Limnology and Fisheries Potential of Lake le Roux

B. R. Allanson and P. B. N. Jackson.

A collaborative report of the Institute for Freshwater Studies, the J.L.B. Smith Institute of Ichthyology, the Cape Department of Nature and Environmental Conservation and the Committee for Inland Water Ecosystems.

SOUTH AFRICAN NATIONAL SCIENTIFIC PROGRAMMES REPORT NO
77
December 1983

Issued by

Cooperative Scientific Programmes
Council for Scientific and Industrial Research
P O Box 395
PRETORIA
0001

from whom copies of this report are available on request

Printed in 1983 in the Republic of South Africa
by Kohler Carton and Print, Port Elizabeth

ISBN 0 7988 2960 5

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PREFACE

The great dams of the Orange River, in common with those elsewhere in the world, were built for benefits such as the provision and storage of water for irrigation and the generation of hydroelectric power. The establishment of a fishery is, in the planning of a new impoundment, almost always a secondary consideration. Yet from the time of the closing of Kariba almost exactly twenty-five years ago, it has been shown without doubt that the establishment of a fishery, in the lake which forms behind the new dam wall, has in nearly every case in Africa been a most valuable benefit additional to those for which the dam was first planned.

Realising this, the South African Council" for Scientific and Industrial Research convened a workshop on man-made lakes in Bloenfontein in 1977. Arising therefrom, under the aegis of the CSIR's Cooperative Scientific Programmes, the project in respect of which this report is presented came into being. It has been a cooperative project in a very real sense of the word, wherein limnologists from the Institute of Freshwater Studies, Rhodes University and ichthyologists and fishery managers from the Cape Department of Nature and Environmental Conservation and the J.L.B.Smith Institute of Ichthyology, Rhodes University came together to get to grips with what is, perhaps even exceeding that of water pollution, the most important problem that there is in South African freshwater resource use. That is to manage in the best possible way, for which a thorough understanding of their hydrobioiogical processes is necessary, the turbid waters heavily charged with suspensoids which are such an .almost universal feature of South African upland dams. As more and more storage dams and manipulations across watersheds come into being, their wise, multipurpose use becomes ever more necessary.

The team has built upon the work of others, whether in South Africa or in countries where problems are often similar and where active collaboration with whose scientists is in progress, such as Australia and the USA. It would be the last to claim that the work is complete. This report is but a step on the road, but nevertheless an important step. It presents much new information and clarifies many difficult aspects, all of great value to the resource manager. Among much else it shows the suspensoids[1] importance in retarding light penetration, limiting heat impact and slowing production, the effect of wind on lacustrine coolness, and the seasonal development of plankton relative to the thermal regime, presenting quantitative models of these things. The life histories of important highveld fish are unequivocally clarified, breeding sites discovered, year-classes defined, rates of growth assessed, and distribution and feeding habits at different growth stadia accurately quantified. It has shown without doubt the desirability and feasability of an industry to harvest the fish, providing thousands of rand and hundreds of tons of fish to an area where work opportunities are limited and where people could enjoy eating, and provide a ready market for, the fish which the great dams produce.

Much remains to be done, perhaps most of all in the now long overdue assessment and establishment of that market, but also in the fields of resource monitoring and population analysis of the fishery, as well as continuing the fundamentally important task of assessing primary productivity as affected by wind and turbidity. The team is proud of what it has been able to achieve between 1978 and 1983, but realises full well that what could be done within this short time span and the limited funds available falls far short of what is necessary if we are to have an adequate understanding of Southern Africa's greatest river.

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ACKNOWLEDGMENTS

We acknowledge with appreciation the help and co-operation afforded to us by Mr K. Coetzee and Mr J. Cambray at the Douglas Hey Limnological Laboratory, Van der Kloof. Our thanks are due to Mr S. Hahndiek who assisted with the limnological measurements required at the beginning of the investigation.

The very material assistance of Mrs Susan Allanson is sincerely recorded. Without her careful attention to detail while preparing the text for printing, the editors and contributors would have been at a loss to adequately prepare the printer's copy. Our thanks are also due to Mrs Pat Eva who gave unstintingly of her time whenever it was necessary, and to Mr W. Uys who translated the abstract into Afrikaans.

LIMNOLOGY AND FISHERIES POTENTIAL OF LAKE LE ROUX A

collaborative report by the IWE/CPA working group

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ABSTRACT

The fisheries potential of the reservoir in the Orange River has been determined by the combined studies of ichthyologists and limnologists. The combination has been synergistic. It has been shown that the physical structure of the reservoir, coupled with its short retention time of less than one year and the rapid attenuation of light by the high suspensoids, are together responsible for the low summer temperature of the lake. Because of this the overall metabolism of the lake is low. It is argued that this is the primary factor in control of the reservoir's production of fish. Included in this is the effect of rapid light attenuation upon the photosynthesis of phytoplankton and therefore the production of immediately assimilable plant cells such as diatoms which are grazed by filter feeding zooplankton. Dense blooms of Microcystis aeruginosa do occur during the second half of summer but they do not seem to increase the standing stock of zooplankton upon which the principal fish with a pelagic life history stage, the smallmouth yellowfish, feed in the subadult stage. This important food fish selects the large zooplankters individually, depending on vision to catch its prey. The maintenance of high suspensoid concentrations therefore reduces the efficiency of foraging. At age 2+ years a return to a more inshore feeding mode is made when considerable natural mortality, up to 80% by the end of the 3rd year, occurs. Annual breeding takes place regularly, confined almost exclusively to the flowing Orange River at the lake's upper end. In contrast the other important food fish, the Orange River labeo, spawns irregularly depending on more local rainfall; therefore strong yearclasses are only produced in some years. Total annual yield is provisionally assessed at 150 - 250 tons, giving, at R 1/kg, a minimum value of R 150 000 per annum. It is therefore recommended that a commercial gill-net fishery be established, primarily for yellowfish, with a mesh size chosen to optimize the capture of subadults up to 30 cm long to harvest these before they die of starvation. Larger fish would remain and form the basis of a recreational angling fishery. This management proposal is unorthodox but essential if the productivity of the lake is to be used economically. Recommendations include the careful monitoring of the commercial catch in conjunction with continued assessment of the response of the stocks to this policy by fisheries biologists of the Cape Department of Nature and Environmental Conservation.

SAMEVATTING

Die visserypotensiaal van die reservoir in die Oranjerivier was deur die gekombineerde studies van viskundiges en limnoloe bepaal. Die kombinasie het 'n sinergistiese effek tot gevolg gehad. Daar was getoon dat die fisiese strukturering van die dam, gekoppel met die kort retensietyd van minder as 'n jaar en die snelle vermindering van lig deur die hoe suspensaatvlakke, saam verantwoordlik is vir die hoe somer temperature van die dam. As gevolg hiervan is die algehele metabolisme van die dam laag. Dit word aangevoer dat dit die primeYe faktor is wat in beheer staan van die reservoir se visproduksie. Ooreenleggend is die effek van snelie ligvermindering op fotosintese van fitoplankton en dus die produksie van ontmiddelik assimileerbare plantselle soos diatome, wat deur filtervoedende zooplankton benut word. Digte bevolkings Microcystis aeruginosa kom wel in die tweede helfde van die somer voor, maar dit blyk nie die staande voorraad zooplankters waarop die belangrikste vis met 'n pelagiese lewenstadium, die kleinbek geelvis, in die subvolwasse stadium voed nie. Hierdie belangrike voedselvis selekteer individuele groot zooplankters en maak op sig staat om sy proei te vang. Die volgehoue hoe vlak van suspensaatkonsentrasies verminder dus die effektiwiteit van hierdie manier om voedsel te bekom. Op 'n ouderdom van 2+ jaar keer die vis terug na 'n vlakwater manier van voeding, wanneer hoe natuurlike sterftes, tot 80% aan die einde van die derde jaar, voorkom. Jaarlikse broeisiklusse vind op 'n gereelde basis plaas en is amper geheel en al beperk tot die vloeiende Oranjerivier aan die bokant van die dam. In teenstelling broei die ander belangrike voedselvis, die Oranjerivier modderbek, ongereeld omdat dit afhanklik is van plaaslike reenval. Sterk jaarklasse kom dus net in sekere jare voor. Die totale jaarlikse lewering word voorwaardelik geskat op 150 - 250 ton. Teen R 1/kg kan dit 'n minimum van R 150 000 per jaar lewer. Dit word dus aanbeveel dat 'n kommersiele stelnetvissery gevestig word, prime"r vir geelvis, met 'n maasgroote wat sal selekteer vir vangste van subvolwasse vis van tot 30 cm lank, om hierdie visse te vang, voordat hulle van die honger omkom. Groter vis sal behoue bly en die basis van 'n sporthengelvissery vorm. Dit mag 'n onortodokse beheervoorstel wees, maar dit is essentieel as die produktiwiteit van die dam ekonomies benut wil word. Onder andere word aanbeveel dat die kommersiele vangste noukeurig gemonitor word, gekoppel met voorgesette raming van die visbevolking se reaksie op hierdie beleid, deur visserywetenskaplikes van die Kaapse Departement Natuur- en Omgewingsbewaring.

CONTENTS Page

PART 1 : SYNOPSIS OF RESULTS AND RECOMMENDATIONS

PART 2 : THE SCIENTIFIC REPORT

1. Introduction

2. Limnology and fish biology

3. Management

PART 1: SYNOPSIS OF RESULTS AND RECOMMENDATIONS

B.R. Allanson a P.B.N. Jackson

SYNOPSIS OF RESULTS, and RECOMMENDATIONS

Preamble

Lake le Roux was created in 1976 by construction of the P.K. le Roux Dam on the Orange River in the vicinity of Petrusville. Collaborative research on this system has been undertaken by the Institute for Freshwater Studies, the J.L.B. Smith Institute of Ichthyology of Rhodes University, and the Cape Department of Nature and Environmental Conservation, with two primary objectives:

(1) To determine the structure and biology of the fish community and its response to the physical, chemical and biological events in the lake, and

(2) to assess the fishery potential of this 130 square kilometre lake from both angling and commercial viewpoints.

This report presents the results of the study initiated in 1977 and completed in 1983, which was funded by the Inland Waters Ecosystems section of the CSIR's National Programme for Environmental Sciences, the Cape Provincial Administration, and Rhodes University.

1. SYNOPSIS

(1) The fish commmunity is described in Chapter 2.4.2 and illustrated in Figure 1. As in most highveld South African reservoirs, it is dominated by fish belonging to the family Cyprinidae (6 out of the 9 species present). The smallmouth yellowfish (Barbus holubi) and Orange River labeo (Labeo capensis) offer the greatest fishery resource potential. The small chubbyhead barb (Barbus anoplus) is also numerous throughout the lake. The carp (Cyprinus carpio) and the sharptooth catfish or barbel (Clarias gariepinus) are less important though well represented in sheltered habitats. Less numerous species are the mogggel (Labeo umbratus), the largemouth yellowfish (Barbus kimberleyensis), the rock catfish (Gephyroglanis sclateri), and a banded tilapia (Tilapia sparrmanii).

(2) This community makes its living in a reservoir characterised by relatively low water temperatures in summer, usually between 19-21°C, and high turbidity due to silty suspensoids. Thermal stratification commences between October and November and continues until May when stratification breaks down. This monomictic pattern, shown in Figure 2.1.3, is characteristic of most South African reservoirs which stratify in summer.

The coolness of the lake is principally a result of high evaporation due to the low ambient relative humidity and persistent windiness. The silty suspensoids limit the vertical penetration of solar radiation so that only the surface waters, certainly not greater than 1 m in depth, heat up during the daytime. This warmer and therefore more buoyant water requires an increase in wind energy to bring about mixing.

SYNOPSIS

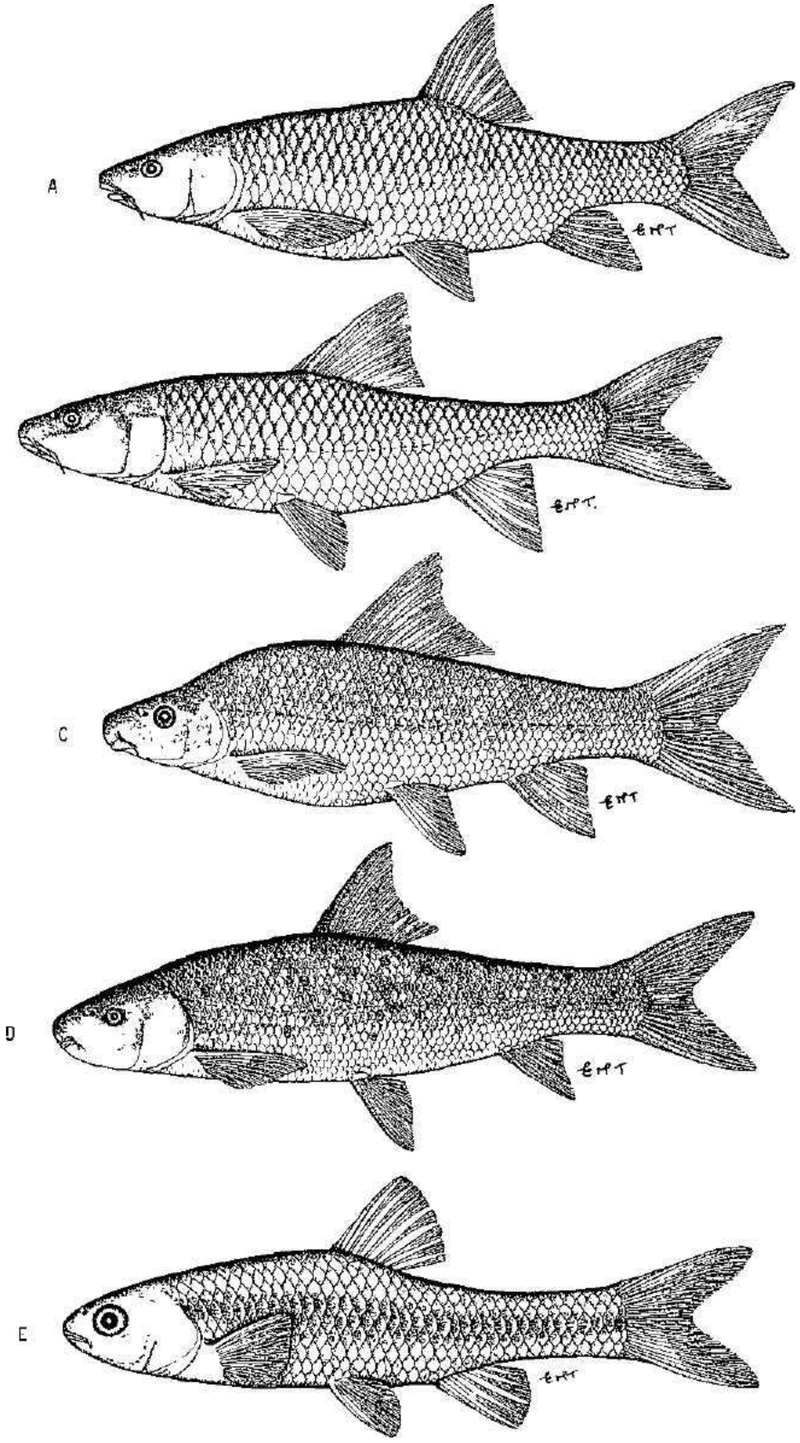


FIGURE 1. The fish fauna of Lake le Roux.
A : Smallmouth yellowfish Barbus holubi.
B : Largemouth yellowfish Barbus lumber leyens is.
C : Orange River labeo Labeo capensis.
D : Moggel Labeo umbratus.
E : Chubbyhead barb Barbus anoplus.

SYNOPSIS

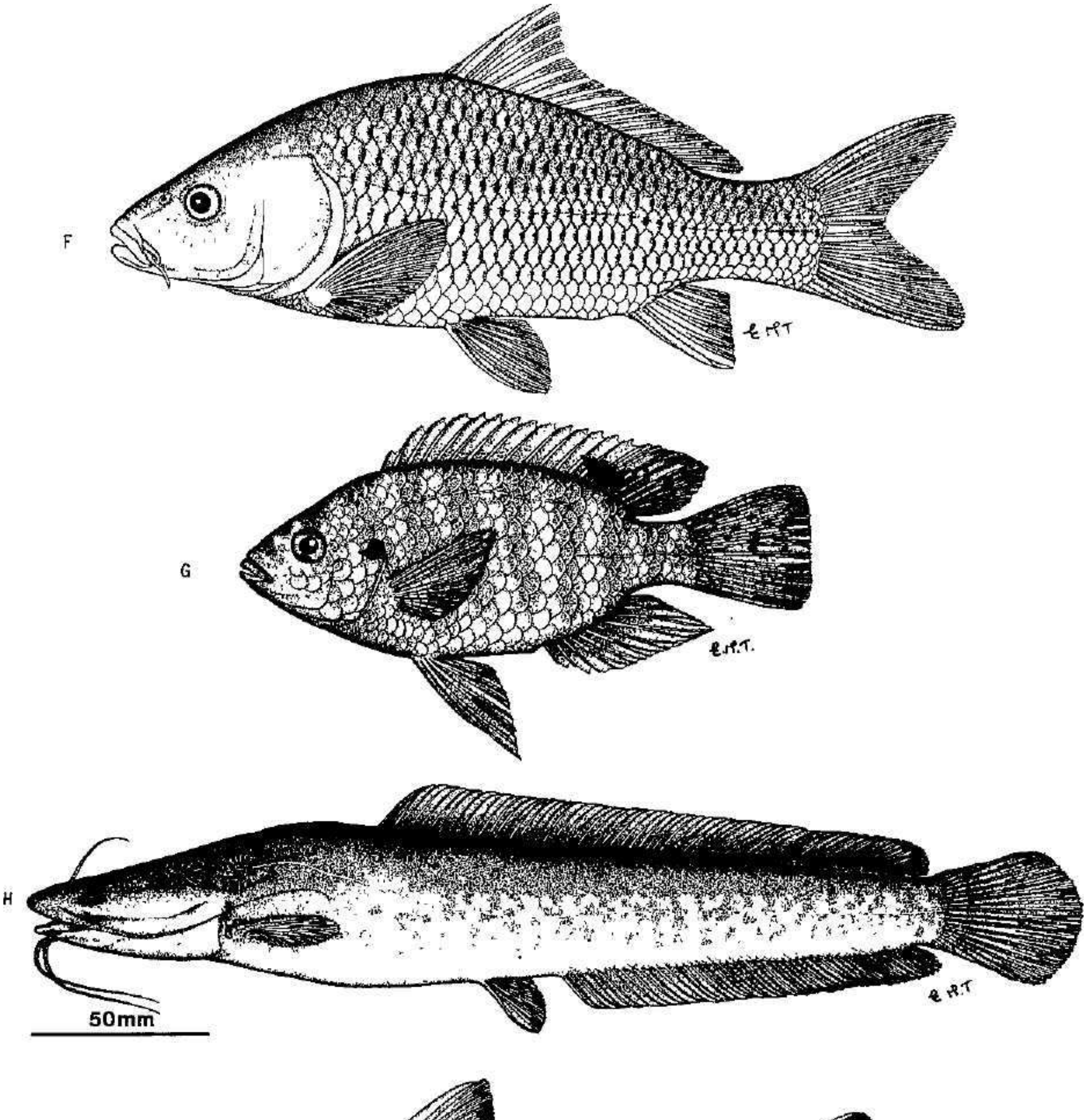


FIGURE 1. The fish fauna of Lake le Roux.
F : Carp Cyprinus carpio (full scale variety).
G : Banded tilapia Tilapia sparrmanii.
H : Sharptooth catfish or barbel Clarias gariepinus.
I : Rock catfish *Gephyroglanis sclateri*.

(All figures by permission of the artist, Elizabeth M.Tarr, and the J.L.B.Smith Institute of Ichthyology.)

During summer the wind strengths, although sustained, are often insufficient to do this, so that the surface water loses heat by radiation, evaporation and sensible loss at night, and as it cools it sinks to isodensity in the upper mixed layer by convection.

A consequence is that the number of days when water temperature exceeds 20°C (degree-days above 20°C) is small, although variation does occur from year to year depending upon meteorological conditions. The waters of the hypolimnion below the thermocline seldom exceed 10°C, the temperature of the lake during complete circulation during the winter.

As temperature is often the primary driving or forcing function in all biological systems, summer temperatures as low as exist in the lake will tend to limit both the number of species of fish which can make up the community, and the rate at which they grow.

