CHAPTER 4

NATURE AND DISTRIBUTION OF THE FISH COMMUNITY

4.1 Introduction

Little was known about the fish community of Hartbeespoort Dam prior to this study being undertaken (Section 2.0). Therefore an initial survey was conducted in order to:

(a) Determine the species composition of the fish fauna of Hartbeespoort Dam.

(b) Identify the species making the major contribution to fish biomass in the lake. Further production studies would then be concentrated on these species.

(c) Establish the distribution of the major species in the dam and the factors influencing this distribution.

(d) Investigate seasonal cycles in the condition factor of the key species.

4.2 Methods

An initial survey of the fish fauna was undertaken in November and December 1981 and for the purpose of this survey the littoral zone of the dam was classified into four major regions (Table 4.1). At this time of year the water was deoxygenated below 12 m and would therefore not support fish.

The top set gill net fleet and the two sizes of seine nets described in Section 3.0 were used for the survey and samples collected from the following sites (Fig. 2.1).

	Sampling sites
Gill Net	4, 3, 6, 13, 17
Seine Net (13 mm)	1, 4, 3, 6, 10
Seine Net (35 mm)	4, 3, 16, 10

Table 4.1. Characteristics of the major shoreline regions in Hartbeespoort Dam. Geological data from maps 2527 DB and DD, Geological Survey, Dept. of Mines, Pretoria

Region (Fig. 2.1)	Characteristics
North eastern shore (zones a2 - g2)	Shale, some diorite Mean gradient = 1:29 (n=6, 2SE = 11.5)
Northern Magalies shore (zones a-h)	Diorite, sand and gravel Mean gradient = 1:18 (n=5, 2SE = 5.1)
Southern Magalies shore (zones i - s)	Shale, soil and gravel, occasional diorite Mean gradient = 1:49 (n=9, 2SE = 14.2)
Southern Crocodile (zones t - z)	Shale Mean gradient = 1:35 (n=4, 2SE = 10.0)

Three hauls of the 35 mm seine net were taken at St. 3 and two at each of the other stations. Two hauls were undertaken at each site with the 13 mm seine net. All fish caught were identified according to Jubb (1967), weighed and total length measured. Random samples of at least 50 fish were taken from large catches of *O. mossambicus* and *C. carpio*, the total number in the catch counted, and the total mass obtained by proportion.

After this initial assessment of the species composition of the dam, the community was monitored by the routine netting and the mark and recapture exercises, which were undertaken in May and October, 1982 and March and October, 1983. During these operations fish were caught, using the 35 mm seine net, at randomly selected littoral sites. On each occasion, it was possible to sample approximately 40 sites. The total lengths of all *O. mossambicus*, *C. carpio* and *C. gariepinus* were measured and the mass then calculated from total length:mass relationships.

Mean condition factor (Kn) was calculated for all three species from routine catches according to the formula:

$$Kn = 100W/SL^b \quad \text{(Bagenal \& Tesch, 1978)}$$

where W = mass (g)

SL = standard length (cm)

and

b = coefficient of the length to mass relationship.

The length to mass relationships determined in this study by linear regression, necessary for the computation of Kn, for the three species were:

O. mossambicus > 100g   Mass = $0.031SL^{3.02}$ ($n = 967$, $r^2 = 0.99$)

O. mossambicus < 100g   Mass = $0.027SL^{3.12}$ ($n = 1750$, $r^2 = 0.97$)

C. gariepinus   Mass = $0.015SL^{2.96}$ ($n = 50$, $r^2 = 0.90$)

C. carpio   Mass = $0.037SL^{2.94}$ ($n = 167$, $r^2 = 1.00$)

O. mossambicus were split into adults (>100g) and juveniles (<100g) for Kn analysis. The scarcity of juveniles of the other two species in all catches prevented this sub-division and results for *C. carpio* and *C. gariepinus* are for adults only. In this report adult refers to fish older than one year and juvenile and fry to fish in their first year unless otherwise stated.

4.3 Results

4.3.1 Fish species composition

By the end of the study, twelve species of fish had been recorded from the lake (Table 4.2). Ten different species were caught during the November 1982 survey but *O. mossambicus* and *C. carpio* accounted for over 90% of the total mass caught (Table 4.3). The other species which made a contribution of greater than 1% of the total mass caught were *Chetia flaviventris*, *C. gariepinus* and *Barbus marequensis*.

Table 4.2. List of fish species caught in Hartbeespoort Dam, November, 1981 to June, 1982

Family	Species	Common Name
Cichlidae	*Oreochromis mossambicus* (Peters, 1852)	Blue kurper
	Chetia flaviventris Trewavas, 1961	Canary kurper
	Pseudocrenilabrus philander (Weber, 1897)	Dwarf kurper
	Tilapia sparrmanii Smith, 1840	Vlei kurper
Cyprinidae	*Barbus marequensis* Smith, 1841	Large-scaled yellow fish
	Barbus mattozi Guimaraes, 1884	Paper mouth
	Barbus polylepis Boulenger, 1907	Small-scaled yellow fish
	Barbus unitaeniatus Gunther, 1866	Longbeard barb
	Neobola brevianalis Boulenger, 1908	River sardine
	Cyprinus carpio Linnaeus, 1758	European carp
Clariidae	*Clarias gariepinus* (Burchell, 1822)	Sharptooth catfish
Centrarchidae	*Micropterus salmoides* (Lacepede, 1802)	Largemouth (Black) bass

On the basis of these results *O. mossambicus* and *C. carpio* were selected as the major species for further detailed studies. However, in the mark and recapture exercise in May 1982, 43 hauls were made with the 35 mm seine net which showed a different community species composition to that obtained in the first survey (Table 4.4).

Table 4.3. Contribution of fish species caught to the total mass of fish sampled in the initial survey (November and December 1981). Full and common names given in Table 4.2

Species	% of total mass
Oreochromis mossambicus	77.83
Cyprinus carpio	12.56
Chetia flaviventris	4.07
Clarias gariepinus	3.64
Barbus marequensis	1.86
Micropterus salmoides	0.03
Tilapia sparrmanii	< 0.01
Pseudocrenilabrus philander	< 0.01
Barbus unitaeniatus	< 0.01
Neobola brevianalis	< 0.01

Table 4.4. Species composition of catches made using the large seine net (May 1982)

Species	No.	Mass (kg)	% mass
O. mossambicus	1858	1676	46.7
C. gariepinus	317	1259	35.1
C. carpio	222	573	16.0
B. marequensis	201	79	2.21

The May 1982 results showed that the November 1981 survey had underestimated the relative abundance of *C. gariepinus* (Table 4.4) and this species was included, with the two already being studied, for production studies. The underestimate of *C. gariepinus* was probably due to the spawning of the species and their resulting absence from the sampling sites on this occasion.

The importance of these three species in Hartbeespoort Dam has been verified by samples taken through the sampling period (Table 4.5). *O. mossambicus*, *C. carpio* and *C. gariepinus* accounted for over 90% of the biomass in the four sampling methods used. Angling returns (Section 6.2.7) demonstrated that *C. carpio* was not accurately represented in netting samples and the species is known for its ability to avoid capture in nets (Beukema & de Vos, 1974; Koch &

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Schoonbee, 1980). The widely differing species composition obtained using the various methods demonstrates the effect of gear selectivity and seasonal behaviour on the species composition of catches. The tables also show the dominance, by mass, of *O. mossambicus*, *C. carpio* and *C. gariepinus*, but the variability in catch composition indicated the need for absolute estimates of abundance.

