	1520	25	486	361	264	191
K332	12/10/1971	36° 49′ S, 175° 20′ E	36° 53′ S, 175° 22′ E	0945	1045	31	552	552	305	0
K333	12/10/1971	36° 55′ S, 175° 22′ E	36° 57′ S, 175° 19′ E	1420	1520	25	126	126	111	0
K334	12/10/1971	36° 58′ S, 175° 18 ′E	36° 54′ S, 175° 17′ E	1655	1755	16	306	306	276	173
K335	13/10/1971	36° 42′ S, 175° 13′ E	36° 37′ S, 175° 11′ E	0925	1125	41	717	717	188	0
K352	3/11/1971	37° 04′ S, 175° 20′ E	37° 05′ S, 175° 21′ E	0715	0745	9	96	96	86	0
K353	3/11/1971	37° 04′ S, 175° 29′ E	37° 02′ S, 175° 29′ E	0855	0925	5	86	86	80	0
K354	3/11/1971	37° 00′ S, 175° 27′ E	36° 59′ S, 175° 26′ E	1000	1030	9	82	82	71	0

* Legal size indicates snapper 25 cm or longer.

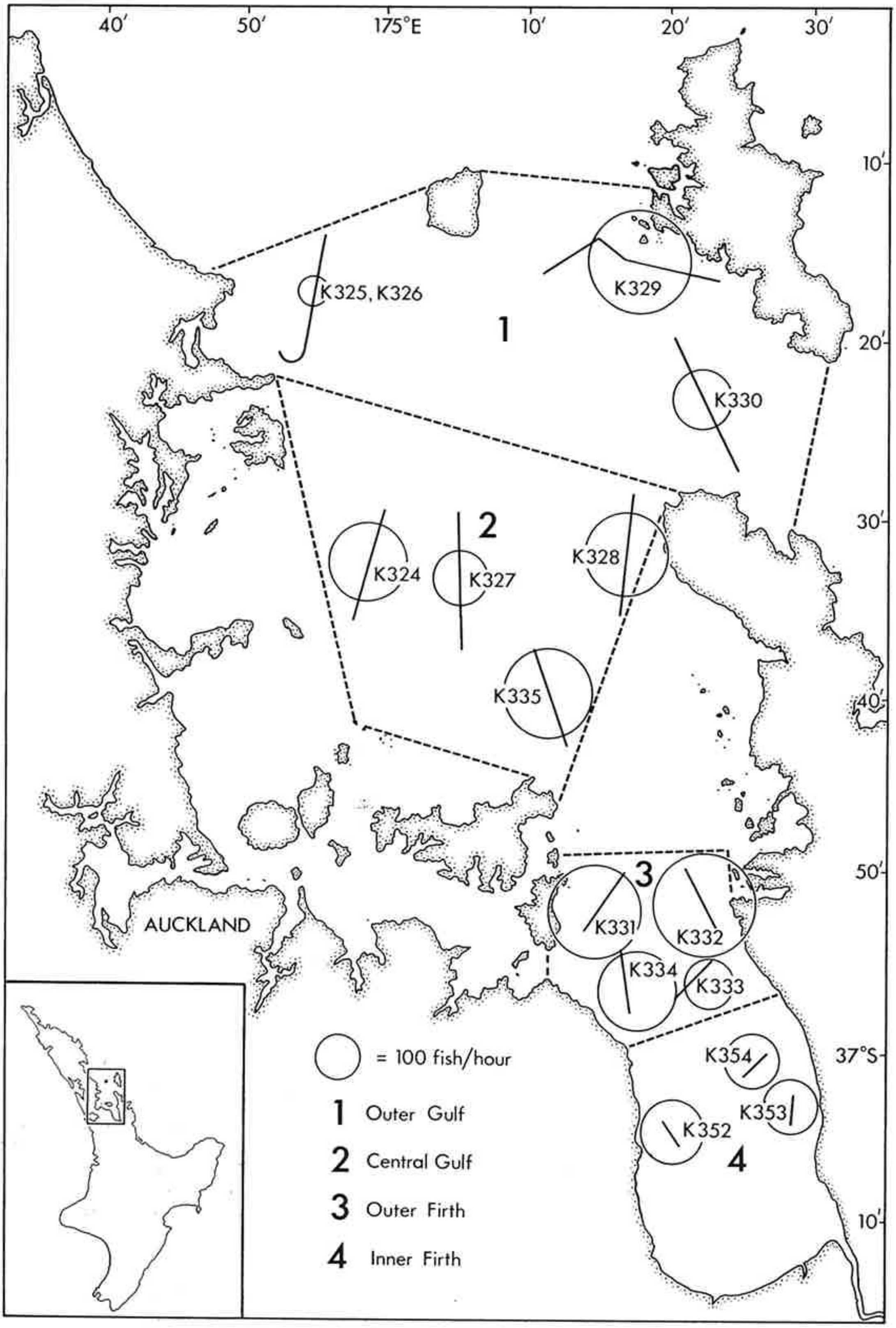

Fig. 1: The Hauraki Gulf, showing sampling areas 1 to 4, trawl stations, and catch rates at the stations. Areas 3 and 4 together constitute the Firth of Thames. The area of each circle is proportional to the number of snapper caught per hour of trawling.

1, 2, and 3, and 150 fish to stratum 4. This sampling plan was based on previous data which have shown that in October strata 1, 2, and 3 coincide approximately with age groups 0, 1, and 2 respectively (Paul 1976). The variation of age within these strata is low. Stratum 4, on the other hand, contains a large number of age groups with overlapping length ranges.

Before being weighed the fish were gutted to obtain a measure of the amount of flesh present without the variation caused by differences in the weight of the guts and gonads. Ages were determined from broken and burnt otoliths. Age groups were numbered according to the system described by Paul (1976), who has defined 1 January as the nominal birthday of snapper year classes. Thus to find the year in which age group n was born for the present data, subtract n from 1971. The peak of spawning in the Hauraki Gulf occurs usually in October–November before the nominal birthday (Cassie 1956); so the actual age of age group n at the time of sampling was about $n + 1$ years.

All otoliths were read independently by four observers. In a random sample of 244 sets of four readings there was agreement between four or three readings in 58% of the sets, and all four readings disagreed in only 9% of the sets. The differences between the readings were mostly 1 year and rarely exceeded

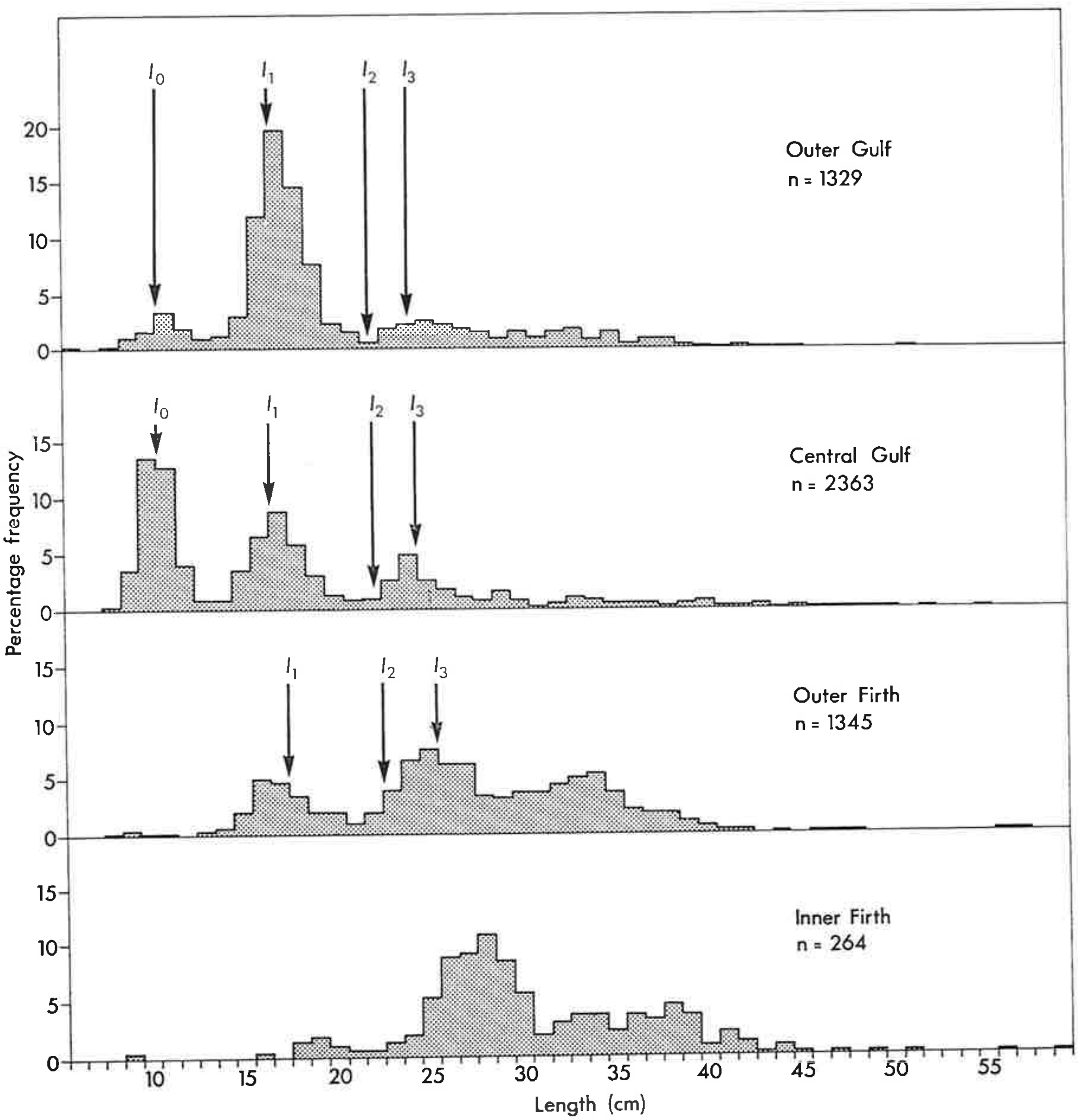

Fig. 2: Length-frequency distributions in each of the sampling areas. l_i is the mean length of age group i.

2 years. There were no systematic differences between the four observers, who therefore interpreted the otoliths in the same way. When fewer than three of the four readings in a set were in agreement or when there was a draw (that is, two readings of one value and two of another), the arithmetical mean of the set was taken as the final value. When three or four readings agreed, the value read by the majority was taken as the final one.

Mesh sizes quoted in this bulletin indicate the stretched mesh, measured knot to knot.

CATCH RATES

Fishermen find that unless the water in the outer Gulf is unusually turbid, trawling for snapper in that area is successful only about dawn and dusk and not during the day. This was also shown by the catches at trawl stations K325 and K326, which covered almost the same track in the outer Gulf, but differed in that K325 was occupied during daytime and K326 about dusk of the same day. The catch rates were: 10 fish per hour at station K325 and 53 fish per hour at station K326. Because the latter catch rate was considered the better measure of the fish density in the outer Gulf, the data from K325 were not used in the analysis. The other two trawl shots in the outer Gulf were made at dusk and dawn.