(3) Algal photosynthesis is limited by both the unfavourable light climate and the level of nutrients. The results reported in Table 2.1.5, p. 23 of- Part 2, show the lake to have a conservative chemical structure. The nutrient anions of nitrate nitrogen and soluble reactive phosphorus (SRP) are generally maintained at 450 and 30 ug/£ respectively throughout the surface waters. At these concentration levels the lake may be described as oligotrophic, a condition which is reinforced by the high suspensoid concentration in the lake which decreases its transparency and thus limits algal growth. Some indication of just how marked is this effect is given by a comparison of the attenuation of light. In clear lakes, the vertical attenuation coefficient approximates 0.25/m, while in Lake le Roux this coefficient varies between 5 and 7/m, which results in a euphotic depth of 1 m! As the upper mixed layer or epilimnion is some 15 to 20 times the depth of the euphotic zone, the phytoplankton spends long periods in the dark water, during which time respiration exceeds photosynthesis. These factors in general result in low levels of pelagic primary productivity (cf. pp. 29-33, Part 2). However, those groups of algae which can adjust their buoyancy, e.g. the blue-greens such as Microcystis aeruginosa and Anabaena circinalis, compete successfully for the available lighf, and even in the absence of increases in nitrate-N and SRP form blooms in the buoyant water at the surface during summer. This was particularly striking during the summer of 1982/83. Under these conditions the lake has characteristics of a eutrophic reservoir.

The phytobenthos, because of the low transparency and the steepness of the lake shore (Figure 2B), is limited to a narrow strip immediately below the water surface. Rapid drawdown exposes this strip to the air, while filling results in marked reduction in light and leads to the death of the algal association. A consequence of this is that the phytobenthos, compared with the phytoplankton, contributes insignificantly to the primary energy fixation processes.

In addition to the planktonic and benthic algae, there also exists an important extraneous input of organic carbon compounds mainly from the inflow of the Orange River. Together they represent the principal sources of food for the lake ecosystem. This investigation has provided a measure of the relative contribution each makes to the whole, and is summarised in Part 2, Figure 2.2.18.

(4) Only one fish species, the Orange River labeo, can make direct use of algae, in this instance the phytobenthos (Part 2, Figure 2.2.16). The pelagic fish depend upon invertebrate herbivores, the zooplankton, to act as an initial converter. This array of small crustaceans consumes the fine organic particulate matter flushed into or produced in the lake, and contributes a vital link in the food web of the pelagic community, particularly for the smallmouth yellowfish, Barbus <u>holubi</u>, at certain stages of its life history.

The development of zooplankton is highly seasonal, and the annual biomass cycles correspond broadly to the annual thermal regime (Part 2, Figure 2.2.11). Species successions occur within the zooplankton in which the copepod Metadiaptomus meridianus dominates the early spring every year, followed by various Daphnia spp. and Moina brachiata (water fleas) in mid-summer, when predatory components, particularly the* copepod <u>Loyenula excellens</u> proliferate^

The horizontal distribution of the zooplankton decreases along the hydraulic axis of the lake and correlates closely with the abundance of phytoplankton as measured by chlorophyll concentration. Their vertical distribution is very largely restricted to the upper 10 m at Station 1 (Figures 2.2.2 and 2.2.9). This is to be expected in turbid waters. The annual production rate of this community varied from as much as 1000 tonnes during 1977/78 to as little as 270 tonnes during 1981/82. This apparently downward trend follows maturation of the reservoir, and will have a material effect upon the production of smallmouth yellowfish which use only 1/3 to 1/7 of the total zooplankton production. This is largely due to the importance of visual cues in the feeding of Barbus holubi, which has been stressed and experimentally confirmed in the investigation of the feeding biology of this species (Part 2, Chapter 2.3). An important development of this ~ study is the link between feeding and temperature in the smallmouth yellowfish. As the lake temperatures during winter are somewhat higher than those which a riverine population would experience, the metabolic requirements will of necessity be higher, and in those individuals which do not feed or experience *wery* long gut passage rates (in excess of 40 hours at 10°C), will impose a drain on their energy reserves* They would, as a result, enter the spring period in a low condition. An array of correlations given in Figure 2.2.20 summarises the interactions which exist between the abiotic and biotic factors which influence the biology and yield of the smallmouth yellowfish.

(5) Of the nine fish species present, the smallmouth yellowfish has, of the likely commercial species, adapted best to lake conditions. It spawns[1] almost exclusively in the main-stem Orange in water entering from Lake Verwoerd and feeds, up to a length of 6-10 cm, on benthic

fauna inshore. Above this length the smallmouth yellowfish spend more time offshore, and fish of 15-35 cm (2nd-4th year) obtain the major part of their diet by exploiting a small part of the stock of zooplankton, visually selecting the largest individuals. As a visual planktivore, the smallmouth yellowfish feeds during the daytime. The effectiveness of feeding is markedly influenced by water transparency. Thus annual growth rates of this fish and experimental catch returns were closely linked to annual zooplankton abundance levels, and transparency conditions during the study (Part 2, Figure 2.2.20).

Above this size/age there is heavy natural mortality, and by the end of this stage 80% or more may have died naturally of starvation. Food resources then suffice for the survivors who return to the littoral eating larger items with a marked vegetable component. Natural mortality is less, though growth is slow, but some reach a large size. Even stunted individuals of this species can spawn.

(6) The only other abundant large species, Orange River labeo, spawns opportunistically, and therefore less regularly, near rivers in flood. It has fewer, though numerically more abundant, year classes than yellowfish. Feeding mainly on algae, detritus and possibly bacteria, labeo suffer natural mortality only by becoming so abundant as to outstrip food supply at times of high water turbidity. This species does not stunt and only fully-grown adults can spawn, which further restricts the number of year classes in the population.

(7) The most numerous small species is the chubbyhead barb, which has adapted very well to lake conditions. It has increased greatly due to multiple spawning and effective niche colonization. It occurs in all habitats even in offshore pelagic waters, except where there is competition from equivalent-sized young of large cyprinids.

(8) Details of all other species are given but none was very abundnant because of lack of suitable habitats and limitations of food and, for banded tilapia, sharptooth catfish and largemouth yellowfish, relatively low summer water temperatures. Flooded tributary valleys (Figure 2A & C) are particularly productive habitats, especially for carp, catfish and labeo. Some potential exists for longlining for catfish (barbel), and angling for carp and catfish.

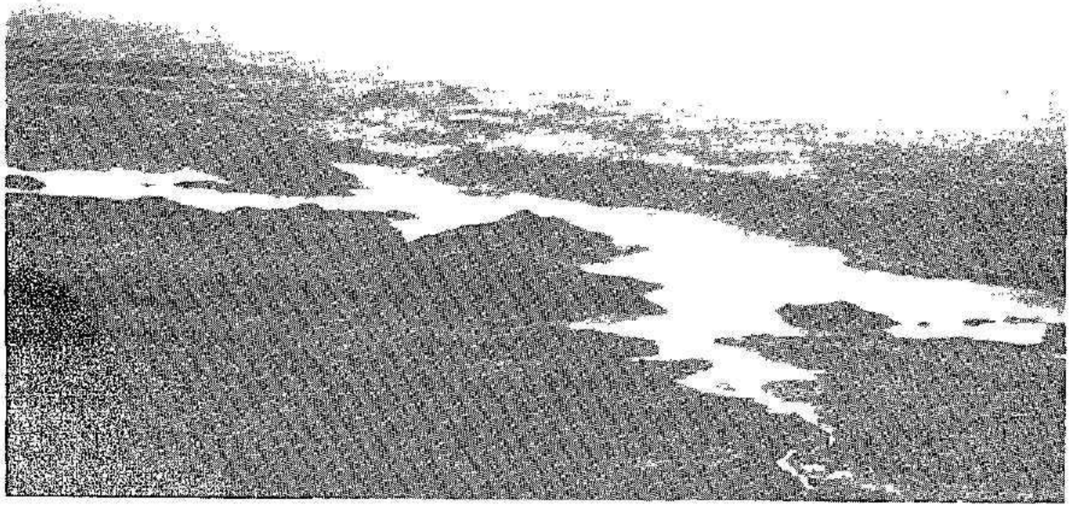
(9) Commercial exploitation is both feasible and desirable in order to harvest the numerous subadult fish which are too numerous for the available food supply and would otherwise starve and die. Management proposals are based on the understanding gained of the limnological regime and aimed at the twin objectives of encouraging simultaneously both commerical and recreational (angling) use of the resource. This is possible without any clash of interests by restricting the use of gillnets to those with a 50-75 mm mesh size. These nets are highly selective and their use would ensure that catches were only in the size range of 20-30 cm where, as explained in Part 2, Chapters 2.4.4 and 2.5.1, high natural mortality is inevitable as the fish begin to change from zooplankton to bottom feeding and die of starvation as a result.

Effort should be moderately intensive, aiming at harvesting some 50-70% of the class annually. Good annual recruitment of yellowfish into these size-classes is expected, ensuring good continuity of yield without overfishing. This fairly high fishing intensity would considerably reduce natural mortality of the survivors because there would then be enough food. Relatively rapid growth and high survival rate of spawners would ensue, to the benefit of the resource. As none of the larger fish will be caught by gill-nets since large meshes are prohibited, a good proportion of large fish will occur.

(10) The management strategies for labeo differ somewhat from those for smallmouth yellowfish. Due to irregular spawning, success-dependent on sporadic floods, the labeo population is composed of fewer year-classes than the yellowfish. Labeo stocks should, therefore, be mainly held in reserve for use in years of poor yellowfish recruitment into the fishery. This can be regulated by setting nets inshore or by the use of bottom-set nets when labeo are desired.

(11) Our findings, on the basis of the fish stocks which currently exist in the reservoir, initially appraised at an annual yield of 150-250 tonnes (Chapter 3.3.1), show that a minimum retail value of some R150 000 per annum might be expected. Thus we might expect this harvest to benefit the local Griqua population in terms of the "resolutions of the 1963 Bloemfontein conference of the South African Association for the Advancement of Science regarding sharing of the Orange River project goods.

A



B

C

FIGURE 2. A : View looking northeast. Kattegat Spruit, one of the numerous minor flooded valleys in right foreground, with Vaalkop mountains (1406 and 1360 m) to its left in centre of photograph, and the entrance to the large Knapsak River valley diagonally opposite on the Orange Free State side.

B : Steep rocky shoreline characteristic of most Lake le Roux littoral. Shallower areas are suitable habitat for smallmouth yellowfish and Orange River labeo.

C : Relatively productive water in the Seekoei River valley, showing calm sheltered conditions, shallow soft substrata formed from eroded banks, inundated terrestrial vegetation and rocks and hard ground forming a base for algae.

(Photographs by P.B.N.Jackson)

2. RESEARCH AND DEVELOPMENT RECOMMENDATIONS

2.1. Development and management of Lake le Roux fisheries

Rationale

Research has shown Lake le Roux to have a fish yield with a tentative estimated value of at least R 150 000 per annum (Chapter 3.3.1). Its exploitation would also create a number of local employment opportunities. To obtain these benefits a commercial fishery should be started immediately. Since very large numbers of fish, especially smallmouth yellowfish, but also Orange River labeo and other species to a lesser extent, are lost to the lake through high natural mortality, the fishery should be so managed as to harvest these fish while still available. Angling would be simultaneously encouraged because larger fish would not generally be affected by controlled netting.

Recommendations

(1) A marketing survey for freshwater fish should be be undertaken to allow rational investment decisions to be made in respect of the Orange River in particular and inland fisheries in general.

(2) Since smallmouth yellowfish is the commercial species best adapted and most sucessful in the lake, but mostly die and are wasted after reaching 20-30 cm in length, a commercial fishery should be established for this species, using gillnets of 50-75 mm mesh to catch them at this size. This should from time to time be supplemented by catches of Orange River labeo of a similar size, especially when yellowfish stocks are low as the result of a poor year-class due to low water temperatures in the relevant spawning season. The controlling authority should monitor the resource and allow heavy exploitation of accumulated stocks of Orange River labeo as an alternative to yellowfish only when stocks of the former species permit, though there will always be some labeo present as a by-catch in a fishery for yellowfish.

The main fishing method for yellowfish should be floating gill nets, set at a minimum distance of 100 m from the shore, since more yellowfish than labeo are caught in open water. These would have a relatively low catch per unit effort, but labour and maintenance costs would be low. Exploitation of accumulated stocks of Orange River labeo could be effected by allowing nets to be set close inshore or permitting the use of bottom-set nets in deep water. Management policy should be sufficiently flexible to allow such changes to be made with quite short notice.

It is important that the stretched mesh size of gill nets should be restricted to the range 50 to 75 mm. These would exploit the yellowfish while they are dependent on zooplankton as their main food source, and before they are subject to the heavy natural mortality which accompanies the change to other food sources. A further reason for encouraging a subadult fishery is that, in its absence, a fishery for adults would be adversely affected by stunting resulting from resource limitation, i.e., too many individuals competing for limited amounts of food. The gill nets of this mesh size would not catch the larger individuals which are sought after by anglers. This fact should be publicized amongst the angling community. In order to exploit, to some extent, the carp populations which favour such areas, some beach seine netting should be permitted during the months of May to August inclusive, under the supervision of the managing authority. Some longlining for sharptooth catfish can similarly be undertaken under supervision.

The fishery should be operated by local people and produce a dried, brined product for the local market, although this should not preclude the sale of fresh fish when opportunity permits. Ownership of the enterprise could be vested in the fishermen themselves, or they could be employed by an individual or a company.

(3) The fishery would be most efficient if it could be based in the area of the drowned farms "Doornfontein" or "Schoonhoek" on the eastern side of the lake in the area of the largest basin, where there are farm tracks running from the lake to the Philippolis/Luckhoff road {Figure 3.4.1 A, B). If more than one fishing unit was established, a second should be based in the valley of the Knapsak river or in the lowest, most productive, basin of the lake either on the town of Vanderkloof or on the north shore.

(4) Commercial gill netting should not be allowed upstream of the confluence of the Seekoei River, nor in the drowned valleys of the Berg, Hondeblaf and Seekoei Rivers. This would preserve populations of potential spawners in areas adjacent to the major spawning grounds.

(5) Catches both of the present angling fishery and of any future commercial fishery should be monitored to determine the effects of the removal of sub-adults on the stock available to angling. If the stock of adults is found to be very lightly exploited, consideration should be given to allowing their occasional exploitation by a commercial fishery using nets of a stretched mesh of at least 100 mm.

(6) The development of a sport angling fishery should be encouraged, by means of publicity, especially at Vanderkloofdam where the infrastructure for tourism exists, and in the water adjoining the Doornkloof and Rolfontein Nature Reserves of the C.D.N.E.C.

(7) The collection of revenue from the fishery should take the form of licence fees rather than of levies on the actual yield of fish. Licences should be valid for a period of five years, subject to the payment of an annual fee, and should be revoked if the privileges of the licence are not exercised.

RECOMMENDATIONS

(8) Both Lake le Roux and Lake Verwoerd should be retained at as high a level as is consistent with the interests of other users, and the spawning of yellowfish should be encouraged by manipulating the discharges from the H.F.Verwoerd Dam so that the highest possible water temperature is attained in the river between September and December, as discussed in Chapter 3.1.

(9) Should the extraction of further potential power from the system be considered desirable, consideration should be given to the construction of one or possibly more barrages with low-head turbines to utilize the 25 m drop between the tailrace from the Verwoerd turbines and the full supply level of Lake le Roux. This would supply additional power from the system without increasing the overall consumption of water from the present storage capacity. It would have the further advantage of increasing the passage time of cool water discharged from Lake Verwoerd before it enters Lake le Roux and would allow this to become warmer during the summer months, thus increasing the total heat content of the lower lake and enhancing its productivity. The validity of this proposal should be examined using the proven reservoir dynamic model 'DYRESM' (Imberger & Patterson 1981). The intermediate lake would also have a certain fisheries potential. However the construction of a barrage across the riverine section below the dam might have adverse effects on the spawning of the yellowfish, and this should be an important consideration when sites are evaluated. As a last resort, provision could be made for hatchery facilities to replace lost spawning grounds.

(10) Inefficient steps in the trophic web of Lake le Roux have been identified, especially that the feeding habits of the fish at present in the dam are such that while the larger members of the zooplankton are picked out individually by yellowfish, the phytoplankton and the smaller zooplankters, which constitute the great bulk of the zooplankton stocks, are not eaten to any significant extent by any fish in the dam, since the catfish, which does filterfeed, is essentially a warm-water species and thus not abundant in the lake. This problem must be examined, with a view to possible introduction of fish, perhaps filter feeders which do not select individual prey items and therefore, especially in a turbid lake, have an advantage over fish which visually select their prey. This will require a literature survey to identify possible fish types for introduction to the Orange River lakes and to assess their potential ecological impact.

(11) Should the Department of Nature and Environmental Conservation of the Cape Province proceed with a project to provide mullet fingerlings for stocking farm dams, these should also be introduced, subject to the findings of (10) above, to Lake le Roux on a trial basis. While these exploit food similar to that of the labeo they are, from sporting and culinary criteria, superior to the native species. Such an action is reversible since mullet do not breed in fresh water.

RECOMMENDATIONS

2.2. Future research recommendations for Lake le Roux

The present study into the fisheries potential of Lake le Roux has, while indicating the presence of a potentially valuable fishery, highlighted the effects that a fluctuating environment has on fish production, population structure and abundance. Although we can predict the direction and to some extent the magnitude of change in the fish population in relation to environmental change, given the range of conditions which have occurred since impoundment in late 1976, and the long life span of the principal fish populations, many more years' work is needed to understand and quantify these relationships adequately.

One of the main limitations of the present programme is the lack of knowledge in absolute population numbers and therefore potential yield. Data from a reasonably intensive fishery (CPUE and age composition of the catch through time) would yield this vital information.

Due to the large environmental fluctuations and their effect on the fish population, a fishery can only be properly managed if environmental changes can be predicted in advance. This requires a more holistic approach {see 1.3) towards reservoir research which must include increased understanding of the factors governing their limnological behaviour.

We therefore recommend the following :-

(1) That the nature of physical and chemical limnological processes in determining and regulating the biological productivity of this monomictic reservoir be examined further in detail. In view of the central importance of temperature data,installation of continuous temperature recording equipment should be considered at all outlets and suitable points on inlets (eg. gauging weirs) to dams and barrages on the greater Orange River system as a whole. Costs of such installation at major dams such as H.F.Verwoerd or P.K.le Roux are infinitesimal in relation to engineering costs. The long term record provided by such installations is essential to any modelling programme of lake hydrodynamics and in assessing potential impacts of altered, hydraulic regimes, and, in conjunction with other information, likely levels of biological production.

(2) That benthic primary and secondary production processes, organic sedimentation, and microbial decomposition be studied in relation to the feeding ecology of labeo and moggel.

(3) That the determinants of blue-green algal blooms in the absence of gross nutrient enrichment be examined in view of their relevance to eutrophication response phenomena of turbid impoundments.

(4) That further research be undertaken on the trophic resources and their utilization by zooplankton in silt-laden waters, as exemplified in the Orange River reservoirs.

(5) That the determinants of resource exploitation by indigenous planktivorous fish be investigated.

(6) That the depth distribution of fish stocks be studied in relation to limnological conditions, especially stratification, wind stress and turbidity.

(7) That catch rates of fish be studied more specifically in relation to limnological conditions.

(8) That finally a refined multivariate analysis of factors influencing reproductive success, growth rates and mortality of the major fish stocks be undertaken with a view to separating the co-varying influences of water temperature, discharge rates and water level, water transparency, food availability, fish abundance, etc. upon the condition of breeding stocks. Simultaneous comparative studies in Lake le Roux, Lake Verwoerd and its Caledon and Orange River inflows could provide internally controlled observations allowing for the elucidation of the relative importance of these factors and an unambiguous identification of direct causality.

2.3. The importance of an holistic approach in research and development of the Orange River Ecosystem

Resource management of the Orange River system should be approached in a holistic manner, ideally under a single authority as for example the Tennessee Valley Authority in the USA or the Avon Water Board in the UK, with representation of all interested parties. Failing this, close liaison between separate management authorities is essential to optimize resource development and exploitation. For example, the management of fisheries in Lake le Roux depends in large measure upon the hydraulic operation of the Verwoerd Dam.

A study of Lake Verwoerd and its catchment should be undertaken, developing upon previous knowledge of Lake Verwoerd and the present findings on Lake le Roux. Particular attention should be given to :-

i) the potential impact of the Highlands/Oxbow scheme on the hydrobiology of the upper Orange River and the existing impoundments;

ii) the general limnology and fisheries of Lake Verwoerd;

iii) the influence of hydraulic management of Lake Verwoerd on downstream impoundments including the proposed Torquay Dam, with a view to the ultimate management and integration of the fishery resource of the system as a whole.

