THE POPULATION DYNAMICS AND SUSTAINABLE YIELD OF THE MAJOR FISH SPECIES IN HARTBEESPOORT DAM

by

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for the Degree of Doctor of Philosophy.

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A B S T R A C T

This thesis examines the population dynamics of the major species of fish in Hartbeespoort Dam and uses a modelling approach to determine the potential long term yield from the lake.

The major fish species were identified as *Oreochromis mossambicus*, *Cyprinus carpio* and *Clarias gariepinus*. The distribution of *O. mossambicus* and *C. gariepinus* in the lake was examined and shoreline gradient found to be the major factor influencing their relative abundance at different sites. The standing stocks of *O. mossambicus* and *C. gariepinus* were determined by mark and recapture methods and that of *C. carpio* by Leslie's method of the relationship between fishing success and catch already taken. The *O. mossambicus* standing stock varied from 323 t in 1982 to 521 t in 1983 through variable young of the year winter mortality. Only one reliable estimate of biomass was made for each of the other two species, 292 t for *C. gariepinus* and 580 t for *C. carpio*. Littoral poisoning was also undertaken to investigate abundance of fry and demonstrated the dominance by mass of the three major species. Standing stock was high in relation to other water bodies and this was ascribed to the hypertrophic conditions.

Growth rates were investigated using growth rings on hard structures and von Bertalanffy curves fitted to the observed data. The asymptotic lengths of male and female *O. mossambicus* were 37.2 and 30.9 cm, for *C. carpio* were 57.6 and 59.5 cm and for *C. gariepinus* were 97.3 and 79.0 cm respectively. The growth of *C. carpio* in the first year was considerably faster than in the other two species and it reached a mass of over 600 g at one year old.

O. mossambicus females were found to reach sexual maturity in their first year in the early part of the study but only in their second year in 1983/84. The probable reason for the delayed onset of maturity was higher density of fish. *O. mossambicus* spawned from late September to March/April. The other two species were found to spawn in summer at the first floods and *C. carpio* females to reach sexual maturity at one year old and *C. gariepinus* only after two years.

Total adult mortality rates were measured by changes in abundance with time for *O. mossambicus* and *C. carpio* and from length frequencies for *C. gariepinus*. Fishing mortality was calculated from the estimated angler catches and the

standing stock estimates for each species, and *C. carpio* accounted for 65% of the total catch. The vulnerability to capture of *C. gariepinus* was found to increase in proportion to mass. Natural mortality was determined from total and fishing mortality, from the equation Z = F + M. Density dependent mortality in young of the year *O. mossambicus* was demonstrated and winter mortality of young of the year *O. mossambicus* was found to have a major impact on yield of the species. Young of the year mortality could only be determined for the other two species by using Leslie matrices and the potential errors of this method are discussed. Lowest survival of young of the year was found in *C. gariepinus* but results from the yield model suggested survival was underestimated for this species. The need for incorporation of density dependent mechanisms in fish yield models was demonstrated.

Variability in juvenile mortality rates, age at maturity and growth occurred in *O. mossambicus* over the study period and it was suggested that variability could occur in all parameters studied for the three species. This inconstancy of important parameters determining fish yield demonstrated the short-comings of most fish yield models, and emphasised the need for identifying environmental and biological parameters which control production and hence yield in populations.

Mechanistic single species models were constructed for the three species and used to determine potential long term yield. Predicted yields for the three species were 1[illegible]0 $t.y^{-1}$ (*O. mossambicus*), 375 $t.y^{-1}$ (*C. carpio*) and 25 $t.y^{-1}$ (*C. gariepinus*) which agreed favourably with predictions made from other models. However, in view of the demonstrated impact of environmental and biological variability on predictions, particularly for *O. mossambicus*, caution was expressed regarding uncritical acceptance of the predictions for management.

A simple, multi-species model, incorporating environmental influences was constructed but was limited by the absence of quantitative information on species competition and factors regulating fish community composition. It is seen as a first step in building a comprehensive yield model for southern African fish communities.

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Kevin [illegible]

Seventh day of May, 1985.

P R E F A C E

This study formed part of the Hartbeespoort Dam Ecosystem Study undertaken by the National Institute for Water Research, Council for Scientific and Industrial Research, Pretoria. The aims of the Ecosystem Study were to investigate and model nutrient cycling within hypertrophic Hartbeespoort Dam, with a view to evaluating methods of reducing the level or symptoms of eutrophication in the lake. The aim of the project, of which this thesis forms a part, was to provide data on the size and production of the major fish species in the lake in order to assist in quantifying the role of fish in nutrient cycling.

