Distribution of the three major species of fish in the Hartbeespoort Dam in relation to some environmental factors

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The catch per unit effort of *Oreochromis mossambicus, Clarias gariepinus* and *Cyprinus carpio* at different localities at Hartbeespoort Dam was investigated. Catches of the three species were between three and ten times higher on the southern shore of the lake than on the northern shore. The gradient of each locality was found to be the most important variable determining catch. Gill-net catches of *O. mossambicus* from littoral and limnetic stations indicated equal abundance of the species in these two habitats. The implications of the results for improved predictions of fish yield from lakes, and for management are discussed.
S. Afr. J. Zool. 1986, 21: 177 – 182

Die vangs per eenheid poging van *Oreochromis mossambicus, Clarias gariepinus* en *Cyprinus carpio* is by verskillende lokaliteite in Hartbeespoortdam ondersoek. Vangste van hierdie drie spesies was tussen drie en tien keer hoër aan die suidelike oewer as wat dit aan die noordelike oewer was. Die gradiënt van elke lokaliteit was die belangrikste veranderlike om vangsopbrengs te bepaal. Vangste van *O. mossambicus* met behulp van kieunette in oewer- en oopwaterstasies, het aangedui dat die vis in gelyke getalle in die twee habitatte voorkom. Die moontlikheid dat die resultate die voorspellings vir visproduksie in mere en die bestuur daarvan kan verbeter, word bespreek.
S.-Afr. Tydskr. Dierk. 1986, 21: 177 – 182

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Received 5 August 1985; accepted 12 December 1985

Hartbeespoort Dam is a major recreational resort situated close to the Pretoria-Witwatersrand-Vereeniging complex and the fish community is heavily exploited (Cochrane 1984). The dam is hypertrophic and the algal community is dominated by *Microcystis aeruginosa* Kütz (Robarts 1984). Twelve fish species have been recorded in the dam of which three species, *Oreochromis mossambicus* (Peters), *Cyprinus carpio* L. and *Clarias gariepinus* (Burchell) accounted for over 90% of the biomass caught in gill nets, seine nets and by anglers (Cochrane 1984).

Hartbeespoort Dam is a dendritic impoundment (Figure 1), the dam wall of which was constructed in a gorge where the Crocodile River flowed through the Magaliesberg. The shore-line can be roughly divided into four regions, the northern Magalies, southern Magalies, southern Crocodile and north-eastern regions (Figure 1). The nature of the shore-line of these regions differs at full supply (Table 1).

Table 1 General geological characteristics of the shore-line of Hartbeespoort Dam. Geological data from maps 2527 DB and DD, Geological Survey, Dept. of Mines, Pretoria

Region	Shore-line zones (Figure 1)	Geological characteristics
Northern Magalies	a – h	Diorite, pyroxenite, sand and gravel. Mean gradient = 1:18 (n = 5, $2SE$ = 5,1)
Southern Magalies	i – s	Shale, soil and gravel, occasional diorite. Mean gradient = 1:49 (n = 9, $2SE$ = 14,2)
Southern Crocodile	t – z	Shale. Mean gradient = 1:35 (n = 4, $2SE$ = 10,0)
North Eastern	$a_2 - g_2$	Shale, some diorite. Mean gradient = 1:29 (n = 6, $2SE$ = 11,5)

During extensive beach-seining exercises, around the perimeter of the dam, as part of mark and recapture experiments (NIWR 1985), it became apparent that there was a pattern to the distribution of fish. The purpose of this paper is to describe the distribution and identify some of the factors causing the heterogenous distribution.

Methods

The seine-netting exercises were carried out in May and October 1982 using a 100 m × 3 m seine net of 35 mm stretch