Table 4.5. Species composition of catches in Hartbeespoort Dam

Method	Gill nets	Seine net (13 mm)	Seine net (35 mm)	Angling
Period of sampling	Nov. 1981- Apr. 1984	Nov. 1981- Jan. 1982	Nov. 1981- Jan. 1983	Mar. 1982- Jan. 1983
Species	% composition of catch by mass			
O. mossambicus	66	86	50	15
C. carpio	1	4	6	74
C. gariepinus	26	3	43	10
Others	7	7	1	1
Total mass (kg)	1 201	142	16 247	59 710

4.3.2 Distribution of fish in Hartbeespoort Dam

O. mossambicus was the only significant inhabitant of the limnetic zone and accounted for 98.6% of the total catch from gill nets set at the limnetic station in 1982. The mean catch from the limnetic station (St. 17) in 1982 was 6.9 kg.100 m^{-1} (n=12, 95% CI =1.41) compared to 6.43 kg.100 m^{-1} (n=22, 95% CI=2.89) for the littoral stations (Sts. 4 and 16). This indicated that there was no significant difference in mean population density in the two zones.

There were clear differences in catches with the 35 mm seine net in November 1981 in the different localities (Table 4.6) with highest catches at St. 16 (southern Crocodile) and lowest at St. 4 (northern Magalies). An analysis of variance of the results showed significant deviations from random distribution for *O. mossambicus* and total catch (Table 4.7).

Table 4.6. Mean catch per haul of the 35 mm seine net at different localities (November 1981)

Station	3	16	10	4
Locality	S. Magalies	S. Crocodile	NE	N. Magalies
No. of Hauls	3	2	2	2
Species		$kg.haul^{-1}$		
O. mossambicus	27.95	1123.23	16.92	16.81
C. carpio	33.19	106.18	40.40	7.25
C. flaviventris	4.16	3.50	55.02	1.63
C. gariepinus	6.54	36.71	13.23	0
B. marequensis	0.43	0.83	25.64	0.40
M. salmoides	0	0	0.54	0
T. sparrmanii	0	0	0.03	0.03
Total	72.27	1270.45	151.78	26.12

Table 4.7. Analysis of variance of the 35 mm seine net catches made in November 1981, to test null hypothesis that there was no difference in catch at the four different localities

Species	F. ratio	Probability of F
O. mossambicus	5.62	< 0.05
C. carpio	3.68	< 0.10
C. flaviventris	4.39	< 0.10
C. gariepinus	1.53	> 0.10
B. marequensis	1.28	> 0.10
Total	5.71	< 0.05

On the basis of the heterogenous distribution of fish determined in 1981 (Table 4.7), the littoral distribution of the three major species (*O. mossambicus*, *C. carpio* and *C. gariepinus*) was investigated more thoroughly in the mark and recapture exercises in May and October 1982. The shoreline was again divided into the four zones used in the initial survey and catches in the different zones compared using the Mann-Whitney U-test (Zar, 1974) to test for significant difference. In May 1982 *O. mossambicus* density was significantly different along the southern shore (including the bay formed by zones d2 and e2 - Fig. 2.1) and the northern shore excluding this bay.

Table 4.8. Comparison of CPUE in major shoreline areas of Hartbeespoort Dam in May and October, 1982. U = Mann-Whitney statistic

Species	mth	Zone 1	CPUE (kg)	Zone 2	CPUE (kg)	U	P(U)
O. moss	May	S.shore + d2e2	50.92	N.Magal + NE-d2e2	7.54	268.5	< 0.05
	Oct	S.shore	200.4	N.shore	18.4	392	< 0.001
C.gar	May	S.shore + NW	25.11	N.Magal.	3.35	242	< 0.01
	Oct	S.shore	144.8	N.shore	50.0	304	< 0.05
C.car	May	S.shore + d2e2	17.21	N. Magal + NE-d2e2	3.01	292.5	< 0.01
	Oct	Total	5.7				

Catches in the former gently sloping zone were approximately six times greater than those in the steeper northern areas (Table 4.8). In October 1982 the trend was similar (Fig. 4.1) but the mean catch along the entire southern shore was more than ten times greater than the mean for the northern. The distribution of *C. carpio* in May 1982 followed that of *O. mossambicus* but in October 1982 samples were too small to analyse. Catches of *C. gariepinus* followed the same trend and highest catches were associated with low gradients (Table 4.8 and Fig. 4.2).

4.3.3 Factors regulating fish distribution

The parameters considered most likely to influence fish distribution were the more permanent geological features, such as gradient, degree of shelter and substrate characteristics of particular sites. Degree of shelter would be inversely proportional to the maximum fetch to which a site was exposed. The prevailing wind directions in Hartbeespoort Dam are north-westerly and east-south-easterly (NIWR, 1985) and the fetch in these two directions and the gradient at individual sites were read from hydrological maps for use in the statistical analyses. The correlation between these variables and the CPUE from sites during the October 1982 mark and recapture, when the lake was virtually at full supply, were examined. Data on certain sediment characteristics, supplied by A. Twinch, were also used where his sampling sites overlapped with sites used for fish sampling. The aim of these analyses was to identify environmental factors closely correlating with fish catch and then to determine which of these were causative relationships.