Throughout the study I received advice and encouragement from Dr F.M. Chutter, the Head, Limnology Division, NIWR and from my sponsors Prof. B.E. Walker, Centre for Resource Ecology and Dr. K.H. Rogers, Dept. of Botany, both of the University of the Witwatersrand. The study would not have been possible without the dedicated assistance of Mrs Helene Herbst (July 1983 - December 1984) and Mr Mike Hills (September 1981 - June 1983) in the field and laboratory. They provided invaluable assistance in the collection and preparation of samples, measurements of fish, egg counts and data capture. Mrs Herbst also made a major contribution to typing of the thesis. Mr Trevor Fenn and several other colleagues from the NIWR provided assistance in the field. Grateful thanks are due to Mrs. Phyllis Vos for typing the final drafts of the thesis.

The Division of Nature Conservation, Transvaal Provincial Administration were extremely co-operative and provided additional labour and nets for the mark and recapture exercises and also angling returns from Hartbeespoort Dam. My thanks are due to the fishing teams for their cheerful and hard work and to Mr. A.J. Malan, Lowveld Fisheries Research Station for supplying me with the monthly angling returns.

I am also grateful to my colleagues at the NIWR and Prof. J. Field of the University of Cape Town, Prof. C. Breen of the University of Natal and Dr H. Wiechers of the Water Research Commission for their stimulating discussion and criticism throughout the study. Dr. P. Fatti, National Research Institute for the Mathematical Sciences, CSIR suggested and assisted with the discriminant analysis of length frequencies.

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I would also like to thank my parents for enduring and supporting the early stages of my education and Prof. Alan Bowmaker, Oceanographic Research Institute who first encouraged my interest in fish and brought about an awareness of their importance as a food resource.

Finally, I wish to thank my wife Hilary and children, Shaun and Tanya, for their continual love and support and for putting up with my frequent neglect and pre-occupation over the last few years. This thesis is dedicated to them.

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GENERAL INTRODUCTION

Comprehensive management of a fishery requires a knowledge of the fecundity, recruitment, mortality, age structure and growth rates of the exploited fish species (Ryder, 1978). The traditional approach has been to consider the target species in isolation from its environment and from other species, and the production of the species has been regarded as a function of its inherent biological characteristics (Gulland, 1978). Furthermore, the assumption of a steady state situation is a feature of most methods of analysing fish stocks (Regier & Henderson, 1973; Gulland, 1978). This approach has frequently failed because of the variability of the environment (Ryder, 1978) and the fact that parameters considered constant, such as natural mortality, are in fact variables influenced by fishing pressure, stock size and environment. That is, the stock is part of a complex and dynamic system and cannot be managed in isolation from it (Ryder *et al.*, 1981).

Hartbeespoort Dam is an artificial impoundment occurring near the urban Pretoria-Johannesburg-Witwatersrand complex. As a result of its accessibility to the residents of this area it is a very popular angling resort (Hofmeyr, 1978). Nevertheless the fish community is largely unmanaged and very little was known about the composition and standing crop of the community or the impact of fishing on stocks. This study attempted to describe the nature and distribution of the fish community and, using a modelling approach, to assess potential yield of the more important fish species and the current extent of exploitation. The study presented an opportunity for a detailed survey of a relatively small and essentially closed system and hence the population dynamics of the target species were examined and described in as much detail as was possible, and comparatively sophisticated models of each population were constructed. However, it was recognised that in southern Africa, and in much of the developing world, there is a need for rapid, first-order estimates of potential yield. Therefore a further aim was to use relevant knowledge, gained in the in-depth study, to construct an empirically based multi-species model for wider application in the management of freshwater fisheries.

Many models exist for the prediction of fish yield. A widely applied, comprehensive model is that of Beverton and Holt, which was developed for a fish population under unusually stable conditions, and has subsequently been found to be inadequate for most exploitive situations (Gulland, 1978). Models such as the Beverton and Holt model, despite their complexity, are frequently incapable of accurate prediction under varying conditions and their use requires detailed information on the biology of the species which is usually unavailable for fisheries in developing countries. The developments in methods of prediction of fisheries yield have therefore tended to follow two distinct directions. The first has been aimed at developing comprehensive, accurate models which satisfy the management requirements of intensive, established fisheries, while the second has been directed at developing rapid, inexpensive means of arriving at first estimates of yield for new or developing fisheries. The second approach attempts to compromise between accuracy and the need for rapid results and, while the initial estimates may only be accurate within orders of magnitude, they can subsequently be refined by feedback from the fisheries themselves (Ryder, 1978).

