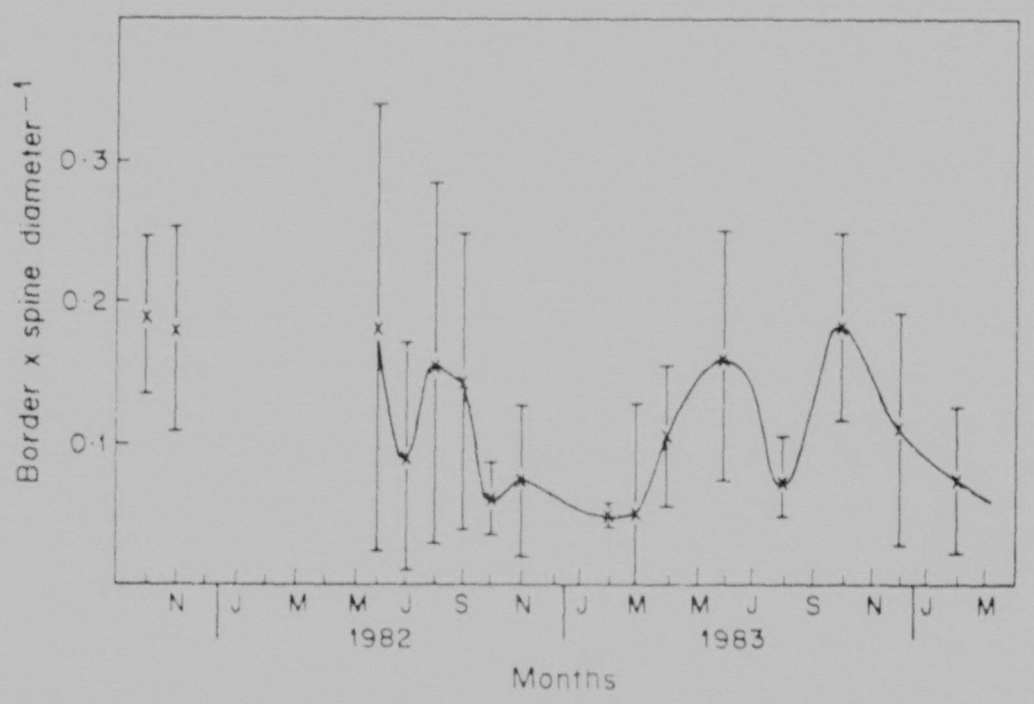

Fig. 6.9. Mean distance, as a proportion of spine diameter, between last ring and pectoral spine border in *C. gariepinus* (November 1981 to February 1984). Bar = 95% CI.

Table 6.8. The length distribution of *C. gariepinus* with different numbers of pectoral spine rings, from Hartbeespoort Dam.

Std length (cm)	No. of fish								
	Pectoral ring number								
	0	1	2	3	4	5	6	7	8
0- 9	-	-	-	-	-	-	-	-	-
10- 19	-	-	-	-	-	-	-	-	-
20- 29	3	-	-	-	-	-	-	-	-
30- 39	1	1	-	-	-	-	-	-	-
40- 49	1	7	5	2	-	-	-	-	-
50- 59	-	4	9	8	7	6	3	2	-
60- 69	-	-	3	4	10	9	1	1	-
70- 79	-	-	-	-	2	6	1	-	2
80- 89	-	-	-	-	1	3	1	-	-
90- 99	-	-	-	-	-	-	1	-	-
100-109	-	-	-	-	-	-	-	-	1

In Lake Sibaya, Lake le Roux and rivers in the Western Transvaal, *C. gariepinus* was found to form one ring per year (Bruton & Allanson, 1980; Quick & Bruton, 1984; van der Waal & Schoonbee, 1975). On the basis of these results and the clear pectoral border minimum recorded in the summer of 1982/83, it is probable that *C. gariepinus* in Hartbeespoort Dam normally forms one ring per year. Calculations of t_o for the von Bertalanffy growth curve produced results of -0.22 (males) and -0.60 (females) if the first ring was assumed to be formed at two years old, and -1.22 and -1.60 respectively if the first ring was assumed to be formed at one year old. The greater deviation from zero of the latter set of results showed that, as in Lake Sibaya (Bruton & Allanson, 1980), the first ring was formed in the Hartbeespoort population at two years old.

The mean length at ring formation was determined using the Fraser-Lee equation. The correction factor, a, was determined from the linear regression of standard length against spine diameter. The equation was,

Table 6.9. Mean standard length at time of ring formation and age, and annual length increment for male and female *C. garlepinus*. SL = standard length (cm), Incr = length increment (cm), CI = confidence interval.

		Males			Females		
Ring	Age (yr)	SL (cm)	95% CI	Incr. (cm)	SL (cm)	95% CI	Incr. (cm)
1	2	35.84	33.57- 38.11	13.10	36.13	33.96-38.31	9.40
2	3	48.94	46.39- 51.49	7.27	45.53	43.32-47.73	5.98
3	4	56.21	53.35- 59.08	5.00	51.51	48.82-54.21	5.00
4	5	61.21	57.50- 64.93	5.59	56.51	53.32-59.69	1.45
5	6	66.80	61.47- 72.13	11.99	57.96	53.61-62.31	1.68
6	7	78.79	63.26- 94.34	2.34	59.64	50.59-68.68	0.84
7	8	81.13	44.68-117.58	2.38	60.48	47.98-72.98	-
8	9	83.51	43.74-123.29	-	-	-	-

$$SL = 14.34 + 224.14SR \quad (n=97,\ r^2 = 0.68)$$

where SL = standard length (cm)

SR = spine radius (cm)

The mean standard length and 95% confidence limits, and annual growth increments were then calculated for males and females of the total sample (Table 6.9).

The data in Table 6.9 were used to calculate the relationships between initial length and growth increment. The equations were,

i) Males

$$Incr = 18.39 - 0.19SL \quad (n=7,\ r^2 = 0.50)$$

ii) Females

$$Incr = 22.82 - 0.37SL \quad (n=6,\ r^2 = 0.97)$$

The regression line for males was not quite significant at the 95% confidence limit. The reason for this lay in the growth increments for the sixth and seventh years, which revealed a growth spurt. This may have been caused by the broad confidence

limits around mean length at the sixth ring (63.24-94.34). Quick and Bruton (1984) found increased growth rate in males and females in their fourth and fifth years which they ascribed to lumen expansion obscuring rings in older fish or a switch from invertebrate to fish feeding. The latter explanation does not apply to Hartbeespoort Dam where zooplankton form the main component of the diet of large fish and piscivory is insignificant (NIWR, 1985). The probable explanation is statistical error caused by increased variation in the length of older fish (Table 6.8) and small sample size of the older fish. For this reason and because it was necessary to have a mathematical description of growth for the production models, the relationship was accepted and von Bertanlanffy curves fitted. The uncertain validity of this growth curve, indicated by the poor fit of the initial length:increment relationships, introduces uncertainty into the yield estimates based on the models in Chapter 7.

The curves were,

i) Males $l_t = 97.32\ (1 - e^{-0.21\ (t + 0.22)})$

ii) Females $l_t = 62.29\ (1-e^{-0.46\ (t - 0.13)})$

where l_t = SL at age t years.

The theoretical asymptotic length of males (97 cm) was a good estimate of the observed (110 cm TL = 96 cm SL, Fig. 5.3) but that for females underestimated the observed maximum (90 cm TL = 79cm SL, Fig. 5.3). The female curve was therefore recalculated using initial length and increment data for the first three rings after which confidence limits became too broad for accurate initial length and increment figures. A regression line was fitted to the data from the first three rings (Table 6.9) and the observed maximum length of 79 cm. The relationship was,

$$Incr = 16.11-0.21SL \quad (n=4,\ r^2 = 0.97)$$

which estimates the theoretical maximum length as 77.45 cm. Therefore the growth coefficient determined from this equation and the observed asymptote of 79.0 cm were used to describe the von Bertanlaffy curve,

$$l_t = 79.0\ (1 - e^{-0.23\ (t + 0.60)})$$

The male and modified female curve provided a good fit to the observed data (Fig. 6.10), suitable for use in the yield models.

6.3.2 Fecundity, age at maturity and breeding seasons

(a) *O. mossambicus*

O. mossambicus females were collected for fecundity analysis during the spawning season of 1982/83 and in October 1983. Fecundity : size relationships were described for the two periods to compare fecundity for the latter period of low dam volume (22%) and hence high density to that of lower density. There was no significant difference in the slopes or y-intercepts of the lines, which were almost identical, showing that changes in fecundity did not occur as a population regulation mechanism (Table 6.10).