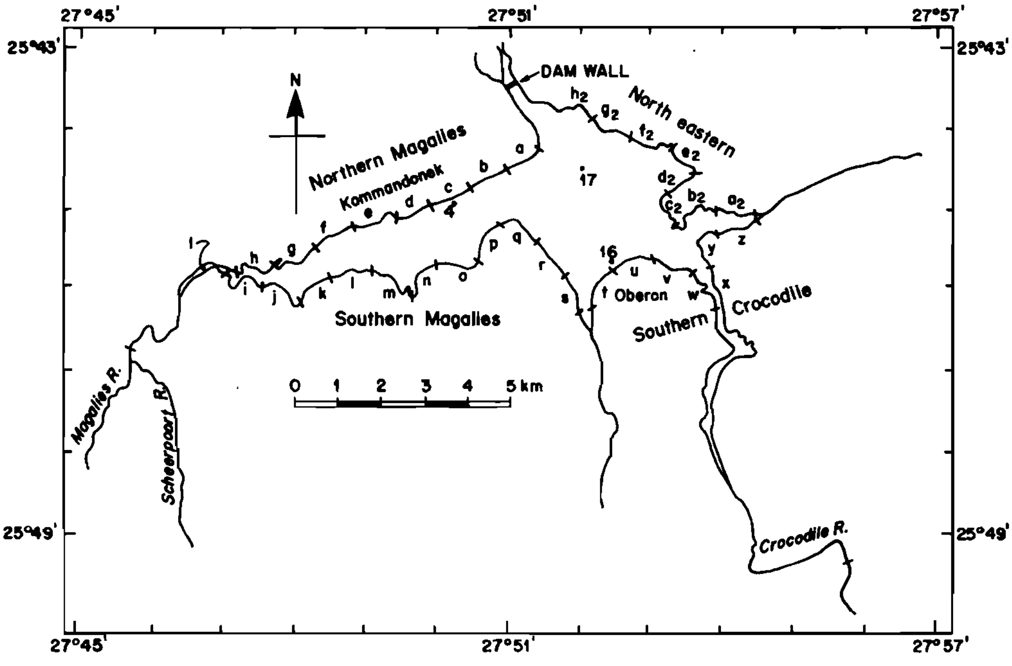

Figure 1 Hartbeespoort Dam showing major shore-line regions and sampling stations.

mesh. Exercises were undertaken over a two-week period during which approximately 40 hauls of the net were undertaken on each occasion. For the purpose of the mark and recapture experiment it was necessary to randomly select the netting sites.

The total length of all fish caught was recorded and the individual, and hence total, mass of each species caught at each station was calculated from length:mass ratios described for the species in Hartbeespoort Dam (Table 2). In October 1982 catches of *C. carpio* were too small to reliably determine the distribution of the species.

Table 2 Length:mass relationships for *O. mossambicus* and *C. gariepinus* in Hartbeespoort Dam. TL = total length (cm), M = mass (g)

Species	Relationship	*n*	r^2
O. mossambicus	$M = 0{,}07\ TL^{2{,}64}$	55	0,58
C. gariepinus	$M = 0{,}13\ TL^{2{,}38}$	37	0,86
C. carpio	$M = 0{,}16\ TL^{2{,}53}$	55	0,87

The nature and relative abundance of the limnetic fish community was examined using two fleets of gill nets made up of seven 20-m panels of 35, 45, 57, 73, 93, 118 and 140 mm stretched multifilament mesh. A top set net was set at Station 17 and a bottom set net at Stations 4 and 16 (Figure 1), each month from January to November 1982. The nets hung to a depth of 2,5 m and were set in 3,5 – 4 m of water at the two littoral stations.

The occurrence of fish in the profundal zone was investigated by undertaking a single survey using a Kelvin-Hughes MS-130 Fish-finder. The survey was conducted in June 1982 when the dam was unstratified and oxygen was present throughout the water column. Six transects were undertaken over the length of the dam and a total of 11,04 km was surveyed. The minimum and maximum depth of fish in each transect was measured and the mean minimum and maximum depths for the six transects calculated. The profundal zone is anaerobic in Hartbeespoort Dam for approximately six months of the year between October and March (NIWR 1985).

Factors regulating the fish distribution were investigated using the October 1982 seine-netting results, when catches were high. The factors considered most likely to influence fish distribution were the gradient, and degree of shelter from wave action, of the particular sites. These could be expected to influence macrophyte and benthic primary production and hence secondary production, including that of fish. The degree of shelter at a given site would be inversely proportional to the maximum wind fetch to which the site was exposed. The prevailing wind directions over Hartbeespoort Dam are north-westerly and east-south-easterly (NIWR 1985). The fetch in these two directions and the gradient at individual sites were read from a morphometric map (NIWR 1985). Data on certain sediment characteristics (A. Twinch pers. comm.) were also used where they had been collected from sites coinciding with netting points.