Studies on the hydrobiology and hydrochemistry of the lower Orange River, i.e. below P.K.le Roux Dam) should be encouraged particularly in view of the potential impact of proposed developments of water management schemes in the Vaal River.

PART 2 : THE SCIENTIFIC REPORT

B.R. Allanson, DM. Eccles, R.C. Hart,
P.B.N. Jackson & T. Tomasson

Chapter 1.

INTRODUCTION

Background and objectives

B.R. Allanson & P.B.N. Jackson.

The study of this large impoundment on the Orange River was initiated primarily to examine the fisheries potential of the lake formed behind the P.K. le Roux Dam. Notwithstanding the availability of comparatively cheap marine fish products, the view that these would become increasingly more expensive was not unreasonable. The protein resources of the lake might be economically competitive, being closer to inland markets, as well as affording additional employment opportunities in the centre of a relatively poor area.

Justifications for the high capital costs needed to build a large impoundment are always in terms of the economic benefits that the project will bring, in provision of hydroelectric power or storage of water for agricultural, industrial or domestic use. Fisheries are seldom considered in such initial planning, yet the fish populations which occupy these large new impounded waters often prove to be an asset additional to the benefits for which the dam was originally constructed. Lake Kariba, where millions of dollars worth of fish are now harvested annually without in any way interfering with the primary purposes for which the dam was built, is a good example of multi-purpose use of a large impoundment. With the large impoundments on the Orange River, similarly, the initial economic justifications and planning of the Orange River Project took no account of their potential as a fish source. This was understandable as reservoirs in the Republic of South Africa are rarely, if ever, thought of as'having an important fisheries' potential, unlike man-made lakes in tropical Africa. However, at a South African Association for the Advancement of Science Symposium on the Orange River Project, held in Bloemfontein in 1963, concern was expressed that the reservoirs, once filled, should become a focus of limnological and fisheries biological studies from which a future management policy of these multipurpose structures could arise. Several recommendations to this effect were made; of particular relevance is Recommendation no.5, which paid attention to the effect of the development on the coloured (Griqua) people whose standard of living would be raised, inter alia, "...as a result of the creation of new productive resources" (Biesheuvel, 1963). Sport fisheries were discussed by du Plessis and le Roux (1965).

INI EDUCTION

An early start was made on Lake Verwoerd by the Institute of Environmental Studies at the University of the Orange Free State under the direction of Professor J. van Zinderen Bakker. The fisheries work was initiated by Hamman (1974 b), who outlined aims and preliminary results of work on the structure of the fish community of Lake Verwoerd; while in 1976 a series of eight reports by K.C.D. Hamman, J.A. Cambray and N. Fairall documented the development of these initial ideas during 1972-1975 (Department of Nature and Environmental Conservation, 1976); and Jackson (1973) recorded breeding of important fish species in Lake Verwoerd in October 1972.

The P.K. le Roux Dam was meanwhile under construction and it was quickly recognized that the lake formed behind it would be quite different in character from Lake Verwoerd. To many fish biologists, the extensive development of the shoreline of Lake le Roux created the potential for rich fisheries, and this characteristic, coupled with the provincial decision to allow Lake Verwoerd to fall under the responsibility of the Orange Free State Department of Nature Conservation, and Lake le Roux under the Cape Provincial Department of Nature and Environmental Conservation, caused the latter Department to build a new limnological-fisheries laboratory on the banks of Lake le Roux.

The opportunity for collaboration which this development allowed was quickly realized, and through the good offices of the Cape Provincial Administration, and funding from Cooperative Scientific Programmes, CSIR (CSP), a collaborative programme between the Cape Department of Nature and Environmental Conservation, the J.L.B. Smith Institute of Ichthyology and the Institute for Freshwater Studies at Rhodes University was agreed upon in mid-1977.

The objective of the programme was to undertake the necessary multi-disciplinary research work for the utilization of the fish resource of Lake le Roux, to assess the desirability or otherwise of establishing commercial and/or recreational fisheries on the dam, and to provide management authorities with the stock assessment information needed for the proper regulation of such fisheries.

Specifically the project was designed to provide answers to the two key questions which were formulated at the January 1977 CSIR workshop on man-made lakes:-

1. "What is the fish production potential of man-made lakes ?"
2. "To what extent can man-made lakes be used for the commercial production of fish ?"

A provisional estimate of 192 tons of fish per year from Lake le Roux was made at that time (see discussion, Chapter 3.3.1), which even at the very low figure of R0.25/kg would yield R48 000 per annum.

INTRODUCTION

The team which assembled to examine the growth and likely magnitude of this resource in Lake le Roux included both fisheries biologists and limnologists: the combination has been particularly productive both of ideas and of results. The Working Group formed under the auspices of the Inland Water Ecosystems section of the Cooperative Scientific Programme and the Cape Provincial Department of Nature and Environmental Conservation met regularly; and individual scientists had many informal discussions during the progress of the investigation, exchanged ideas and data, and quickly recognized the contribution each specialist in the team could make, eventually answering the prime question: Did the limnological character of the reservoir and the response of the principal fish species present favour the establishment of a commercial fishery, no matter how simple ?

The job is certainly not complete, but sufficient is known to allow management decisions both at a dam operation level and at a provincial fisheries level. In addition and complementary to this aspect of our work is the realization that the conditions of this reservoir, as of other impoundments in South Africa, are unique. There is consequently a very real need to establish the principles of reservoir structure and function, including their response to a diverse array of environmental factors and multipurpose use. The present critical drought emphasizes the need in our minds to respect these resources and to ensure that during the years of plenty their potential is not squandered: wise use must replace the present ad hoc management procedures. No such use is possible without the closest collaboration between engineer, administrator, and biologist. To ignore this is to repeat, in our inland waters, the primary cause of the crisis in the fishing industry along our west coast.

This collaborative report is presented in the hopes that it will contribute to the protection and wise utilization of this very important reservoir.

Chapter 2. LIMNOLOGY AND FISH BIOLOGY

2.1. THE PHYSICAL AND CHEMICAL LIMNOLOGY OF LAKE LE ROUX

B.R. Allanson, C.L. Beuthin, C.J. Jansen & W.T. Selkirk.

2.1.1. Introduction

Lake le Roux {Figure 2.1.1) was created by damming of the Orange River (29°51S 24°43E) at the end of a narrow, sinuous gorge which runs in a NW-SE direction, and which the river has dissected through the Karoo dolerite and lower horizons of Beaufort shales. The tributaries of the main stem river in this vicinity had cut downwards and flowed at the bottom of deep clefts. As a consequence of this dissected nature of the gorge, the lake is narrow, deep, and possesses a well-developed shoreline.

TABLE 2.1.1. Morphometric parameters of Lake le Roux.
Those used to define the reservoir are : length (1); mean breadth (6); area (Ao) (FSL); volume (Vo) (FSL); mean depth (z); maximum depth (zm); relative depth (zr); length of shoreline (lo) (FSL); shoreline development (Dl); development volume (Dv).

	l km	$\bar{b}$ km	A_o km²	V_o km³	z_m m	$\bar{z}$ m	z_r %	l_o km	D_l	D_v
Whole lake	73.44	1.74	128.1	2.93	73	23	0.57	404.5	10.1	0.95
Basin 1	2.40	1.73	4.15	0.12	73	29.1	3.17	36.8	5.1	1.20

The lake is the second in a series of three, of which the first, Lake Verwoerd, upstream of Lake le Roux, was formed in 1970, and its limnology has been briefly recorded by van Zinderen Bakker (1974). The limnology of Lake le Roux contrasts sharply with what has been reported for Lake Verwoerd. Of particular significance is the thermal regime of Lake le Roux. The lake is cool in summer with a mean midsummer temperature of 22°C. This coupled with a high but varying turbidity is in effective control of its biological production.

The purpose of this chapter is to describe and interpret the physical and chemical features of the lake with a view to examining the validity of this view.

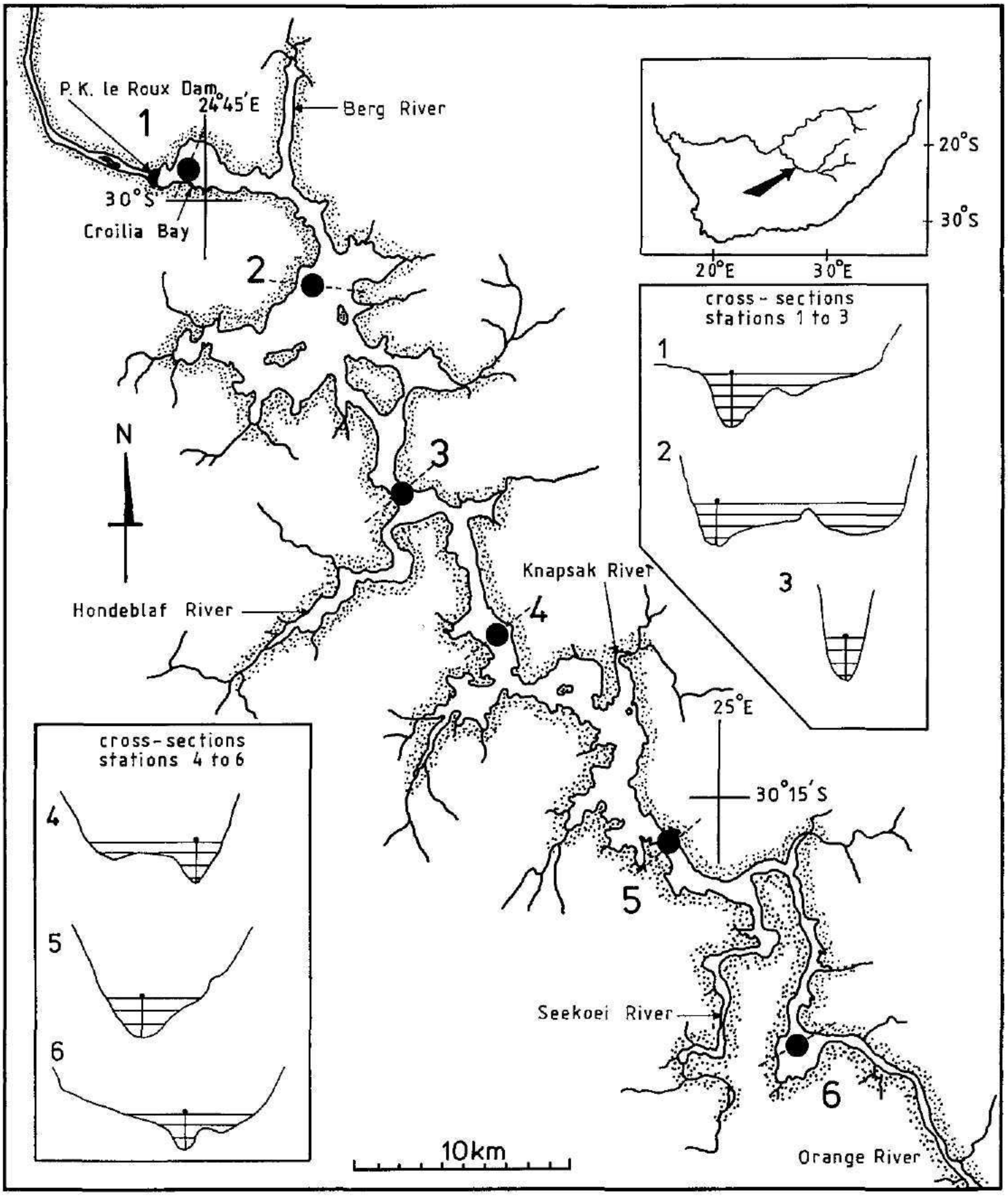


FIGURE 2.1.1. The shoreline of Lake le Roux showing the routine limnological stations.

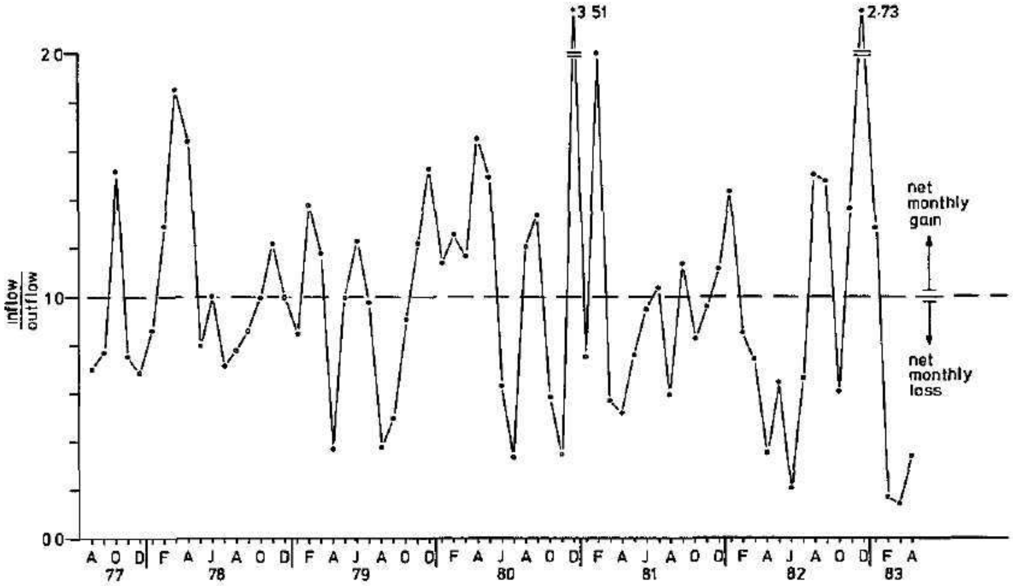


FIGURE 2.1.2. The ratio of inflow/outflow for Lake le Roux during the period of investigation. The preliminary water budget is given for each month below each relevant year, expressed as E = volume (n-1) - volume (n) + inflow - outflow. E = evaporation + unexplained loss, V_{n-1} = mean volume of month n-1; V_n = mean volume of month n. All values in m³.

Month	1977	1978	1979	1980	1981	1982	1983
1	0	-974	1918	1850	1486	2850	857
2	0	5956	1338	1484	51	1810	516
3	0	-11165	725	404	1511	2151	2
4	0	861	945	1368	1390	402	303
5	0	-104420	-330	1150	982	1023	0
6	0	-439	941	431	1185	55798	0
7	0	127	20	422	1339	-2010	0
8	0	1745	-890	315	-818	-51176	0
9	-2402	1475	-35	840	1131	883	0
10	8336	1621	-223	797	958	193	0
11	-7650	2554	1568	248	1300	539	0
12	-3612	2088	1628	97	921	1967	0

These figures represent the value of E from $E_n = V_{n-1} - V_n + I_n - O_n$ (see page 7)

2.1.2. Water budget

The reservoirs of the elevated plateau of South Africa are usually fed predominantly by the main stem river in which they are constructed and in the case of Lake le Roux, the aridity of its environment emphasises the episodic nature of its minor river inflows. A preliminary budget has been calculated using the expression:

$$^{E}n = {}^{V}n\text{-}1 \text{ " } {}^{V}n \; {}^{+} \; {*}n \text{ " } {}^{\circ}n$$

where: En = evaporation and other unexplained loss, given in m^3 ; Vn-1 = the volume the month before; Vn = the volume in the current month; In = inflow; and On = outflow. (Figure 2.1.2).

So far no account has been taken of inflows of tributary rivers. These very likely account for the negative values shown on page 6. The unexplained charge rarely exceeds 3% of the storage capacity and this shows that it is justified to assume that the tributaries exert only minor influence upon the water budget. The dominance of the Orange River in this budget is paramount, and would as a consequence be expected to influence the limnological features of the reservoir.

2.1.3. The thermal regime

The dam was closed in September 1976 and the Institute for Freshwater Studies, Rhodes University, has been monitoring its thermal features since August 1977. The reservoir, in common with most southern African reservoirs, is monomictic, with destruction of the thermocline or thermal stratification in April-May of each year. These thermal events define the limnological year from August to the following July. This pattern is illustrated in Figure 2.1.3.

The data used in the construction of Figures 2.1.3a,b and 2.1.4 are taken from records for Station 1 and represent the general thermal behaviour of the lake along its course to and including Station 5. Essentially the lake is stratified between November and March with the thermocline and metalimnion descending to 30 m. A group of temperature profiles are shown in Figure 2.1.3b.

While this pattern of thermal behaviour is normal, it is the pronounced vertical extent of the epilimnion which is extraordinary, as is its relatively low temperature, and the duration and shallowness of summer water, of 20°C or warmer, within the epilimnion. These figures are shown clearly in Figure 2.1.4.

Notwithstanding the major inflow of the Orange River, the reservoir possesses a distinctive set of lake-like characteristics, defined in part by the influence of the principal inflow, the pattern of outflow, its length and depth, and heat energy absorbed from the sun.

Although retention time is dependent upon hydro-electric power generation by ESCOM, it is obviously of sufficient magnitude to allow the reservoir to develop marked lake-like characteristics.

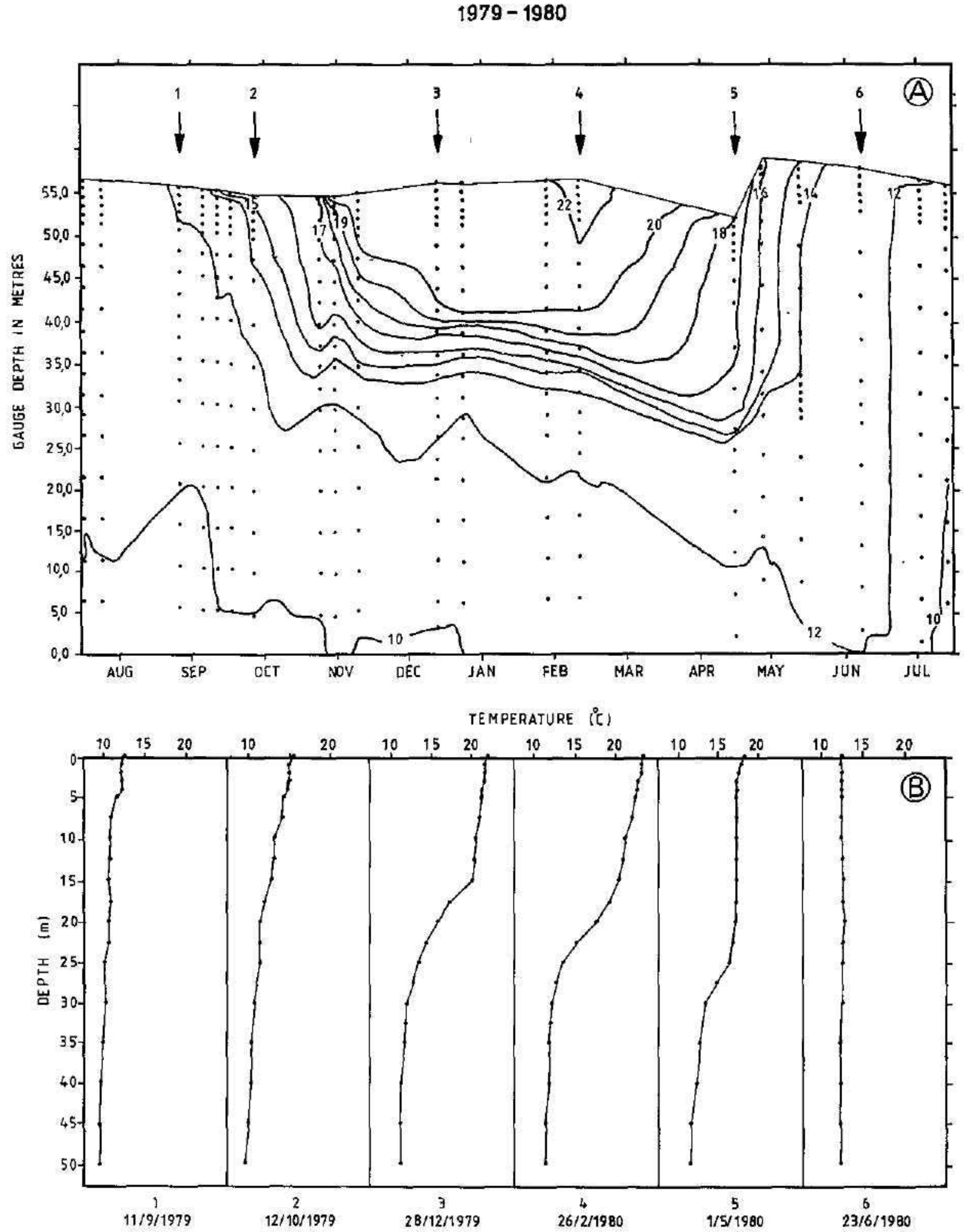


FIGURE 2.1.3a. The thermal structure at Station 1, Lake le Roux during 1979-1980 showing typical monomixis or period of mixing once a year. As lake level varied, the gauge depth was used to determine the position of lake level.