Snapper were caught at all stations (Table 1). The catch rate, that is, the average number of fish caught per hour of trawling, was highest in the outer Firth and lowest in the inner Firth (Table 2). The catches in the outer and central Gulf consisted mainly of fish smaller than 25 cm, which is the legal minimum size for snapper in commercial landings. Under-sized fish were far less numerous in the Firth of Thames (Fig. 2). The catch rate of fish of commercial size in the Firth of Thames was between three and five times higher than in the outer and central Gulf (Table 2). Such a difference was also found by three commercial trawlers chartered for research purposes between November 1970 and May 1971. These boats used an 11.4-cm cod-end mesh, which retains few fish smaller than 25 cm. Their catch rates were: 3.6 baskets per hour in the central Gulf, averaged over 29.3 hours' trawling, and 10.7 baskets per hour in the Firth of Thames, averaged over 23.1 hours' trawling (Fisheries Research Division, unpublished data; catches measured in 45-kg baskets).

TABLE 2: Catch rates per hour of trawling in the four areas

	Total number of fish	Number of fish ⩾25 cm
Outer Gulf	249	58
Central Gulf	279	61
Outer Firth	368	276
Inner Firth	176	158

GROWTH

No significant differences were found between the sexes for mean length at age, mean weight at age, or mean weight at length (Tables 3 and 4). The growth patterns of the sexes are therefore considered to be essentially the same and are treated together in the rest of the bulletin.

Paul (1976) has suggested that among younger snapper a gradation in mean length at age exists between the outer Firth and outer Gulf, length being least in the outer Gulf, intermediate in the central Gulf, and greatest in the outer Firth. The present data show a similar trend for the younger age groups, as can be seen from Fig. 3 and Tables 3 and 5. However, the differences are small and statistically insignificant and are not considered important in the population as a whole.

The relationship between fork length and gutted weight is shown in Table 6 and Fig. 4. The equations obtained for the separate sampling areas and for areas 1, 2, and 3 combined were very similar. There

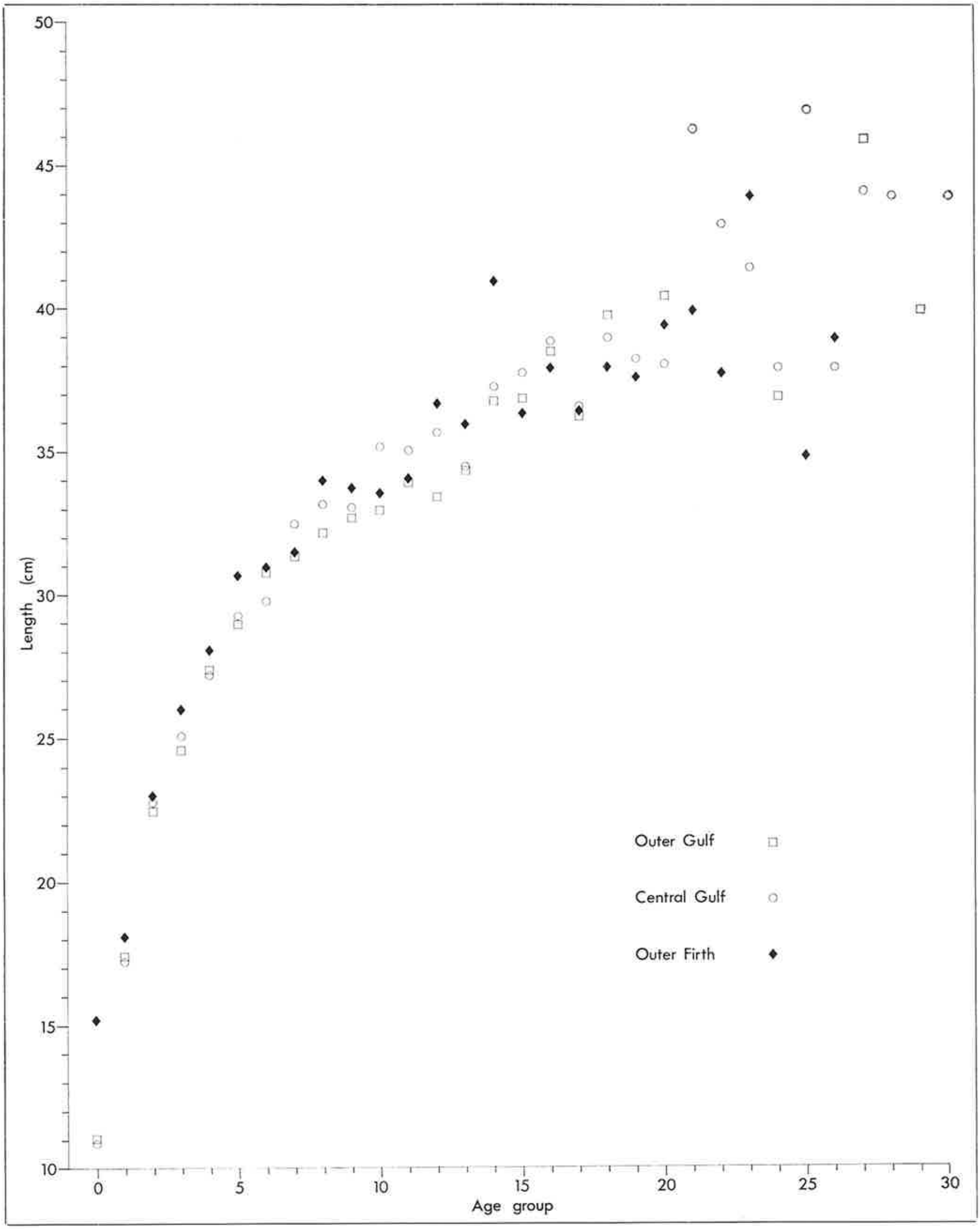

Fig. 3: Mean lengths of the age groups in each of the sampling areas.

were therefore no substantial differences in the length-weight relationship between the areas, and the equation for the three areas combined is generally valid for the Hauraki Gulf snapper at the time.

The estimated mean lengths of age groups 0, 1, and 3 coincided with the major length-frequency modes (Fig. 2). The length-frequency distributions of the age groups illustrate the reasons for the stratification chosen in the sampling plan (Fig. 5). Age groups 0 and 1 fell almost entirely within strata 1 (0–14 cm) and 2 (15–19 cm) respectively. The centre of the distribution of age group 2 fell in stratum 3 (20–24 cm) and the older age groups occurred mostly in stratum 4 (25 cm or longer).

Von Bertalanffy growth equations were fitted to the mean lengths at age by Ford-Walford plots. A single equation did not fit the data satisfactorily and two equations were used, one for ages 1 to 7 and another for ages 7 to 30 (Table 7). The resultant compound curves fitted the data very well, as can be seen in Figs. 6 and 7. The fitted growth data are tabulated (Table 8).

TABLE 3: Differences between mean lengths at age (cm) by sex and by area and between mean weights at age (g) by sex

Age group	Females minus males all samples Length	Females minus males all samples Weight	Outer Firth minus outer Gulf length	Outer Firth minus central Gulf length	Central Gulf minus outer Gulf length
0	–*	–	–	–	-0.1
1	–	–	0.7	0.9	-0.2
2	-1.0	-14.6	0.5	0.2	0.3
3	-0.1	-9.9	1.4	0.9	0.5
4	0.1	5.3	0.7	0.9	-0.2
5	-0.8	-51.1	1.7	1.4	0.3
6	-0.7	-34.5	0.2	1.2	-1.0
7	0.9	57.7	0.1	-1.0	1.1
8	1.6	78.0	1.8	0.8	1.0
9	0.3	75.0	1.1	0.7	0.4
10	0.8	67.8	0.6	-1.6	2.2
11	-0.9	-84.2	0.1	-1.0	1.1
12	1.9	188.6	3.2	1.0	2.2
13	2.1	181.8	1.6	1.4	0.2
14	0.7	110.2	4.2	3.7	0.5
15	0.4	25.0	-0.5	-1.4	0.9
16	-2.2	-212.5	-0.5	-0.9	0.4
17	-1.4	-91.6	0.2	-0.1	0.3
18	1.4	-36.9	-0.2	-1.0	-0.8
19	-2.3	-163.3	–	-0.6	–
20	-1.7	-270.9	-1.0	1.4	-2.4
Mean	-0.05	-9.48	0.84	0.35	0.34
Standard error	0.31	27.86	0.29	0.29	0.23

* – indicates no data available.

TABLE 4: Mean weights of the length groups in all samples combined and differences in mean weight at length between the sexes

Length group (cm)	Mean weight (g)	Weight difference female minus male (g)
8	9.0	–*
9	11.9	–
10	27.0	–
11	32.9	–
12	40.5	–
13	38.2	–
14	57.5	–
15	80.0	–
16	95.3	3.0
17	111.6	-3.2
18	131.5	-6.0
19	153.8	3.2
20	192.3	12.5
21	217.3	45.0
22	230.0	8.0
23	272.8	-20.7
24	298.1	-6.6
25	334.9	-13.3
26	380.6	-4.5
27	417.6	-0.6
28	473.6	-10.8
29	504.9	8.0
30	570.6	26.1
31	637.8	-15.1
32	704.1	18.9
33	748.9	13.9
34	818.1	22.3
35	888.3	5.1
36	1004.4	32.2
37	1003.6	49.4
38	1164.0	-32.8
39	1209.0	-30.3
40	1322.9	-40.6
41	1530.7	-266.7
42	1470.7	5.7
43	1560.0	-119.0
44	2016.7	–
45	1750.0	–
46	1820.0	-40.0
48	2470.0	240.0
49	2130.0	–
51	2440.0	–
55	2020.0	–
56	3200.0	–
57	3050.0	–
68	4160.0	–
Mean		-3.90
Standard error		13.40

* – indicates no data available.

TABLE 5: Mean lengths (cm) of the age groups with 95% confidence limits for the age groups of which there were 5 or more fish in the samples in each area

Age group*	Outer Gulf	Central Gulf	Outer and central Gulf combined	Outer Firth
0	11.0 (± 0.4)	10.9 (± 0.3)	11.0	15.2
1	17.4 (± 0.4)	17.2 (± 0.3)	17.3	18.1 (± 0.4)
2	22.5 (± 1.1)	22.8 (± 0.7)	22.7	23.0 (± 0.6)
3	24.6 (± 0.2)	25.1 (± 0.2)	24.9	26.0 (± 0.3)
4	27.4 (± 0.7)	27.2 (± 0.5)	27.3	28.1 (± 0.7)
5	29.0 (± 1.0)	29.3 (± 1.1)	29.2	30.7 (± 0.5)
6	30.8 (± 1.4)	29.8 (± 1.1)	30.2	31.0 (± 0.9)
7	31.4 (± 1.4)	32.5 (± 2.1)	32.1	31.5 (± 1.4)
8	32.2 (± 1.1)	33.2 (± 1.6)	32.5	34.0 (± 2.2)
9	32.7 (± 0.8)	33.1 (± 1.6)	32.9	33.8 (± 1.2)
10	33.0 (± 1.1)	35.2 (± 1.4)	34.0	33.6 (± 1.0)
11	34.0 (± 2.0)	35.1 (± 2.4)	34.5	34.1 (± 0.7)
12	33.5 (± 1.2)	35.7 (± 2.9)	34.0	36.7 (± 1.9)
13	34.4 (± 1.6)	34.6 (± 3.5)	34.5	36.0 (± 3.1)
14	36.8 (± 1.3)	37.3 (± 2.1)	36.9	41.0
15	36.9 (± 1.3)	37.8 (± 3.2)	37.4	36.4 (± 1.2)
16	38.5	38.9 (± 1.6)	38.8	38.0
17	36.3	36.6 (± 1.8)	36.5	36.5 (± 2.2)
18	39.8 (± 1.8)	39.0 (± 2.3)	39.4	38.0
19	–†	38.3 (± 2.0)	38.3	37.7
20	40.5	38.1 (± 2.7)	39.3	39.5
21	–	46.3	46.3	40.0 (± 2.8)
22	–	43.0	43.0	37.8
23	–	41.5	41.5	44.0
24	37.0	38.0	37.5	–
25	–	47.0	47.0	35.0
26	–	38.0	38.0	39.0
27	46.0	44.2 (± 15.4)	44.5	–
28	–	44.0	44.0	–
29	40.0	–	–	–
30	–	44.0	44.0	–
32	42.0	–	42.0	–
41	–	51.0	51.0	–

* Ages in years are almost 1 higher than the numbers of the age groups.
† – indicates fewer than 5 fish.