The curve for the combined data with the highest level of significarce and explaining 75.8% of the variance observed in fecundity was used to describe the fecundity : mass relationship. In all subsets mass showed a slightly higher correlation to fecundity than standard length.

Table 6.10. Fecundity to mass relationships for *O. mossambicus* collected in the summer of 1982/83 and in October 1983. F = no. of mature eggs, M = mass(g).

Time	n	r^2	Significance	Equation	SEa	SEb
Summer						
1982/83	33	0.798	0.99	$F = 40.45\ M^{0.64}$	0.35	0.06
Oct. 1983	20	0.633	0.99	$F = 40.45\ M^{0.63}$	0.31	0.11
Total	53	0.758	0.99	$F = 40.45\ M^{0.63}$	0.31	0.05

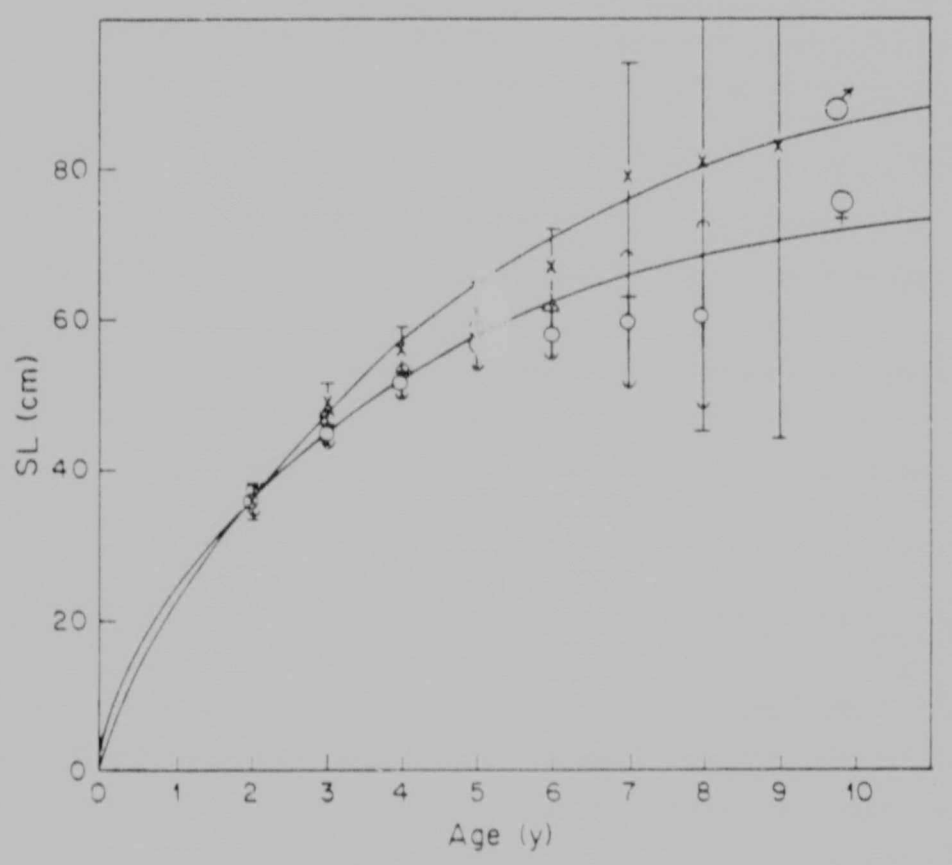

Fig. 6.10. Length at age and fitted growth curves of male (x) and female (o) *C. gariepinus*. ⊢⊣ = 95% CI of male length at age and (---) = 95% CI of female length at age.

The breeding season of *O. mossambicus* can be identified from the monthly occurrence of active-ripe and ripe females in the population (Fig. 6.11). This shows sexually active females present in the population from September to February with a low percentage remaining in March and April. Fry were observed and caught in the lake from the end of September, and 23% of a sample of 91 female *O. mossambicus* caught in October 1982 were mouth brooding, confirming that spawning started in late September.

During 1983, a total of 453 females and 330 males were caught in gill nets and sexed. This gives a sex ratio of 1:1.37 males to females. During the breeding season, mature males are territorial and remain in limited areas in shallow water and the results were therefore biased towards female dominance. A 1:1 ratio was assumed in the yield model (Section 7.2.1).

Power curves fitted to the three sets of data used to back-calculate the time of spawning and hence to determine the length of mouth-brooding (Table 6.11) were highly significant. From these curves the time for larvae to reach 10.0 mm, the maximum recorded length of fry still being mouth-brooded, was calculated. The mean period was 23 days (2SE = 3.3 days). This agrees with the figure of 20-22 days recorded from Lake Sibaya (Bruton & Boltt, 1975).

Table 6.11. Daily mean length of larvae/fry from three female *O. mossambicus* reared in the laboratory

Replicate	1		2		3	
Mean temp.	23.2		23.1		22.9	
Temp. range	22-24.5		22-24.5		21.9-24.5	
Days from time of capture	Total length (mm)					
	$\bar{X}$	2SE	$\bar{X}$	2SE	$\bar{X}$	2SE
1	6.10	0.06	6.36	0.22		
3	7.12	0.07	7.02	0.14		
5	8.16	0.16	7.86	0.22	8.30	0.13
7	8.98	0.10	8.92	0.12	9.12	0.21
9	9.94	0.08	9.84	0.21	10.08	0.04
11	10.04	0.11	10.04	0.18	10.29	0.29
13	10.63	0.15	10.76	0.29	11.28	0.26

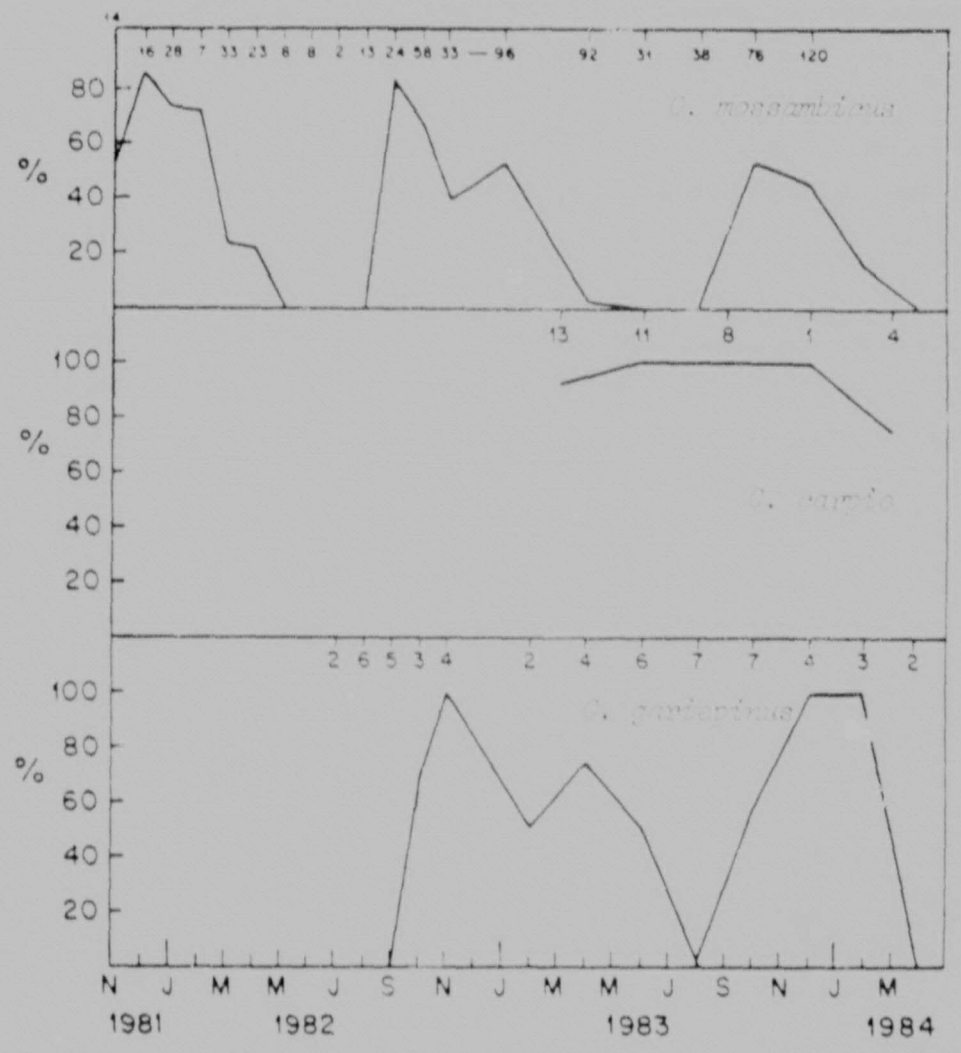

Fig. 6.11. Monthly percentage of total female catches, of active-ripe and ripe females in gill nets (*C. mossambicus* and *C. gariepinus*) and 35 mm seine net (*C. carpio*) from November 1981 to April 1984. Numbers at the top of each graph show sample size.