Most of the comprehensive models have been based on the model of Beverton and Holt or on the surplus yield model of Schaefer (Taylor, 1981). Attention has also been given to the relationship between stock and recruitment (Gulland, 1978) as recruitment provides the major source of variability in production of fish stocks (Sissenwine, 1981). Stock:recruit relationships have been formulated by Beverton and Holt, and Ricker (Ricker, 1975) and a single relationship incorporating the characteristics of these two has been developed by Shepherd (1982). However, the value of such relationships is limited, as the true relationship will be modified by environmental variability (Gulland, 1978). The ability to manage even established fisheries, where there are a lot of historical fisheries data and which have been the subjects of extensive study, is thus limited by the complexity of the systems and limitations in the available models.

In developing nations and in new fisheries there is frequently a lack of biological and catch:effort data, and a number of techniques have been developed for rapid assessment of potential yield. These include:

> The morphoedaphic index. This was first developed by Ryder (1965) but a model particularly for tropical African lakes was produced by Henderson & Welcomme (Ryder, 1978) and an improved relationship for southern African impoundments was described by Marshall (in press).

The morphoedaphic index (MEI) is described as:

MEI = CONDUCTIVITY (μmhos.cm^{-1})/MEAN DEPTH (m) (Coulter, 1977).

An empirical relationship is described between the morphoedaphic index and actual yield for existing fisheries which can then be used to predict potential yield for unexploited or unmanaged systems.

It has been argued that conductivity or total dissolved solids will be proportional to the limiting components in a system, e.g. carbon or phosphorus, and mean depth is related to the extent of the 'euphotic-littoral' area and shoreline development. Therefore, the MEI in fact incorporates many interrelationships in the system which will influence fish yield, and its relationship with fish yield is more than incidental (Ryder *et al.*, 1974). A problem with morphoedaphic index is that a relationship will only hold when all cases in the data set have similar characteristics, such as geological and climatic type (Ryder *et al.*, 1974). Oglesby (1977a) suggested that considerable error might be introduced into predictions based on the MEI in culturally eutrophic lakes and even in natural systems through geochemical variability.

Other production indices. Similar relationships have been described between potential fish yield and other predictors. Hanson & Leggett (1982) described a series of relationships for a range of environmental conditions using, amongst others, phosphorus as a predictor. Melack (1976) established a relationship between primary production and yield for a number of African and Indian lakes. The same parameters were used by Oglesby (1977a) to develop a similar relationship and have been used for yield prediction in fish ponds by Liang *et al.* (1981). Primary production in a given system will generally determine secondary production and primary production will reflect many of the constraints, such as temperature, mean depth and nutrient limitation, on overall system production (Oglesby, 1977a and 1977b). Therefore, this relationship should be more accurate than some of the less direct relationships, such as the morphoedaphic index. The major limitation in use of primary production as a yield predictor is that accurate estimates of primary production are less common than morphoedaphic data (Oglesby, 1977a).

Particle size hypothesis. This was first put forward by Sheldon *et al.* (1972) and a theoretical explanation of the hypothesis was proposed by Kerr (1974). The theory states that when particles are grouped in order of magnitude categories on the basis of size, there is an approximately equal concentration of material in all categories. The theory was developed for simple food chains in pelagic systems but was used by Ryder (1978) to determine fish biomass from the estimated zooplankter biomass in Nasser Reservoir, Egypt.

Catch per unit effort (CPUE) monitoring. This method is commonly used for assessing potential yield and relies on the assumption that CPUE is proportional to stock abundance (Ryder, 1978). It has been used for monitoring fish stocks in conjunction with returns from existing commercial fisheries (Fryer & Iles, 1972; Coulter, 1977; Marshall *et al.*, 1982; Allanson & Jackson, 1983). It permits analysis of the behaviour of a fish stock but relies, for optimum usefulness, on accurate data returns from existing fisheries.