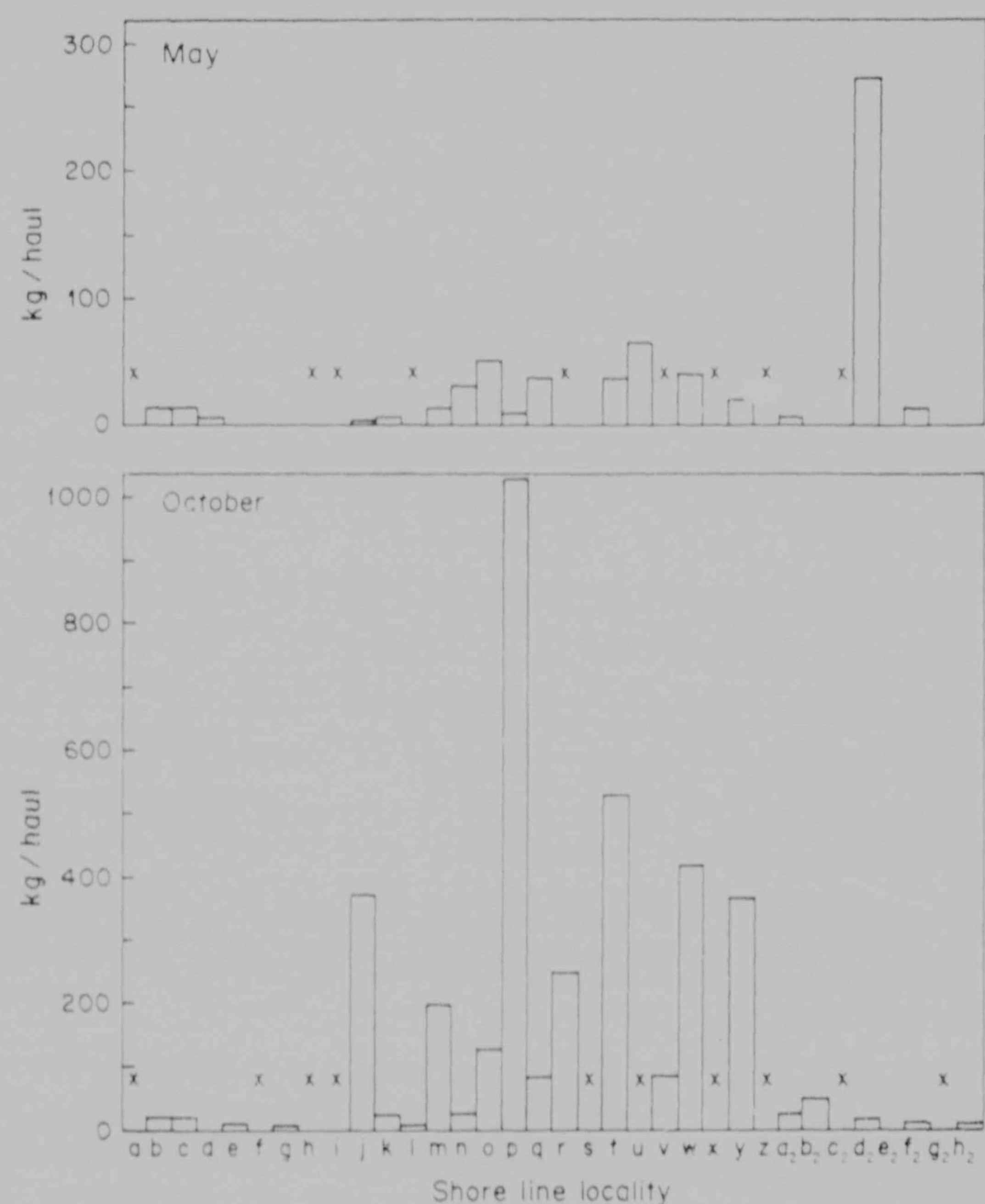

Fig. 4.1. Mean catch per seine net haul of *O. mossambicus* at different shoreline localities (May and October 1982). X indicates no samples taken at the site.

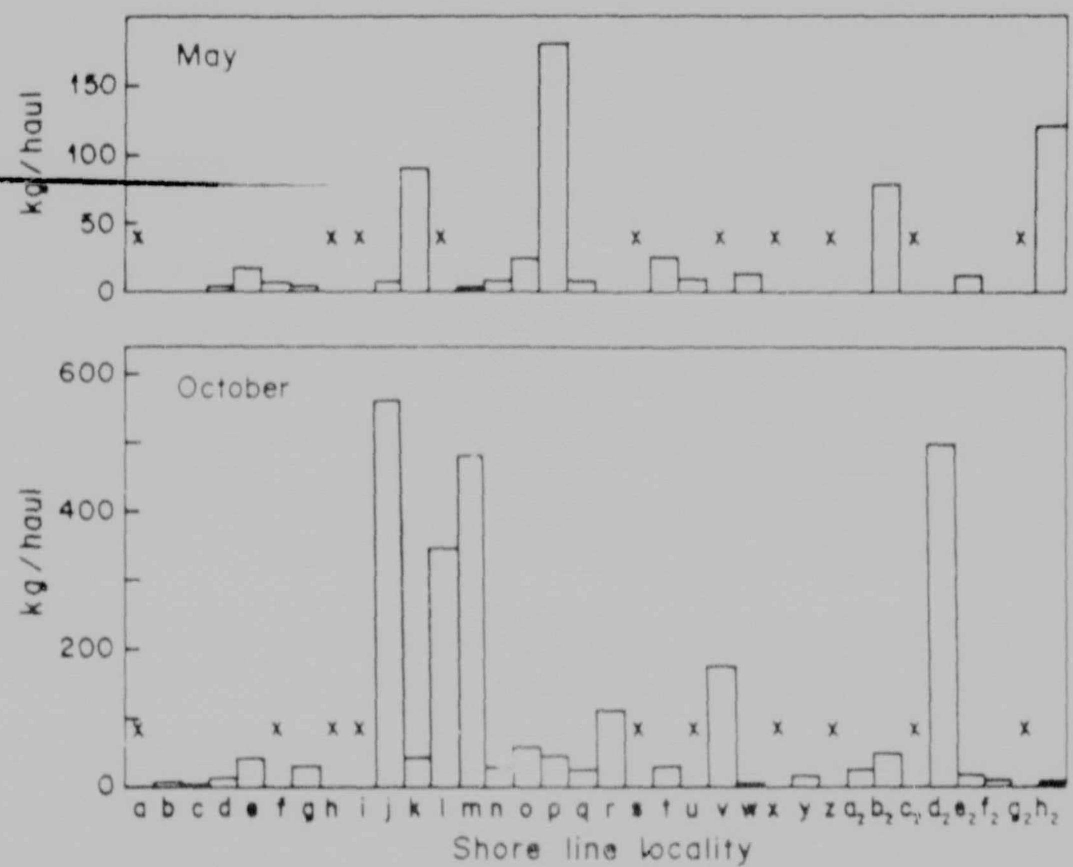

Fig. 4.2. Mean catch per seine net haul of *C. gariepinus* at different shoreline localities (May and October 1982). X indicates no samples taken at the site.

Table 4.9(a) Correlation Coefficients for *O. mossambicus* and *C. gariepinus* CPUE (October 1982) and certain physical and sedimentary variables

Ind. variable	n	r	Significance
1/Gradient	24	0.42	0.95
ESE Fetch	24	-0.35	<0.95
NW Fetch	24	0.25	<0.95
% Clay	11	-0.005	0.50
% Silt	11	0.22	0.70
% Org. Carbon	11	0.23	0.70
Tot. Sed. P	11	0.23	0.75

Table 4.9(b) Multiple Correlations (ln transformation)

Variable(s)	n	Adjusted R^2 (Galpin, 1981)	Significance
1/Gradient	24	0.43	0.95
1/Gradient, NW fetch	24	0.49	0.99
1/Gr., NW fetch, ESE Fetch, % Clay	11	0.67	0.97

The environmental variables correlating most closely with *O. mossambicus* and *C. gariepinus* CPUE were Table 4.9(a).