There was a large standard error of the mean percentage of females mouth-brooding (Table 6.12a) and the samples could be split into two groups (<11% and ≥50%) showing that mouth-brooding females shoaled together. The mean percentage of 28.7% (2SE = 24.05% calculated from sample percentages) coupled with the mean brooding time of 23 days gave a mean interval of 80 days between spawnings. The breeding season in 1982/83 extended from September to April, with decreasing intensity in March and April (Fig. 6.11) or approximately 212 active days if 50% activity during March and April is assumed. This leads to a figure of a mean 2.7 spawnings per female per summer. The estimated interval between spawnings of 80 days is higher than that recorded by other workers. Balarin (1979) cited five authors who recorded various intervals between spawnings (Table 6.12b) with a mean of approximately 38 days between spawnings. This would result in five spawnings per female during the Hartbeespoort breeding season. The lower frequency in Hartbeespoort Dam is a result of lower water temperature (Section 6.4.2).

Table 6.12a. % *O. mossambicus* mouth-brooding in seine net catches in October and November 1982

Date	Site	n	n mouth-brooding	% mouth-brooding
25 Oct	o	27	2	7.4
25 Oct	o	38	4	10.5
27 Oct	16	4	0	0
27 Oct	16	8	5	62.5
27 Oct	s	10	8	80
27 Oct	d2	4	2	50
17 Nov	16	17	10	58.8
TOTAL		108	31	28.7

Table 6.12b. Recorded intervals between spawnings of *O. mossambicus* from other sources (from Balarin, 1979)

Interval (days)	Source
23 - 61	Vehida & King
42	Bruton & Boltt
30 - 40	Kelly
21 - 42	Bardach *et al.*
42	Maar *et al.*

From 1981 to 1983 female *O. mossambicus* matured at a length greater than 15 cm (age = 1.5 yrs) at which stage 26% of fish examined were ripe and 5% active-ripe (Fig. 6.12). Over this period fish in the size range 19-25 cm were largely absent from the population due to elimination of most of the year class in the winter of 1981. In 1983/84 the density of fish was considerably higher (Section 6.3.3.4) and this resulted in a delay in age at maturity and females matured at a minimum length of 20 cm (Fig. 6.12). At this time 2+ females of 18 cm SL were not mature, in comparison with 15 cm 1+ females maturing between 1981 and January 1983. This delayed onset of maturity is a potential population regulation mechanism and is a further example of population response to environmental change.

(b) *C. carpio*

Samples of *C. carpio* were only collected from March 1983 onwards. In *C. carpio* SL explained a marginally greater proportion of the variance than the mass. The best fit equation was:

$$F = 0.45\ SL^{3.58} \quad (n=30,\ r^2 = 0.64)$$

where SL = standard length (cm)

The breeding season or time of spawning of *C. carpio* could not be defined from female gonad activity as the majority of females were ripe in all samples (Fig. 6.11). Continually dropping water levels during the summer of 1982/83 resulted in a failure of the population to spawn and gonad condition remained high until after spawning in November/December of the following year. It was noted that the eggs in June were being resorbed and examination of ovaries under the microscope showed the eggs to be partially collapsed and fragmenting. By the time the following sample was taken in September, the eggs were mature and ready for spawning. The normal cycle of gonad maturation and spawning was therefore prevented by the unusual conditions.

Intense breeding activity occurred in October/November 1983 particularly in the flooded *Polygonum* sp. beds in the Magalies River mouth (Fig. 2.1), after rains had resulted in a lake rise.

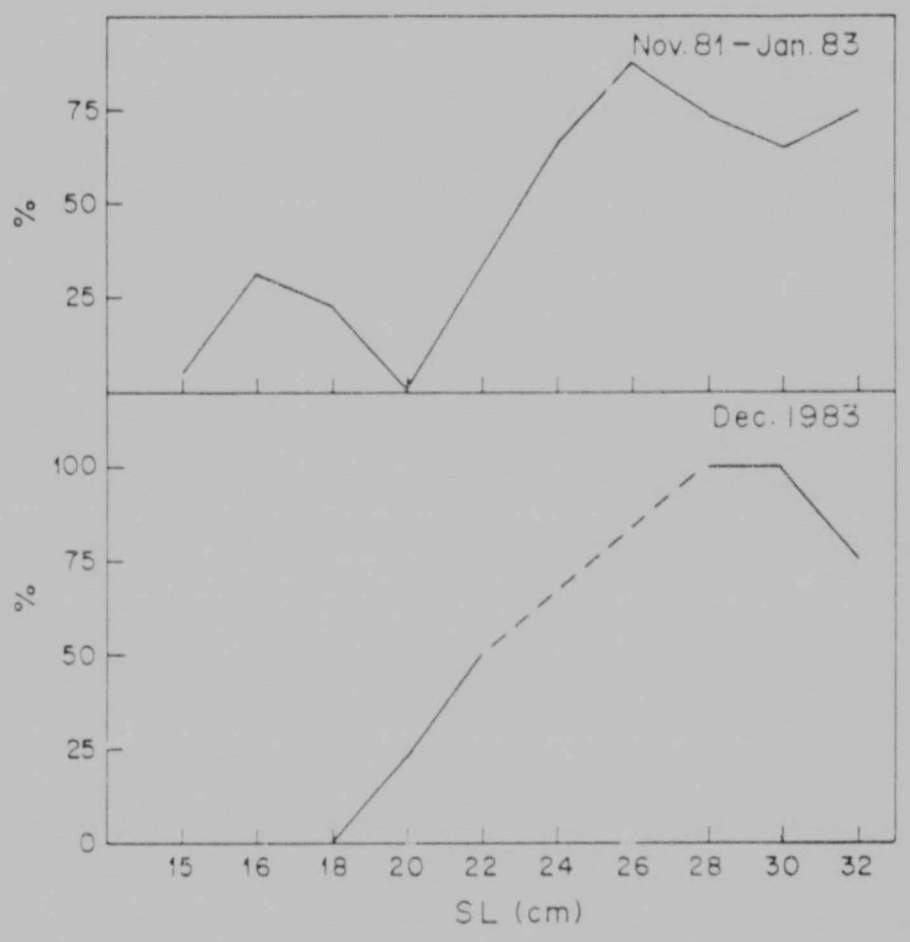

Fig. 6.12. The percentage by size class, of *O. mossambicus* females, active-ripe and ripe in the period November 1981 to January 1983 and in December 1983. Broken line indic no fish caught in size range.

Three of the four females caught in March 1984 were in active-ripe or ripe condition showing that breeding was still continuing. However, the low catch of *C. carpio* at this time and the absence of visible spawning behaviour in March showed that spawning intensity was very much reduced. Seine-netting during spawning would be biased towards the fish actually breeding which come into shallow water to spawn. Reference to other studies suggests that *C. carpio* spawns under favourable conditions in November/December (Section 6.4.2).

A total of 67 males and 37 females were caught between March 1983 and March 1984. The December sample consisted of 24 ripe-running males and only one female, and was the major cause of the total sample bias towards males. The dominance by males in this sample showed that most females had already spawned and moved back into deeper water at this time, while the males remained reproductively active and in shallow water. Analysis of the unbiased samples resulted in an estimated sex ratio of 1:0.84 males to females.

C. carpio females were sexually mature by 37.5 cm standard length (Table 6.13) at which time they would be in their second year. Therefore they are able to spawn in their second summer.