The correlations between the sum of *O. mossambicus* and *C. gariepinus* catches and the environmental parameters were examined using least squares linear regression and the multiple regression package REGPAC (Galpin 1981).

Results

The catch per unit effort (CPUE) of *O. mossambicus* (Figure 2) and *C. gariepinus* (Figure 3) showed clear trends. Catches were essentially lower on the northern and north-eastern shores than on the southern shore. The shallow bay formed by the zone d_2 and e_2 in the north-eastern region (Figure 1) provided high yields of *O. mossambicus* and *C. gariepinus* in May and October respectively (Figures 2 & 3).

Differences in catches between the four shore-line zones were examined using the Mann-Whitney *U* test (Zar 1974). This test confirmed the pattern suggested by Figures 2 and 3 (Table 3). In May 1982 *O. mossambicus* density was significantly different in the southern shore (including the bay formed by zones d_2 and e_2) and the northern shore excluding this bay. Catches in the former zone were approximately six

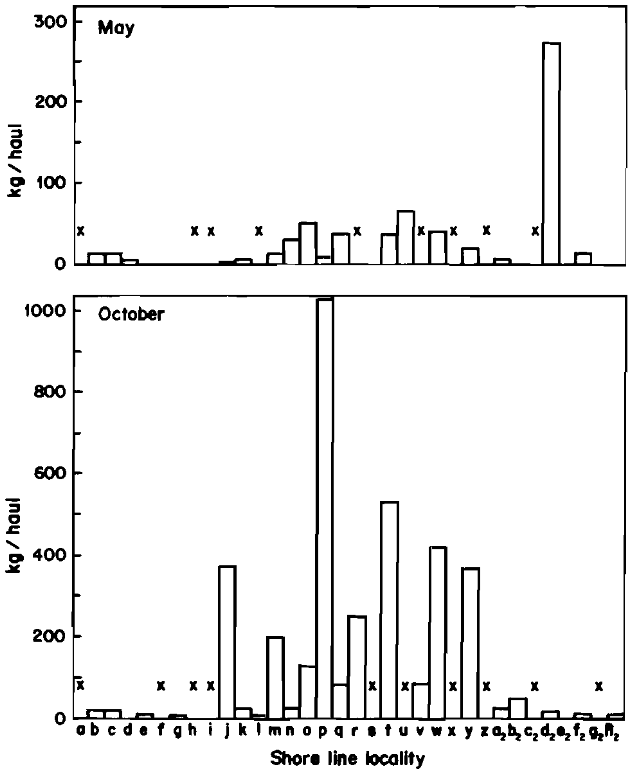

Figure 2 Mean catch per unit effort of *O. mossambicus* at different localities around Hartbeespoort Dam (May and October 1982). For key to localities see Figure 1. X indicates no samples collected.

times greater than those in the latter (Table 3). In October 1982 the trend was similar (Figure 2) but the mean catch along the entire southern shore was more than ten times greater than the mean for the northern shore. The distribution of *C. carpio* in May 1982 followed that of *O. mossambicus* but in October 1982 samples were too small to analyse. In May the mean *C. gariepinus* catch along the northern Magalies shore was approximately one tenth of that along the rest of the shoreline while in October the most significant difference was between the northern and southern shore-lines with the mean catch in the latter approximately three times greater than that in the former (Table 3 & Figure 3). The northern Magalies and north-eastern shores lie along the base of the Magaliesberg range and hence have higher gradients (Table 1) which could result in lower standing stocks of fish.

The environmental variables correlating most closely with *Oreochromis* and *Clarias* CPUE were (Table 4a)

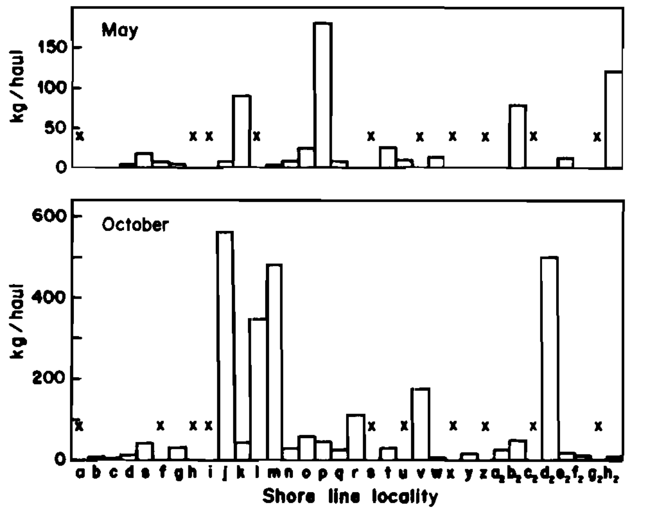

Figure 3 Mean catch per unit effort of *C. gariepinus* at different localities around Hartbeespoort Dam (May and October 1982). For key to localities see Figure 1. X indicates no samples collected.