(a) 1/Gradient

(b) ESE fetch (negative)

(c) NW fetch (positive)

The multiple correlations gave additional information and a five variable equation, based on 11 data points accounted for 67% of the variation observed in the CPUE, while a three variable equation, based on 24 data points, accounted for 49% of the variability (Table 4.9(b)). The form of these two equations was:

$$\text{(a)} \ln(\text{CPUE}) = -3.7 - 0.54\ \text{Cl} + 2.03\ \text{Gr} + 0.29\ \text{Nw} + 0.17\ \text{Ese}$$

$$\text{(b)} \ln(\text{CPUE}) = 83.8 + 9.16\ \text{Gr} + 0.06\ \text{Nw}$$

where Cl = ln (% clay in sediments)

Gr = ln (1/Gradient)

Nw = ln (NW fetch (m))

and

Fse = ln (ESE fetch (m))

These equations were not intended to be used as predictive equations, but an examination of residuals was undertaken using a one-sample runs test (Siegel, 1956). The results were:

(a) (-) = 5, (+) = 6, runs = 6

(b) (-) = 14, (+) = 6, runs = 9

$r_{(0.05,5,6)}$ = 3 - 10

and $r_{(0.05,14,6)}$ = 5 - 13

and thus the distribution of residuals in both equations can be said to be random which reduces the risk of error in prediction (Galpin, 1981).

The relatively high correlations between fish catch and the geomorphological parameters of gradient and fetch in all analyses indicated that these could be influencing fish density.

4.3.4 Seasonal variations in condition

In both size classes of *O. mossambicus* there was a decline in condition factor in winter and a peak in summer (Fig. 4.3 & 4.4). However, the Kn of juveniles was significantly lower in the summer of 1983/84 (mid-December lake volume = 35%) than in the summer of 1982/83 (mid-December volume = 53%). This could have been as a result of higher population density at the time of low lake volume, increasing competition for food resources amongst fry.

Condition factor of *C. gariepinus* remained relatively constant over the study period with no significant change (Fig. 4.5). *C. carpio* showed a marked drop in Kn between September and December 1983 and had not recovered by March 1984 (Fig. 4.6).

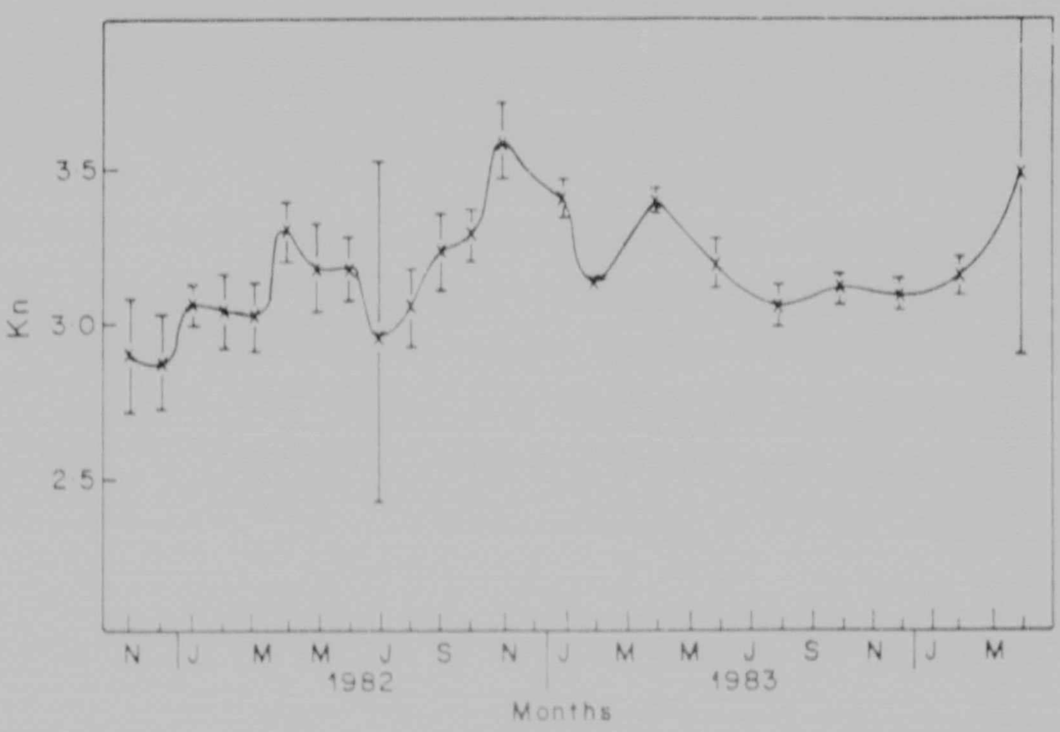

Fig. 4.3. Mean monthly condition factor of adult *O. mossambicus* (>100 g) caught in gill nets (November 1981 to April 1984). Bar = 95% CI.

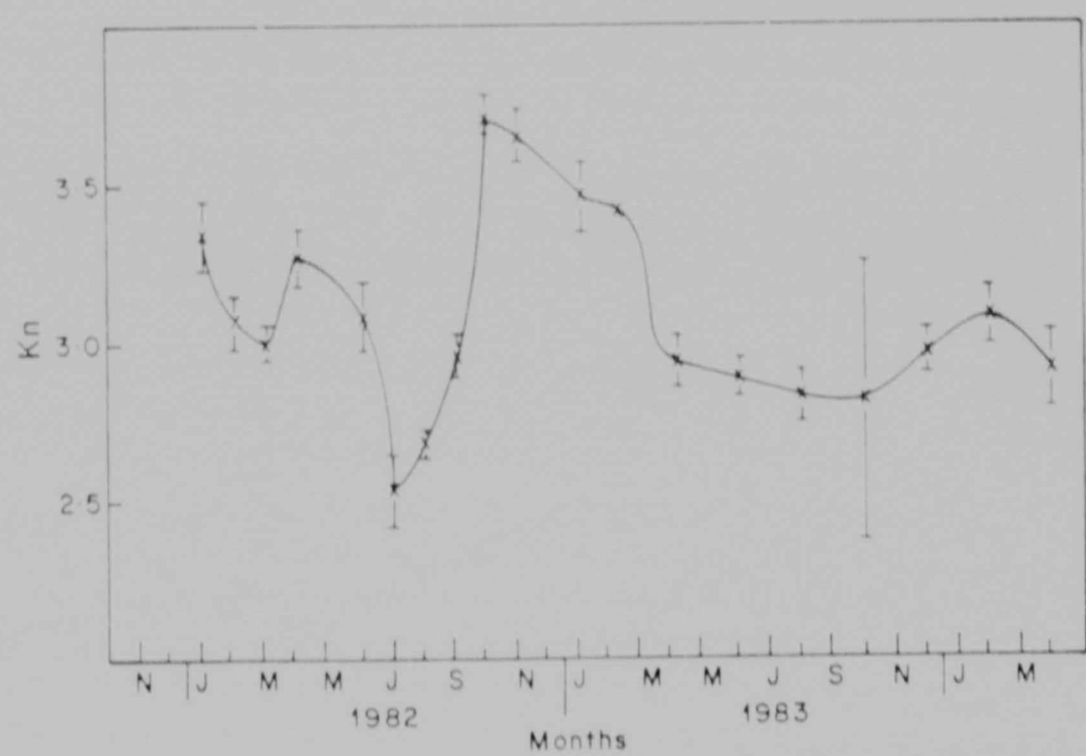

Fig. 4.4. Mean monthly condition factor of juvenile (<100 g) *O. mossambicus* caught in gill nets (November 1981 to April 1984). Bar = 95% CI.