FIGURE 2.1.3b. Vertical distribution of temperature in the water column at the arrows marked in A.

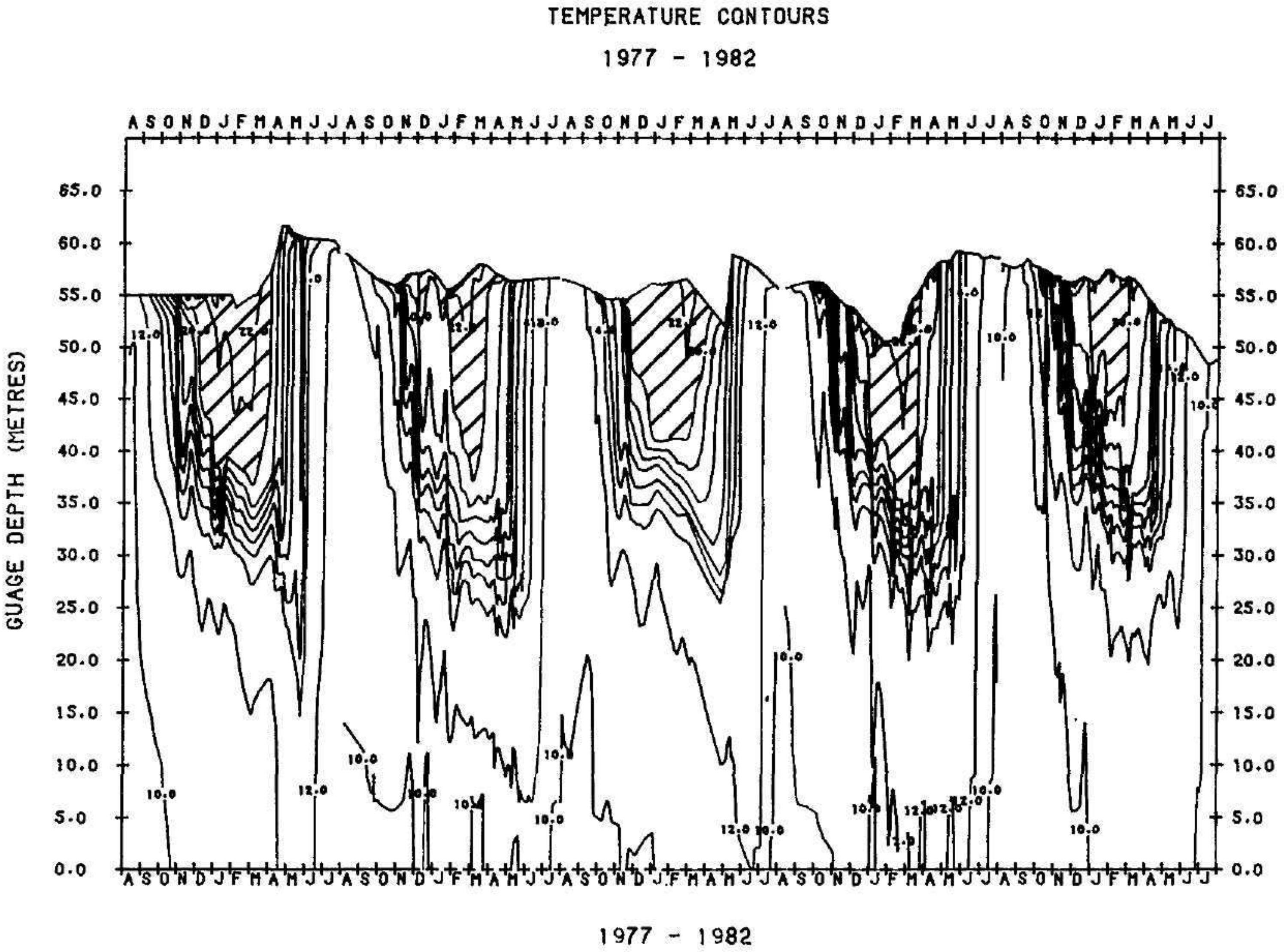


FIGURE 2.1.4. The repetitive pattern of monomixis showing in particular the restricted volume of summer water (>20°C) and variation in temperature across the thermocline.

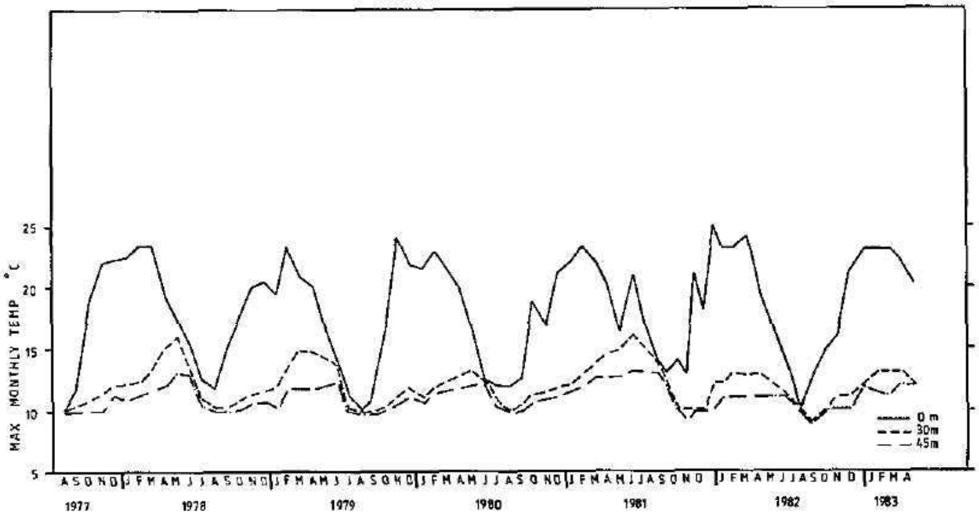


FIGURE 2.1.5. The variation in temperature at 3 depths in Lake le Roux,

The separation of the surface isotherms from those at 30 and 45 m during summer is shown in Figure 2.1.5, and emphasises in a somewhat different way the increase in temperature of the upper water layers. This increase is in response to an array of environmental factors other than the major inflow of the Orange River. We are best served in understanding the relative contribution of these factors by an examination of the heat budget of the lake and of the components which define its magnitude.

The Birgean heat_budget (BAHB). This is defined, in a lake which does not undergo winter freezing, by the total amount of heat that enters the lake between the times of its lowest and highest heat content (Hutchinson, 1957). It is, of course, possible to obtain the heat gain or loss for each month of the limnological year. This has been done for the lake at Stations 1 and 5. In a monomictic lake in which winter temperatures are somewhat above 4°C, the mean monthly heat budget is determined by choosing a conveniently small depth interval (z) expressed in cm, measuring the area of this slab (Az) and multiplying by the difference between the mean temperature for the month (e mz) and the lowest winter temperature for this slab. Summing the products, and dividing by the surface area (Ao) of the zone of the lake which the station characterises, gives the heat content for the month. This simple arithmetical procedure is summarised in the expression:

$$BAHB = A_o^{-1} \sum_{z=o}^{z=n} A_z \, (t_{mz} - t_{wz})$$

which gives the values shown in Figure 2.1.6.

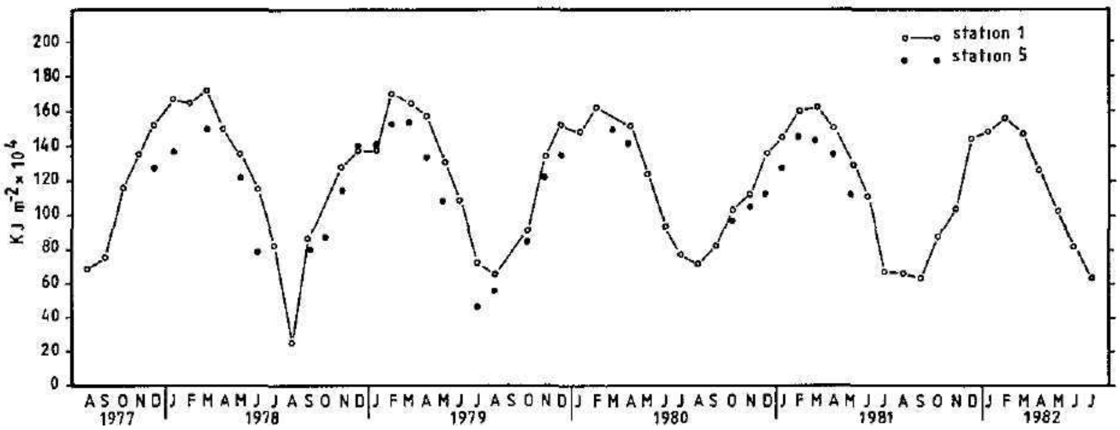


FIGURE 2.1.6. Variation in heat content (KJ/m^2 x 10) at Station 1 (open circles). The heat content values for Station 5 (closed circles) are superimposed upon the figure for comparative purposes.

The close similarity of the heat budgets of these two stations, widely spaced some 55 km along the long axis of the lake, allows the conclusion that the data from Station 1 are reasonably representative of conditions in the lake as a whole.

As the winter water temperature normally remains between 9 and 10°C, this analysis also provided an opportunity of examining the tropicality index (TI) of the lake as used by Coche (1974) for Lake Kariba. Coche's analysis of the thermal properties of Lake Kariba has provided a useful basis for comparison with those of Lake le Roux. Consequently it has been possible to determine the magnitude of the most significant parameters which make up the heat budget, and to discover what possible relationships may exist between them. These values are given in Table 2.1.2.

The residual heat is a measure of the permanent heat stock of the lake which, when subtracted from the maximum heat content (i.e. the heat content of the lake at maximum summer temperature), gives some idea of how marked was the heat loss during each of the years investigated. The magnitude of this decrease defines the tropicality index (TI), which is obtained by dividing the residual heat content by the mean depth. Tropical monomictic lakes will tend to have a high residual heat and consequently a high tropicality index. The values reported for Station 1 place it much closer to the temperate monomictic lakes of the northern hemisphere than to Lake Kariba. These comparative data are given in Table 2.1.3, in which the mean values for Lake le Roux from 1977-1981 are used.

TABLE 2.1.2. The principal parameters defining the thermal status of Lake le Roux at Station 1. They are (1) Birgean annual heat budget (BAHB); (2) residual heat content (RH); (3) maximum heat content (MHC); (4) tropicality index (TI). The values of these parameters were calculated on rising and falling reservoir levels (gauge plate 55-58 m). « «

All units are KJ/nr x 10

Year	1977/78	78/79	79/80	80/81	81/82
BAHB	98.11	90.85	95.69	81.66	90.35
RH	67.03	73.97	67.03	66.98	67.31
MHC	171.31	171.33	162.93	163.94	157.66
TI	2.30	2.54	2.30	2.48	2.32

TABLE 2.1.3. A comparison of the principal components of the heat budgets of Lake le Roux with other lakes of the world. The comparative data are from Coche (1974).

? «
Units are KJ/nr x 10

Lake	Mean depth (m)	BAHB	RH	TI	MHC	RH/BAHB
Victoria (Africa)	40	41.86	318.12	7.95	355.81	7.60
Kariba (Basin 2)	24	83.72	163.25	6.80	246.97	1.95
le Roux	29	91.58	68.76	2.37	167.38	0.75
Lugano	130	167.44	71.16	0.55	238.60	0.43
Ness (UK)	133	155.72	61.12	0.46	216.83	0.39
Mead (USA)	59	101.30	92.09	1.56	178.41	0.91

Clearly Lake le Roux, with respect to both its residual heat and its maximum heat content, is close to the group of the temperate lakes like Loch Ness and Lake Mead. Its tropicality index is intermediate between those of the truly tropical and the temperate lakes.

The ratio RH/BAHB has been introduced to show the importance of residual heat in defining the heat budget of the lake. One can see that the BAHB of Lake Victoria is small, because, due to the high value of RH, it takes relatively little heat input to raise it to its maximum heat content. Lake Kariba is somewhat similar, and although the values of RH and MHC are smaller, the effect of seasonality is evident in the lake. Lake le Roux, unlike the northern hemisphere lakes with comparable RH values, has a much lower BAHB than either Loch Ness or Lake Lugano. The latter seem to make more effective use of the heating agents during summer, as revealed by their increase in heat content (MHC-RH), for example. This has the effect of lowering the expected summer water temperature in Lake le Roux. As temperature, or more correctly heat content, is the principal limiting factor defining the magnitude of biological production, some explanation of the factors in control seemed necessary. By this means, a factor or factors could be exposed which could be manipulated during the operation of the dams forming the lakes in question.

While the analysis so far has comparative value, it fails to identify which of the many factors in control of heat loss or gain is really significant. This is answered by analysing the heat budget.

The importance of this analysis in the study of the thermal properties of Lake le Roux was recognised at the beginning of the investigation into the fisheries potential of the lake. Consequently the relevant variables from which these components are derived have been measured either daily, or weekly, since the dam was closed in 1977. Unfortunately it was only recently discovered that water temperatures at the turbine outlets were not recorded. This has limited the assessment of heat inflow via the Orange River.

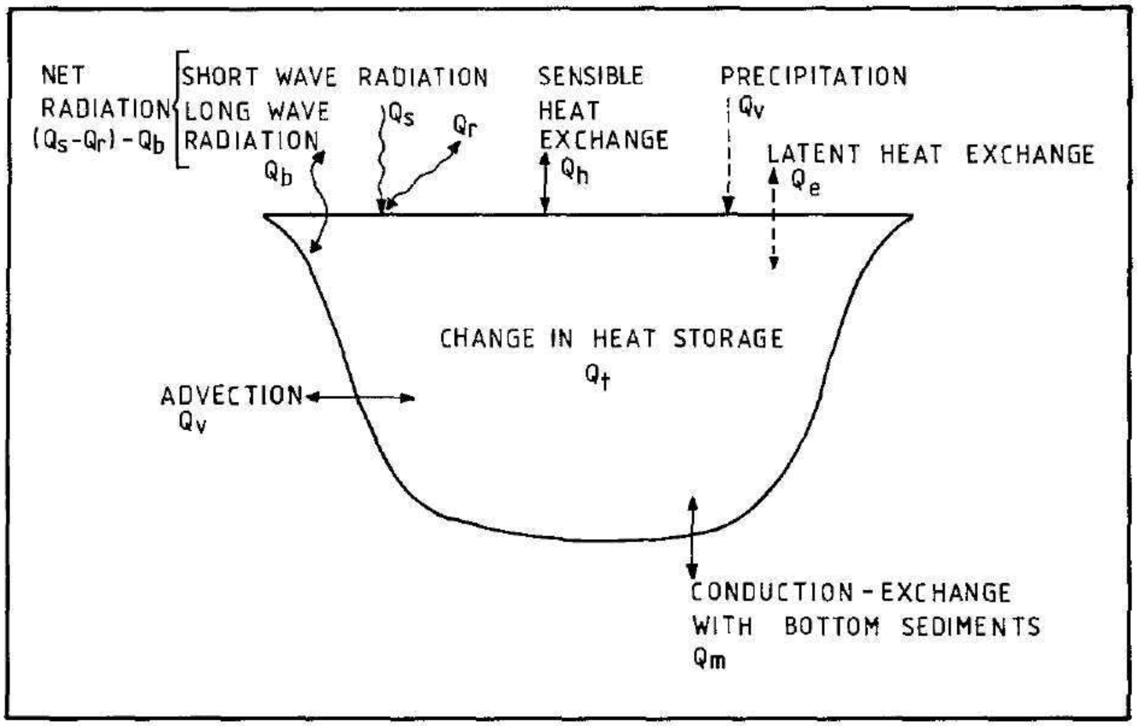


FIGURE 2.1.7. Heat budget components for a lake during summer. After Wetzel & Likens (1979).

Many of the variables shown in Figure 2.1.7 are relatively easy to determine, such as incident solar radiation (Qs) and reflection (Qr); the temperature of the water column; relative humidity; rainfall and principal inflows and outflows. Others are more difficult, of which evaporation from the free water surface of the lake is paramount. Fortunately a number of empirical expressions have been developed which allow estimates to be made. Of particular significance is that derived by Bowen (cf Hutchinson, 1957) which relates the energy exchanged across the air/water interface, so-called sensible heat, to the energy lost by evaporation. Longwave radiation (Qb) is yet another energy exchange which is difficult to measure directly, but as any heated substance emits longwave radiation, it follows that the lake not only is heated by the shortwave radiation directly from the sun and sky, but also receives much longer radiation from water vapour in the atmosphere. Similarly the heated lake surface radiates longwave energy. It is these various incomes and deficits which constitute the analytical heat budget of a lake. They are simply illustrated in Figure 2.1.7 and more precisely expressed in the following equation:

$$Q_s - Q_r - Q_b - Q_e - Q_h - Q_t + Q_v + Q_m = 0$$

where: Qs = solar radiation incident to the water surface; Qr = reflected solar radiation: (7%) of Qs; Qb = net energy lost from lake through exchange of longwave radiation between the lake and the atmosphere;
Qe = energy used for evaporation;
Qh = energy conducted from or to the lake as sensible heat;
Qt = change in heat stored in the lake; Qv = net heat advected into the lake by inflows; Qm = net heat gain from sediments.

A theoretical treatment of the analytical heat budget is given by Hutchinson (1957) and Ragotzkie (1978). The application of this theory by Dutton & Bryson (1962) to Lake Mendota, and more recently by Frempong (1983) to diel changes in Esthwaite water, have proved invaluable aids in this current analysis.

Normally the terms in the above equation are reported in cal/cm^2/hr. With the introduction of SI units, those terms as they apply to Lake le Roux are given in KJ/m^2/d. Calculation of the budget terms assumes that the radiation fluxes occur at the air-water interface. We may accept at this stage that heat losses or gains through the sediments and basin of the lake are minimal.

The advective heat due to inflows, as either rain or river flow, is defined by the term

$$Q_v = \frac{V_i t_i - V_o t_o}{A}$$

where: Vi and Vo are inflows and outflows, $1 \times 10^{-6} m^3$;
ti is the temperature of the inflows;
to is the temperature of the outflow;
A is the surface area of the lake in $1 \times 10^{-4} m^2$ (Frempong, 1983).

The mean daily values for each month of the components of the aforementioned equation, with the exception of advective heat (Qv) which is reported for specific days, are given in Figures 2.1.8a and 2.1.8b.

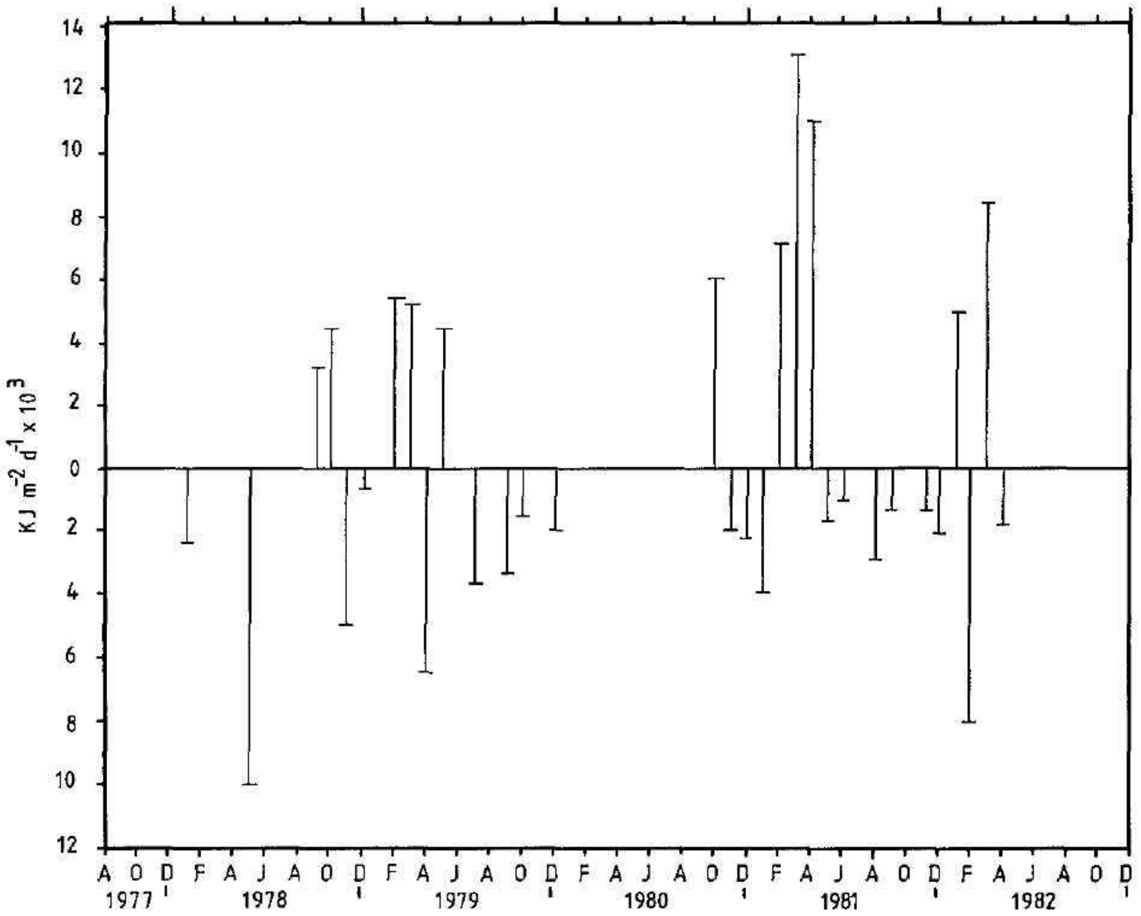


FIGURE 2.1.8a. The advective heat flux (Qv) into Lake le Roux due to the Orange River.