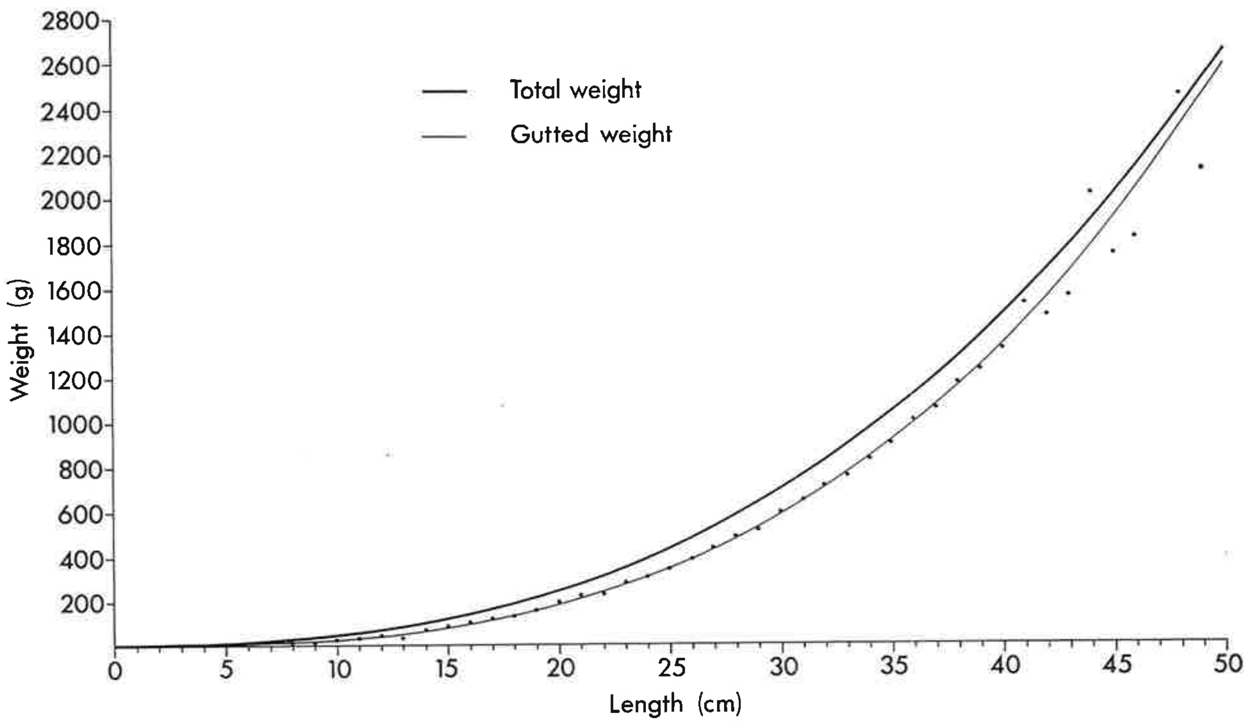

Fig. 4: Relationship between mean body weight and length. The points represent the observed mean gutted weights of the length groups. The curve of expected gutted weight represents the equation which was fitted to the data. The curve of expected total weight is derived from Cassie (1957).

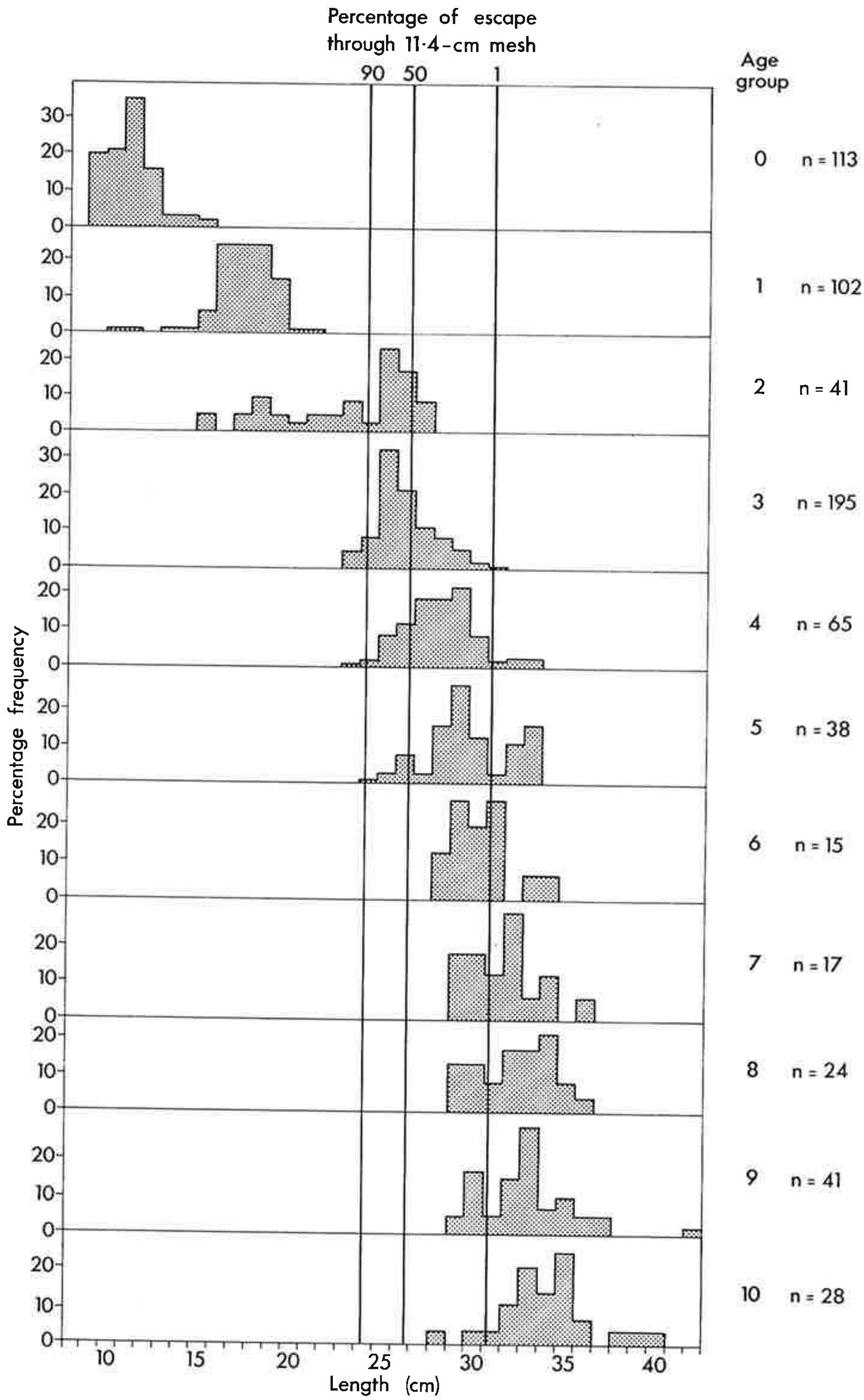

Fig. 5: Length-frequency distributions of age groups 0 to 10 in the outer and central Gulf. n is size of stratified sample. Escape levels after Cassie (1955).

TABLE 6: Least squares estimate of linear regression of $\log_e$ weight on $\log_e$ length

Area	Equation	R	N
Outer Gulf	$\log_e W = -3.6524 + 2.9446 \log_e L$	0.9879	351
Central Gulf	$\log_e W = -3.8113 + 2.9822 \log_e L$	0.9881	575
Outer Firth	$\log_e W = -3.7106 + 2.9562 \log_e L$	0.9879	363
Combined areas	$\log_e W = -3.7661 + 2.9726 \log_e L$	0.9885	1289

W: Gutted weight (g).
L: Fork length (cm) rounded off to whole centimetre below actual length.
R: Correlation coefficient.
N: Sample size.

TABLE 7: Parameters of the von Bertalanffy growth equation based on mean length at age of snapper in the Hauraki Gulf, October 1971

	Central and outer Hauraki Gulf			Outer Firth of Thames		
		Compound curve			Compound curve	
Growth parameters	Single curve	Lower part	Upper part	Single curve	Lower part	Upper part
K*	0.23 (0.25)	0.35	0.07	0.27	0.37	0.10
L_∞ (cm)*	38.18 (37.72)	32.79	44.82	36.30	33.50	41.00
W_∞ (g)	1168.57 (1124.40)	743.33	1882.15	1030.60	792.20	1444.27
t_0 (years)	−0.61 (−0.39)	−0.15	−9.14	−0.53	−0.14	−7.21
t_0 ages†	1–6	1–7	7–21	2–7	2–7	7–14

* K and L_∞ were calculated from the geometric mean estimate of the Ford-Walford regression. Some values calculated from the least squares estimate of the Ford-Walford regression are listed in parentheses.

† t_0 ages indicates the age range used in estimating t_0.