The Gulland model. This model is of the form:

$Y = XMB$ (Gulland, 1970),

where Y = long term yield,

X = the proportion of the stock available to the fishery, usually taken as 0.4 - 0.5,

M = natural mortality rate of unexploited population,

and

B = virgin biomass

The model actually assumes that, at the sustainable yield, fishing mortality will be approximately equal to natural mortality but this suggested equivalence has been attacked on theoretical and empirical grounds (Francis, 1974; Deriso, 1982). The model has been used in Lake Kariba (Marshall *et al.*, 1982) and Lake Tanganyika (Coulter, 1977 & 1981).

There are therefore a number of approaches to assessing potential yield from a system. Comprehensive management requires detailed knowledge of the biological characteristics of the stock, the interrelationships between the stock and its environment and the response of the stock to exploitation. Such information is rarely available and is time consuming and costly to obtain. In contrast, order of magnitude estimates are more easily and quickly obtained but are inadequate for correct management of an intensive fishery. In southern Africa attempts to manage inland fisheries have relied heavily on the simple order of magnitude approach (e.g. Marshall et al., 1982; Coulter, 1977).

1.1 Objectives

The aim of this study was two-fold. The first stage was to develop single-species models for the dominant species in Hartbeespoort Dam, incorporating the essential aspects of the biology of the species and those interactions with the environment necessary for realistic yield prediction. The next step was to utilise output from the single-species models to build a multi-species model, incorporating community response to important environmental parameters, but requiring the minimum amount of data. The approach to achieving these objectives was to:

(a) Determine the species composition of the Hartbeespoort Dam community and identify the major species in terms of current and potential yield.

(b) Determine the distribution of the major species within the lake and factors influencing their distribution.

(c) Describe the essential rates governing the population dynamics of the major species under existing harvesting conditions.

(d) Determine the current rate of harvest of the major species and the impact of this exploitation on the fish populations.

(e) Construct single species models to simulate the population dynamics of the species under existing environmental conditions.

(f) Construct a multi-species model using output from the single species models and information on the roles of important environmental parameters.

(g) Recommend a management strategy for the fish resource.

CHAPTER 2

DESCRIPTION OF THE STUDY AREA

Hartbeespoort Dam (25°34'S,27°51'E) is situated approximately 37 km west of Pretoria and 11 km south of Brits, the nearest major town. It is also within 50 km of much of the Johannesburg and Witwatersrand areas.

The wall was completed in 1923 and dammed the Crocodile River where it passes through the Magaliesberg Mountain range. In 1969 the wall was raised by 2.4 m to 59 m (Scott *et al.*, 1977). The lake formed by the damming of the Crocodile River has a volume, at full supply, of 192.8×10 m^3 and covers an area of 2 000 ha . The mean and maximum depths of the lake are 9.6 m and 30 m respectively (Scott *et al.*, 1980).

The lake is fed by two major river systems (Fig. 2.1). These are the Crocodile-Juskei-Hennops which drains mainly urban and industrial land, feeding into the lake as the Crocodile River, and the Magalies-Skeerpoort which drains mainly agricultural land. The dam was constructed originally as a source of irrigation water for downstream areas in the Brits magisterial district (Hofmeyr, 1978) but is currently used for irrigating approximately 130 km^2 of agricultural land, as a supply of water for the towns of Brits and Schoemansville and as an important recreational centre (Scott *et al.*, 1977).

The impoundment is classified as warm and monomictic and the annual turnover occurs in April (Scott *et al.*, 1980). Water temperatures range from a minimum of 9°C in winter (June/July) to a maximum of 28°C in summer (December/February). The hypolimnion becomes anaerobic from October to April and up to 40% of the volume of the dam can become anaerobic (Scott *et al.*, 1980). The physico-chemical characteristics of the lake are summarised in Table 2.1.