While the magnitude of the heat gains and losses is comparable with other monomictic lakes in the northern hemisphere, the overwhelming importance of energy loss by evaporation is underlined. It is a large percentage of the energy of both longwave and shortwave net incoming radiation received at the surface of the lake and transferred downwards into the water column.

A feature of this budget is the magnitude of Bowen's ratio, B = Q_h which when negative implies that heat is transferred from the Q~ air to the lake, the reverse occurring when the sign changes. ^{e} This occurs usually in March, and provides a quantitative expression of the importance of the interaction between air and lake temperature, as shown graphically in Figure 2.1.9.

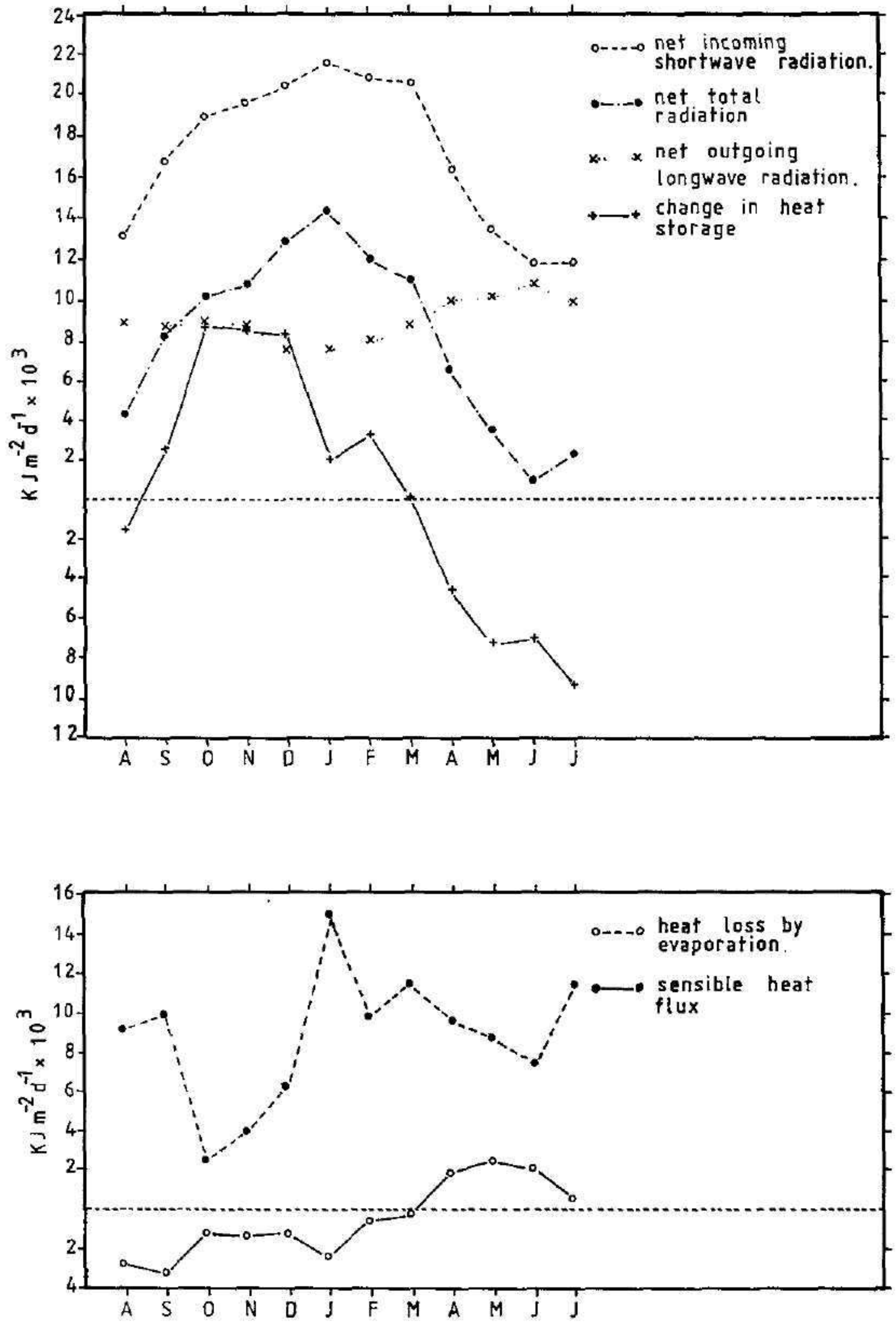


FIGURE 2.1.8b. Mean daily values of some of the components of the analytical heat budget.

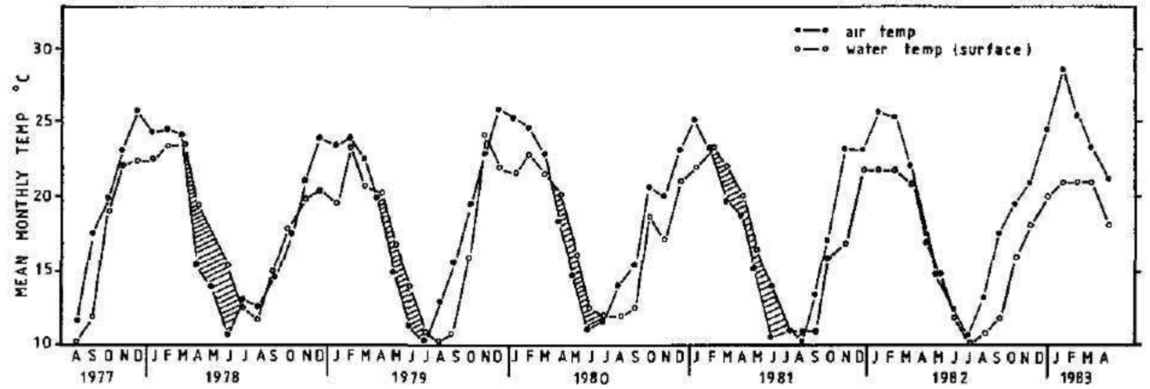


FIGURE 2.1.9. Air and surface water temperature at Station 1, Lake le Roux, 1977-1981. The cross-hatched areas of the temperature sequences refer to periods when the air temperature is lower than that of the lake. Under these conditions we may expect a sensible heat loss from the lake to the atmosphere.

Such losses coincide with, and are of course contributory towards, the striking decreases in heat content experienced during autumn and winter, particularly in July.

Shortwave radiation received on the lake surface from sun and sky (Qs) varied somewhat between summers, and was highest during 1977/78. In contrast, the magnitude of both outgoing and incoming longwave radiation, while showing some seasonal change, has proved to be similar in dimension during each year. This is to be expected, given the limited inter-annual variation in both surface water temperatures and vapour content of the atmosphere above the lake.

We must keep in mind that as the surface water of the lake is at an elevated temperature, it will, in common with all heated bodies, radiate longwave energy; similarly water vapour, carbon dioxide and clouds in the atmosphere will result in some back radiation to the lake. In Lake le Roux the difference between these two energies is such that there is a net loss of longwave radiation from the lake surface. This is commonly experienced in the northern hemisphere lakes, but as the back radiation component, Qa, is dependent upon two empirical constants and a sensitive estimate of vapour pressure of the air above the lake, it is possible that the application of Frempong's (1983) constants for the UK may well underestimate this component at the latitude and overall aridity of the lake environment. Dutton & Bryson (1962) argue that the magnitude of the net longwave radiation (Qb) *^{oss} decreases with increasing water temperature and relative humidity. In Lake Mendota the total heat loss via this route is less in the summer months. While there is some suggestion of this for at least two months of summer in Lake le Roux, during the majority of the limnological year Qb remains fairly constant. This may reduce the effectiveness of the positive feedback which would produce high temperature increases and therefore rapid heating during early summer in the lake.

Effect of wind. cf. heat budget on p. 11. Wind is a primary factor in carrying the heated and therefore buoyant water from the surface into the depths of the lake, and so producing the thermal structure of the lake. In some tropical lakes nocturnal cooling, particularly of the littoral waters, is primarily responsible for bringing about patterns of temperature stratification. While this process is of relevance even in more temperate lakes during summer, the influence of the wind appears to be overriding. In a recent analysis of wind effects upon lakes, Imberger and his colleagues at the University of Western Australia have introduced a further dimensionless number, the Wedderburn number (W), which describes the manner in which winds of varying strengths, acting upon increasing density differentials in the water column, bring about mixing.

$$W = \frac{g'h}{U_*^2} \cdot \frac{h}{L}$$

where: g*= reduced gravity across the interface; U*
= wind shear velocity; L = the reservoir or
basin length; h = epilimnetic depth.

This depth is approximated by the depth at which the Brunt-Vaisala buoyancy function (N) is maximum, ignoring changes in N within the first 2 metres of the water column.

This derived number is particularly valuable in that from its magnitude, the nature of the internal forces at work in the epilimnion is explained. Thus where W ^(1), Paterson ejt al^ (in press) argue that the stress of the wind upon the surface is primarily responsible for shearing movements and associated turbulence. With an increase in the value of W » (1), wind-induced stirring becomes increasingly dominant and the epilimnion rapidly deepens. Some idea of the rate at which this occurs in Lake le Roux, as well as its decay, is given in Figure 2.1.10 for 1981/82.

This rapid deepening of the epilimnion is primarily due to the windiness of the terrain in which the reservoir was formed. The data available from an OTT wind recorder are analysed in Table 2.1.4 which illustrates a number of important features of the wind regime of the lake.

Indeed, as Table 2.1.4 shows, there is no period of the calendar year when the wind does not blow. While the modal winds are not strong, they are sustained; *^/ery* much a condition required by Patterson et aj_ (in press) to bring about stirring during early summer within the mixecT or epilimnetic layer.

TABLE 2.1.4. Percentage breakdown by month (down) and wind run class (across) of daily wind runs (km/d) measured at Lake le Roux during 1980-1982. The upper values represent breakdowns of daily wind run classes in each particular month. The lower values represent the percentage breakdown of each wind run class by month during the year.

	0-125	125-250	250-375	375-500	500-625	625-750	750-875	Total
JAN	0.0 0.0	9.7 1.8	64.5 14.4	21.0 14.0	4.8 12.5	0.0 0.0	0.0 0.0	7.3
FEB	1.8 0.9	39.3 6.5	48.2 9.7	7.1 4.3	1.8 4.2	1.8 50.0	0.0 0.0	6.6
MAR	4.6 3.7	62.1 15.9	27.6 8.6	4.6 4.3	1.1 4.2	0.0 0.0	0.0 0.0	10.3
APR	18.9 15.6	56.7 15.0	22.2 7.2	2.2 2.2	0.0 0.0	0.0 0.0	0.0 0.0	10.6
MAY	28.0 23.9	48.4 13.3	18.3 6.1	2.2 2.2	3.2 12.5	0.0 0.0	0.0 0.0	11.0
JUN	27.8 22.9	48.9 13.0	16.7 5.4	5.6 5.4	1.1 4.2	0.0 0.0	0.0 0.0	10.6
JUL	35.5 20.2	30.6 5.6	22.6 5.0	8.1 5.4	3.2 8.3	0.0 0.0	0.0 0.0	7.3
AUG	16.1 9.2	30.6 5.6	29.0 6.5	12.9 8.6	9.7 25.0	0.0 0.0	1.6 100.0	7.3
SEP	1.7 0.9	36.7 6.5	38.3 8.3	16.7 10.8	6.7 16.7	0.0 0.0	0.0 0.0	7.1
OCT	3.2 1.8	41.9 7.7	30.6 6.8	22.6 15.1	1.6 4.2	0.0 0.0	0.0 0.0	7.3
NOV	1.7 0.9	21.7 3.8	53.3 11.5	18.3 11.8	3.3 8.3	1.7 50.0	0.0 0.0	7.1
DEC	0.0 0.0	29.0 5.3	46.8 10.4	24.2 16.1	0.0 0.0	0.0 0.0	0.0 0.0	7.3
TOTAL	12.9	40.1	32.9	11.0	2.8	0.2	0.1	100.0

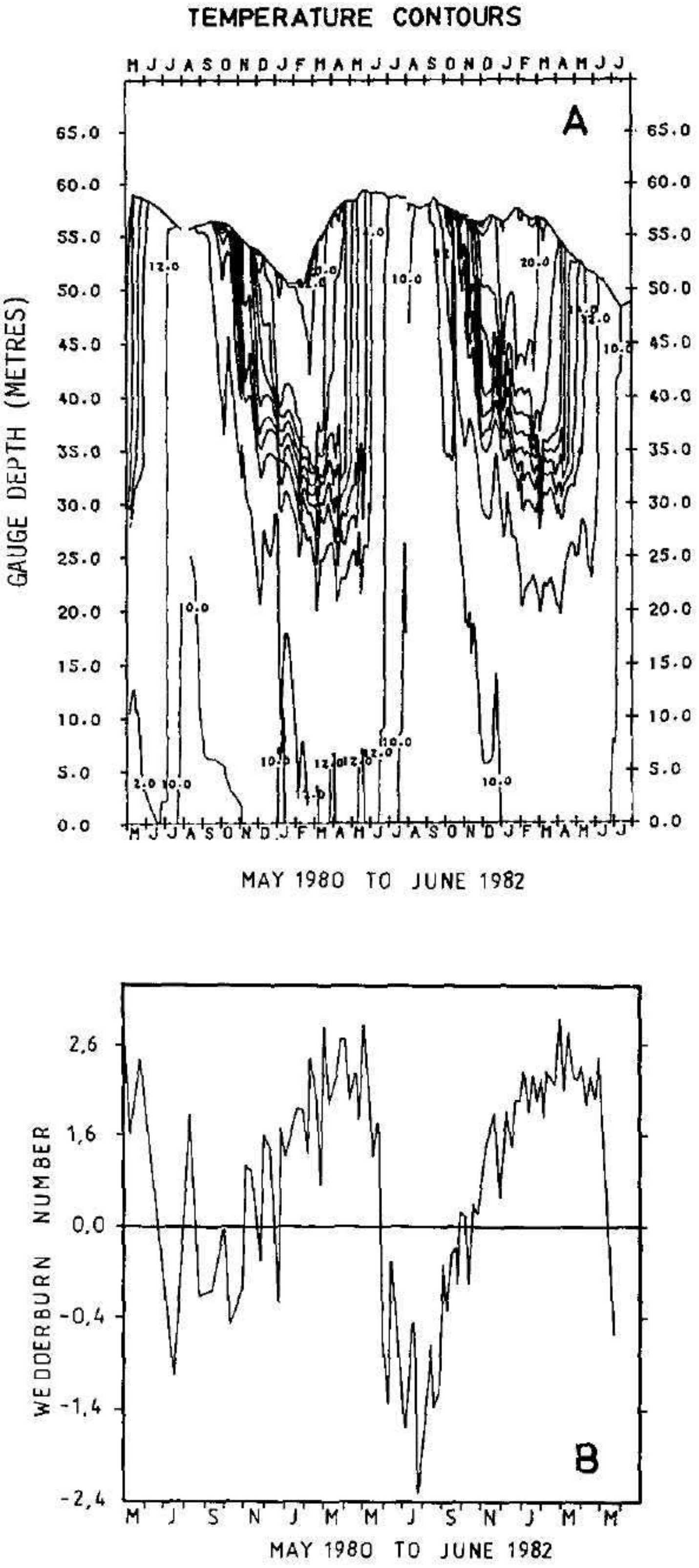


FIGURE 2.1.10.

(a) The pattern of stratification and destratification for the time period illustrated in (b).

(b) Variations in the value of Wedderburn number on log scale. Values greater than 0 ($\log_{10} 1$) are obtained during onset and development of stratification. Increased mixing leading to isothermal conditions implies numbers less than 1.

Implicit in this argument is that the net radiation components are of significant magnitude to cause the elevation of epilimnetic temperatures. The efficiency with which this is done is also a function of the attenuation characteristics of the water of the lake upon the down-welling irradiance from the surface. In highly transparent lakes this attenuation is small and warming of the epilimnion can be marked. The opposite is true of highly turbid water with which the attenuation coefficients as in Lake le Roux are high (2.9 - 13.9, Selkirk 1982 b). The turbidity in the reservoir is predominantly due to silt and clays in suspension, so that irradiance is scattered and absorbed within a short vertical distance of the surface. As a consequence, only a narrow superficial layer of 1 - 1.5 m of water is heated. As the buoyancy of this surface layer rises during summer, an increase in wind energy is required to mix the layer downwards. Holloway (1980) has demonstrated the close relation which exists between turbidity and therefore the attenuation coefficient, and the critical wind speed required to mix such buoyant layers. We have calculated on the basis of his equations that winds in excess of 8 m/s would be required to mix the warm surface layers of Lake le Roux into the water column. These winds are not frequent during summer, so we may reasonably expect diurnal variation in surface temperature due to sensible heat loss to the atmosphere and the resulting cool water passing downwards by convection. This, coupled with a tendency for some of the early summer heat to be lost by advection (Figure 2.1.8b), maintains cool water temperatures, in the epilimnion.

2.1.4. Summary : physical limnology.

1. Lake le Roux, in common with many southern African reservoirs, is monomictic, with isothermal conditions developing rapidly from May to July. The limnological year is from August to July.

2. The lake is cool in summer relative to other monomictic reservoirs in southern Africa. This is due to the combined effect of evaporative heat loss and inorganic suspensoids which rapidly disperse the downwelling radiation, so effectively heating only a shallow (1-1.5 m) layer of surface water. The sustained winds rapidly mix this heated surface water downwards in spring, but as summer advances and wind speeds tend to fall there is insufficient energy to continue this mixing.

3. The heat content of the lake varies markedly between winter and summer which further exacerbates the influence of temperature upon biological processes.

2.1.5. The chemical regime

While this investigation was not directed towards a complete chemical analysis of the reservoir, sufficient information was obtained to describe the general pattern of its chemical structure. Emphasis was, however, given to nutrient regimes of nitrogen and phosphorus.

The reservoir was filled during the summer of 1976/1977. In April 1977 deoxygenation of the hypolimnion was observed in the vicinity of Station 1. This initial anaerobiosis disappeared rapidly once the mineralisation of the inundated plant material was complete, so that by the summer of 1977/78 the summer vertical distribution of dissolved oxygen varied by some 3 mg/£ from surface to bottom. This pattern has been maintained throughout the period of investigation: surface values reached 8.5 pg/£ with summer hypolimnetic concentrations of 5 mg/£. This is in keeping with the generally low productivity of the lake as well as a variable but usually short retention time. The chemical characteristics of the reservoir are summarised in Table 2.1.5.

The variation with depth in the lake of its chemical characteristics was unremarkable at all stations, which emphasises both the low level of biological activity and the unimportance of density currents in the hydrodynamic regime of the reservoir. Even seasonal variation is poorly marked: normally the coefficient of variation for each variable measured is sufficiently large to make seasonal differentiation difficult. Horizontal variation is, however, obvious in some variables. The waters of the reservoir are considered 'soft'. The calcium concentration is low, 5.2 - 2.7 mg/£ (Selkirk, 1982 b) and is comparable with that reported by Stegmann (1974) for Lake Verwoerd. Since pH is less than 8.3, inorganic carbon is predominantly in the bicarbonate form. The reasons for the downstream increase of alkalinity are not understood, except possibly in terms of the 'maturation' of the river water as it flows through the reservoir. This is matched by an equivalent elevation in conductivity towards the dam. Suspended solids are noticeably decreased down the length of the reservoir by some 68%. This matches the annual mean reduction reported by Selkirk (1982 b) of 64%. In terms of transparency this represents a change from 0.13 m to 0.28 m in Secchi disc depth, which emphasises the importance of the fine suspended load upon the light regime of the lake (cf. Chapter 2.1).