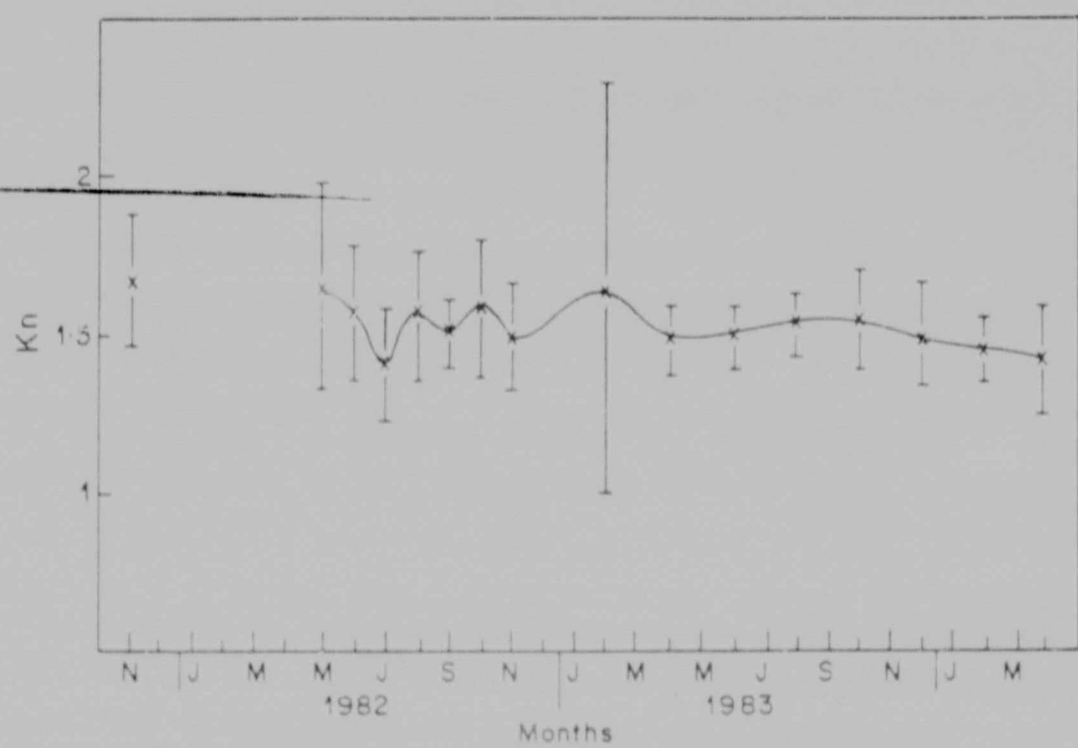

Fig. 4.5. Mean monthly condition factor of *C. gariepinus* caught in gill nets (November 1981 to April 1984). Bar = 95% CI.

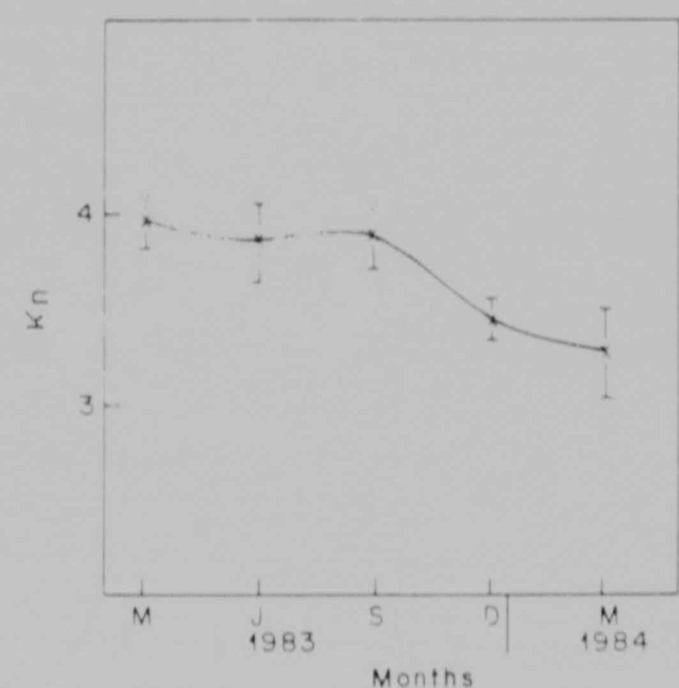

Fig. 4.6. Mean monthly condition factor of *C. carpio* caught with the 35 mm seine net (March 1983 to March 1984). Bar = 95% CI

4.4 Discussion

The fish population was dominated by three species, *O. mossambicus*, *C. carpio* and *C. gariepinus*. The large *Barbus* species, *B. marequensis*, *B. mattozi* and *B. polylepis* were found in the lake but did not reach their full size and were uncommon. *Micropterus salmoides* was extremely scarce despite the stocking programme of the Division of Nature Conservation (Cochrane, 1984).

The reasons for the scarcity of predatory species and the dominance of the three major species have been discussed (Cochrane, 1984). The hypertrophic conditions have led to poor water quality, with a mean pH of 9.3, conditions approaching anoxia at turnover and supersaturation of water with oxygen in the vicinity of *Microcystis* scums. These factors are the probable causes of the lack of success of the more sensitive *Barbus* species and *M. salmoides* (black bass).

The dominant species are more tolerant of poor water quality and *O. mossambicus* has been shown to be tolerant to pH between 5 and 11 while *C. carpio* is able to survive within a range from 4.5 to 12 (Balarin, 1979). The lower limit of dissolved oxygen concentration tolerated by *O. mossambicus* has been recorded as between 0.1 and 0.38 $mg.\ell^{-1}$ (Balarin, 1979) while *C. carpio* and *C. gariepinus* are known for their ability to survive very low or even anaerobic conditions (Bok & Jongbloed, 1984; Burton & Heath, 1980; Lomholt & Johansen, 1979; Clay, 1979). The pH tolerance of *C. gariepinus* has not been studied but it is able to survive in a wide variety of habitats (Clay, 1979) and gave no indication of environmental stress in Hartbeespoort Dam. However, *O. mossambicus* in Hartbeespoort Dam does not achieve the size reached by the species in nearby Roodeplaat Dam, probably as a result of the dominance of *Microcystis*, which has been suggested to be nutritionally inferior to other algal species (de la Fuente *et al.*, 1977), or the high pH of the water (Cochrane, 1984).

It has been suggested that *C. gariepinus* is not well suited to lacustrine conditions and that the size of populations has declined after an initial high biomass following impoundment (Marshall, 1977). The lack of success has been ascribed to absence of fish in the diet of *C. gariepinus* in dams (Bruton, 1976). The data from Hartbeespoort

Dam (Table 4.5) do not support these hypotheses and show that the population is well established and makes a large contribution to community biomass. This is probably a feature of the hypertrophic conditions in Hartbeespoort Dam which, either through abundance of suitable food or through adversely affecting potential competitors, favour *C. gariepinus*. In several impoundments the species feeds mainly on zooplankton (Bruton, 1976) and this is also true of Hartbeespoort Dam, where the major food items are zooplankton and zoobenthos (NIWR, 1985).