Table 6.13. The percentage of *C. carpio* females sampled in 1983 which were active-ripe (AR) or ripe (R) split up by size class

Standard length (cm)	%AR or R	Total
< 35	-	0
37.5	80	5
42.5	100	7
47.5	100	2
52.5	100	9
57.5	-	0
62.5	100	6
67.5	100	4

(c) *C. gariepinus*

Samples of *C. gariepinus* ovaries were collected in September/November 1982 and October-December 1983 and analysed separately to investigate possible differences in fecundity with the change in density. In *C. gariepinus*, SL was a better predictor of fecundity than mass. There was no significant difference between the slope and intercept for the two years, however, the correlation in the combined sample explained less variance in fecundity than the curve for summer 1982. As there was no spawning in the summer of 1982, *C. gariepinus* ovaries remained ripe until spawning in November the following year. This could have had an influence on the fecundity in November 1983, therefore the curve for summer 1982/83 was accepted as that best describing fecundity in *C. gariepinus*.

Table 6.14. The relationship between fecundity and standard length for *C. gariepinus* in 1982 and 1983

Time	n	r^2	Sig.	Equation	SEa*	SEb
Sep-Nov 1982	16	0.61	0.99	$F= 0.17\ SL^{3.30}$	2.80	0.70
Oct-Dec 1983	8	0.31	<0.95	$F=38.09\ SL^{1.88}$	4.72	1.49
Total	24	0.40	0.99	$F=10.18\ SL^{2.25}$	2.37	0.59

*SEa = SE of natural log-transformed data.

C. gariepinus was reproductively active from October in 1982 and 1983 (Fig. 6.11). As with *C. carpio*, *C. gariepinus* failed to spawn in 1982 and spawned in October/November 1983. Ripe and active ripe females persisted in the population from October 1982 to June 1983 but resorption had taken place by July and females were again ready to spawn in October. Therefore, in normal years, *C. gariepinus* would spawn after September, when the lake level first rose or the rivers flooded.

C. gariepinus can easily be sexed externally and all fish caught in the October 1982 and 1983 mark and recapture exercises were sexed. The results were,

Year	No. males	No. females	Males:Females
1982	643	468	1:0.73
1983	889	793	1:0.89
Total	1532	1261	1:0.82

Samples of *C. gariepinus* females of the smaller size groups were too small to determine the size at sexual maturity (Table 6.15). Fish of 45 cm standard length were sexually mature and this represented an age of three years. The smallest active-ripe or ripe female caught was 43.5 standard length which represents an age of 2-3 years. Other workers have also found *C. gariepinus* to mature at approximately two years old (Section 6.4.2).

Table 6.15. The percentage of *C. gariepinus* females sampled between October and December 1981 1982 and 1983 which were active ripe or ripe, split up according to size

Standard length (cm)	%AR or R	Total
< 39.9	0	1
40 - 40.9	67	6
50 - 50.9	100	6
60 - 60.9	67	3
70 - 70.9	100	2

(d) Effect of the drought on spawning of *C. carpio* and *C. gariepinus*

Both *C. carpio* and *C. gariepinus* failed to spawn in the summer of 1982/83 but spawned in 1983/84 when the water level rose, flooding an estimated 120 ha. Both species spawn in freshly inundated vegetation (Crivelli, 1981; Edwards & Twomey, 1982; Bruton, 1979). *C. carpio* was found to require temperatures of 15-16°C to induce spawning in southern France (Crivelli, 1981) and *C. gariepinus* generally spawns between November and April in central and southern Africa (Clay, 1979). The water temperature in Hartbeespoort Dam is generally below 15°C from the beginning of June to mid-September (Scott *et al.*, 1977). On the basis of temperature, only floods occurring from October to May are

likely to stimulate spawning. A flood would also have to be large enough to inundate large areas of marginal vegetation to stimulate spawning, such as the 120 ha inundation in 1983. The lake volume was only 19% full at this time and approximately 100 ha probably represents the minimum inundation which will be large enough to stimulate spawning. However, such a parameter could not be defined with certainty and therefore, for this analysis, floods between 50 and 100 ha were excluded and only floods less than 50 ha were treated as being too small to cause *C. carpio* and *C. pariepinus* to spawn.

The monthly mean area of Hartbeespoort Dam was plotted (Fig. 6.13) and all increases in surface area tabulated (Table 6.16) and classified according to the probability of their stimulating spawning according to the above criteria.

Table 6.16. Occurrence and extent of rises in lake level from January 1965 to May 1984 (from Fig. 6.13). Symbols refer to the probability that the timing and extent of the flood would be sufficient to stimulate spawning. + = probable, ? = possible, - = unlikely.

Year	Months	Flooded area(ha)	Spawning	Year	Months	Flooded area(ha)	Spawning
1965	Jan-Feb	60	?	1973/74	Dec-May	590	+
1966	Feb-Mar	220	+	1974	Nov-Dec	150	+
1966	Oct-Nov	160	+	1975	Jan-Mar	400	+
1967	Jan-Apr	1000	+	1975/76	Oct-Jan	200	+
1968	Mar-May	100	?	1976	Mar-Jun	30	-
1969	Mar-Jun	100	?	1976	Oct-Nov*	40	?
1969/70	Oct-Jan	220	+	1977	Jan-Feb*	40	?
1970	Oct-Nov	20	-	1977	May-Jun*	30	?
1971	Jan-Jun	980	+	1978	Jun-Jul	20	-
1971/72	Nov-Apr	880	+	1979	Nov-Dec	40	-
1972	Nov-Dec	50	?	1980	Feb-May	80	?
1973	Apr-May	100	?	1980/81	Nov-Apr	300	+
1973	Oct-Nov	390	+	1981/82	Dec-Feb	160	+
				1983/84	Oct-Feb	320	+

* = Lake full

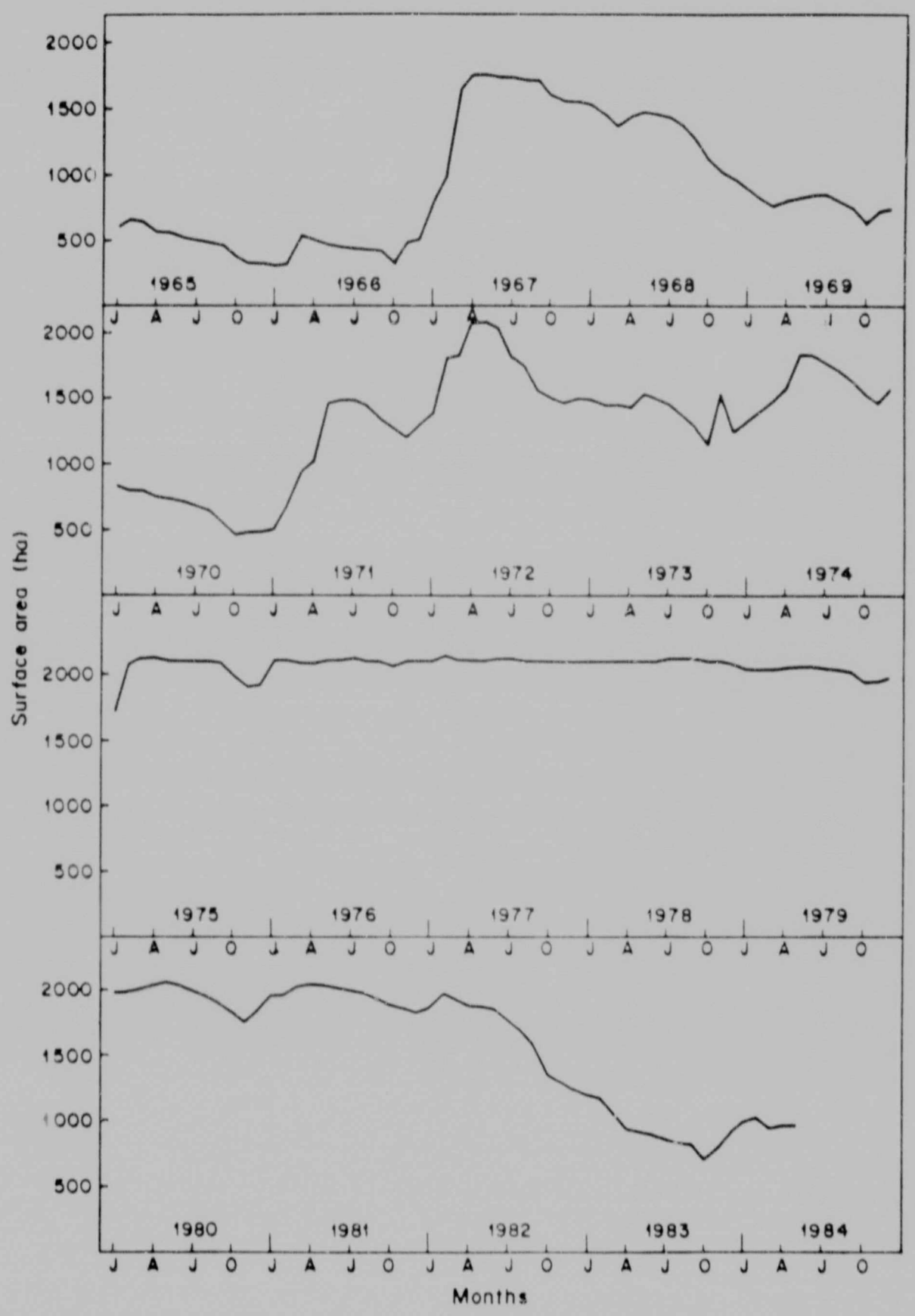

Fig. 6.13. Surface area of Hartbeespoort Dam (January 1965 to May 1984). Dept. of Water Affairs, Pretoria (unpublished data).