The all-important nutrient anions of nitrate and phosphate show little horizontal variation. While the concentrations of nitrate and soluble reactive phosphorus (SRP) are low compared to many other southern African reservoirs, they are double those reported by Mitchell (1973) for the oligotrophic Lake Kariba.

These concentrations of SRP and nitrate in Lake le Roux are sufficient to allow algal blooms, of both Anabaena circinalis and Microcystis aeruginosa, the latter in February and March. During the summer oT V982/83 this succession was particularly obvious and led to a dense and extensive bloom of M.aeruginosa, the direct cause of which is unknown (but see Chapter 2.2.2), as no substantive change in the concentration of N or P had occurred. These data are reported in Table 2.1.6.

TABLE 2.1.5. Summary of chemical features of surface water sampled at Stations 1 - 6 along the long axis of the lake. Numbers in brackets indicate the number of samples analysed. The standard deviation follows the mean.

Station No.	1	2	3	4	5	6
Part 1.			1980-1981			
Conductivity µ Siemens 1×10^{-2}m	154 (10)	150 (10)	150 (10)	147 (10)	147 (10)	145 (10)
pH	7.88 (10)	7.95 (10)	8.00 (10)	7.98 (10)	7.97 (10)	7.98 (10)
TDS mg/ℓ	159	-	-	-	-	-
Part 2.			1977-1982			
Alkalinity $CaCO_3$ mg/ℓ	78±14 (190)	69±5 (45)	70±5 (59)	67±4 (43)	69±8 (67)	61±3 (32)
TSS mg/ℓ	37±16 (127)	47±26 (74)	56±28 (74)	64±34 (74)	85±45 (74)	117±39 (32)
NO_3N µg/ℓ	410±132 (257)	405±130 (76)	401±131 (76)	413±133 (76)	396±120 (80)	477±107 (32)
TP µg/ℓ	94±61 (174)	91±49 (73)	92±45 (71)	101±68 (73)	110±71 (74)	87±43 (32)
SRP µg/ℓ	27±15 (279)	31±14 (68)	31±16 (73)	29±13 (72)	30±14 (72)	28±14 (32)
Zone*	F	E	C		B	A
Chl a µg/ℓ	1.6±1 (45)	1.8±1 (110)	3.0±15.8 (100)		2.2±17 (110)	4.0±4.6 (60)

*From Selkirk (1982 b).

TABLE 2.1.6. Features of the chemical environment before and during the development of the major Microcystis aeruginosa bloom 1982/83: S = surface; B = bottom; concentrations in

Station	TDS	NO_3N		SRP		pH	Total pigment	Secchi disc(m)
		S	B	S	B			
1982 A	130	477	440	20.0	20.3	7.94	1.8	0.20
S	88	462	455	22.0	21.0	7.93	3.3	0.25
O	110	450	459	21.6	25.3	7.98	4.2	0.35
N	72	464	431	18.1	23.0	7.95	8.4	0.30
D	116	574	536	17.0	21.5	8.09	13.5	0.35
1983 J	116	426	473	16.3	24.4	7.97	6.3	0.30
F	98	470	529	19.6	31.0	8.12	31.5	0.35

While there is a reduction in surface SRP prior to the major phase of growth of M.aeruginosa, it is not very striking, and even the increase in nitrate-N must be viewed cautiously as similar increases have occurred in previous years without the same response.

Selkirk (1982 a) has shown that algal biomass increases significantly if lake water is exposed to increasing light, and provided the concentrations of N and P *are* kept at the levels found in the reservoir, high concentrations of chlorophyll can be achieved. This and his later work (Selkirk, 1982 b) stress the importance of the ratio of the euphotic depths (z.eu) to the mixed depth (z.m) of the reservoir (z.eu / z.m = 0.03). Values as low as this imply that an algal cell slowly circulating in the epilimnion will not receive sufficient light flux to facilitate rapid logarithmic growth leading to high cell densities. In this regard M.aeruginosa is a special case. It is capable of regulating its depth by secretion of gas into vacuoles, so effectively out-competing the other algal flora for what light is available, by maintaining a buoyant position near the surface, which in a turbid system is where optimal light conditions occur.

2.1.6. Summary : chemical limnology.

1. The chemical structure of the reservoir is conservative. The nutrient anions of nitrate-N and SRP are generally maintained at ^450 and *2Q\ig/l* respectively throughout the surface waters of the reservoir.

2. With the exception of a period immediately following filling, when deep water anaerobiosis was found, the hypolimnion of the reservoir shows only some 3 mg/j? reduction in dissolved oxygen over surface values of 8.5ng/£. This indicates the general low productivity of the lake.

3. The suspensoids of surface waters concentrations decrease markedly down the length of the reservoir, but the fine fraction remaining in suspension is still sufficient to maintain low transparency and control algal growth.

4. A striking bloom of Microcystis aeruginosa during the summer of 1982/83 was not associated with any major change in either nitrate-N or SRP.

2.2. THE BIOLOGICAL BASIS OF FISH PRODUCTION

R.C. Hart, B.R. Allanson & W.T. Selkirk.

2.2.1. Introduction

The general ecological principles which influence and govern aquatic productivity are well known from studies on systems ranging from the smallest of ponds to the largest of oceans. Quantitative considerations vary considerably however, confounding realistic extrapolation and prediction even between systems which may not appear to vary greatly. For this reason, any serious analysis of fishery-potential demands site-specific research either to provide a self-sufficient scientific basis for assessment, or to scale or calibrate site-specific characteristics against more general 'models' such as Ryder's morpho-edaphic index (Ryder et al. 1974) derived for particular sub-sets of systems. Given the remarkably limited quantitative understanding of biological production in silt-laden inland waters, an intensive study was warranted to meet the objectives of this project.

It was not possible to meet this ideal requirement of examining in detail all components of production in Lake le Roux. Neither was it possible to identify at the outset which fish species would have the greatest commercial potential and therefore to choose the most appropriate subsystem for study. Accordingly, a rather broader-based study was initiated. Nevertheless, attention soon focussed on the pathway algae—»- zooplankton—»- smallmouth yellowfish from early indications of this species' commercial potential. We believe this approach has been vindicated. The smallmouth yellowfish (Barbus holubi) is now recognized as the species with the best commercial potential. A detailed understanding of the production pathways and mechanisms important to this species has been achieved. In so doing, a general understanding of the nature and magnitude of, and constraints to, the biological production of this turbid lake has been gained. In consequence it is possible to assess, with some assurance, those environmental factors which are likely to be significant in understanding the ecology of additional exploitable species.

In aquatic ecosystems, planktonic and benthic invertebrates frequently represent the trophic link between primary producers and larger secondary producers, such as fish, which represent a resource which can be directly exploited by Man. This is shown in Figure 2.2.1. The link can involve direct herbivory, common in zooplankton, or detritivory, which is widespread among zoobenthos, or a mixture of feeding modes. Regardless of the pathway involved, the invertebrates which form this link provide a protein-rich, high energy food resource upon which many fish species feed. Such food may indeed be nutritionally essential for juveniles of certain species.

Obviously not all fish species feed partly or exclusively upon invertebrates for all or some of their life. Some graze directly on plant material, particularly benthic algae. Others feed on organic matter which accumulates in surface sediments. Yet others are carnivores, feeding on other fish. Lake le Roux has a depauperate fish community of 10 recorded species. Yet all these feeding modes are exhibited within its fish community, as Figure 2.2.1 shows.

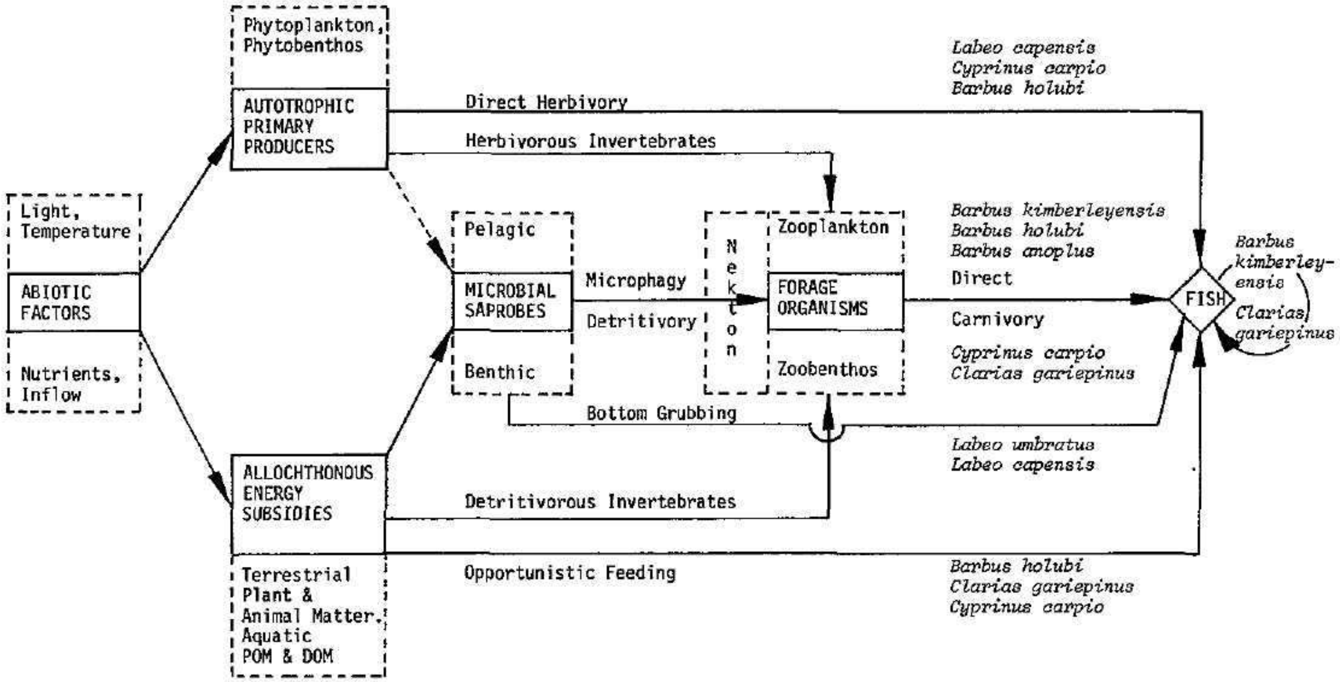


FIGURE 2.2.1. The general trophic pathways leading to fish production in Lake le Roux, indicating principal fish species involved.

Its two Labeo species are specialised bottom-feeders, the Orange River labeo (L.capensis) being adapted to scraping algae off rocks while the moggel (L.umbratu?) tends to be more associated with muddy bottoms. In Lake le Roux both species are found inshore, the former being the more abundant and extending into deeper water. Both ingest large quantities of fine bottom material and detritus and probably share the demonstrated capability of certain species of Mugil (mullet) and Oreochromis mossambicus to digest bacteria contained therein.

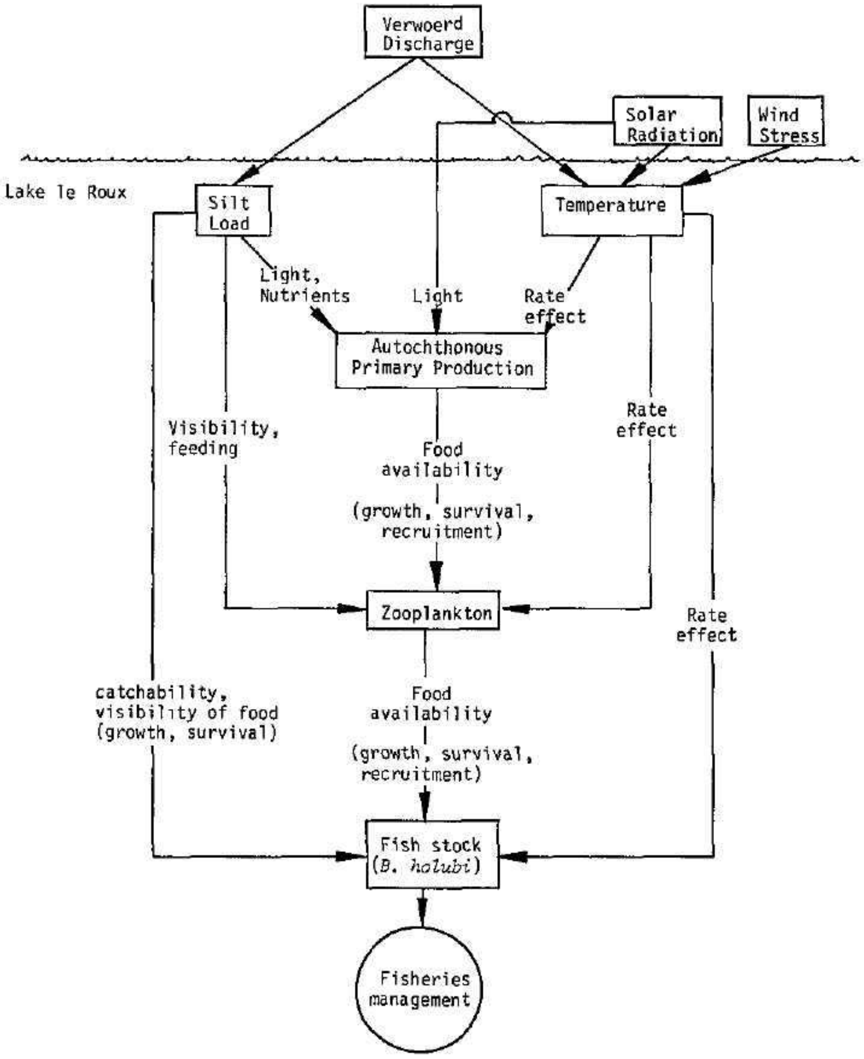


FIGURE 2.2.2. The principal biotic/abiotic interactions and influences regulating biological production in Lake le Roux, with special reference to the smallmouth yellowfish.

The carp (Cyprinus carpio) is a generalised bottom-feeder, taking bottom-living invertebrates" algae and detritus. The sharp-tooth catfish (Clarias gariepinus) is also a bottom-feeder, taking insects, detritus and fish.

The three species of Barbus which occur in Lake le Roux are largely carnivorous, although the smallmouth yellowfish (B.holubi) has a relatively longer gut than the other species and becomes increasingly vegetarian at larger sizes. The chubbyhead minnow (B.anoplus) feeds on bottom-living invertebrates, planktonic Crustacea and aquatic insects. The largemouth yellowfish (B.kimberleyensis) has a similar diet while immature but, at larger sizes becomes mainly a predator of fish.

The remaining three species in the lake, the rock barbel (Gephyroglanis sclateri), the banded tilapia (Tilapia sparrmanii) and the brown trout (Salmo trutta) are rare and inconsequential from a commercial viewpoint.

Figure 2.2.2 provides a general framework around which the analysis of biological production in this lake has been focussed. Certain of the abiotic influences reflected in this figure have been considered in the preceding section, and subsequent sections examine fish stock and fishery management considerations.

2.2.2. Some properties of the primary production system of the lake

The characteristically high suspensoid concentration in the lake creates a turbid environment and consequently rapidly attenuates the down-welling irradiance. A detailed analysis of the photosynthetic light climate of the lake is given by Selkirk (1982.b). It is especially important that this marked attenuation, particularly in the blue region of the spectrum, reduces the particular red and blue wavelengths of light utilized by chlorophyll in the photosynthetic conversion of solar radiation to organic matter. The consequent effect of such differential wavelength attenuation (Figure 2.2.3) would be to limit the growth of the algal community, particularly during spring and early summer.

TABLE 2.2.1. The contribution of the littoral and pelagic primary production compartments in Lake le Roux. This data was obtained in December 1978.

	Littoral Benthic algae	Pelagic Phytoplankton
Areal Production ($g\ C/m^2/d$)	0.66	0.26
Whole lake (kg C/d)	267	359×10^3

Two principal areas of primary energy fixation exist in the reservoir: (a) benthic production on the steep rocky littoral which dominates the shoreline of the lake, and (b) the pelagic open water zone. Some indication of the relative size of these compartments on an areal and whole-lake basis during the summer of 1978/79 is given in Table 2.2.1.

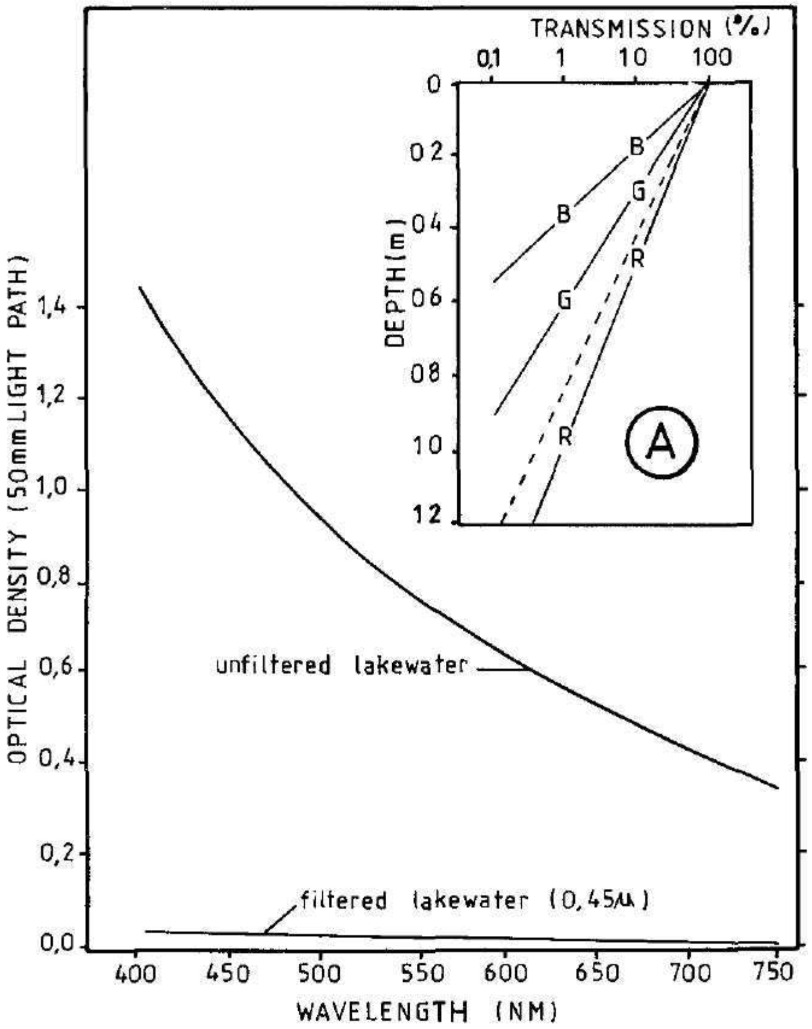


FIGURE 2.2.3. Optical density (absorbance) of unfiltered and 0,45 *pm* membrane-filtered surface water from Lake le Roux in Ouly 1982. Inset: The mean attenuation profiles of blue (B) green (G) and red (R) light between July 1981 and June 1982 at Station 1. The average attenuation of Photosynthetically Active Radiation (PAR) is represented by the dashed line.

The dominant position of the open waters of the lake in energy fixation is indisputable, but to the benthic feeding animal community, the areal production of the littoral is of prime importance. Unfortunately the effect of drawdown upon a steep littoral is to expose this narrow band of benthic algae. It takes at least 4 weeks for a new community to develop, so that the frequency and rate of drawdown are important factors in the maintenance of a productive littoral.

The first estimates of pelagic production were made using the ^{14}C technique during the summer of 1978/79 at Station 1, under extremely turbid conditions. An expanded programme between 1981 and April 1983 provided a series of observations upon which conclusions regarding the nature of lake productivity are largely based.

The primary productivity (Figure 2.2.4) of the lake is highly variable. During the early transparent phase (1977/78) when Secchi disc readings as high as 1.5 m were recorded, a mean integral of 24.7 $mgC/m^2/hr$, and a specific productivity of 3.23 mgC/mgChla_ was obtained. Thereafter increases in total suspended solids decreased Secchi disc transparency markedly. This resulted in a mean productivity as low as 5.6 $mgC/m^2/hr$ during the 1981/82 summer. The following summer of 1982/83 proved to be significantly more productive with a mean value of 33 $mgC/m^2/nr$. it led to a marked and extensive bloom of Microcystis aeruginosa during which total pigment values rose to 34jug/£ (34 mg/m*) from levels of 1 *}ig/i.* Areal production reached a maximum of 120 mgC/m*/h.