Hakanson & Jansson (1983) show that the abundance and species diversity of benthic invertebrates decreases with increasing depth although in eutrophic impoundments a second peak in abundance may occur in the profundal zone, dominated by oligochaetes. They also show that the abundance of organisms is considerably higher in zones of sediment accumulation than in zones of transportation. Sediment accumulation in lakes will occur in regions where the effective fetch is small (i.e. sheltered areas) or where the depth exceeds a certain critical depth (in Hartbeespoort Dam, with a potential maximum effective fetch of approximately 10 km, this critical depth is approximately 14.6 m (Hakanson & Jansson, 1983)). Emergent and submerged aquatic plants, which also support high biological activity (Hakanson & Jansson, 1983), similarly occur in shallow, sheltered areas (Hutchinson, 1975).

Therefore greatest production of food organisms will occur in shallow, sheltered areas and it is in such regions that highest fish densities will be found. The gradient of a shore line will directly affect the surface area of the bottom available for maximum macrophyte and zoobenthos production. Thus the gradient, the most important independent variable in the analyses, was largely responsible for determining the fish density in different parts of the lake.

Gradient would also influence the area over which the seine net used for fish capture was effective and thus the differences in CPUE for the different localities may be exaggerated by differences in gear efficiency. The distance from the shore at which the bottom line of the net would touch the bottom, thus preventing escape of fish beneath the net, would be positively and linearly related to gradient. Therefore gear efficiency could be expected to differ by a mean of no more than 2.7 (relative gradients of northern Magalies and southern Magalies, Table 4.1) between the different shoreline zones. Combined catches of *O. mossambicus* and *C. gariepinus* for the different zones were five times greater on the southern shore than the northern shore in October 1982 and catches of the separate species for the different zones were six and ten times greater in May 1982 (Table 4.8). Therefore, while the influence of gradient on gear efficiency would have affected catches, the major influence of gradient was on production of food organisms and hence on actual fish standing stock.

Zones of sediment accumulation occur where there is a small fetch and thus a negative correlation between fetch and CPUE could be expected. This occurred in the case of ESE fetch but there was a positive correlation between CPUE and NW fetch (Table 4.9a). There are two probable explanations for this contradiction:

(a) ESE winds may account for greater turbulence or wave action by predominating in frequency or strength

(b) The correlations between CPUE and fetch may be fortuitous and reflect the influence of a fourth factor, on independent and dependent variables.

The second explanation is more likely and is supported by the fact that the correlation coefficients between gradient and NW and ESE fetch were 0.15 and -0.52 respectively. Thus the relationships between CPUE and fetch appear to be indirect and caused by correlations between gradient and fetch.

Condition factor of *O. mossambicus* was mainly influenced by temperature (Fig. 4.3 and 4.4). The winter minima occurred as feeding slowed down and halted. Caulton (1979) stated that *O. mossambicus* stops feeding at temperatures between 16 and 18°C and the minimum mean water temperature of Hartbeespoort Dam is 13 to 14°C in July each year. The increasing density of adult fish over the study period, as a result of falling lake volume and high recruitment, did not affect adult Kn, showing that food stress did not occur. In contrast juveniles exhibited declining Kn over the spawning season (October to March) indicating that food stress occurred as juvenile density increased. This could introduce density influences on juvenile growth and survival. The summer decline was most marked in 1982/83 when there was a complete absence of macrophytes and did not occur in 1983/84 when macrophytes were most abundant. The abundance of epiphytic and littoral flora and fauna, the food items of juvenile *O. mossambicus*, would be influenced by size of macrophyte beds.

The Kn of *C. gariepinus* showed no significant response to season or density. The catholic diet of *C. gariepinus* would enable it to take advantage of whichever food sources were most abundant at any given time, thus minimising the impact of seasonal or long term variability in individual food sources.

C. carpio Kn remained high in March 1983, following the failure of the species to spawn in the summer of 1982/83. Spawning in October/November 1983 led to a sharp decline in Kn by December 1983. This had not been overcome by March 1984, indicating food stress during the abnormally high fish density occurring at the time.

The major contribution to biomass of *O. mossambicus*, *C. carpio* and *C. gariepinus* was thus clearly established and their numerical importance is demonstrated in Section 5.3.3. The role of shoreline gradient in determining distribution could be used in predictive models incorporating spatial distribution but such models are beyond the scope of this thesis. Gradient influences fish abundance through determining production of food organisms and this indicates food was limiting total fish production in Hartbeespoort Dam and hence density dependent population regulation mechanisms could be important in attempting to simulate population behaviour.

CHAPTER 5

NUMBERS AND BIOMASS OF THE MAJOR SPECIES

5.1 Introduction

Fish populations or stocks can frequently be managed without information on the actual biomass of the target stock. Trends in catch per unit effort (CPUE) and the relationships between effort and CPUE are used to provide data for management and plots of catch against effort can be used to estimate fishing rate (Ricker, 1975). Potential yield of a fishery can be estimated roughly by a number of techniques such as morphoedaphic index, gill net monitoring (Ryder, 1978) and other empirical models such as those of Oglesby (1977a) and Melack (1976). Once a fishery has become established further management decisions can be taken on the basis of feedback on catch and effort statistics.

In this study it was felt that knowledge of the standing stocks of the species was important for the following reasons.

(a) At the start of the project it was not known whether the level of effort was sufficiently large to measurably influence stock size. Without such impact, catch:effort relationships cannot be used to provide information on the fishery.

(b) The recreational fishery on Hartbeespoort Dam is a multi-species fishery and unbiased information on the relative abundance of the three major species was considered essential for correct management.

(c) While order of magnitude estimates of the potential yield were obtainable from various empirical relationships, the project aimed to provide more accurate yield estimates which incorporated information on species composition and took cognisance of the major constraints on production and yield. With this information a more comprehensive management strategy, aimed at optimal utilisation of the stock, should be possible. Such predictions require a knowledge of the fish standing stock.

The objectives of this chapter were therefore to establish the standing stocks of the major species in order to provide unbiased estimates of relative abundance, to assist in determining potential yield and to provide starting values for the yield models (Chapter 7).

5.2 Methods

5.2.1 General discussion of methods

Youngs and Robson (1978) list three general approaches to estimating population size,

(a) ratio methods, including mark and recapture

(b) catch-effort methods

(c) direct enumeration

(a) Mark and recapture

Mark and recapture methods have been extensively used to estimate population size and form one of the principle techniques used (Ricker, 1971). The Petersen single census method can be used to estimate the population as (Ricker, 1975):

$$N = MC/R$$

where
N = estimate of actual population
M = total no. marked
C = number of fish in recapture sample
R = marked fish recaptured

The above method has, however, been shown to overestimate the true population and the modified Petersen equation is used to overcome this bias (Ricker, 1975). The modified formula is:

$$N = (M + 1)\ (C + 1)/(R + 1)$$

Approximate confidence intervals may then be determined from binomial or Poisson tables using R as the entering variable.

Multiple census methods are also used and the results analysed in several ways, including a mean of Petersen estimates, Schumacher and Eschmeyer's estimate and Schnabel's formula (Ricker, 1975). Differences in results obtained using the latter two estimates are small in relation to the confidence limits.