(i) 1/Gradient
(ii) ESE fetch (negative)
(iii) NW fetch (positive)

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 4b). The form of these two equations was

(i) TRCP = −3,7 − 0,54 Cl + 2,03 Gr + 0,29 NW + 0,17 ESE
(ii) TRCP = 83,8 + 9,16 Gr + 0,06 NW, where
TRCP = ln (CPUE),
Cl = ln (% clay in sediments),
Gr = ln (1/Gradient),
NW = ln (NW fetch) (km) and
ESE = ln (ESE fetch) (km).

These equations were intended to assist in the identification of the regulatory parameters and not to be used as predictive equations, but an examination of residuals was undertaken using a one-sample runs test (Siegel 1956). The results were
(i) (−) = 5, (+) = 6, runs = 6
(ii) (−) = 14, (+) = 6, runs = 9
r (0,05, 5, 6) = 3 − 10 and r (0,05, 14, 6) = 5 − 13.
Thus the distribution of residuals in both equations can be said to be random which reduces the risk of error in prediction (Galpin 1981).

Table 3 Comparison of catch per seine net haul (CPUE) in major shoreline areas of Hartbeespoort Dam in May and October, 1982 (*U* = Mann-Whitney statistic)

Species	Month	Zone 1	CPUE(kg)	Zone 2	CPUE(kg)	*U*	*P(U)*
O. moss	May	S.shore + d_2e_2	50,92	N.Magal. + NE-d_2e_2	7,54	268,5	0,05
	Oct	S.shore	200,4	N.shore	18,4	392	< 0,001
C. gar	May	S.shore + NE	35,11	N.Magal.	3,35	242	< 0,01
	Oct	S.shore	144,8	N.shore	50,0	304	< 0,05
C. car	May	S.shore + d_2e_2	17,21	N.shore + NE-d_2e_2	3,01	292,5	< 0,01
	Oct	Total	5,7				

Table 4a Correlation coefficients for *O. mossambicus* and *C. gariepinus* CPUE (October 1982) and certain morphometric and sediment parameters (See text for key to abbreviations)

Ind. Variable	*n*	Corr. coeff.	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	0,5
% Silt	11	0,22	0,7
% Org. Carbon	11	0,23	0,7
Tot. Sed. P.	11	0,23	0,75

Table 4b Multiple correlations (1n 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

Analysis of gill-net catches for the period January to November 1982 showed that *O. mossambicus* accounted for 98,6% of the limnetic catch (St. 17) with the only other two species being *Barbus marequensis* and *Barbus mattozi*. The mean catch of *O. mossambicus* at St. 17 was 6,90 kg 100 m^{-1} (n = 12, 95% CI = 1,41) and for Stations 16 and 4, 6,43 kg 100 m^{-1} (n = 22, 95% CI = 2,89). These show that there was no significant difference between catches at the limnetic and littoral stations and that *O. mossambicus* densities in the two habitats did not differ markedly.

Fish were identified on the echo traces as discrete vertical targets occurring largely in the upper half of the water column (Figure 4). The mean minimum and maximum depths at which fish occurred in the six transects were 1,53 m (n = 6, $2SE$ = 0,18) and 6,79 m (n = 5, $2SE$ = 0,67) respectively showing that the littoral and limnetic zones were utilized by fish. No targets were recorded in the profundal zone suggesting that fish were absent from or scarce in this region of the dam.