Nutrient loading rates via the Orange River inflow were not measured, but the seasonal stability of residual concentrations of nitrate and phosphate and their absolute values in surface waters (Chapter 2.1.5), together with results of in situ and laboratory bioassays to determine algal responses to increased nutrient levels (Selkirk 1982 b) exclude any likelihood of nutrient limitation to algal growth. Light is unquestionably the principal limiting factor. The pattern and magnitude of its vertical attenuation based upon the logarithmic attenuation coefficient (k) for PAR during 1981-1983 is given in Figure 2.2.4. During the summer of 1981/82 this coefficient increased, indicating a progressive elevation in turbidity, and photosynthetic activity was correspondingly suppressed. While this was followed by a decrease in the coefficient, and therefore an increase in transparency during the winter of 1982, algal responses to the improved light climate were seemingly offset by low water temperatures and less favourable photoperiod. The decrease in attenuation was maintained into the spring of 1982 and summer 1982/83. Figure 2.2.4 shows that attenuation decreased by one order of magnitude during this period. The corresponding mean Secchi disc transparency values during these 'phases' are poor at resolving comparatively small changes in light attenuation, although they do provide a useful indication of real change which may prove significant.

The increase in water transparency, coupled with rising water temperatures, increased photoperiod, and nutrient sufficiency, produced two important algal successions: firstly a growth of Anabaena circinalis during early summer, which was responsible for the peak in both areal and specific productivity (Figure 2.2.4); and during February to March the striking growth of Microcystis aeruginosa referred to above.

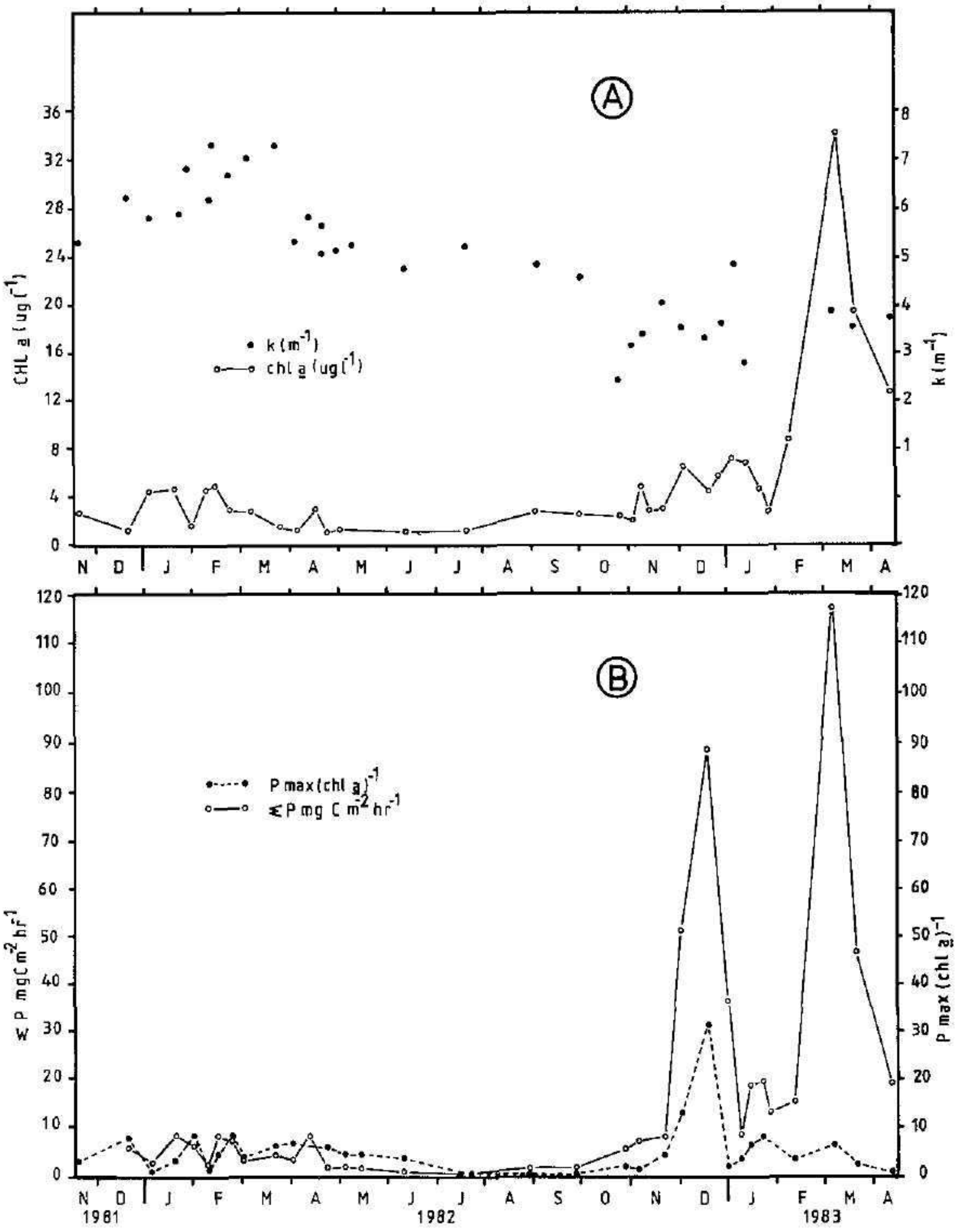


FIGURE 2.2.4. (a) Changes in the extinction co-efficient k/m of PAR.
(b) Variation in surface chlorophyll concentration, areal and specific primary production in Lake le Roux.

It is noteworthy that relatively small changes in attenuation have brought about major biological responses in certain years.

This decrease in light attenuation is attributable to the reduction in controlled releases from H.F. Verwoerd Dam occasioned by a turbine failure during 1982. This loss in generating capacity was made good from turbines in the P.K.le Roux Dam, resulting in a marked drawdown of Lake le Roux. This, and the slow recovery of level in Lake le Roux during the summer of 1982/83, due very largely to the severe drought, provided conditions in which settling of suspensoids could occur without being replaced from the upstream storage.

In view of this increase in transparency and the associated high phytoplankton productivity, we may reasonably expect a good production of secondary and tertiary consumers in the following summer. If this does occur, it would imply that the hydraulic management of the two reservoirs can be matched in a manner likely to allow suspensoid settling in October and November. This would ensure that sufficient light flux would become available to allow a marked rise in phytoplankton biomass, and therefore secondary production, at a time when the 'young of the year' among the fish varieties, particularly the smallmouth yellowfish, are eager seekers after food.

2.2.3. Allochthonous energy subsidies

Preformed organic matter blown, washed *or* carried into water bodies from elsewhere in the watershed, can represent a significant energy subsidy. In the case of shaded rivers draining woodland or forest, inputs of leaf litter from the terrestrial production system can represent the principal energy source of the aquatic system. Lake le Roux receives waters which have been variously enriched by the organic production processes in the standing waters of the upstream Lake Verwoerd, as wel1 as from the greater catchment.

Table 2.2.2 shows the mean concentrations of dissolved (DOC) and particulate organic carbon (POC) recorded in the lake, and in its influent and effluent waters (Hart 1982, 1983). While the values recorded were not striking, corresponding mass fluxes of DOC and POC were considerable. At mean DOC and POC concentrations of 2.87 and 2.0 mg/£ respectively, the mean daily inflow of £ 13x10^6 m^3 from Lake Verwoerd between September 1977 and April 1982 represents a daily input of about 38 tonnes DOC and 26 tonnes POC. Concentrations of DOC barely decreased down the lake, suggesting a predominant throughflow pattern for this fraction. Nevertheless, a decrease of as little as 0.1 *mg/S.* is indicative of utilization or sequestration of approximately 1 tonne DOC per day.

No analyses of POC content *are* available for the effluent waters of Lake Verwoerd> but Station 6 values (Table 2.2.2) are indicative of concentrations in the influent waters of Lake le Roux. Unlike the dissolved fraction, POC values decreased consistently downstream, indicative of biological entrainment and/or physical sedimentation of this particulate material. The decrease down the lake was on average from 2.0 to 0.9 mg/4, or 1.1 mg/4 over and above any increments from in-lake production processes. It represents a minimum daily subsidy of some 14>600 kg C, about half the amount of carbon fixed photosynthetically during summer.

The extent and nature of utilization of this subsidy is obscure. Certain bottom-grubbing fish probably exploit this detritic material. Filter-feeding zooplankton ingest large quantities of this predominantly inorganic particulate matter, but may derive benefit from its small organic fraction.

TABLE 2.2.2. Concentrations of dissolved and particulate organic carbon in influent and effluent Orange River water, and within Lake le Roux (Stations 1 - 6), for various periods, as determined by various agencies. Surface and deep water samples are designated S and B, respectively. CV% is coefficient of variation.

Sampling Site	Dissolved Organic Carbon (mg/ℓ)				Particulate Organic Carbon (mg/ℓ)				
	Mean	CV%	Range	n		Mean	CV%	Range	n
Lake Verwoerd discharge	2.87	12	2.4-3.6	13[a]					
Station 6		-			S	2.0	24	1.3-2.8	16[c]
					B	2.0	27	1.2-3.2	16[c]
Station 5		-			S	1.5	22	1.0-2.3	16[c]
					B	2.1	33	0.9-3.6	16[c]
Station 4		-			S	1.3	30	0.6-2.2	16[c]
					B	1.7	35	0.6-2.9	16[c]
Station 3		-			S	1.1	26	0.5-1.4	16[c]
					B	1.0	58	0.1-2.7	16[c]
Station 2		-			S	1.0	18	0.7-1.4	16[c]
					B	1.0	61	0.1-2.2	16[c]
Station 1	2.83	24	2.0-4.0	11[a]	S	1.1	36	0.5-2.0	16[c]
					B	0.7	62	0.1-1.7	16[c]
Lake le Roux discharge	2.49	13	2.0-3.0	16[a]		1.6	29	0.8-2.4	17[d]
	2.25	19	1.7-3.4	28[b]					

a = Department of Environmental Affairs: January 1982 to June 1982.
b = SCOPE/UNEP International Carbon Laboratory: August 1981 to October 1982
c = I.F.W.S. : March 1981 to June 1982.
d = I.F.W.S. : January 1982 to September 1982.

2.2.4. Secondary Production : Invertebrates

2.2.4.1. The zooplankton

Composition

The zooplankton of Lake le Roux consisted principally of copepods and cladocerans (water fleas). These crustaceans, illustrated in Figure 2.2.5, dominated the zooplankton both numerically and in terms of biomass. Various species of rotifers (wheel animalcules) became abundant periodically. These were not major food items of the potentially exploitable larger fish species and were accordingly not studied in detail. Low numbers of phantom midge larvae (Chaoborus sp.), benthic ostracods (seed shrimps) and chydorid cladocerans were encountered sporadically in the deep water plankton. These were likewise excluded from detailed analysis. Nevertheless, the r61e, especially of rotifers and chaoborids, in the overall ecology of the pelagic subsystem should not be disregarded.

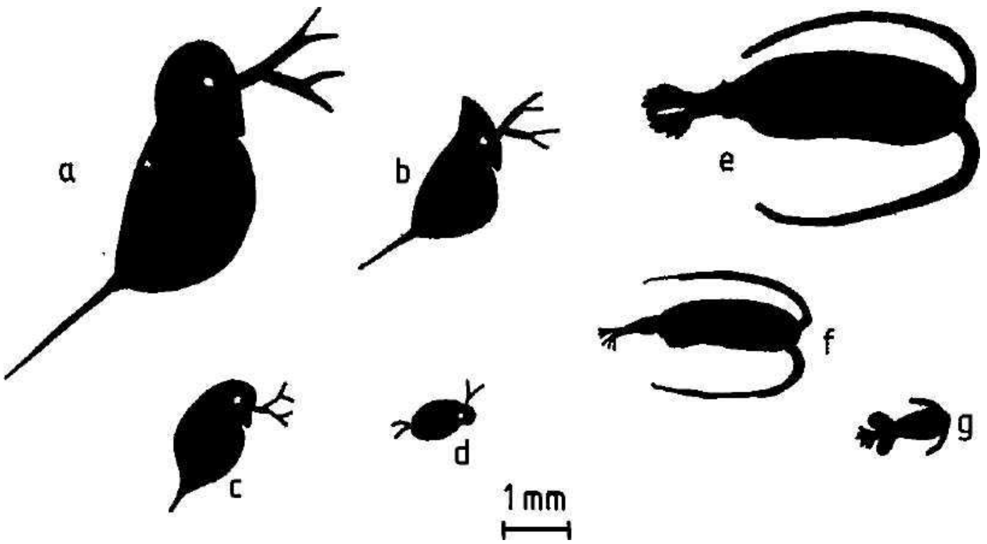


FIGURE 2.2.5. The principal entomostracan zooplankton of Lake le Roux. The silhouettes, which are drawn to scale, represent the maximum sizes attained by the organisms in Lake le Roux. (a) Daphnia gibba (b) Daphnia barbata (c) Daphnia longispina (d) Moina brachiata (e)Loyenula excel lens (f) MetaoTaptomus meridianus (g) Cyclopoid copepods.

The composition of the zooplankton varied both within and between years, as well as spatially within the lake. The most extensive observations on zooplankton were made at Station 1 (Figure 2.1.1) and appeared generally representative. Table 2.2.3 shows the gravimetric contribution of the principal entomostracan taxa to the zooplankton community during each year

TABLE 2.2.3. Annual mean standing stock (mg/m^2 dry mass) of principal entomostracan zooplankton at Station 1 in Lake Le Roux.

	77/78	78/79	79/80	80/81	81/82	82/83
Copepods						
Metadiaptomus meridianus	192	108	165	137	83	121
Lovenula excellens*	72	32	18	46	18	32
Cyclopoid copepods*	23	5	13	8	2	6
Cladocerans						
Daphnia gibba	66	3	77	1	5	43
Daphnia barbata	49	0	4	10	0	3
Daphnia longispina	0	0	0	49	0	0
Moina brachiata	17	7	29	13	6	5
Total "herbivores"	324	118	275	210	94	174
Total "raptors"	95	37	31	54	20	38
Total Entomostraca	419	155	306	264	114	212

* Raptorial organisms.

of the study. It reflects the annual differences in total zooplankton abundance, as well as the differences in relative contribution made by given species from year to year. The copepod Metadiaptomus meridianus clearly dominated *&\iery* year. Within the Cladocera, paphnia gibba and Moina brachiata were annually present most consistently^ while UTbarbata aW especially D.longispina occurred intermittently. The large predatory copepod Lovenula excel lens occurred each year; its biomass contribution belies its numerical scarcity. At least two species of cyclopoid copepod occurred, but were not distinguished routinely. Intra-annual and spatial variations in zooplankton are considered subsequently in this account.

Trophic relations

The majority of the zooplankters were microphagous filter feeders which ingested algal cells and other small organic particles suspended in the water. This category consisted of the copepod M.meridianus and the water fleas D.gibba, D.barbata, D.longispina and W. brachiata. The copepod L.excelTens appeared to be exclusively predatory, preferring M.meridianus as a prey organism. The cyclopoid copepods were considered to~be raptorial, feeding on larger particles which they grasped and tore apart. Their likely food included plant material in addition to other animals.

The trophic relations perceived within the entomostracan zooplankton are shown in Figure 2.2.6. In addition to conventional food resources (autotrophic algae, and dead organic detritus particles with associated bacteria), Figure 2.2.6 demonstrates the possible existence of a subsidiary food resource in the form of organic compounds adsorbed onto the surface of inorganic sediment particles (Hart 1980; Arruda, Marzolf & Faulk 1983).

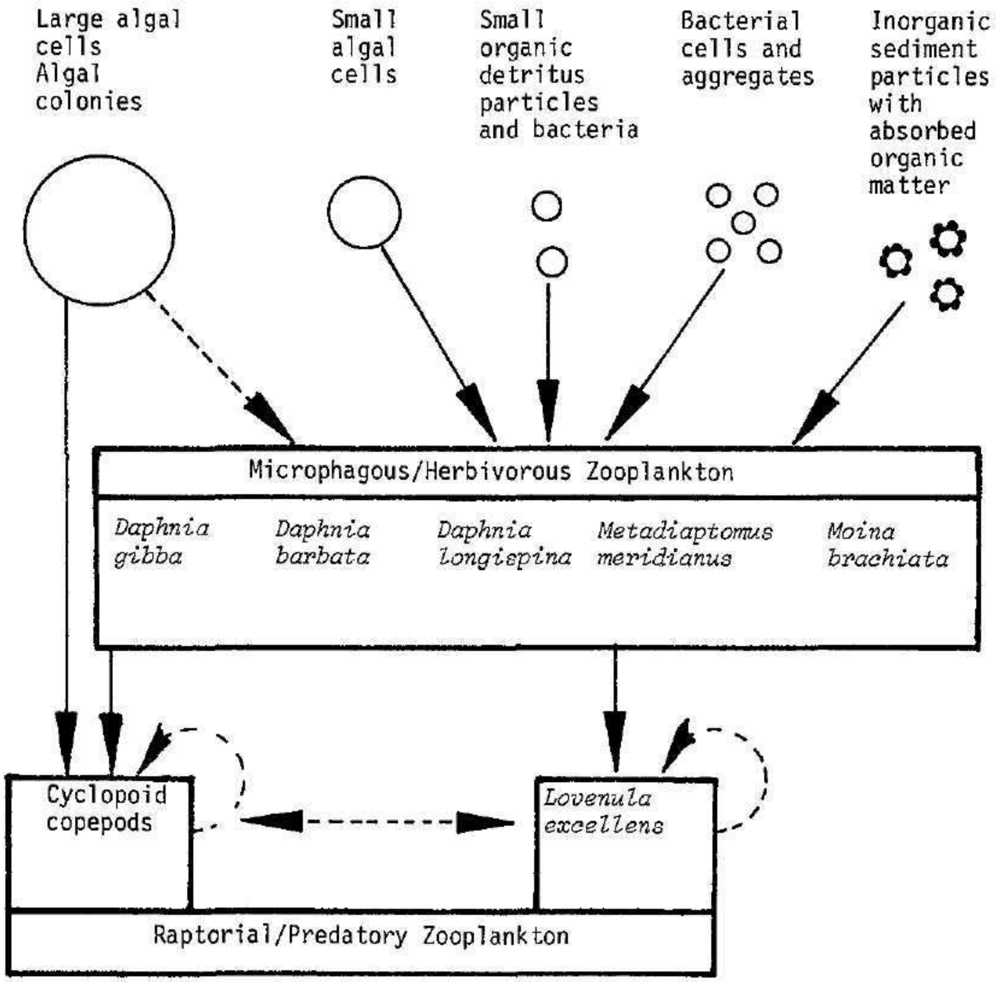


FIGURE 2.2.6. Trophic relations within the Lake le Roux crustacean zooplankton.

y°rl?2D£§I_distribution

Zooplankton is notoriously patchy in its three-dimensional distribution. Both fixed and ephemeral components can lead to horizontal patchiness (Lewis 1979). The former frequently arise from consistent predation gradients offshore, or hydraulic gradients associated with unidirectional flow patterns. Hydrodynamic factors and inter-specific interactions result in ephemeral patchiness. Understandably, considerable horizontal variation in terms of both zooplankton structure and abundance existed over the surface of this large lake. It is difficult to discern discrete patterns within the synoptic distributions recorded for total zooplankton biomass in Figure 2.2.7. Instead, Figure 2.2.7 serves to emphasize the variability which exists. Certain trends do emerge from statistical analysis, however.