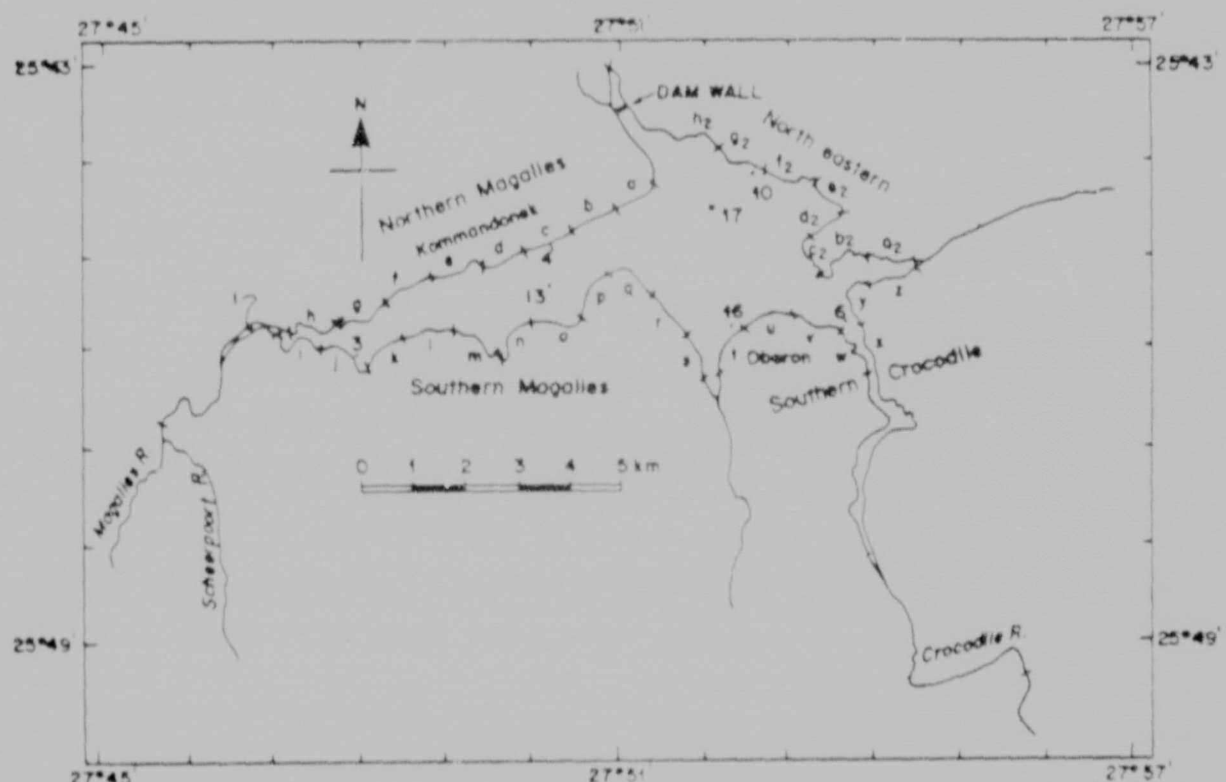

Fig. 2.1. Hartbeespoort Dam at full supply with major inflowing rivers and sampling sites. Numerically labelled sites refer to routine sampling sites and alphabetically labelled areas to shoreline zones used in mark and recapture exercises.

Table 2.1. Lake mean values of the major physico-chemical parameters in Hartbeespoort Dam (from Scott *et al.*, 1977).

Parameter	Mean
	mg/ℓ (except for *)
NH_3-N	0.69
NO_3-N	2.09
Total N	3.82
PO_4-P	0.41
Total P	0.64
pH*	8.15
Conductivity*	54 $mS.m^{-1}$
Na	41.9
K	7.34
Ca	35.5
Alkalinity	128.7
SO_4	64.2

The nutrient load to the lake was calculated as 128 g $N.m^{-2}.y^{-1}$ and 20.9 g $P.m^{-2}.y^{-1}$ of which an estimated 99% came from the Crocodile-Jukskei-Hennops system (Scott *et al.*, 1980). As a result the lake is hypertrophic and during 1976 water hyacinth, *Eichhornia crassipes* (Mart.) Solms, underwent a population explosion, as a result of the eutrophic conditions. The population reached proportions where it seriously impeded recreation on the lake (Scott *et al.*, 1979) until it was brought under control by aerial spraying of a herbicide. Chemical spraying along the shoreline is continued as a preventative measure. During the study period, standing crops of the blue-green alga, *Microcystis aeruginosa* Kutz, in excess of 1 000 mg Chl $a.\ell^{-1}$ occurred (Robarts, 1984). *Microcystis aeruginosa* was the dominant algal species and accounted for over 90% of the algal volume from December to May. *Melosira granulata* was dominant in August and *Oocystis* sp. during September and October. Primary production in Hartbeespoort Dam is currently light limited (Robarts, 1984).