During the period 1965 to 1984, there were two summers when spawning would not have occurred (Table 6.16) (78/79; 82/83) and six when the occurrence of spawning could not be determined (67/68; 68/69; 72/73; 76/77; 77/78; 79/80) out of a total of 19. The position between January 1976 and August 1978 is unclear as the lake was at full supply for much of this period and thus small fluctuations in water level or inflowing water may have stimulated spawning in *C. carpio* and *C. gariepinus* respectively (Edwards & Twomey, 1982; Clay, 1979). In those years when predictions could be made with confidence, spawning was unlikely to have occurred (-) in approximately 15% of the summers. The actual impact was examined using the yield models (Chapter 7).

6.3.3 MORTALITY

Estimates of mortality are necessary for most yield predictions (Section 7.4.1) and were required for the computer simulation models (Chapter 7). There is little data available for comparison on mortality rates for these species under similar conditions. The objective of this section is therefore to analyse the data, to present the results and to discuss their validity.

6.3.3.1 Fishing mortality

There was greatest angling pressure on carp with 970 t of carp, 311 t of *O. mossambicus* and 220 t of *C. gariepinus* caught during the period. The monthly CPUE for the period March 1982 to April 1984 (Fig. 6.14 & Table 6.17) also showed the dominance of carp. Carp catches showed clear winter peaks but the size of the 1983 peak was suspect as it was based on a small number of anglers. The other two species showed the reverse trend with lowest catches in winter. There was an increase in fishing pressure from October 1983 onwards, caused by increased numbers of anglers and higher CPUE (Fig. 6.14). The mean annual catch during the period was 449 t carp, 144 t *O. mossambicus* and 102 t *C. gariepinus* and the mean number of angler days per annum was 233 723.

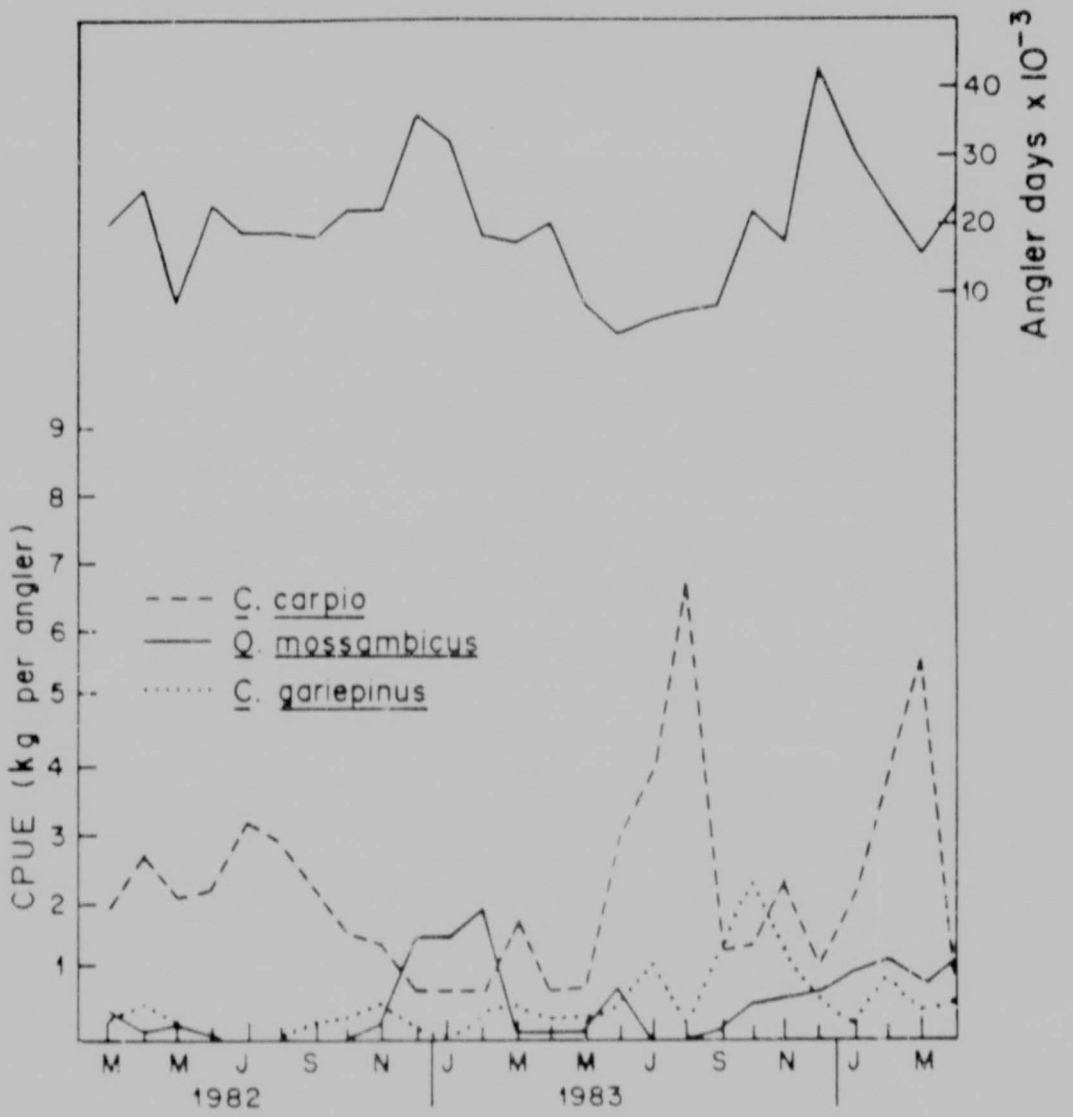

Fig. 6.14. Mean CPUE (kilograms per angler day) of the three species (March 1982 to April 1984) and total monthly effort (number of angler days). Division of Nature Conservation, TPA, Pretoria (unpublished data).

a) *C. mossambicus*

The estimated total catch for the period October 1982 to September 1983 was 274 719 fish (Table 6.17). This consisted of fish of

Table 6.17. A summary of angling and catch per unit effort from the Division of Nature Conservation angling returns, March 1982 to April 1984

Month	No. returns	No. anglers	Catch per angler day					
			C. mossambicus		*C. carpio*		*C. pariepinus*	
			No.	kg	No.	kg	No.	kg
Mar 1982	197	20058	0.38	0.40	0.98	1.89	0.04	0.27
Apr	302	24906	0.05	0.09	0.98	2.70	0.07	0.48
May	145	9285	0.21	0.16	0.91	2.05	0.08	0.22
Jun	138	23271	0.01	0.03	0.81	2.24	0.01	0.01
Jul	128	19362	0	0	0.80	3.22	0	0
Aug	358	18655	0.02	0.02	0.83	2.86	0.01	0.03
Sep	394	17938	0.03	0.02	0.79	2.31	0.11	0.21
Oct	360	21633	0.03	0.04	0.99	1.57	0.12	0.31
Nov	248	21646	0.21	0.22	0.43	1.37	0.15	0.49
Dec	192	36266	3.06	1.49	0.92	0.69	0.03	0.07
Jan 1983	267	31716	3.01	1.52	0.22	0.71	0.003	0.30
Feb	376	18414	2.74	1.89	0.29	0.74	0.06	0.35
Mar	120	17238	0.27	0.13	0.76	1.81	0.29	0.48
Apr	197	20253	0.07	0.04	0.28	0.71	0.09	0.34
May	40	8149	0.15	0.05	0.75	0.78	0.13	0.32
Jun	28	3928	1.07	0.76	1.36	3.03	0.18	0.46
Jul	31	5637	0	0	2.21	3.86	0.29	1.07
Aug	15	6833	0	0	2.33	6.73	0.07	0.17
Sep	92	8099	0.14	0.13	0.65	1.33	0.26	1.44
Oct	299	21636	0.69	0.48	0.42	1.38	0.66	2.16
Nov	354	17456	1.35	0.62	0.51	2.32	0.73	1.21
Dec	719	41510	1.34	0.71	0.40	1.11	0.32	0.58
Jan 1984	242	30701	1.60	0.98	0.55	2.08	0.004	0.017
Feb	232	22672	2.20	1.16	1.02	3.89	0.17	0.92
Mar	132	16152	1.50	0.81	1.19	5.61	0.23	0.44
Apr	172	22986	1.60	1.22	0.19	0.56	0.07	0.47