TABLE 8: Expected mean lengths at age (cm), weights at age (g), and annual increments of snapper in the central Hauraki Gulf and the Firth of Thames derived from the compound growth curves

	Mean length at end of year		Length increment during year		Mean weight at end of year		Mean weight during year	Weight increment during year	
Year	Gulf	Firth	Gulf	Firth	Gulf	Firth	Gulf	Gulf	Firth
1	10.99	11.56	10.99	11.56	28.82	33.58	14.41	28.82	33.48
2	17.49	18.37	6.50	6.81	114.84	132.74	71.83	86.02	99.16
3	22.06	23.06	4.57	4.69	228.78	261.03	171.81	113.94	128.29
4	25.26	26.30	3.20	3.24	342.31	385.74	285.55	113.53	124.71
5	27.51	28.53	2.25	2.23	440.97	491.53	391.64	98.66	105.79
6	29.08	30.07	1.57	1.54	520.40	574.74	480.69	79.43	83.21
7	30.20	31.15	1.12	1.08	582.00	638.00	551.20	61.60	63.26
8	31.21	32.10	1.01	0.95	641.71	698.05	611.86	59.71	60.05
9	32.12	32.95	0.91	0.85	699.22	754.47	670.47	57.51	56.42
10	32.98	33.72	0.86	0.77	755.87	808.03	727.55	56.65	53.56
11	33.77	34.42	0.79	0.70	811.38	858.59	783.63	55.51	50.56
12	34.51	35.05	0.74	0.63	865.54	906.09	838.46	54.16	47.50
13	35.21	35.62	0.70	0.57	918.18	950.52	891.86	52.64	44.43
14	35.85	36.13	0.64	0.51	969.17	991.94	943.68	50.99	41.42
15	36.45	36.60	0.60	0.47	1018.38	1030.41	993.78	49.21	38.47
16	37.01	37.02	0.56	0.42	1065.76	1066.05	1042.07	47.38	35.64
17	37.54	37.40	0.53	0.38	1111.26	1098.97	1088.51	45.50	32.92
18	38.02	37.74	0.48	0.34	1154.85	1129.33	1133.06	43.59	30.36
19	38.48	38.06	0.46	0.32	1196.52	1157.26	1175.69	41.67	27.93
20	38.91	38.34	0.43	0.28	1236.27	1182.91	1216.40	39.75	25.65
21	39.31	38.59	0.40	0.25	1274.14	1206.43	1255.21	37.87	23.52
22	39.68	38.82	0.37	0.23	1310.15	1227.97	1292.15	36.01	21.54
23	40.02	39.03	0.34	0.21	1344.35	1247.67	1327.25	34.20	19.70
24	40.34	39.22	0.32	0.19	1376.78	1265.67	1360.57	32.43	18.00
25	40.65	39.39	0.31	0.17	1407.49	1282.10	1392.14	30.71	16.43
26	40.93	39.54	0.28	0.15	1436.55	1297.07	1422.02	29.06	14.97
27	41.19	39.68	0.26	0.14	1464.01	1310.72	1450.28	27.46	13.65
28	41.43	39.80	0.24	0.12	1489.94	1323.14	1476.98	25.93	12.42
29	41.66	39.92	0.23	0.12	1514.40	1334.44	1502.17	24.46	11.30
30	41.87	40.03	0.21	0.11	1537.46	1344.72	1525.93	23.06	10.28

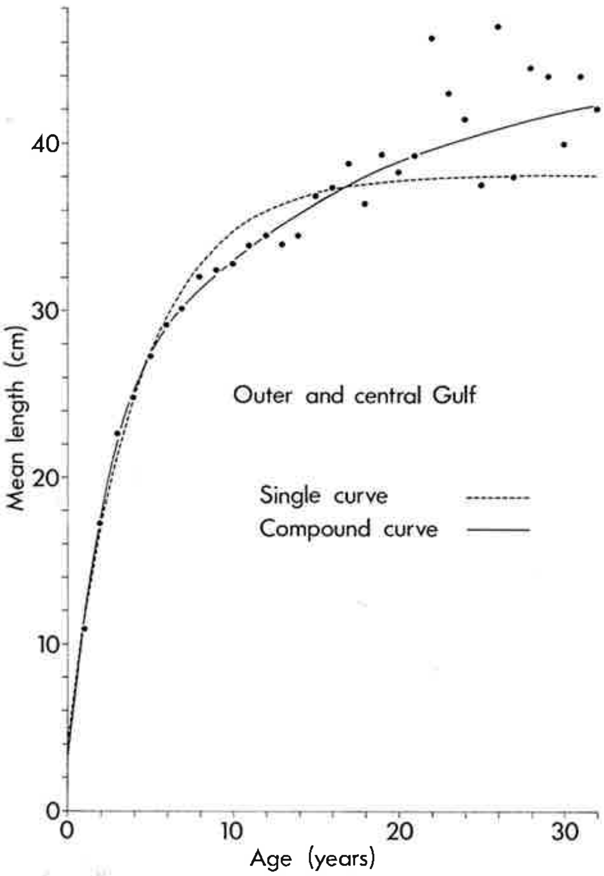

Fig. 6: Length-age data from the outer and central Hauraki Gulf and fitted curves.

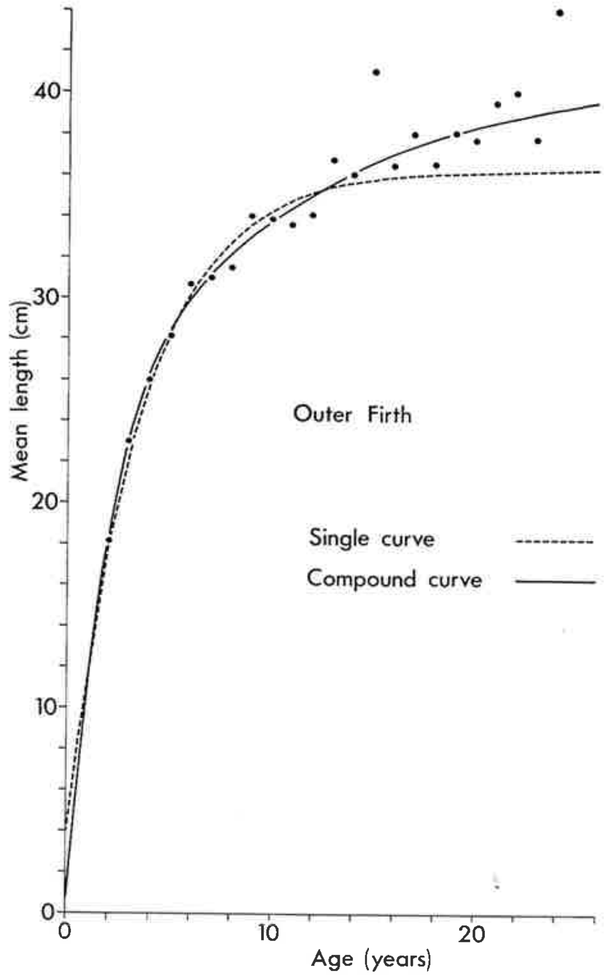

Fig. 7: Length-age data from the outer Firth of Thames and fitted curves.

AGE COMPOSITION

Young fish (age groups 0 to 3) dominated the catches in the outer and central Gulf (Fig. 8, Table 9). The catch rate of age group 0 was highest in the central Gulf. Age group 1 was most abundant in the outer Gulf. Recent fluctuations in year class strength, already noted by Paul (1974), were also apparent in the present data: 1968 showed up as a strong year class and 1969 as a weak one.

Data collected over 12 years between 1949 and 1970 have shown a general scarcity of fish of less than 1 year old in the Firth of Thames and, except in 1951 and 1970, fish of between 1 and 2 years were also scarce (Paul 1976). The virtual absence of age group 0 there during the present survey agrees with this. The high catch rate of age group 1 in the outer Firth was entirely due to large catches at the outer two stations K331 and K332, so that these juveniles were not distributed evenly over the entire area. The length-frequency distributions at stations K333 and K334 were in fact very similar to those found in the inner Firth. Thus the occurrence of fish of between

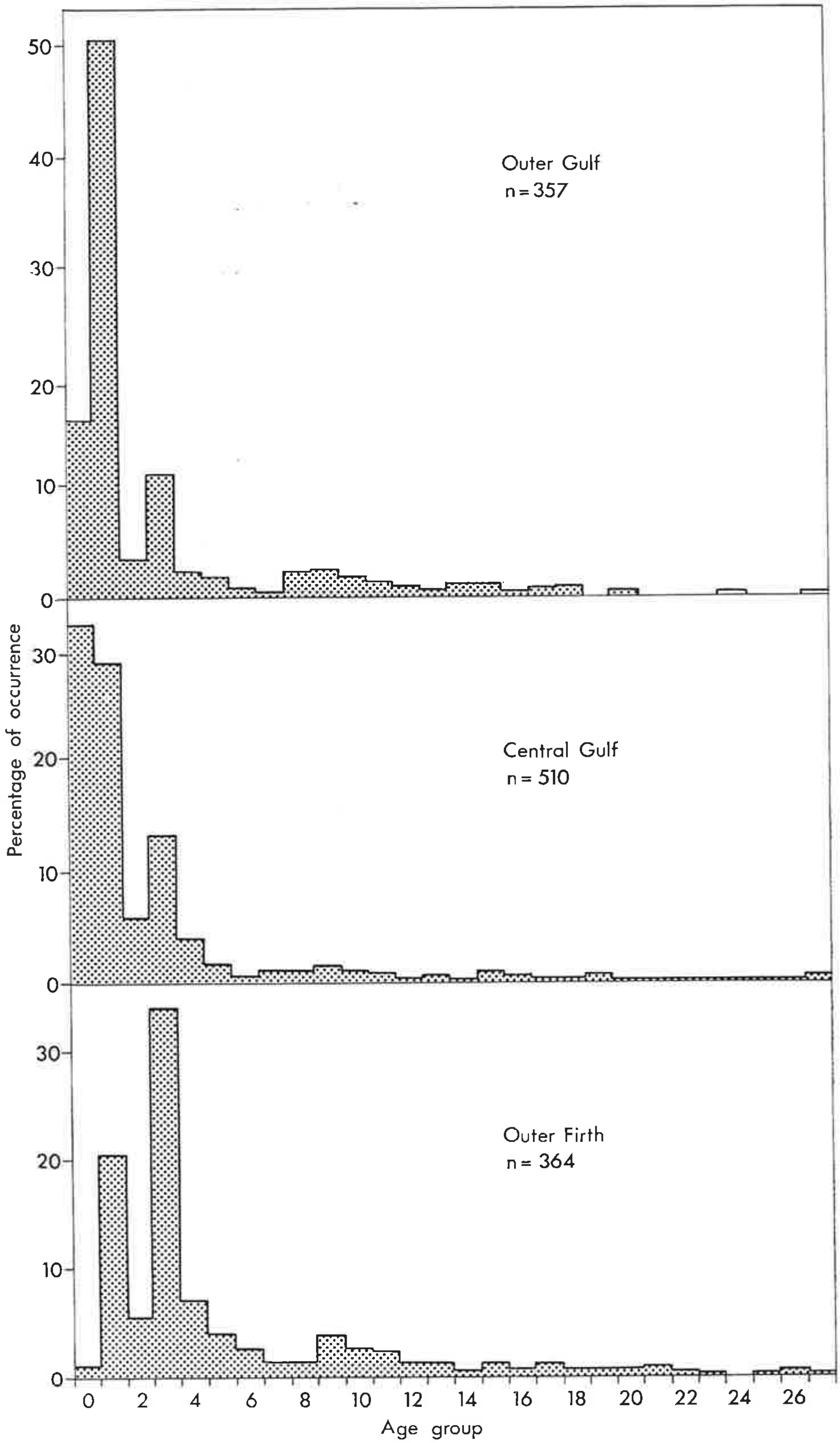

Fig. 8: Age compositions in the sampling areas. Negligible percentages of age groups 28, 30, 32, and 41 are not plotted.