Severe reduction of dissolved oxygen concentrations was observed after turnover in 1981 when the surface oxygen concentration fell from 170% to 5.7% saturation following overturn. No fish kills were observed at this time although the fish population was reported as being under stress (Robarts *et* *al.*, 1982). The historical occurrence of this phenomenon prior to 1981 is not known and it did not occur again during the study.

Seaman (1977) studied the zooplankton population and concluded that zooplankton production was detritus based and that the organisms did not utilize *Microcystis*. The dominant species were *Daphnia longispina*, *D. pulex* and cyclopoid copepods.

Prior to this study very little work had been done on the fish population of the dam. Botha (1968) recorded *Sarotherodon (Oreochromis) mossambicus* as occurring in the dam while Seaman (1977) reported *O. mossambicus and Chetia flaviventris* as forming the bulk of the population. Kleynhans (1980) stated that the exotic species *Cyprinus carpio* and *Micropterus salmoides* occurred in Hartbeespoort Dam and collected the following species from the Crocodile River, immediately below the dam wall.

Family	Species
Cyprinidae	*Barbus marequensis* Smith
	Barbus unitaeniatus Gunther
	Mesobola brevianalis Boulenger
Poecil.idae	*Aplocheilichthys johnstonii* Gunther
Cichlidae	*Oreochromis mossambicus* (Peters)
	Chetia flaviventris Trewavas
	Pseudocrenilabrus philander (Weber)

The lake is a very important recreational centre and it has been estimated that 691 000 visitor days per annum were spent there in 1976. Of this total 200 000 visitor days were spent for angling purposes and the anglers spent an estimated R772 000 per annum (Hofmeyr, 1978). Cadieux (1980) estimated that 263 147 angling days were spent at Hartbeespoort Dam during the year 1977 - 78. The reason for the popularity of Hartbeespoort Dam is its proximity to the Pretoria-Johannesburg-Witwatersrand complex and the quality of angling at the dam (Hofmeyr, 1978).

Despite the importance of the fish resource, very little is known about the nature and size of the fish community or about the impact of angling on the population. While all anglers in the Transvaal, and hence at Hartbeespoort

Dam, are required to be licensed there is no control kept over the number of anglers fishing the dam and little attempt is made to manage the fish. Up until 1982 the Nature Conservation Division of the Transvaal Provincial Administration (DNC) stocked the dam with *M. salmoides* fry, and surplus *C. carpio* fry from the Hartbeespoort Dam Hatchery were released into the lake (F. van der Merwe, DNC, pers. comm.). An on-going creel survey was instituted by the DNC at a number of dams, including Hartbeespoort, in 1982 and this represents a first step towards successful management.

In an attempt to control the eutrophication in the lake an effluent standard is being introduced, and from August 1985 water users will have to comply with a maximum 1 mg.ℓ^{-1} effluent standard for all water discharged into certain catchment areas, including that of the Crocodile River. Predictions made by the National Institute for Water Research (NIWR, 1985) indicate that the standard will result in a decrease in soluble reactive phosphorus concentration in Hartbeespoort Dam from the current 0.5 mg.ℓ^{-1} to approximately 0.1 mg.ℓ^{-1}. However, nutrient limitation of the phytoplankton will still not occur and there is likely to be little change in phytoplankton production or species composition. Nevertheless, the effluent standard is the first step in controlling nutrient enrichment and other control measures may be introduced, resulting in a decline in degree of eutrophication. Cochrane (1984) has shown that the growth of *O. mossambicus* is being retarded, probably as a result of the high pH or *Microcystis* dominance of the phytoplankton community of Hartbeespoort Dam, resulting from the high nutrient loads. The impact of potential control measures on this and other aspects of the fish community must be considered in predicting future fish yield from the lake.

During the period of this study, the water level of the lake charged considerably as a result of a severe drought. The percentage volume of the lake fell from a peak of 100% in 1981 to approximately 20% in 1983 (Fig. 2.2). As a result the three years differed considerably and the conditions in the three seasons are summarised below :

(a) 1981/82 - greater than 80% full, submerged *Potamogeton pectinatus*, emergent marginal vegetation around the fringe of the dam;

(b) 1982/83 - receding water level, falling from 78% to 37% full. As a result, there was a complete absence of any submerged or emergent vegetation; and