1+ and older. The population estimate for October 1982 was 1 763 452 (Section 5.3.1). Therefore parameters can be calculated as follows (Ricker, 1975).

u (expectation of capture by man) = 274729 / 1 763 452
= 0.16

The Tight Lines angling returns (Table 6.18) showed that all age groups from 1+ were being exploited and showed the strength of the 2+ class. There was no evidence of size selection.

b) *C. carpio*

The estimated total catch for the period March 1982 to Feb. 1983, was 192 917 fish. The estimate, also based on angler returns, for standing stock in March 1982 was 242 997 (Section 5.3.2). Therefore,

u = 192917/242997
= 0.79

The absence of recruits from 1982/83 was reflected by the Tight Lines angling returns (Table 6.18) and the bulk of the catch was from the 2+ class which was the dominant class. There was no evidence of size selection.

Table 6.18. Mass distribution of *O. mossambicus* and *C. carpio* caught by anglers August to December 1983

O. mossambicus		*C. carpio*	
Mass (kg)	No.	Mass (kg)	No.
0 - 0.25	16	0 - 0.99	4
0.26 - 0.50	57	1 - 1.99	12
0.51 - 0.75	1	2 - 2.99	22
0.76 - 1.00	0	3 - 3.99	43
1.01 - 1.25	1	4 - 4.99	7
		5 - 5.99	1
		6 - 6.99	6
		>6.99	1
Total	75		96

(c) *C. gariepinus*

The total catch of *C. gariepinus* over the period October 1982 to September 1983 was 20 953 fish. The mark and recapture result for October 1982 was unreliable therefore a stable population was assumed and the population estimate for October 1983 was used as an estimate for that in October 1982.

$$u = 20\ 938/175\ 276$$
$$= 0.119$$

However, total mortality was found to increase with age (Section 6.3.3.2). Size specific mortality was investigated using the Tight Lines angling returns (Table 6.19).

Table 6.19. Mass and age (computed from growth curves) of *C. gariepinus* caught by anglers, August - December 1983

Mass (kg)	Approx. Age (yr) Male	Female	No. caught	% of total
0 - 0.9	2+	2+	1	0.9
1 - 1.9	3+	3+	8	7.0
2 - 2.9	4+	>3+	18	15.7
3 - 3.9	5+	>3+	9	7.8
4 - 4.9	6+	>3+	24	20.9
5 - 5.9	7+	>3+	13	11.3
6 - 6.9	8+	>3+	11	9.6
7 - 7.9	9+	>3+	31	26.9
Total			115	100.1

Substantial angling mortality was only exerted on fish over four years old and almost 70% of the angling mortality was concentrated on fish over six years old. The relationship between mass and number caught was best described by,

$$\text{No. caught} = 3.35\ \text{Mass}^{1.01}$$

$$(r^2 = 0.75,\ n = 8)$$

The actual fishing mortality rates show that *C. carpio* was the most heavily exploited species with almost 80% of the population vulnerable to angling likely to be removed in any one year. By comparison the

other two species were lightly exploited at rates of less than 20% of the vulnerable population. *C. gariepinus*, a clariid, is not a popular eating fish, and is probably not sought after. The relatively low fishing mortality experienced by *C. mossambicus* is related to its seasonal behaviour. In winter the species stops feeding and is essentially not vulnerable to angling for three to four months of the year (Fig. 6.14).

6.3.3.2 Total mortality

(a) *O. mossambicus*

The best fit curve for the change in gill net catch with time was the exponential curve (Fig. 6.15)

$$CPUE = 75.38\ e^{-0.08t}$$

(n = 12, 95% CI b = 0.015)

t = time in months

Using this curve to calculate the change in CPUE in one year resulted in an annual expectation of mortality, A, of 0.62 or

$$Z = \frac{-\ln(1-A)}{0.97}$$

(b) *C. carpio*

The best fit curve for change in angling CPUE with time was the exponential curve (Fig. 6.16)

$$CPUE = 1.36\ e^{-0.16t}$$

(n = 14, 95% CI b = 0.06)

Using this curve to calculate the change in CPUE in one year results in an annual expectation of mortality of 0.85,

$$Z = 1.90$$

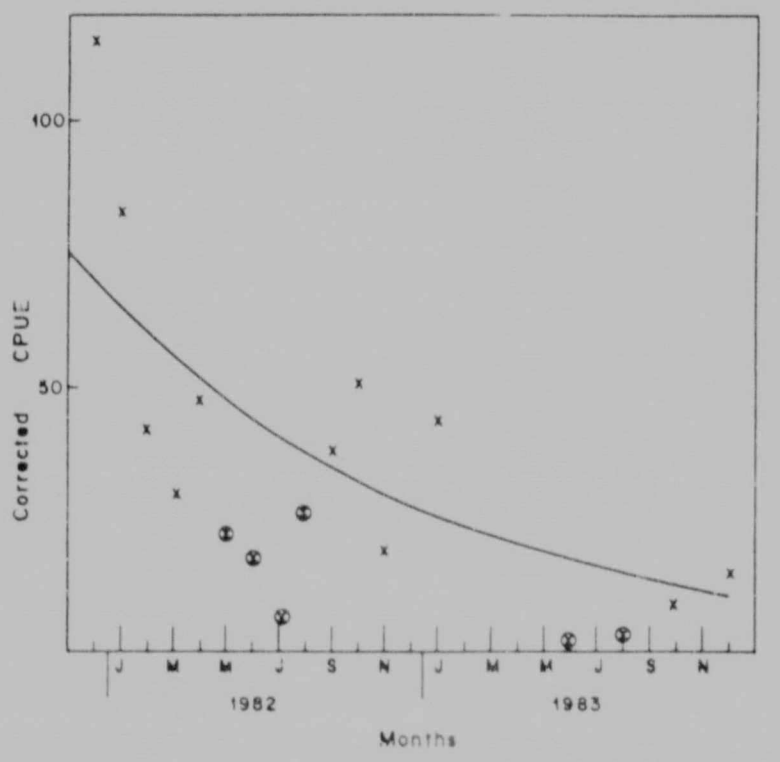

Fig. 6.15. Gill net CPUE (number per 1 000 m of net), corrected for lake volume, of *O. mossambicus* older than three years (December 1981 to December 1983). The curve is the best-fit line to the data points, excluding the ringed points which are low catches caused by winter low water temperatures.