TABLE 9: Catch rates of age groups in the sampling areas in number of fish per hour of trawling

Age group	Year class	Outer Gulf	Central Gulf	Outer Firth
0	1971	39.4	91.5	4.8
1	1970	128.3	81.9	75.2
2	1969	8.0	16.7	21.0
3	1968	28.2	37.9	125.9
4	1967	5.5	11.2	26.2
5	1966	3.9	5.1	13.6
6	1965	1.4	1.9	8.8
7	1964	1.2	2.7	6.4
8	1963	5.5	2.7	6.4
9	1962	5.8	3.7	14.4
10	1961	3.6	3.0	10.4
11	1960	2.9	2.7	8.8
12	1959	3.1	1.1	5.6
13	1958	1.2	1.8	5.6
14	1957	2.9	1.1	1.6
15	1956	2.6	3.2	5.6
16	1955	0.5	1.9	2.4
17	1954	1.2	1.3	4.8
18	1953	1.4	1.3	3.2
19	1952	0	1.5	3.2
20	1951	0.5	0.6	3.2
21	1950	0	0.5	4.0
22	1949	0	0.5	3.2
23	1948	0	0.2	0.8
24	1947	0.2	0.2	0
25	1946	0	0.5	0.8
26	1945	0	0.5	1.6
27	1944	0.2	1.1	0
28	1943	0	0.2	0
29	1942	0.2	0	0
30	1941	0	0.5	0
31	1940	0	0	0
32	1939	0.2	0	0.8
41	1930	0	0.2	0

1 and 2 years old in the Firth of Thames is irregular. They are usually scarce, but in some years locally abundant. The present data suggest that they may not penetrate far into the Firth of Thames, but may be restricted to its northern boundary.

TABLE 10: Percentages of snapper older than 10 years by numbers and by weights

	Outer Gulf	Central Gulf	Outer Firth
Numbers	8	8	18
Weights	33	37	38

The catch rates of age groups 3 and older were much higher in the outer Firth than in the outer and central Gulf. The age compositions in all three areas showed a very gradual decline in abundance from age group 4 to age group 30; there were very few fish older than 30 years (Table 9, Fig. 8). Year class 1962, represented as age group 9, was more abundant than several previous and subsequent year classes, but apart from this there were no consistent trends throughout all the samples.

Fish older than 10 years made up 8% of the samples from the outer and central Gulf and 18% of those from the outer Firth. The numbers of fish in the age groups listed in Table 9 were converted into weights of catch by use of Table 8. This showed that in all three areas between 30 and 40% of the weight of the catch was made up of fish older than 10 years (Table 10). Paul (1974) has reported similar and higher proportions of such old fish in snapper catches from the Hauraki Gulf taken in 1964–73 by commercial trawlers and Danish seiners. It can be concluded that the snapper stock in the Hauraki Gulf contains a large proportion of fish older than 10 years, especially in terms of weight, and that the age composition found during the present study is typical for the part of the stock which is vulnerable to trawling.

GENERAL DISCUSSION AND CONCLUSIONS

RECRUITMENT

The legal minimum cod-end mesh size is 10.2 cm (4 in.) for trawlers and 12.7 cm (5 in.) for Danish seiners. However, on all of the 17 commercial trawlers visited between 1966 and 1972 in the Hauraki Gulf by staff from the Fisheries Research Division, a cod-end mesh of 11.4 cm (4.5 in.) was in use. It appears that this is the mesh size generally used in the trawl fishery in the Hauraki Gulf, so that the recommendation by Cassie (1955) to increase the cod-end mesh size of commercial trawlers to 12.7 cm (5 in.) has been partly implemented. The escape of snapper of the legal minimum size (25 cm) is only 20% at a cod-end mesh of 10.2 cm, but is about 80% at a cod-end mesh of 11.4 cm (Cassie 1955), so that the change in mesh size may well have been made to avoid large catches of under-sized fish. Thus the legal minimum fish size may have had the effect of a mesh size regulation. From the length composition of the age groups and the escape curves by Cassie (1955) it follows that snapper younger than 2 years are not vulnerable to commercial trawl gear in its present form, and that escape decreases from 81% at the age of 3 years to 7% at the age of 7 years (Figs. 5 and 9, Tables 11 and 12). If a 12.7-cm cod-end mesh is indeed used in Danish seining, full recruitment to that fishery may occur at an even higher age.

Whether or not gradual recruitment actually occurs in this way is not known. If it does occur, the mortality in the fished stock is likely to be size selective at certain ages. This would affect estimates of growth based on back calculation and length at capture (Ricker 1969). A special study on the effects of gradual recruitment on the apparent growth pattern of the snapper is necessary not only to determine the

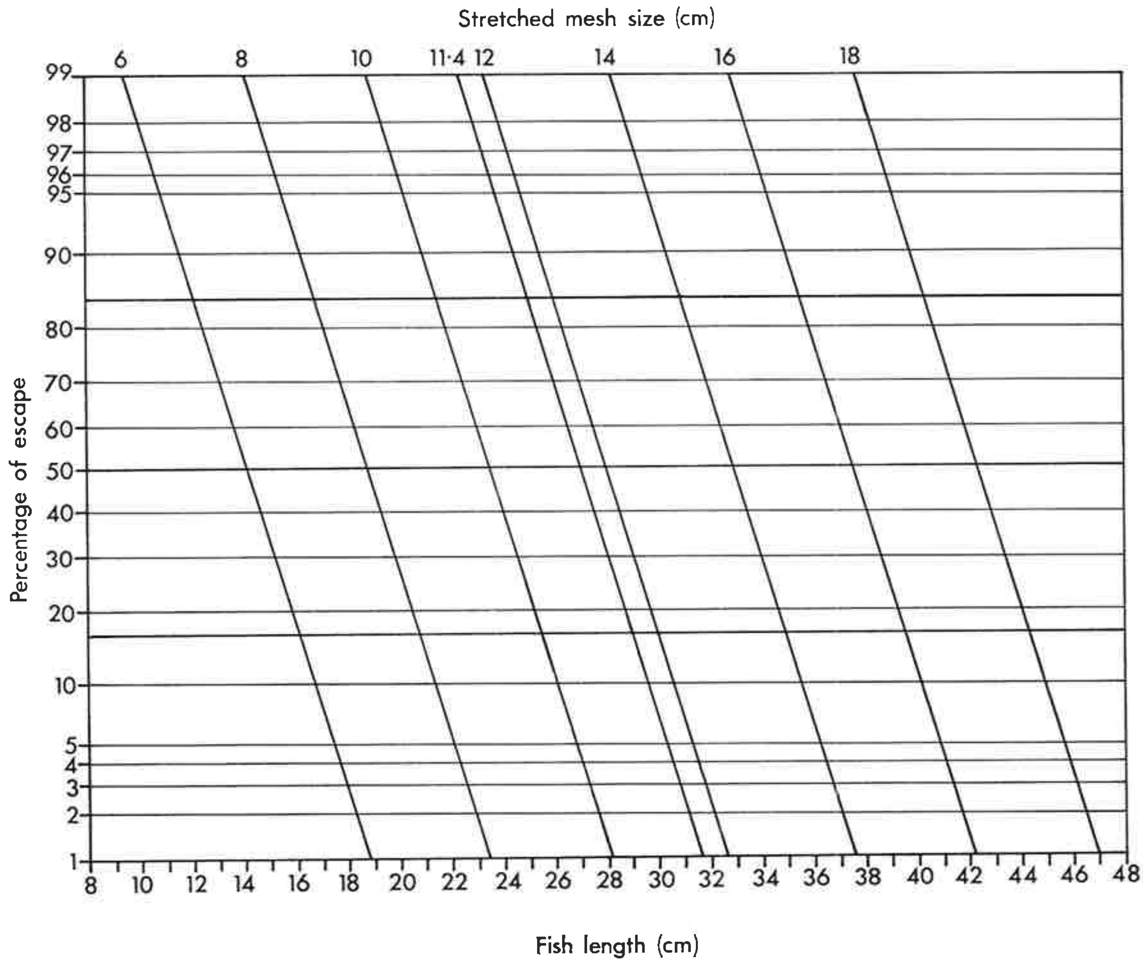

Fig. 9: Relationship between cod-end mesh size, true fork length, and escape of snapper from trawl nets. Modified after Cassie (1955). Escape index E=2.35 × mesh size (cm); selection index S=2.03 cm.

innate growth pattern, but to distinguish the effects on growth of other variables, such as population density, food supply, and temperature.

Since information on size-selective mortality in Hauraki Gulf snapper is not available, the growth curves derived from length at capture are treated in this bulletin as descriptions of the innate growth pattern.

CATCH RATES AND GROWTH

Water clarity in the Hauraki Gulf ranges from high in the outer Gulf to low in the Firth of Thames (Paul 1968). Gear avoidance in the trawl and Danish seine fishery for snapper has not been studied, but fishermen find that the results of fishing during the day depend strongly on water clarity and are much better in turbid than in clear water. Trawling in the very clear outer Gulf during daytime is therefore not considered profitable and this was confirmed during the present investigation. This suggests that the snapper avoids trawl and Danish seine nets largely by visual means. Consequently gear avoidance may be less effective in the Firth of Thames than in the outer and central Gulf. The high catch rate of older, commercial-

TABLE 11: Length composition by percentage of age groups 0 to 32 of snapper in the outer and central Hauraki Gulf in October 1970

Fork length (cm)	Age groups* 0	1	2	3	4	5	6	7	8	9	10	>10†
9	20	0	0	0	0	0	0	0	0	0	0	0
10	21	1	0	0	0	0	0	0	0	0	0	0
11	35	1	0	0	0	0	0	0	0	0	0	0
12	16	0	0	0	0	0	0	0	0	0	0	0
13	3	1	0	0	0	0	0	0	0	0	0	0
14	3	1	0	0	0	0	0	0	0	0	0	0
15	2	6	5	0	0	0	0	0	0	0	0	0
16	0	24	0	0	0	0	0	0	0	0	0	0
17	0	24	5	0	0	0	0	0	0	0	0	0
18	0	24	10	0	0	0	0	0	0	0	0	0
19	0	15	5	0	0	0	0	0	0	0	0	0
20	0	1	3	0	0	0	0	0	0	0	0	0
21	0	1	5	0	0	0	0	0	0	0	0	0
22	0	0	5	5	0	0	0	0	0	0	0	0
23	0	0	9	9	1	0	0	0	0	0	0	0
24	0	0	3	33	2	1	0	0	0	0	0	0
25	0	0	23	22	9	3	0	0	0	0	0	0
26	0	0	17	12	11	8	0	0	0	0	0	0
27	0	0	9	9	19	3	0	0	0	0	0	0
28	0	0	0	7	19	16	13	0	0	0	4	1
29	0	0	0	2	22	27	27	18	13	5	0	1
30	0	0	0	1	9	13	20	18	13	17	4	1
31	0	0	0	0	2	3	27	12	8	5	4	4
32	0	0	0	0	3	11	0	29	17	15	11	5
33	0	0	0	0	3	16	7	6	17	29	21	7
34	0	0	0	0	0	0	7	12	21	7	14	8
35	0	0	0	0	0	0	0	0	8	10	25	9
36	0	0	0	0	0	0	0	6	4	5	7	6
37	0	0	0	0	0	0	0	0	0	5	0	12
38	0	0	0	0	0	0	0	0	0	0	4	11
39	0	0	0	0	0	0	0	0	0	0	4	9
40	0	0	0	0	0	0	0	0	0	0	4	11
41	0	0	0	0	0	0	0	0	0	0	0	1
42	0	0	0	0	0	0	0	0	0	2	0	6
43	0	0	0	0	0	0	0	0	0	0	0	3
44	0	0	0	0	0	0	0	0	0	0	0	1
45	0	0	0	0	0	0	0	0	0	0	0	1
46	0	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	1
49	0	0	0	0	0	0	0	0	0	0	0	1
50	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	1
52	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	1
57	0	0	0	0	0	0	0	0	0	0	0	1
Sample size	113	102	41	195	65	38	15	17	24	41	28	157

* Ages in years are about 1 higher than the numbers of the age groups.
† Age groups >10 = age groups 11 to 32.

sized snapper in the Firth of Thames may therefore be a result of greater catchability, higher population density, or both. Population density could be higher because the outer and central Gulf are fished intensively by trawlers and Danish seiners, but the Firth of Thames is entirely closed to these methods of fishing. The snapper stock in the latter area is subjected only to some sport fishing and a moderate amount of commercial line and gill net fishing.