Discussion

Catches of carp were considerably lower than those of the other two species (Table 3) and yet the species accounted for 74% of the angler catches (Cochrane 1984). *C. carpio* is known for its ability to avoid capture by nets (Beukema & de Vos 1974; Koch & Schoonbee 1980) which probably explains the discrepancy. The species is commonly found in shallow water (Edwards & Twomey 1982) and in the P.K. le Roux Dam occurred in water less than 2 m deep (Allanson & Jackson 1983). However, anglers in Hartbeespoort Dam preferentially fish in deeper channels close to the shore where *C. carpio* are most common, and would be less vulnerable to the seine net used. Therefore, the low incidence of carp in the seine-net catches is probably a combination of avoidance ability and habitat preference, and not an indication of low relative abundance. The much lower catches in Zone 2 (3,01 kg $haul^{-1}$) than in Zone 1 (17,21 kg $haul^{-1}$) in May 1982 (Table 3) do suggest that *C. carpio* has the same general shore-line distribution as the other two species.

O. mossambicus and *C. gariepinus* seine-net catches were between two and fifteen times higher in summer than in winter, indicating a seasonal migration into the littoral areas during summer, and a movement into deeper water in winter. These movements have been recorded in *O. mossambicus* in Lake Sibaya and in other tilapia species in other parts of Africa and have been ascribed to convergence on selected breeding and feeding sites in summer (Bruton & Boltt 1975). Clay (1979) suggested that *C. gariepinus* juveniles in Lake McIlwaine, Zimbabwe, inhabited the littoral areas in the summer months when temperatures were high and moved into deeper water in winter where temperatures were more stable. He stated that diurnal and seasonal migrations between littoral and deeper waters by juvenile *C. gariepinus* were the result of preference for the temperatures at which growth would be optimum. A similar view, emphasizing the importance of temperature in regulating the distribution of cichlids, has been put forward by Caulton (1978). Caulton (1978) showed that high temperatures during the day (30°C) and low temperatures at night (18°C) would result in optimal growth in *Tilapia rendalli* Boulenger. The highest diurnal temperatures in any water body could be expected to occur in shallow, sheltered areas where wind-induced mixing would be reduced.

Hakanson & Jansson (1983) showed that the abundance and species diversity of benthic invertebrates decreases with increasing depth although in eutrophic impoundments a second peak in abundance, dominated by oligochaetes, may occur in the profundal zone. They also showed that the abundance of organisms in littoral regions 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). In the summer of 1982/83, however, aquatic vegetation was not present in Hartbeespoort Dam because of the low water level. Therefore greatest production of food organisms will occur in shallow, sheltered areas and it is in such regions that highest fish densities could be expected.

Gradient would also influence the area over which the seine net used for fish capture was effective and thus differences in CPUE for the various localities may have been exaggerated by differences in gear efficiency. The distance from the shore

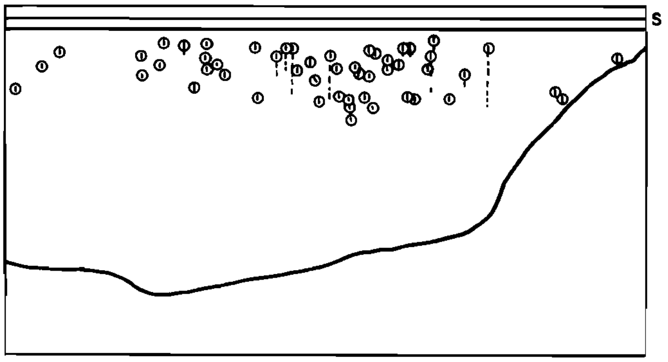

Figure 4 A diagram of an echo-trace obtained travelling south from the vicinity of St. 17 to shore-line region t in June 1982. Targets representing fish are enclosed in circles. Vertical scale 1:263, horizontal scale 1:12225. S = water surface.

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 1) between the different shore-line 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 3). Hence, while the influence of gradient on gear efficiency would have affected catches, it was not the major causative factor.

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 the ESE fetch but there was a positive correlation between CPUE and NW fetch. There are two probable explanations for this contradiction: (i) ESE winds may account for greater turbulence or wave action by predominating in frequency or strength, and (ii) 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 gradient and fetch may be generating meaningless correlations between CPUE and fetch.

Therefore gradient was the major factor determining seine-net CPUE in Hartbeespoort Dam. Some of the influence was through the impact of gradient on seine-net efficiency but most of the influence was due to greater abundance of fish in shallow, sheltered areas. The accumulation of fish in these areas was probably the result of selection of the optimum combination of preferred temperature and maximum food availability, moderated in summer by selection of breeding sites.