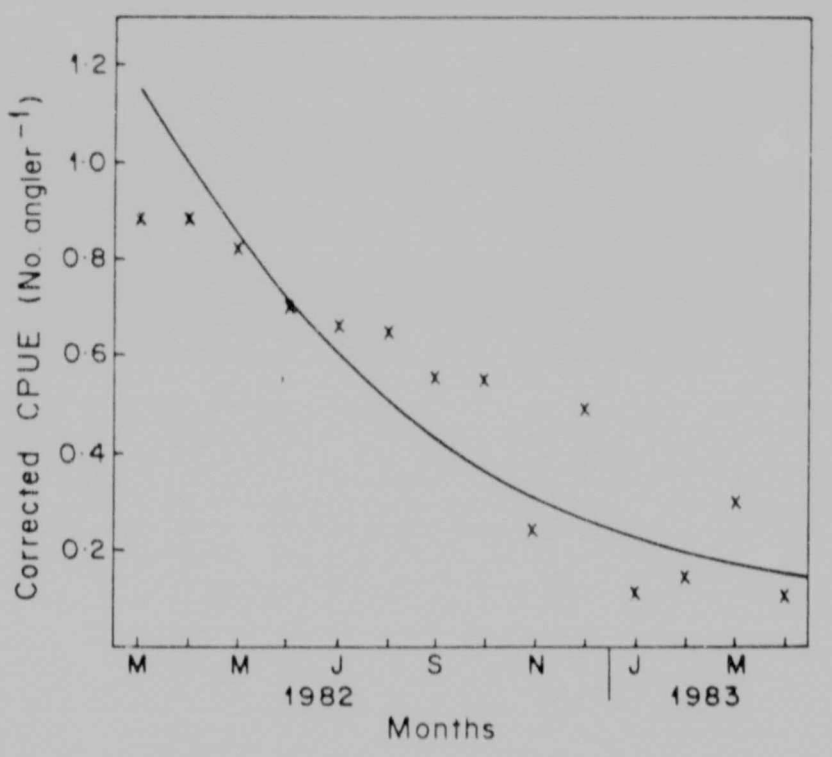

Fig. 6.16. Angling CPUE (numbers per angling day), corrected for lake volume, of *C. carpio* (March 1982 to April 1983). The curve is the best-fit regression line.

(c) *C. gariepinus*

The year class break down of length frequencies was obtained by discriminant analysis, in October 1982 and October 1983, (Table 6.20). The annual expectation of mortality was calculated from Heincke's estimate, $A = N_o/N$ (Ricker, 1975).

The analyses for females are not included as these were influenced by the underestimates of standard length in the older age groups referred to in Section 6.3.1. Fish were only fully recruited to the seine-netted population at the age of five years (Table 6.20). Prior to this the fish probably remained in slightly deeper water or in macrophyte beds. There was a clear increase in mortality rate with increasing age and this prevented the application of catch curve analysis (Ricker, ' 5). The most likely reason for increasing mortality is heavi angling pressure on the larger fish (Ricker, 1975) as was demonstrated for this species (Section 6.3.3.1c).

An exponential curve was fitted to the data in Table 6.20. The best-fit relationship was

$$A = 0.055\, e^{0.327\, t}$$
$$(r^2 = 0.92,\ n = 6)$$

where t = age in years

Table 6.20. Age class distribution of male *C. gariepinus* in samples taken in October 1982 and 1983 and Heincke's estimate of mortality (A)

	October 1982 Male		October 1983 Male	
Age	No.	A	No.	A
2	20		17	
3	37		47	
4	66		65	
5	125		195	
6	160	0.348	240	0.423
7	160	0.533	201	0.613
8	103	0.736	94	0.740
9+	37		33	

This relationship was used to predict A over the range of male age classes. The predictions were,

Age	0	1	2	3	4	5	6	7	8	9
A	0.06	0.08	0.11	0.15	0.20	0.28	0.39	0.54	0.76	1.05

As the cause of increasing mortality with age was differential fishing pressure, the mortality rate must tend towards the natural mortality rate with decreasing age. This trend can therefore be used to estimate natural mortality (Section 6.3.3.3c).

6.3.3.3 Synthesis of mortality data and natural mortality rates

(a) *O. mossambicus*

With the previously calculated parameters,

$u = 0.16$
$A = 0.62$
$Z = 0.97$

the following can be calculated (Ricker, 1975)

$u = FA/Z$
$F = uZ/A$
$= 0.25$
$A = u + v$ (v = actual natural mortality rate)
$v = 0.46$
$Z = F + M$
Therefore $M = 0.72$

(b) *C. carpio*

As for *O. mossambicus*

$u = 0.79$
$A = 0.85$
$Z = 1.90$

and therefore,

$$F = 1.77$$
$$v = 0.06$$
$$M = 0.13$$

(c) *C. garlepinus*

The relationship between size and number of fish caught was (Section 6.3.3.1c).

$$\text{No caught} = 3.35\ \text{Mass}^{1.01} \qquad \ldots(1)$$

and that between age and total mortality for males was (Section 6.3.3.2c).

$$A = 0.055\ e^{0.327t} \qquad \ldots(2)$$

where t = age (y)

From (1), assuming a maximum mass of eight kilograms (Table 6.19), the proportion of each size group in the total angler catch was calculated. These data together with data predicted from (2) (Table 6.21) were used to calculate the relationship between A and vulnerability to capture

Table 6.21. Mortality and vulnerability to capture at age for male *C. garlepinus*

Age	A	Prop of total catch
6	0.39	0.14
7	0.54	0.17
8	0.74	0.20

These data show a relationship of the form,

$$A = 0.09\ e^{10.68*(\text{Prop.})}$$
$$(r^2 = 1.00,\ n = 3)$$

From this relationship the total mortality, A, when there is zero vulnerability to capture can be computed. This value is the y-intercept, 0.09 which compares favourably with the value

Table 6.22. Mortality rates for different age classes of male and female *C. carpionae*.

Age	Male Mass (kg)	Male A	Male v	Male u	Female Mass (kg)	Female A	Female v	Female u
1	0.14	0.09	0.09	0	0.19	0.09	0.09	0
2	0.62	0.11	0.09	0.02	0.61	0.11	0.09	0.02
3	1.41	0.15	0.09	0.06	1.18	0.15	0.09	0.06
4	2.39	0.20	0.09	0.11	1.82	0.15	0.09	0.06
5	3.46	0.28	0.09	0.19	2.46	0.20	0.09	0.11
6	4.53	0.39	0.09	0.30	3.06	0.28	0.09	0.19
7	5.55	0.54	0.09	0.45	3.62	0.28	0.09	0.19
8	6.48	0.76	0.09	0.67	4.09	0.39	0.09	0.30
9	7.31	1.00	0.09	0.91	4.50	0.39	0.09	0.30

of 0.08 estimated for 1+ fish by fitting an exponential curve to the data in Table 6.19. The natural mortality is assumed to be constant at this value for all age groups greater than 0+ and fishing mortality to increase according to the power relationship for age against A (2). Because vulnerability varies as a result of increasing mass rather than age itself, the vulnerability of males and females differs in the older age groups. Female fishing mortality was computed as equivalent to the male age class of the same mass. On this basis, the mortality parameters were calculated for the different age classes of both sexes (Table 6.22).

Adult natural mortality was highest in *C. mossambicus* which is the smallest of the three species. The reason for this could be related to predation. The major predators are piscivorous birds and one was found to have eaten a two year old *C. mossambicus* (Section 6.4.3). Other possible causes of natural mortality are discussed in Section 6.4.3. The low natural mortality rate of *C. carpio* is probably a feature of the high fishing mortality. The removal of 80% of the fishable stock per year would rapidly deplete the population, effectively removing fish before they could die from natural causes. Such high fishing mortality would also result in a relatively low mean annual standing stock which could influence factors such as resource limitation and disease. A significant change in fishing mortality in

ary of the three species would probably result in a change in natural mortality rate.

6.3.3.4 0+ Mortality

(a) *C. mossambicus*

A line was fitted to the catch-curve data for each month from the length of full recruitment to the maximum length caught (Fig. 6.17).

The growth data calculated in Section 6.3.1 reflect the mean growth of the year class. For the catch-curve analyses, the growth rates of the oldest surviving recruits were necessary to derive mortality rates. Growth in the first six to seven months was approximately linear and the mean monthly growth rate for each year was calculated, but there was no significant difference in the growth rates determined in this manner (Table 6.23).