Spawning of snapper has not been observed in the Firth of Thames (Cassie 1956). The present survey was carried out at the beginning of the spawning season, that is, at a time when the sexually ripe fish of the population of the Firth of Thames could be expected to have moved temporarily to the spawning grounds in the central Gulf. Therefore the stock density of snapper in the Firth of Thames may be greater at other times of the year.

One of the objects of this study was to investigate a suggestion that a higher population density in the Firth of Thames has reduced the growth rate of older fish in this area relative to that of fish in the rest of the Hauraki Gulf. As has been shown, however, regional differences in growth rate are very small, and reduction of the population density by fishing would have no significant effect on snapper growth rate.

LENGTH-WEIGHT RELATIONSHIPS

The combined length-weight relationship (Table 6) can be rewritten as:

$$W = 0.023\ (L + 0.5)^{2.97} \quad . \quad . \quad . \quad (1)$$

where W is the gutted weight (g) and L is the length to the nearest centimetre below the actual length. The term $(L + 0.5)$ refers the length measurement to the mid point of the length group concerned.

This may be compared with the relationship obtained by Cassie (1957):

$$W = 0.079\ L^{2.66} \quad . \quad . \quad . \quad . \quad (2)$$

where the lengths and weights have been converted from inches (to the nearest 0.5 in.) and ounces (to the nearest ounce) for comparison. The weight in this

TABLE 12: Percentage of escape of snapper of centimetre groups 9 to 47 through bottom trawls with stretched cod-end mesh sizes of 6–18 cm, estimated from Fig. 9

True fork length	Mesh sizes (cm)							
(cm)	6.0	8.0	10.0	11.4	12.0	14.0	16.0	18.0
9.5	99	100	100	100	100	100	100	100
10.5	96	100	100	100	100	100	100	100
11.5	90	100	100	100	100	100	100	100
12.5	79	100	100	100	100	100	100	100
13.5	61	100	100	100	100	100	100	100
14.5	42	98	100	100	100	100	100	100
15.5	24	95	100	100	100	100	100	100
16.5	11	87	100	100	100	100	100	100
17.5	4	74	100	100	100	100	100	100
18.5	2	55	100	100	100	100	100	100
19.5	0	36	98	100	100	100	100	100
20.5	0	19	93	100	100	100	100	100
21.5	0	9	84	100	100	100	100	100
22.5	0	3	69	99	100	100	100	100
23.5	0	1	50	96	99	100	100	100
24.5	0	0	31	90	96	100	100	100
25.5	0	0	16	77	89	100	100	100
26.5	0	0	7	60	77	100	100	100
27.5	0	0	2	40	59	100	100	100
28.5	0	0	0	22	40	99	100	100
29.5	0	0	0	10	22	96	100	100
30.5	0	0	0	4	10	89	100	100
31.5	0	0	0	1	4	76	100	100
32.5	0	0	0	0	1	58	100	100
33.5	0	0	0	0	0	39	98	100
34.5	0	0	0	0	0	21	93	100
35.5	0	0	0	0	0	10	84	100
36.5	0	0	0	0	0	4	70	100
37.5	0	0	0	0	0	1	50	99
38.5	0	0	0	0	0	0	31	97
39.5	0	0	0	0	0	0	16	92
40.5	0	0	0	0	0	0	6	82
41.5	0	0	0	0	0	0	2	66
42.5	0	0	0	0	0	0	0	46
43.5	0	0	0	0	0	0	0	27
44.5	0	0	0	0	0	0	0	13
45.5	0	0	0	0	0	0	0	5
46.5	0	0	0	0	0	0	0	2
47.5	0	0	0	0	0	0	0	0

expression is the total weight and thus the difference in the exponent suggests that the gut represents a decreasing proportion of the body weight as the fish increases in size (Fig. 4).

MORTALITY AND MIGRATIONS

A catch curve was fitted by eye to the logarithms of the age-frequency distributions in the central Gulf (Fig. 10). The points for year classes 1941–66 vary about a line with a slope that indicates a value of Z (instantaneous rate of total mortality) of 0.1, corresponding to an annual mortality rate of about 10%. Beverton and Holt (1959) list values of M (instantaneous rate of natural mortality) for a variety of fish species and it appears that M is rarely lower than 0.1. The value of M in two species occurring near Japan and related to the New Zealand snapper has been estimated at 0.2 (Doi 1955, Shindo 1960). The value of $Z=0.1$ estimated here for the older snapper includes both M and F (instantaneous rate of fishing mortality) and is therefore unexpectedly low in view of the fact that an important snapper fishery has existed in the Hauraki Gulf for a long time.

Little is known about the natural enemies of the New Zealand snapper. This fish is a strong swimmer with well-developed eyes, a robust scale covering, and an impressive array of dorsal spines. The demersal fauna in the Hauraki Gulf does not appear to contain predatory species fast and powerful enough to make a great impact on the population of older snapper and it seems probable that the Hauraki Gulf snapper have a very low natural mortality rate (M less than 0.1) at least after the age of 5 or 6 years. A similarly low mortality rate seems to apply to Australian snapper (Morgan 1972).

The line through the points for the six youngest year classes (1966–71) is much steeper and indicates that during the first 6 years $Z=0.62$, which corresponds to an annual mortality rate of 46% (Fig. 10). Fluctuations in year class strength have occurred among the older year classes (Paul 1976), but on a logarithmic scale such fluctuations are evidently not large enough to obscure the general trend over age groups 6 to 30. Therefore variation in year class strength probably does not affect the catch curve of the younger fish very much either. The steep slope of the catch curve for age groups 1 to 6 may represent a higher mortality in these fish or may reflect migration of young fish away from the Hauraki Gulf.

A similar catch curve fits the data for age groups 2 to 26 (year classes from 1969 to 1945) in the outer Firth (Fig. 10). The similarity of the trends over age groups 5 to 26 suggests that the total mortality rate of snapper older than 6 years is low in the Hauraki Gulf as a whole, and that there is little difference in mortality rate between the Firth of Thames and the outer and central Gulf, despite the difference in fishing intensity between these areas. Either there is much mixing between the snapper populations of the Firth of Thames and the rest of the Hauraki Gulf, or the additional mortality caused by trawling and Danish seining in the outer and central Gulf is so low that it has little effect on the total mortality rate in these areas

A possible explanation for the differences in the catch curves between young and old fish is that snapper live inside the Hauraki Gulf until they are 6 to 7 years old and then shift to deeper rough grounds outside it and visit the Gulf each year in spring to spawn. This would explain the phenomenon of "school snapper" described by Longhurst (1958). A comparison of the present data with samples taken outside the spawning season should test this idea; however, such samples are not available at present. Inside the Hauraki Gulf the fish are continually subjected to the fishery: outside the Gulf they spend most of their time on rough grounds unsuitable for trawling and Danish seining. Young fish, once recruited, would thus be subjected to a higher fishing mortality than the older fish until they moved away from the Gulf. However, we have noted earlier that recruitment is a gradual process, so that the pattern shown in the catch curve for the young fish results from a combination of factors. The major component is probably the progressive movement of young fish out of the area to deeper water, which is largely complete by the time the fish are 6 to 7 years old. However, some snapper seem to remain in the Hauraki Gulf as local populations of old resident fish.

The introduction of a new type of high-opening Danish seine into the Hauraki Gulf in 1968 resulted in higher catch rates (Paul 1974), and pair trawling with a high-opening bottom trawl in the Bay of Plenty gave similar results, the snapper catch rates per boat being several times higher than with the conventional single-boat trawl (Fishing Industry Board 1972). This indicates that the vulnerability of snapper to the traditional low-opening trawl and Danish seine is low, which in turn could explain the low level of F in the outer and central Hauraki Gulf notwithstanding the presence of a large and active fishing fleet.

The present findings are similar to those of Cassie (1955, page 67), who estimated the total mortality rate about the year 1950 to be "approximately 45 percent per annum between the third and seventh year, corresponding to an instantaneous rate of 0.6 per annum". Cassie did not show data for the older age groups.

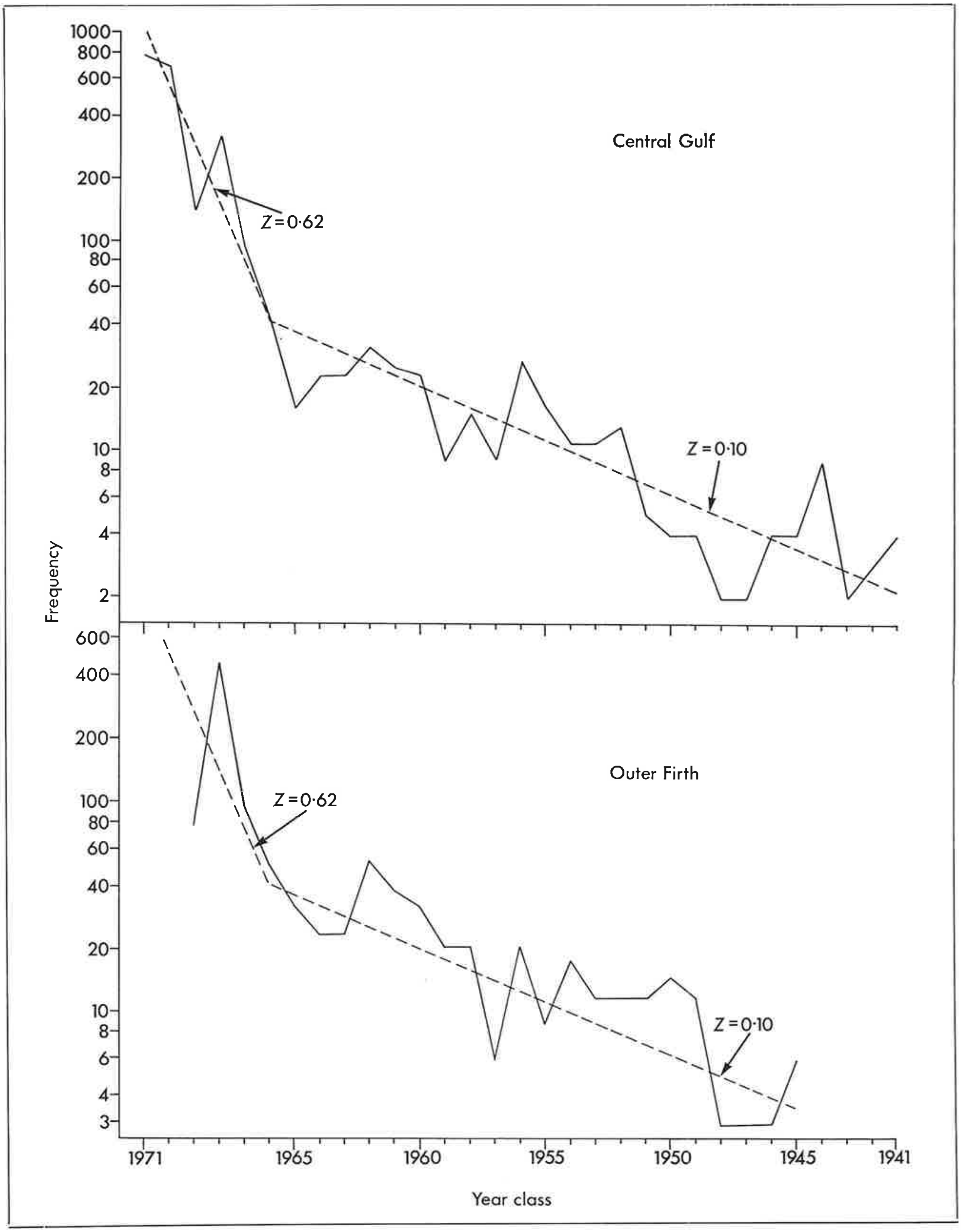

Fig. 10: Catch curves for the central Gulf and the outer Firth. The points for the poorly represented age groups 0 and 1 in the outer Firth are not plotted. Z is the instantaneous rate of total mortality.