The Schnabel formula is, for an exercise conducted over n days:

$$N = \Sigma\,(C_t M_t)/\Sigma R_t$$

where t = 1 to n

C_t = total sample taken on day t

M_t = total marked fish at large at the start of the t th day

R_t = recaptures on day t.

Again, R can be treated as a Poisson variable and used to obtain confidence limits.

The validity of mark and recapture population estimates depends on certain conditions being met. These are given by Youngs and Robson (1978) as,

(a) the population is closed to recruitment and immigration

(b) marked fish do not differ from unmarked fish in terms of mortality or vulnerability to capture

(c) marked fish do not lose their marks

(d) all marked fish are reported upon recapture

(e) either the marking or recapture samples are random or there is random mixing of marked with unmarked fish.

Ricker (1975) lists the same set of conditions and states that, while natural mortality during an experiment will not influence a Petersen estimate, provided it is the same for marked and unmarked fish, it will tend to result in an underestimate of N by the Schnabel method. However, Ricker states that multiple census techniques are useful even if the necessary assumption of no mortality is only approximately satisfied and that, generally, the shorter the time in which recoveries are made, the better the estimate.

The size of the samples taken in mark and recapture experiments can bias the results. Robson and Regier (1964) showed that an unbiased estimate of population size will be obtained if there is no possibility of R being zero through sampling variability. They calculated that, if

M*C approx. = N then the Petersen estimate will underestimate N by approximately 37%. The following biases also apply,

M*C approx. = 3N, bias = approx. 5%

M*C approx. = 4N, bias = approx. 2%

Ricker (1975) stated that the probability of introducing bias in this manner can be ignored, for both single and multiple censuses, if the number of recaptures is greater than 3 to 4.

The gear used for mark and recapture exercises can influence results. It was demonstrated that estimates of *C. carpio*, using the Petersen single-census method, were only reliable if the gear used in collecting samples for marking and the census had different selectivities (Beukema & de Vos, 1974). In the Hartbeespoort Dam study the only means of collecting large enough samples was with a 100 m long seine net and the bias identified by Beukema & de Vos had to be assumed to be negligible in the Petersen estimates undertaken.

(b) Leslie's fishing success method

Catch:effort methods are based on the assumption that, in a closed population, the CPUE is proportional to the number of individuals in the population at any given time. Thus in a closed population the catch per unit effort should decline with time (Youngs & Robson, 1978). Youngs and Robson listed two methods of analysing such data, the Leslie method for variable effort and the Moran-Zippin method for constant effort. Ricker (1975) added the De Lury method, which compares fishing success to cumulative effort, for use when the fraction of the stock taken by a unit of effort is small.

Leslie's method estimates population size at time 0 from the relation of fishing success to catch already taken. Using this method, a plot of CPUE during any interval, t, against the cumulative catch should give a straight line with slope equal to the catchability and the X - intercept equal to the population at time 0 (Ricker, 1975). This is derived from the equation

$$C_t/f_t = qN_t - qK_t$$

where C_t/f_t = CPUE

q = catchability

N_t = population size at time t

K_t = cumulative catch at the start of interval t plus half of that taken during the interval.

Ricker (1975) lists two major sources of systematic error in the fishing-success methods of population determination.

These are:

(i) inconstant catchability caused by, for example, seasonal environmental change or change in vulnerability

(ii) additions to or natural removals from the population which can introduce serious error into the calculations. It is desirable to concentrate fishing effort into a short period of time to overcome these influences.

(c) Direct enumeration

Direct enumeration of fish stocks involves the direct estimation of the number of fish in a given area and the extrapolation of these results to ascertain the total in the water body. Commonly used methods of direct enumeration are:

(i) Spot poisoning e.g. Mitchell (1976)

(ii) Use of fishing gear such as nets and traps e.g. Bagenal (1981)

(iii) Echo sounding or acoustic techniques e.g. Coulter (1977)

(iv) Concussion methods such as explosives (Lagler, 1978).

Poisoning has been widely used and successful results have been reported by Mitchell (1976), Marshall & Lockett (1976) and van der Waal (1980). Hanson & Leggett (1982) stated that the cove rotenone poisoning method for estimating fish biomass had been validated. The major advantage of poisoning is the high efficiency of capture while problems lie mainly in selection of sites which are both suitable for poisoning and representative of the habitat (Henderson *et al.*, 1973). All the above authors used rotenone or a rotenone derivative, such as Pro-noxfish. Rotenone, at the concentrations used for fish poisoning, is not toxic to mammals and breaks down naturally within approximately one week (Mitchell, 1976).

Various types of fishing gear have been used but generally do not give reliable quantitative estimates. In extensive tests on a lake in Finland, five different types of gear were tested on a 14.4 ha lake stocked with known numbers of fish, but none of the methods was able to provide a corroborative estimate (Bagenal, 1981). Van der Waal (1980), using two seine nets of different mesh size, obtained biomass estimates of 58.6% and 47.2% of that obtained by poisoning.

Echo sounding and acoustic methods have been used extensively in studying fish populations (Coulter, 1977; Bruton & Boltt, 1975; Bagenal, 1981). Bagenal (1981) described the use of an echo-sounder in conjunction with an analogue-to-digital converter which provided accurate results. The major disadvantages of this method are,

(i) the cost of the equipment

(ii) the bias introduced by avoidance action of fish at the surface (Bagenal, 1981) which reduces the efficiency of the equipment in the generally productive littoral zones

(iii) fish recorded by this method cannot be identified and hence only a total estimate can be obtained.

5.2.2 Methods applied to biomass determinations in Hartbeespoort Dam

At the st rt of the study the impact of the recreational fishery on stocks and its potential use in stock assessment was unknown and it was decided that standing stock investigations would be undertaken using mark and recapture methods for adults of the three species. Littoral poisoning was selected as the most practical method to investigate the relative abundance of fry of the three major species in view of the labour and equipment available.

On the basis of available time and the other requirements of the project it was decided that two mark and recapture exercises could be undertaken per year, in May and October, and that littoral poisoning exercises would be undertaken at three sites around the lake, once per year in mid to late summer, when the breeding seasons of all species were well advanced. Littoral poisoning was undertaken at three sites in 1982 and in 1984. The number of replicates was lower than the optimum for statistical accuracy but was the maximum which could be undertaken in view of the time required per station and the ecological impact of the method.

After the second mark and recapture exercise, undertaken in October, 1982, it was apparent that carp could not be caught in sufficient numbers to obtain a population estimate by this method. However, angler catches of *C. carpio* were found to be considerably higher than anticipated and the possibility of using a catch:effort relationship existed. The most suitable method was Leslie's method of fishing success against catch already taken, and this method was used to obtain a population estimate for *C. carpio*.

(a) Mark and recapture

It was necessary initially to establish whether the requirements for correct usage of mark and recapture methods, as listed in Section 5.2.1, could be met in Hartbeespoort Dam.

The first requirement, that of a closed system, could be assumed to be correct. Only 1+ and older fish were tagged and these were clearly distinguishable, by size, from the younger age group. Therefore, recruitment did not interfere with results. *C. gariepinus* migrates up rivers to spawn but exercises were limited so as not to coincide with the breeding period. The exercises were conducted over a 12 day period which should have further increased the reliability of the closed system assumption.