The demonstration that, in Hartbeespoort Dam, gradient alone accounted for 43% of the variation observed in CPUE supports the contention, implicit in the morpho-edaphic index (Ryder 1965), that fish yield is inversely related to mean depth. The relationship also refutes the suggestion that the correlation found between fish yield and morpho-edaphic index is incidental and results from the obvious positive correlation between fish yield and surface area (Youngs & Heimbuch 1982).

Mean depth has been used in combination with total dissolved solids as a predictor of potential yield in lakes since the description of the morpho-edaphic index (MEI) by Ryder (1965). Relationships between yield and MEI have also been described for African water bodies (Henderson & Welcomme 1974; Marshall 1984). These models provide valuable mean lake predictions. Relationships of the sort described in this study between CPUE and morphometric and sedimentary parameters could be used to extend the mean lake predictions by predicting the distribution of potential yield within a water body. An improved relationship between catch per unit effort and gradient for different localities within a lake or impoundment could be used to predict the surface distribution of the potential yield from the water body. While this may be of little use in a relatively small water body, such as Hartbeespoort Dam, it could be useful in large lakes where effort is concentrated in specific localities. Two dimensional predictions based on easily measured parameters, such as morpho-edaphic index and a gradient grid woud be particularly useful in the early development of fisheries, even at the pre-impoundment planning stage. In lakes where there is a distinct limnetic fish community which does not move freely between limnetic and littoral regions, the proportion of the total yield available in each region would also need to be determined. The simplest method would require measuring relative CPUE in each region and considering differences in production:biomass ratios between the two communities.

The importance of gradient in determining standing stock has relevance to management. The fish community at Hartbeespoort Dam is currently being heavily exploited by anglers (NIWR 1985). As population and urban growth continue, pressure on existing resources will increase and it is possible that Hartbeespoort Dam will be over-exploited. The creation of artificial bays of low shore-line gradient on the relatively unproductive northern shore would increase benthic and plant production and support a higher fish biomass. These could be used to increase the yield from the dam.

The gill-net catches showed that the limnetic water was being occupied by *O. mossambicus*. This species is generally regarded as a detritivore and epiphytivore (Bruton & Jackson 1983) but specimens were frequently found to have been ingesting *Microcystis aeruginosa* in Hartbeespoort Dam and probably filter-feed while in limnetic water. The ability of *O. mossambicus* to utilize *Microcystis aeruginosa* is uncertain and it has been suggested that the species is under some stress in Hartbeespoort Dam (Cochrane 1984). The possibility exists that fish yield from the dam could be increased by the introduction of a robust phytoplanktivore but, before this is considered, the current status of *O. mossambicus* in this limnetic, phytoplanktivorous niche needs to be ascertained. If a species could be identified which would be able to better utilize *M. aeruginosa* and did not pose a conservation threat, its introduction could be seriously considered.

The estimated sustainable yield from Hartbeespoort Dam is 260 kg ha^{-1} which ranks amongst the top 5% of yields recorded from lakes in Africa (Cochrane 1985). This sustainable yield is largely exploited by anglers (NIWR 1985). The development of the northern shore to increase the yield of fish as food may not be a commercial proposition at present as the capital cost of the construction of artificial shallows would be high. However, the increased resource could be exploited for recreation, and prime angling sites developed, either privately or by the Provincial Administration, for which profitable entrance fees could be charged. Such schemes are in existence for trout waters in South Africa and habitat modification in rivers has been widely practised (Hynes 1970). The potential for such a scheme on Hartbeespoort Dam must be jeopardized at present by the poor water quality. A decrease in eutrophication and consequent increase in species diversity, including the re-establishment of black bass, *Micropterus salmoides*, would increase the desirability of Hartbeespoort Dam as an angling venue. Without an improvement in water quality, the Dam may lose its appeal as a recreational resource. If this occurs, the revenue generated by the recreational fishery could fall to such an extent that the utilization of the fish resource as a protein source could become socioeconomically preferable.

Acknowledgements

This is contribution No. 19 to the Hartbeespoort Dam Ecosystem Study. The assistance in the collection of data of the staff of the Division of Nature Conservation, Transvaal Provincial Administration is gratefully acknowledged. Valuable comments on the original manuscript were provided by an anonymous reviewer. Funding for the research was provided by the National Institute for Water Research and the Foundation for Research Development, CSIR, Pretoria.

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