YIELD

A model was designed which predicts the yield per recruit as a function of cod-end mesh size, natural mortality, fishing mortality, and growth and which takes the age-related variation in growth and mortality into account. The variables and symbols used are:

Y = yield in grams
w = mean gutted weight at age in grams
λ = maximum age in the fishable life span
F' = virtual rate of fishing
F = instantaneous rate of fishing mortality
M = instantaneous rate of natural mortality
Z = instantaneous rate of total mortality
m = annual rate of fishing mortality
n = annual rate of natural mortality
a = annual rate of total mortality
v = vulnerability
R = number of fish present at the beginning of a year
u = number of deaths due to fishing during a year.

A subscript attached to a symbol specifies the year in the life of the fish for which the variable is considered.

The relationships between the variables are as follows:

$$m_i = 1 - e^{-F_i} \quad . \quad . \quad . \quad . \quad (3)$$

$$m_i = v_i\,(1 - e^{-F'}) \quad . \quad . \quad . \quad . \quad (4)$$

$$Z_i = F_i + M_i \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$a_i = m_i + n_i - m_i n_i \quad . \quad . \quad . \quad (6)$$

$$u_i = \frac{F_i}{Z_i} a_i R_i \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The relationships between the two other pairs of annual and instantaneous mortality rates are as in equation 3.

The total yield from a year class during its fishable life span at specified levels of F' and v_i is found by summation:

$$Y = \sum_{i=1}^{i=\lambda} u_i w_i \quad . \quad . \quad . \quad . \quad (8)$$

The value of λ was set at 30 years and the value of R_1 at 100, so that equation 8 gave the yield per 100 recruits. M was assumed to decrease from 0.6 in the first year to 0.05 after the sixth year, as follows:

$M_1 = 0.6$, $M_2 = 0.6$, $M_3 = 0.5$, $M_4 = 0.4$,
$M_5 = 0.2$, $M_6 = 0.1$, $M_{>6} = 0.05$.

The data on length, weight, and age used were those for the outer and central Gulf combined (Table 8). The vulnerability was calculated for each mesh size and age separately by use of the data on escape from trawl nets (Cassie 1955) and the length compositions of the age groups (Table 13). The time spent by individual fish inside the Hauraki Gulf was assumed to be between 1 and 2 months annually after their sixth year, so that they are then vulnerable to the fishery during about one-tenth of the year. The vulnerability derived from the escape data was therefore multiplied by 0.1 for fish older than 6 years.

The growth data used in calculating w and v were collected at the end of a year. Strictly, however, the values used in the equation should be the average weight and vulnerability during the year. These averages were approximated by the mean of the values measured at the end of a year and the end of the preceding year:

$$\bar{v}_i = \frac{v_{i-1} + v_i}{2} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

and similarly for $\bar{w}_i$ (Tables 8 and 14).

Thus two yield isopleth diagrams were derived, one by use of v_i and w_i (end-of-year values) and one by use of $\bar{v}_i$ and $\bar{w}_i$ (mean-of-year values) (Fig. 11).

When mesh size increases beyond 12 cm, yield decreases sharply (Figs. 11 and 12). The reason for this is that fish younger than 6 years are not vulnerable because they escape at mesh sizes greater than 12 cm, and the vulnerability of the older fish is very low at any mesh size owing to their migratory behaviour. Therefore mesh sizes which allow the escape of most fish younger than 6 years give low yields. The decrease in vulnerability after the sixth year has the same effect on the yield as a large increase in natural mortality.

At mesh sizes of 12 and 14 cm the yields are higher (relative to those of other mesh sizes) under mean-of-year values of v and w than under end-of-year values (Fig. 12). Thus if vulnerability does not decrease abruptly as in Fig. 11 (a), but lessens more gradually after the sixth birthday as in Fig. 11 (b), the ridge of the yield isopleths shifts towards larger mesh sizes. This is probably due to the fact that at mesh sizes of 12 and 14 cm the mean-of-year vulnerability is higher for the seventh year than the end-of-year vulnerability (Tables 13 and 14).

At mesh sizes up to 12 cm the yield curves flatten out at about $F' = 0.5$ and show little change in yield if F' increases beyond 0.6 (Fig. 12). In the more realistic model with gradual decrease in vulnerability after the sixth birthday, optimal yields at $F' > 0.5$ are obtained at mesh sizes of 8 to 12 cm. Although the yields at these mesh sizes are very similar, the age and size composition of the catch will undoubtedly vary considerably with mesh size.

The cod-end mesh size now used in the trawl fishery for snapper is 11.4 cm. At this mesh size, and

if $F' = 0.65$, the expected values of Z are similar to those measured in the present study and follow a similar trend with age (Table 15). Thus, if the model and the assumed values of M are a valid approximation, F' is at present between 0.6 and 0.7. At the current trawl mesh size this level of F' gives a yield which is close to the optimum (see Fig. 12).

The rate at which the larger, faster-growing members of the partially vulnerable age groups are caught can be expected to depend on the mesh size and the magnitude of F'. Therefore the mean body weight of the partially vulnerable age groups in the commercial catch will vary with mesh size and F'. The selective removal of the larger, faster-growing fish will also

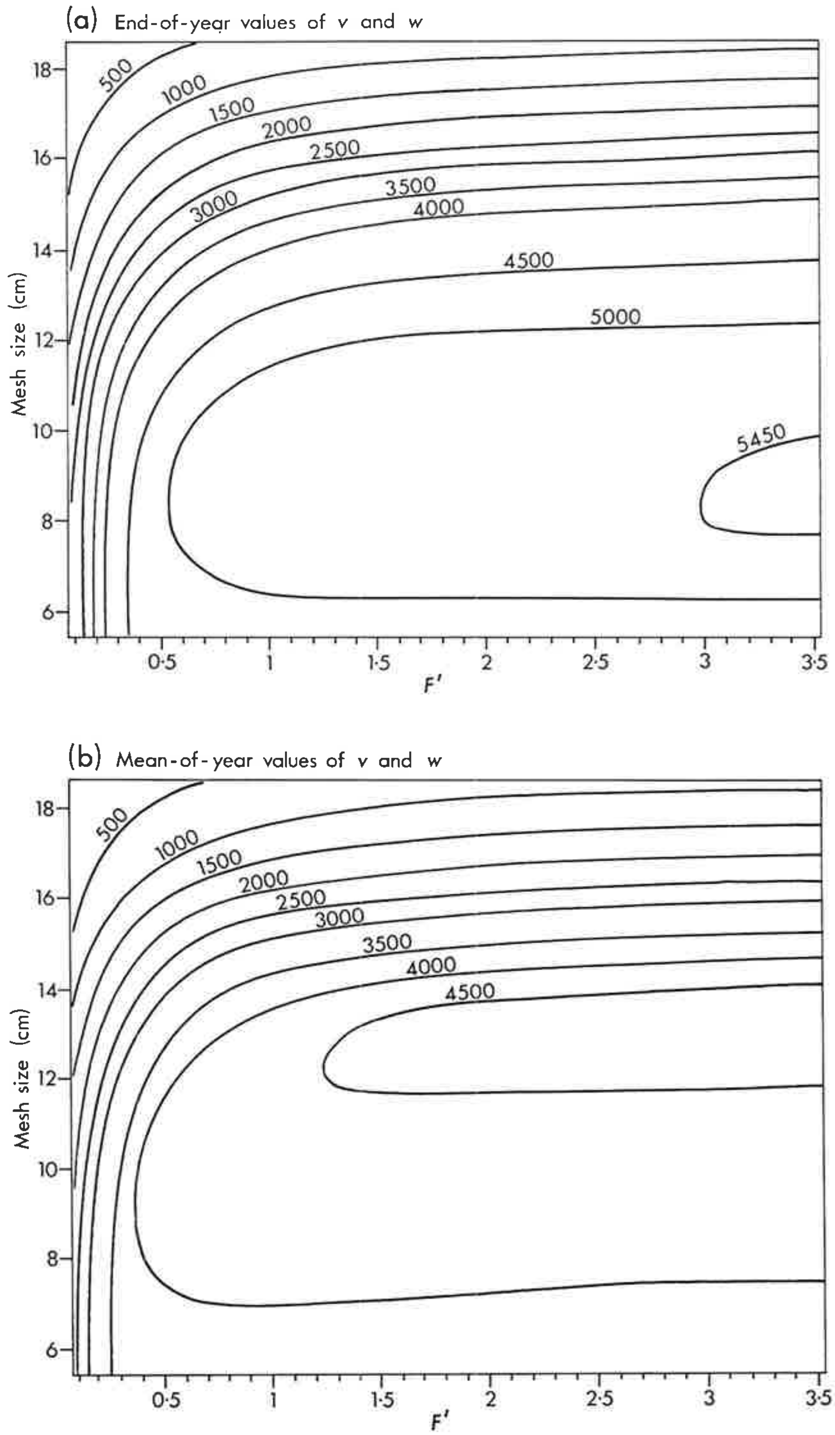

Fig. 11: Isopleth diagrams of yield per 100 recruits (g). F' is virtual rate of fishing, v is vulnerability, and w is mean body weight.