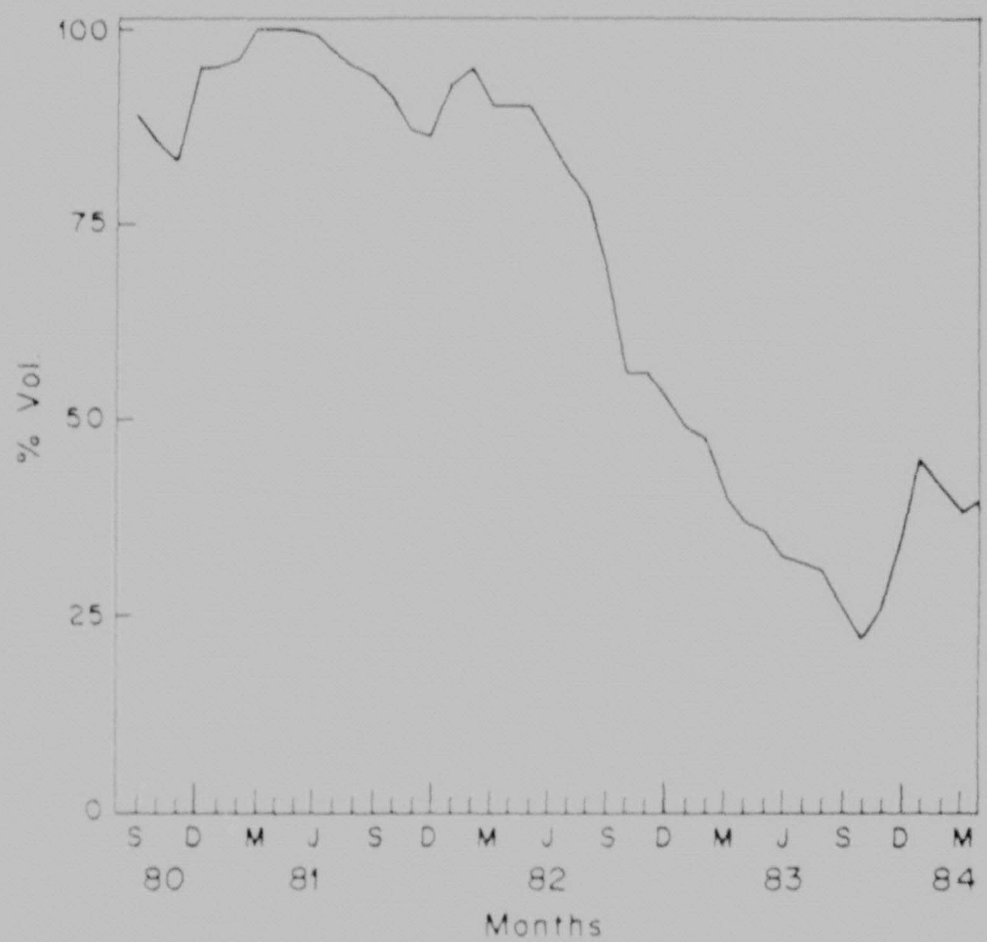

Fig. 2.2. Lake volume as a percentage of full supply volume (September 1980 to April 1984). Dept. of Water Affairs, Pretoria (unpublished data).

(c) 1983/84 - water level rising from 21% in October 1983 to 45% in January 1984. This resulted in large areas of terrestrial vegetation, largely *Polygonum* sp. and *Panicum* sp., being flooded. This vegetation survived and grew in water up to approximately two metres deep, which meant that approximately 230 ha or 20% of the lake surface area at 45% full had established aquatic vegetation.

The impact of these changes on the fish community is discussed in the relevant chapters.

CHAPTER 3

COLLECTION AND INITIAL TREATMENT OF FISH SAMPLES.

Following an initial survey of the nature and distribution of the fish population in November, 1981 (Chapter 4) a programme of routine netting was initiated in January 1982. Samples were collected with gill nets and a seine net. Two fleets of gill nets were used, each measuring 120 m made up of 20 x 2.75 m panels of 35, 45, 57, 73, 93 and 118 mm stretch mesh multifilament net.

Hamley (1975) referred to bias in size selection of nets caused by the leading of fish from small to larger mesh sizes where they may be caught. In order to eliminate such bias the different panels were not mounted in order of mesh size but were arranged in the order 35, 73, 45, 118, 57, 93 mm mesh and a one metre space was left between all panels. In June 1982, a 20 m panel of 140 mm stretch mesh was added to the fleet and the panel order changed to 35, 93, 57, 140, 73, 45 and 118 mm meshes. The problem of gill net selectivity and its influence on interpretation of age group structure has been widely discussed (Hamley, 1975). The impact of such selectivity would be considerably reduced by the range of mesh sizes used in this study and it was therefore considered to have a negligible impact on the results.