Table 6.23. Maximum *C. mossambicus* 0+ lengths per monthly sample and derivation of mean monthly growth rate for use in catch curve analysis

Year	Age(mths)	Max std len (cm)	Growth rate (cm. mth^{-1})	2SE
1982	3.5	8.5	2.43	
	4.5	9.5	2.11	
	5.5	10.5	1.91	
		Mean	2.15	0.30
1983	3.5	8.5	2.43	
	4.5	8.5	1.89	
	6.5	10.5	1.62	
		Mean	1.98	0.48
1984	3.5	7.5	2.14	
	4.5	8.5	1.89	
	5.5	8.5	1.55	
		Mean	1.86	0.34
		Grand Mean	2.00	0.21

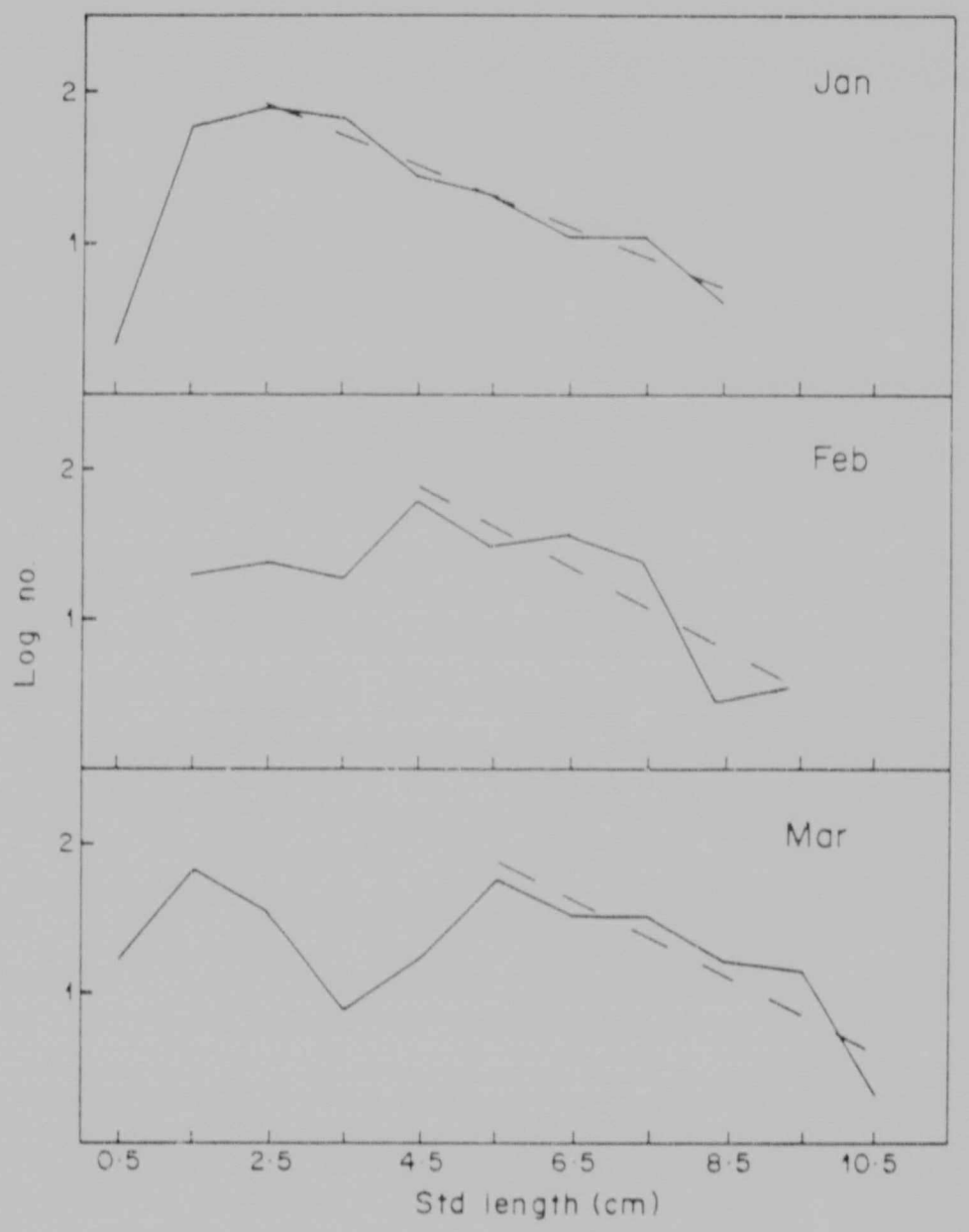

Fig. 6.17. Example of catch curves fitted to length frequencies of *O. mossambicus* fry (January to March 1982).

The catch curve relationships for each monthly sample were calculated (Table 6.24). Using a growth rate of 2.0 cm.month^{-1} (Table 6.23) the equations in Table 6.24 were used to calculate the monthly survival (S) for each relationship and the mean of the three estimates for each year (Table 6.25).

The densities of *O. mossambicus* in each year were derived from the population estimates made in October 1982 and 1983 (Section 5.3.1). The former estimate was used to determine biomass in January 1982 and 1983 using an annual expectation of mortality, A, of 0.62 (Section 6.3.3.3) and the latter to determine biomass in January 1984 in the same way. Somatic growth of the 1+ class between October 1982 and January 1983 (individual increase from approx. 30 g to 144 g) was incorporated, but in all other cases somatic growth was ignored. The results showed decreasing survival with increasing density (Table 6.25).

Table 6.24. Relationships between the logarithm of frequency and standard length derived for 0+ *O. mossambicus* from January to March 1982 - 1984. SL = standard length (cm)

Year	Month	Equation	r^2	n
1982	Jan	Log No = 2.46 - 0.21SL	0.96	7
	Feb	Log No = 3.13 - 0.27SL	0.80	6
	Mar	Log No = 3.40 - 0.26SL	0.83	6
1983	Jan	Log No = 2.70 - 0.30SL	0.97	7
	Feb	Log No = 3.18 - 0.36SL	0.93	7
	Apr	Log No = 3.03 - 0.29SL	0.97	9
1984	Jan	Log No = 3.83 - 0.48SL	0.81	5
	Feb	Log No = 3.35 - 0.32SL	0.93	5
	Mar	Log No = 3.96 - 0.48SL	0.90	5

The data in Table 6.25 were used to develop a density dependent relationship from the equation of Shepherd (1982). This

The catch curve relationships for each monthly sample were calculated (Table 6.24). Using a growth rate of 2.0 cm.month^{-1} (Table 6.23) the equations in Table 6.24 were used to calculate the monthly survival (S) for each relationship and the mean of the three estimates for each year (Table 6.25).

The densities of *O. mossambicus* in each year were derived from the population estimates made in October 1982 and 1983 (Section 5.3.1). The former estimate was used to determine biomass in January 1982 and 1983 using an annual expectation of mortality, A, of 0.62 (Section 6.3.3.3) and the latter to determine biomass in January 1984 in the same way. Somatic growth of the 1+ class between October 1982 and January 1983 (individual increase from approx. 30 g to 144 g) was incorporated, but in all other cases somatic growth was ignored. The results showed decreasing survival with increasing density (Table 6.25).

Table 6.24. Relationships between the logarithm of frequency and standard length derived for 0+ *O. mossambicus* from January to March 1982 - 1984. SL = standard length (cm)

Year	Month	Equation	r^2	n
1982	Jan	Log No = 2.46 - 0.21SL	0.96	7
	Feb	Log No = 3.13 - 0.27SL	0.80	6
	Mar	Log No = 3.40 - 0.26SL	0.83	6
1983	Jan	Log No = 2.70 - 0.30SL	0.97	7
	Feb	Log No = 3.18 - 0.36SL	0.93	7
	Apr	Log No = 3.03 - 0.29SL	0.97	9
1984	Jan	Log No = 3.83 - 0.48SL	0.81	5
	Feb	Log No = 3.35 - 0.32SL	0.93	5
	Mar	Log No = 3.96 - 0.48SL	0.90	5

The data in Table 6.25 were used to develop a density dependent relationship from the equation of Shepherd (1982). This

Table 6.25. Mean monthly survival (S) and annual expectation of mortality (A) of 0+ *C. mossambicus*, under different densities of the species, for the years 1982 - 1984.

Year	S	2SE	A	Density ($g.m^{-3}$)
1982	0.32	0.06	$1 - 1.153 * 10^{-6}$	3.26
1983	0.23	0.04	$1 - 2.191 * 10^{-8}$	3.96
1981	0.15	0.08	$1 - 1.297 * 10^{-10}$	4.68

equation was modified (Section 6.2.3.4) to the form

$$S = 1/(1 + (P/K)^b)$$

where P = size of parental stock

Rearranging this equation,

$$1/S = 1 + (P/K)^b$$

$$1/S - 1 = P^b (1/K^b) \qquad \ldots(1)$$

This is a power relationship where $1/K^b$ and b are constants. A new value, $1/S - 1$ was computed for each year and plotted against density (P). The resulting power curve was

$$(1/S - 1) = 0.09 (P^{2.70})$$

$$(n = 3, r^2 = 0.99)$$

From (1), $1/K^b = 0.09$

$b = 2.70$

Therefore $K = 2.44$

These constants can be substituted into the survival equation to produce the relationship

$$S = 1/(1 + (P/2.44)^{2.70}) \qquad \ldots(2)$$

where S = monthly survival rate

P = density ($g.m^{-3}$)