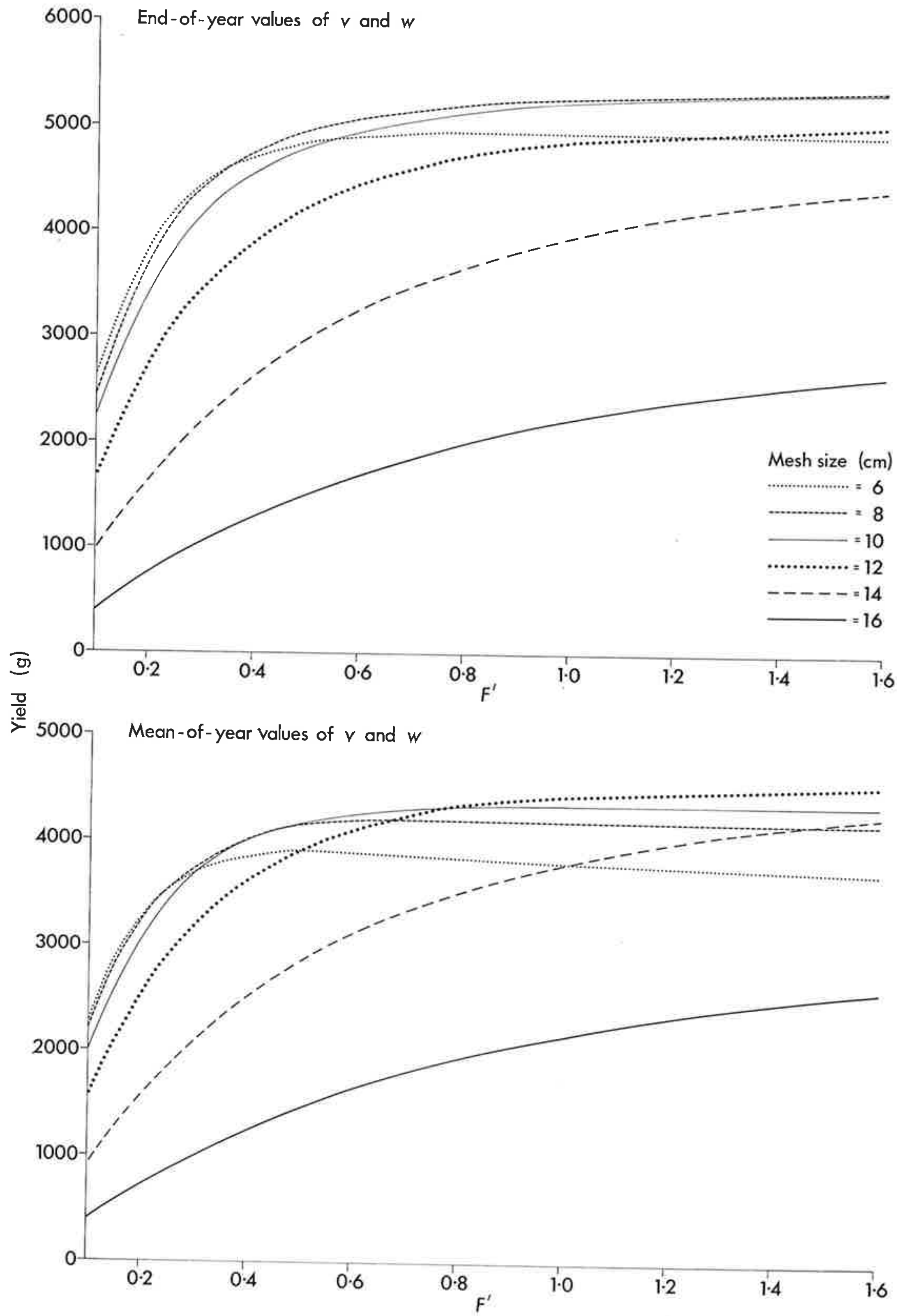

Fig. 12: Sections along selected planes through Fig. 11.

TABLE 13: Percentage of vulnerability (v_i) of snapper at the end of ages 1 to 33 years, to bottom trawls with stretched cod-end mesh sizes of 6–18 cm, estimated from Tables 11 and 12*

Age (years)	Mesh sizes (cm) 6.0	8.0	10.0	11.4	12.0	14.0	16.0	18.0
1	12	0	0	0	0	0	0	0
2	92	32	2	0	0	0	0	0
3	98	83	54	19	11	0	0	0
4	100	100	77	27	17	1	0	0
5	100	100	96	69	56	6	0	0
6	100	100	99	84	75	17	0	0
7	10	10	10	9.3	8.6	1.9	0	0
8	10	10	10	9.7	9.3	3.6	0.2	0
9	10	10	10	9.8	9.5	4.8	0.3	0
10	10	10	10	9.9	9.7	5.4	0.9	0.1
11	10	10	10	9.9	9.9	6.9	0.9	0
>11†	10	10	10	10	10	7.9	4.1	1.4

* Percentage of vulnerability equals 100 minus percentage of escape, multipled by 0.1 if age is over 6 years to account for a change in behaviour during the 6th year.
† Ages >11 = ages 12 to 33 years.

TABLE 14: Mean percentage of vulnerability ($\bar{v}_i$) of snapper, during each age 1 to 33, to bottom trawls with stretched cod-end mesh sizes of 6–18 cm, estimated from Table 13

Age (years)	Mesh sizes (cm) 6.0	8.0	10.0	11.4	12.0	14.0	16.0	18.0
1	6	0	0	0	0	0	0	0
2	52	16	1	0	0	0	0	0
3	95	57.5	28	9.5	5.5	0	0	0
4	99	91.5	65.5	23	14	0.5	0	0
5	100	100	86.5	48	36.5	3.5	0	0
6	100	100	97.5	76.5	65.5	11.5	0	0
7	55	55	54.5	46.7	41.8	9.5	0	0
8	10	10	10	9.5	9	2.8	0.1	0
9	10	10	10	9.8	9.4	4.2	0.3	0
10	10	10	10	9.9	9.6	5.1	0.6	0.05
11	10	10	10	9.9	9.8	6.2	0.9	0.05
>11	10	10	10	10	10	7.9	4.1	1.4

TABLE 15: Instantaneous mortality rates during successive years of life

Year	Z (observed)	M (assumed)	F (expected) End-of-year vulnerability	F (expected) Mean-of-year vulnerability	Z (expected) End-of-year vulnerability	Z (expected) Mean-of-year vulnerability
1	0.62	0.60	0.00	0.00	0.60	0.60
2	0.62	0.60	0.00	0.00	0.60	0.60
3	0.62	0.50	0.10	0.05	0.60	0.55
4	0.62	0.40	0.14	0.12	0.54	0.52
5	0.62	0.20	0.40	0.26	0.60	0.46
6	0.62	0.10	0.51	0.46	0.61	0.56
7	0.10	0.05	0.05	0.25	0.10	0.30
>7	0.10	0.05	0.05	0.05	0.10	0.10

Z: Total mortality.
M: Natural mortality.
F: Fishing mortality.
The values of F are as expected when F' (the virtual rate of fishing) is 0.65.

have an effect on the average growth pattern of the survivors and may influence the relationships between age and body weight and between age and vulnerability. These effects of mesh size and F' on w and v were not taken into account in the present model. The vulnerabilities and body weights used were those estimated under the current conditions, that is, at a commercial trawl mesh size of 11.4 cm and an F' level of 0.65. The mean body weight in the commercial catch from a partially vulnerable age group was assumed to be equal to the mean body weight in this age group as a whole. It is in fact likely to be higher. The effect of this procedure may be to underestimate Y slightly because of an underestimate of the yield taken at certain ages. This would shift the yield isopleths to the left without altering their general pattern.

In recent years between 50 and 60% of the annual snapper catch in the Hauraki Gulf has been taken by Danish seiners (Paul 1974). The escape of snapper from the gear used by these boats has not been studied. They have a larger cod-end mesh size (12.7 cm) than the trawlers, and the general opinion

of the fishermen is that for a given mesh size more and larger snapper escape from the Danish seine than from the trawl. The vulnerability of a given age group to trawling may therefore differ from its vulnerability to Danish seining, and the difference between the two may change with age.

Danish seiners and trawlers operate in different parts of the Hauraki Gulf: the latter in and beyond the outer Gulf, the former also in these areas but more intensively in the central Gulf. Thus the two fishing methods exploit different portions of the stock in different ways. In this bulletin only data on trawling were used in the yield model. Yield predictions for the snapper fishery in the Hauraki Gulf must remain tentative until more is known about recruitment and vulnerability of snapper to the Danish seine fishery.

CONCLUSIONS

The population density of snapper older than 3 years is considerably higher in the Firth of Thames than in the central and outer Gulf. However, the higher catch rates recorded in the Firth of Thames probably also reflect a higher catchability by trawl gear.

The differences in growth between snapper in the Firth of Thames and those in the rest of the Hauraki Gulf are slight. Reduction of the population density in the Firth of Thames by increased fishing is unlikely to have a pronounced beneficial effect on the growth rate of snapper in that area.

The Firth of Thames is not important as a nursery ground for snapper. Fish of less than 1 year old are scarce; fish of between 1 and 2 years old are at times abundant, but they occur only near the northern boundary of the Firth.

Recruitment of snapper to the trawl and Danish seine fisheries in the Hauraki Gulf is likely to be gradual, starting during the third year and being completed only at the age of 7 or 8 years. There may be size-selective mortality between the third and eighth years. This has important implications for the measurement of growth rates and for the design and analysis of tagging experiments.

SUMMARY

The stock of snapper, *Chrysophrys auratus*, in the Hauraki Gulf was surveyed by bottom trawling between 4 October and 3 November 1971. The main purpose of the survey was to compare the growth rate and stock density on the trawling and Danish seining grounds in the central and outer Hauraki Gulf with those in the Firth of Thames, where trawling and Danish seining are prohibited at the time of writing.

The catch rate of snapper with fork length of 25 cm or more in the Firth of Thames was between three and five times higher than in the central and outer Hauraki Gulf. This indicates greater stock density in the Firth of Thames, but catchability may also be greater.

In the Firth of Thames young snapper grow faster than those in the central and outer Hauraki Gulf. However, the growth differences are slight and do not have a major effect on the snapper populations as a whole.

The age-length data were best fitted by a compound curve consisting of two von Bertalanffy growth curves, one for ages 1 to 7 years and one for the higher ages. Asymptotic lengths and weights of the upper limbs of the curves were: 44.8 cm and 1882 g in the central and outer Hauraki Gulf and 41.0 cm and 1444 g in the Firth of Thames.

Snapper of less than 2 years old were abundant and widespread in the central and outer Hauraki Gulf and scarce in the Firth of Thames. Apart from this, the age compositions in the two areas were similar. Snapper older than 10 years made up 8% by numbers (33 to 37% by weight) of the catches in the outer and central Hauraki Gulf and 18% by numbers (38% by weight) in the Firth of Thames. The age compositions suggested that instantaneous total mortality rate (Z) was about 0.6 during the first 6 years of life and 0.1 thereafter.

The low mortality rate of the older fish led to the following hypothesis: Snapper live inside the Hauraki Gulf during their first 6 to 7 years and shift subsequently to deeper waters outside the Gulf, returning each year for a short period to the trawling and Danish seining grounds inside the Gulf to spawn. Thus older snapper are subjected to the fishery during only a small part of the year.

Estimates of age-specific natural mortality rate and vulnerability to trawl gear were used in a model which predicted yield from a year class as a function of mesh size and virtual rate of fishing (F'). Yields are optimal at mesh sizes between 8 and 12 cm and at F' values between 0.5 and 0.7. The mesh size used at the time of writing in the trawl fishery for snapper is 11.4 cm. The total mortality rates measured in this study are simulated by the model if $F'=0.65$. Thus the yields at the current levels of mesh size and F' are within the predicted optimum range. The vulnerabilities used in the model were estimated from data on trawling only. However, about 60% of the annual snapper catch in the Hauraki Gulf is taken by Danish seining. Reliable yield predictions will be possible only when a study has been made on vulnerability and recruitment of snapper to the Danish seine fishery.

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