Both fleets were mounted at 50% of their total length and one was mounted for bottom setting while the other was mounted so that the top rope would hang 1 m below the surface of the water. The latter arrangement was designed to minimise the chance of damage to the nets by boats, which were used extensively for recreation on the dam. The nets were set for 4.5 h during daylight, from approximately 10h00 to 14h30. This was found to be adequate to collect large numbers of *O. mossambicus* in summer, and large catches and the resulting entanglement of nets frequently rendered panels ineffective by the end of 4.5 h. Catches of *C. gariepinus* were erratic and *C. carpio* were rarely caught in the gill nets.

From November 1981 to November 1982 samples were collected monthly, and thereafter, every second month until April 1984. In November and December 1981 gill nets were set at six localities, to investigate fish distribution (Sect. 4.2). Thereafter they were set at three stations; 4, 16 and 17 (Fig. 2.1) Station 17 was taken to be representative of the open or limnetic zone and the surface net was set at this locality. Stations 4 and 16 were used to sample the Magalies and Crocodile arms of the lake respectively. The bottom net was set at both of these localities in approximately four metres of water (approx. 150 m from the shore) and parallel to the shore.

The seine net used for routine sampling of fry measured 20 x 1.5 m and was made of 13 mm stretch mesh. Initially it was planned to collect samples with the seine net at Stations 1, 3, 4, 10 and 16 (Fig. 2.1). However, by January 1982 the water level had risen considerably flooding the marginal vegetation which consisted mainly of *Panicum* sp. and *Polygonum* sp. In addition the submerged macrophyte, *Potamogeton pectinatus* L., became widespread. The vegetation frequently prevented seine netting and, thereafter, samples were collected at four localities which varied according to suitability for netting at the time, but included sites in the southern Crocodile, north-east, southern and northern Magalies arms. The variable conditions prevented the use of catch per unit effort (CPUE) as an indicator of fry biomass. It was also found that fish moved off-shore with the onset of winter and no fish were caught after May 1982, except during the winter mortality in June and July 1982. At this time, comatose fish were carried inshore by wind-induced currents and were easily captured in the small seine-net. In October 1982, fish were again caught as the 1982/83 recruits were spawned and became susceptible to netting. The small seine net was not used from April to September 1982.

The total mass of fish caught per haul of the small seine net was recorded and sub-samples of fry were collected and preserved in 4% formaldehyde solution. Within 48 h these preserved fish were rinsed in fresh water and standard and total length and mass measured. Preservation can influence both length and mass of specimens (Lagler, 1978) but the consistency of the preservation method used permitted comparison of samples. Some discrepancy could have occurred in combining results from preserved juvenile and fresh adult fish but significant length:mass relationships were obtained for such combined samples (Section 4.2) and errors introduced through preservation were considered to be negligible.

By November 1982, after a full years sampling, it was apparent that *C. carpio* could not be caught in sufficient numbers by either of the gill nets or by the small seine. Attempts were made to catch this species using long lines made up of 20 m of 3 mm cord with hooks of varying sizes attached with fishing line every 2 m and set on the lake bottom. The bait used was brown bread mixed with raw chicken egg which was a common bait used for *C. carpio* on Hartbeespoort Dam. Forty metres of line was set on six occasions between January and March 1983 but without any success. Therefore a seine net measuring 100 x 3 m and made of 35 mm stretch mesh was used to catch carp.

Samples were collected with this net every three months from March 1983 to March 1984 from three localities, Stations 3, 6 and d2 (Fig. 2.1), the only localities where sufficient numbers of carp could be found in shallow water. Even using this net the catch per haul varied between a daily mean of less than one to a mean of five fish.

Fish caught in the gill nets and seine-netted *C. carpio* were taken back to the laboratory and total mass and number of each species, in each mesh size, recorded. Standard and total length and mass of each fish, or a representative subsample, from each mesh were measured. Hard parts were removed for growth analysis (Section 6.2.1) and sex and gonad condition recorded for fecundity and breeding season analysis (Section 6.2.2).

Specific methods for determination of biomass and population dynamics parameters are discussed in the relevant chapters.