Point 4, that all marked fish are reported, was dealt with by at least two people checking each fish in the census samples for tags.

Random mixing of marked fish with unmarked fish, point 5, could not be assumed, particularly as each exercise was run over only 12 days. This problem was overcome by the random selection of sites for both marking and census exercises. The lake shoreline was divided into 33 approximately one kilometre zones (Fig. 2.1), each of which was further sub-divided into 10 sites. Zones and sites within each zone were selected randomly. In order to save travelling time, sites were selected for each of the two, 4-5 day sampling periods per exercise, and were then sampled approximately sequentially around the lake each week. Thus by the end of each exercise the lake shore would have been covered twice. Approximately 40 sites were sampled in each exercise. This method of sampling coupled with natural movements of the fish, would have resulted in random sampling of marked and unmarked fish.

Table 5.1. Number of replicates and fish, duration of experiment and size of cages used to measure tag loss and mortality of tagged fish

Date	Species	Cage (m)	Duration (d)	Replicates x no. of fish
May 82	*O. mossambicus*	2x2x1	14	1x15
May 82	*C. gariepinus*	2x2x1	14	1x4
Oct 82	*O. mossambicus*	2x0.7x1	23	1x10, 1x9, 1x4
Oct 83	*C. gariepinus*	2x2x1	17	2x6, 1x4

The requirements 2 and 3, that marked fish suffered the same mortality and were equally vulnerable to capture as unmarked fish, and that tagged fish did not lose their tags, were investigated. Three separate experiments were done, in May and October 1982 and in October 1983, in which fish were captured, tagged and placed in holding cages. Cages were checked daily for mortalities and at the end of the experiment fish were checked for tag loss. As the greatest stress would have occurred during capture of the fish, untagged, control fish were not included in the trials.

A total of 38 *O. mossambicus* and 20 *C. gariepinus* were held in cages in the series of experiments (Table 5.1). All fish were tagged with Floy-type spaghetti tags, inserted in the flesh alongside the dorsal fin using a Dennisson Mark II tag gun. In order to cut costs colourless, nylon, unnumbered clothing tags, 35 mm long were used. The results of the experiments showed no tag loss in either species for the duration of the trials and no mortality amongst the *C. gariepinus*. In the October 1982 experiment there was no mortality or sign of stress amongst the *O. mossambicus* but in May 1982 one fish died after nine days and a second after 10 days. The surviving fish had moderate to severe fin and tail rot which would have made them more vulnerable to capture. In May low water temperatures would place the species under cold-stress (Allanson *et al.*, 1962) and the additional stress of capture and tagging was sufficient to cause fungal infections which were fatal to two fish. In October when temperatures were higher and the condition of the fish better, they were able to survive the handling stress.

From these results it was concluded that mortality and tag loss did not occur in *C. gariepinus* or in *O. mossambicus* in summer. In winter (May) the influence of mortality would have been to give an over-estimate of *O. mossambicus* population size while the results of increased vulnerability to capture would be to give an underestimate of size. While the impact of mortality could be calculated from the experimental results, the influence of the fungal infections on vulnerability to capture could not be quantified, therefore the May 1982 results are considered unreliable.

In view of the stress on *O. mossambicus* in winter and the low catches it was decided to hold the first 1983 mark and recapture experiment in March 1983. However, even that early in the year, *O. mossambicus* had moved offshore after breeding and catches were low. Therefore no experiment was run in early 1984.

A total of four experiments was undertaken, in May and October 1982 and March and October 1983. In the first two the Petersen method was used with 4 days devoted to marking, a two day break, and then 4 days spent on the census sample in May, and 5 days each, with a two day break in the middle, in October. In March and October 1983, in an attempt to increase the number of recaptures, a multiple census technique, and Schnabel's formula were used. On these occasions tagging was undertaken for 8 days and the census continued, without tagging, on the 9th day. Work was not undertaken over week-ends as the heavy recreational usage of the dam prevented netting.

The tags used for each exercise were marked with a soldering iron to avoid confusion with recaptures from different exercises. The total length of all fish caught was measured and mass calculated from computed total length:mass relationships, for computing biomass and for use in describing littoral distribution of fish (Section 4.3.2).

(b) <u>Leslie's fishing success method for *C. carpio*</u>

Catch per unit effort for *C. carpio*, was calculated from angling returns submitted to the Nature Conservation Division (Fig. 5.1).

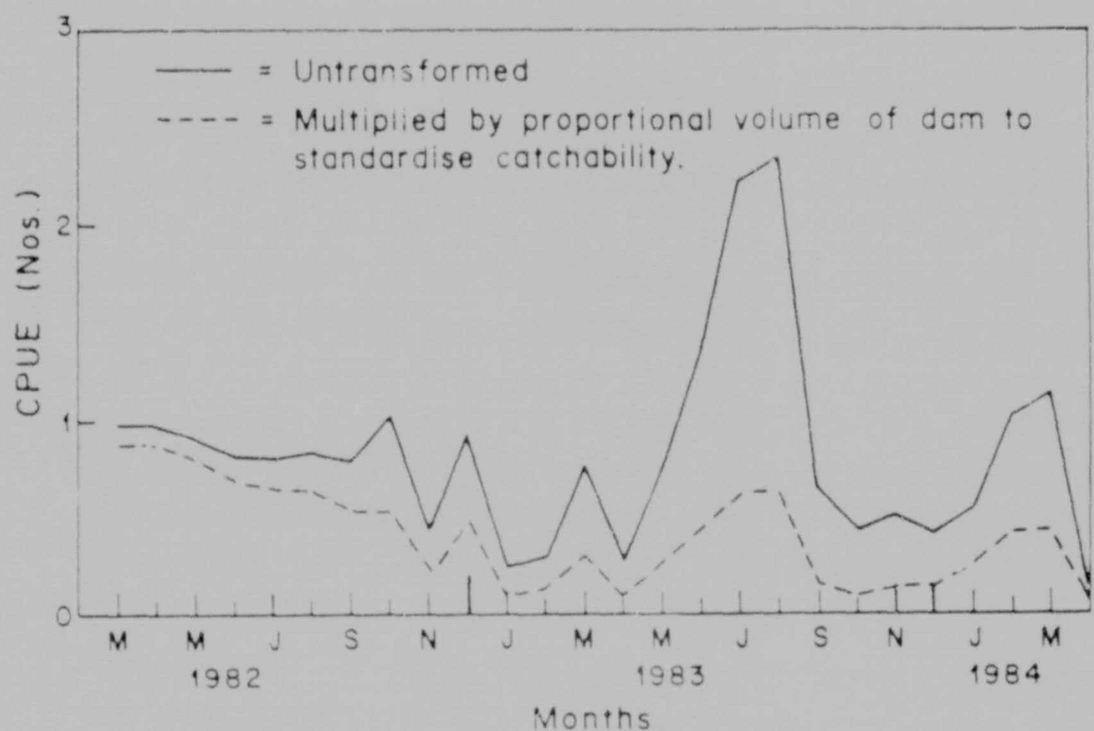

Fig. 5.1. The mean number of *C. carpio* caught per angler day (March 1982 to April 1984). Division of Nature Conservation, TPA, Pretoria (unpublished data).