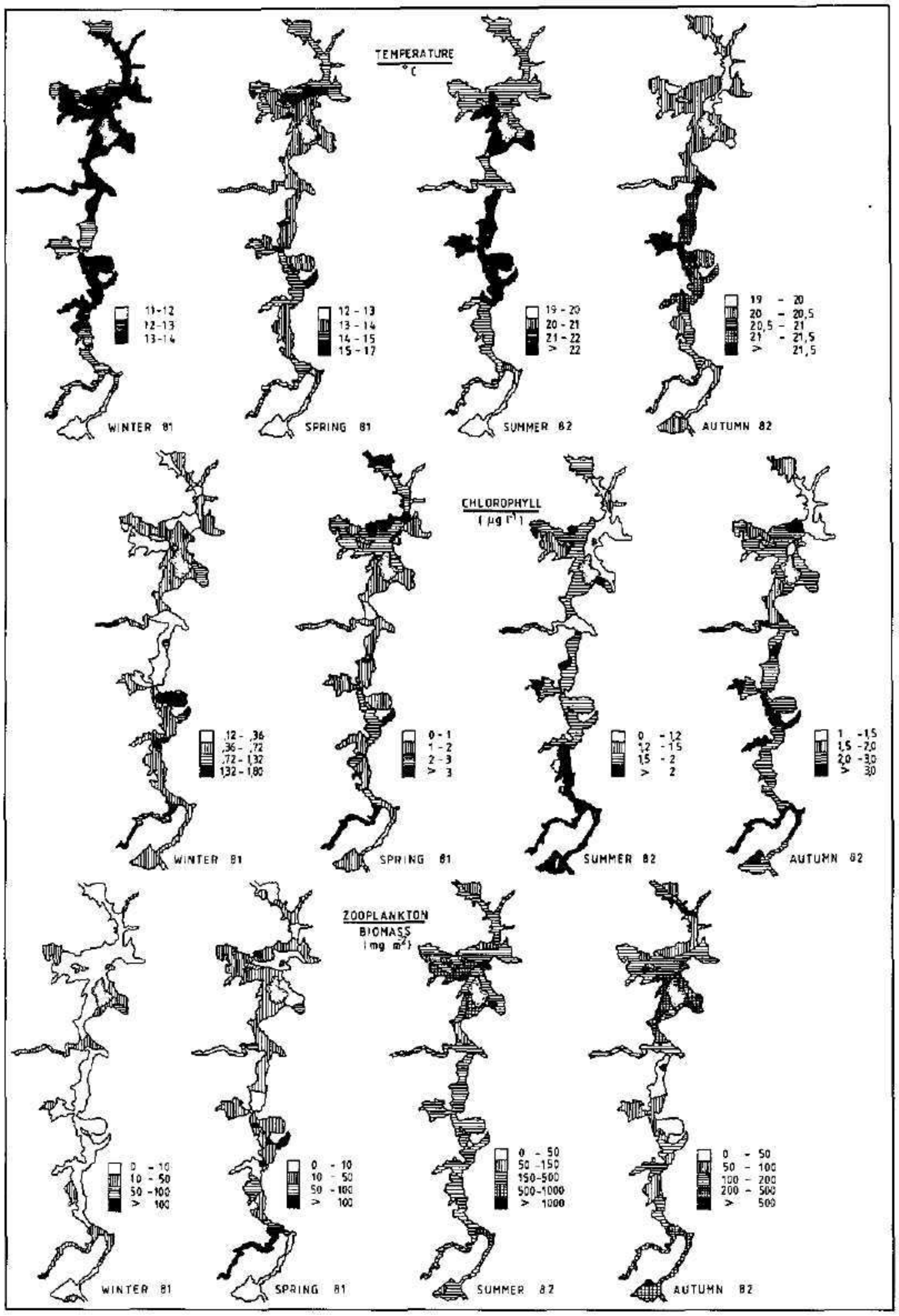


FIGURE 2.2.7. Synoptic distribution patterns of surface temperature, surface chlorophyll and total zooplankton standing stocks over Lake le Roux during 1981/82.

TABLE 2.2.4. Seasonal and annual means of zooplankton standing stocks and selected limnological variables over the entire lake (n = 90 per season) during the 1981/1982 season.

		Winter	Spring	Summer	Autumn	Annual ($\bar{x}$ ± SD)
Herbivorous zooplankton	(mg/m²)	6	17	255	145	106±149
Predatory zooplankton	(mg/m²)	8	15	79	46	37±57
Total zooplankton	(mg/m²)	14	32	334	191	143±187
Chlorophyll	(µg/ℓ)	0.7	2.7	1.7	2.4	1.9±1.9
Surface temperature	(°C)	12.7	13.8	21.6	20.4	17.1±4.0
Transparency	(cm)	18.3	15.7	16.4	16.7	16.8±3.4

Seasonal afld^annual mean values of selected variables measured at 90 sites over the lake are summarized in Table 2.2.4, which demonstrates their pronounced seasonality. Table 2.2.5 shows that annually overall, and during summer, zooplankton abundance was most strongly correlated with temperature. In winter, spring and autumn, however, the strongest correlation was with chlorophyll concentration, which represents a measure of food availability. Given the limited temperature range, but larger variations in food availability (as chlorophyll), over the lake at a given time, it is not unreasonable to expect the latter to influence zooplankton abundance more than temperature. The absence of a demonstrable correlation between zooplankton and chlorophyll during summer is probably a reflection of the severe control exerted on food resources by the grazing activities of the zooplankton (see below). These serve to depress chlorophyll concentrations during summer.

TABLE 2.2.5. Pearson correlation coefficients between total zooplankton abundance estimates and selected limnological variables lakewide during 1981/82.

Zooplankton		Winter	Spring	Summer	Autumn	Annual
with:	Temperature	-0.283*	0.232*	0.257*	-0.132	0.667**
	Chlorophyll	0.447**	0.441*	0.108	0.452**	0.148*
	Transparency	-0.020	-0.283*	-0.053	-0.336**	-0.136*

* $\underline{p} \leqslant 0{,}01$ ** $\underline{p} \leqslant 0{,}001$

TABLE 2.2.6. Seasonal and annual mean values of selected variables in zones along the hydrological axis of Lake le Roux during 1981/82.

		Herbzoo mg/m^2	Predzoo mg/m^2	Totzoo mg/m^2	Chloro µg/ℓ	Secchi cm
Riverine	winter	17	20	37	1.0	12.7
n=12	spring	28	40	68	7.5	13.8
	summer	247	110	357	2.5	14.3
(Zone 7)	autumn	306	121	427	3.8	13.3
	average	149	72	222	3.7	13.5
Upper lake	winter	2	2	4	0.7	13.5
n=22	spring	21	25	46	2.1	14.6
	summer	251	81	332	1.8	15.5
(Zone 5+6)	autumn	101	46	147	2.5	14.7
	average	94	39	132	1.8	14.7
Mid-lake	winter	3	7	10	0.6	16.9
n=20	spring	15	7	22	1.3	16.6
	summer	218	46	264	1.7	16.7
(Zone 3+4)	autumn	112	34	146	2.5	15.5
	average	87	23	110	1.5	16.2
Backwater	winter	19	35	54	0.8	25.2
n=5	spring	13	2	15	1.8	15.6
	summer	574	56	630	1.3	16.4
(Zone 2)	autumn	389	54	443	2.2	16.8
	average	249	36	285	1.5	18.5
Rolfontein	winter	3	4	7	0.5	22.4
n=22	spring	16	5	21	2.5	17.3
	summer	260	114	374	1.4	17.1
(Zone 2)	autumn	87	25	112	2.0	18.4
	average	92	37	129	1.6	18.8
Lower lake	winter	5	4	9	0.5	26.9
n=9	spring	5	5	10	2.0	16.9
	summer	168	30	198	1.4	18.9
(Zone 1)	autumn	114	20	134	1.6	22.7
	average	73	15	88	1.4	21.3

TABLE 2.2.7. Rank abundance frequencies of zooplankton biomass at transect stations 1 to 5 on 46 dates between December 1977 and June 1982 in respect of areal (mg/m^2) and volumetric (mg/m^3) standing stocks.

Rank (as mg/m^2)

STATION NUMBER	1	2	3	4	5
1	3	6	9	10	18
2	5	5	5	14	17
3	13	14	9	8	2
4	6	13	13	8	6
5	19	8	10	6	3

Rank (as mg/m^3)

STATION NUMBER	1	2	3	4	5
1	1	5	5	14	21
2	3	6	4	18	15
3	8	15	16	6	1
4	8	12	12	6	8
5	26	8	9	2	1

The lake can be subdivided along its principal axis into zones (Figure 3.2.1) which broadly reflect a hydraulic/morphometric gradient. Only the eastern 'backwater' area of zone 2 does not accord with this criterion. Seasonal and annual means of selected variables determined for sampling sites within these zones are given in Table 2.2.6. Apart from the restricted shallow 'backwater' zone, zooplankton abundance generally tended to decrease on average along the hydraulic axis of the lake. This tendency was clearly demonstrated from routine sampling at Stations 1 to 5 (Figure 2.1.1) over 5 years. It broadly matched decreases in concentrations of nitrate-N and phosphate, as well as chlorophyll down the lake. The trend for zooplankton standing stocks was more evident on a volumetric (per m^3) than an areal (per m^2) basis, as shown by Table 2.2.7. This table shows, for example, that the highest standing stock (/m^2) (rank = 1) on a given sampling date was recorded at Station 5 on 19 occasions, but only 3 times at Station 1. Conversely, the lowest biomass (rank = 5) was recorded at Station 1 on 18 dates and only 3 times at Station 5. Concurrent sampling which included Station 6 confirmed the decline below Station 5, but revealed that zooplankton standing stocks were consistently lower upstream at Station 6 than at Station 5.

Zooplankton exist in a three-dimensional environment, and frequently demonstrate more striking and consistent distribution patterns in the restricted vertical plane than exist in the horizontal. In addition, the widespread phenomenon of diel vertical migration confers a capability to control their vertical distribution, which has no counterpart in the horizontal plane apart from the 'shore-avoidance' migratory responses

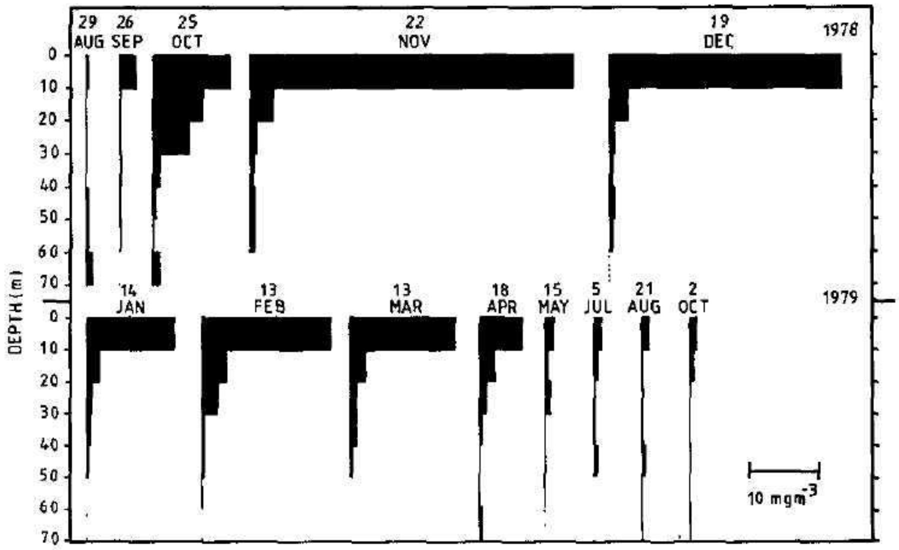


FIGURE 2.2.8. Daytime vertical distribution profiles of total zooplankton standing stock at Station 1 during 1978/79.

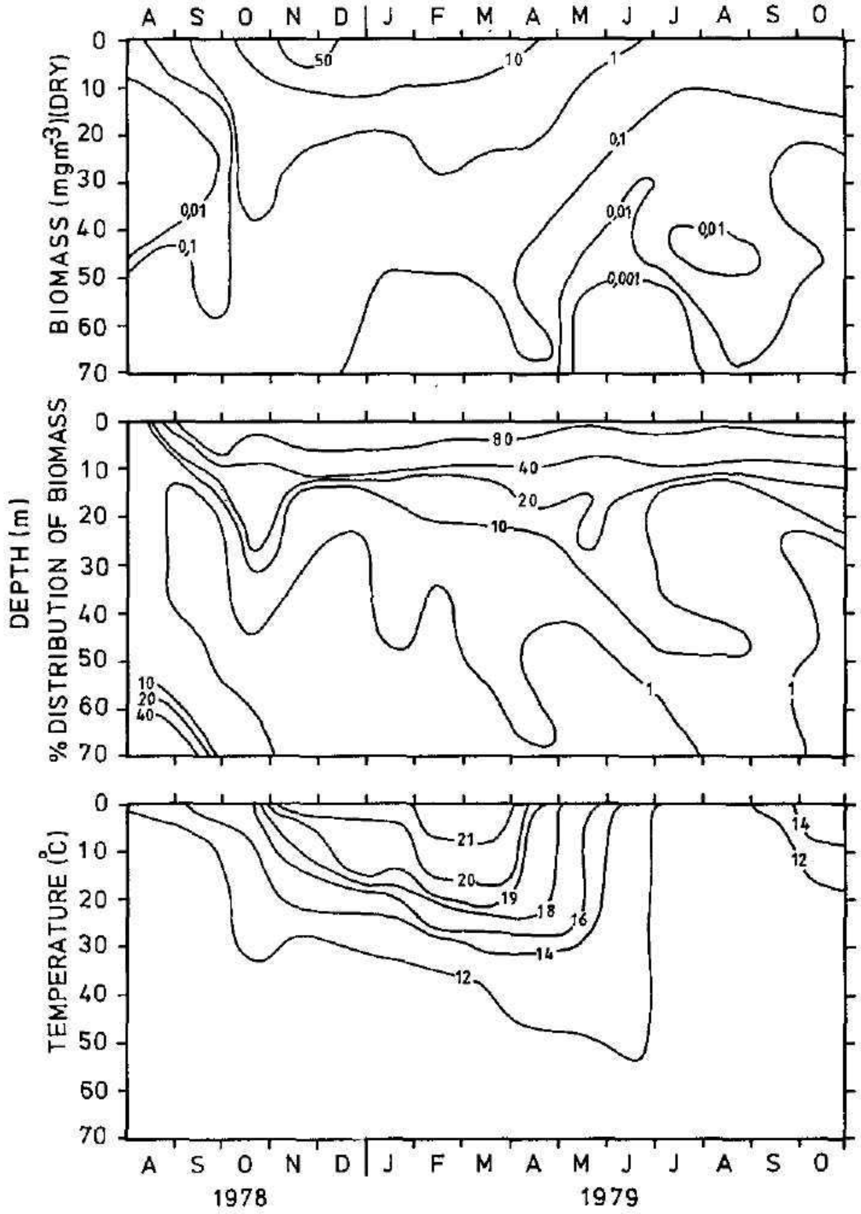


FIGURE 2.2.9. Seasonal vertical distributions of absolute and relative total zooplankton biomass in relation to temperature at Station 1 during 1978/79.

recorded in a few species. Vertical distribution has particular significance to clear-water zooplankton in counter-balancing the conflicting pressures of 'eat' and 'be eaten[1]. Susceptibility to visual predators is increased in surface waters during daylight, while existence in deeper, darker waters generally removes them not only from visual predation, but also from their principal autotrophic food resources. These issues have not been specifically addressed in turbid waters, although it might not be unreasonable to expect a compressed vertical distribution of zooplankton under such conditions.

Studies of the vertical distribution in Lake le Roux revealed that the bulk of zooplankton (>75% by weight) inhabited the upper 10 m at Station 1 (Figures 2.2.8, 2.2.9). A slight progressive dispersion of zooplankton biomass into deeper waters accompanied the seasonal descent of the thermocline and associated increase in depth of circulating epilimnetic water. As this occurred in a declining population, zooplankton standing stock (per m^3) was additionally diluted. More detailed studies in shallower waters in Croilia Bay (Figure 2.1.1) confirmed that zooplankton was most heavily concentrated in the uppermost 2 to 3 m and demonstrated limited diel differences in vertical distribution profiles (Figure 2.2.10). The accumulation of zooplankton in surface waters, and the absence of pronounced diel vertical migration, are readily understandable in turbid waters. The euphotic zone is shallow enough to permit animals to inhabit warmer, more productive surface waters without a strong concomitant risk of perception by visual planktivores. In this respect, inorganic turbidity provides zooplankton with a refuge from visual predators.

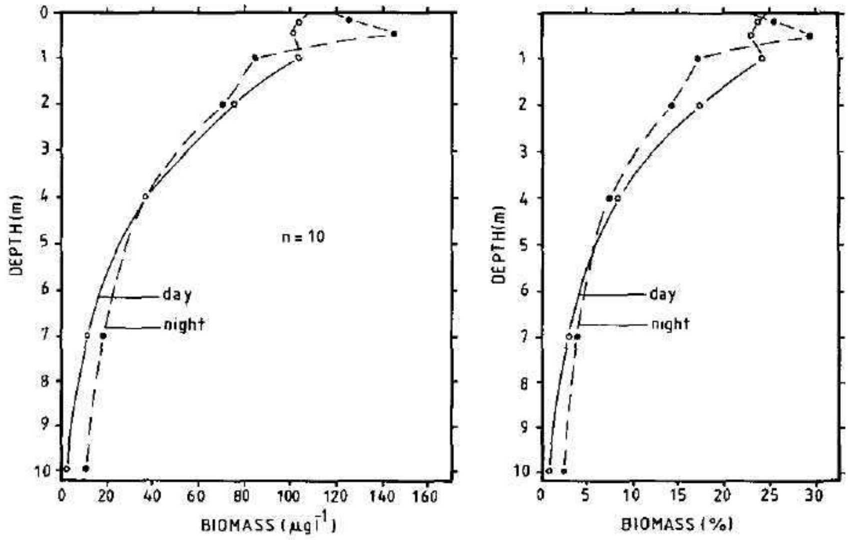


FIGURE 2.2.10. Average daytime and night-time distribution profiles of zooplankton standing stock in the surface 10 m in Croilia Bay from ten series during 1981-1983. Both absolute ($\mu g/\ell$) and relative (% of total) distributions are shown.

Seasonal abundance and composition

Zooplankton was highly seasonal in its occurrence in Lake le Roux. Total standing stocks increased from near zero levels in winter to variable mid-summer maxima, followed in certain years by a subsidiary peak in late summer

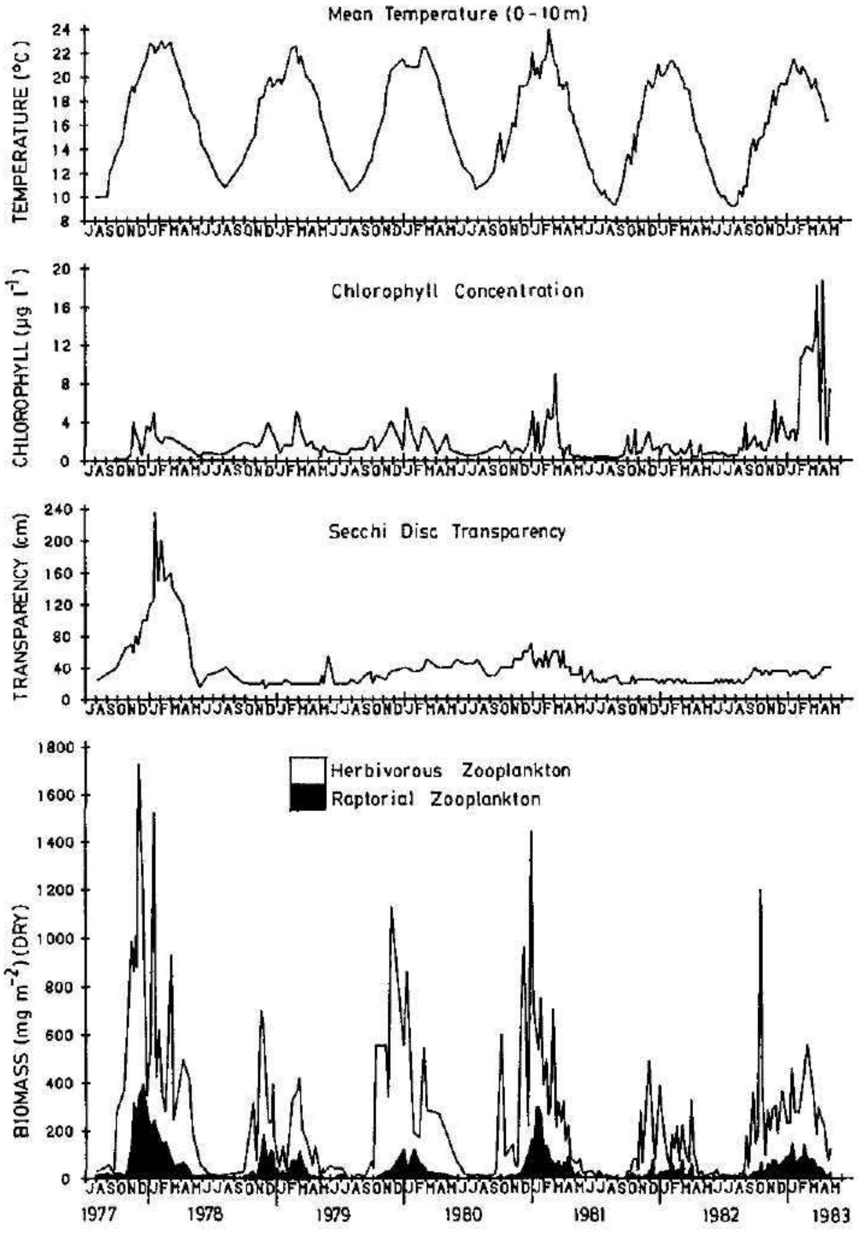


FIGURE 2.2.11. Temporal variations in total zooplankton biomass (herbivores and raptors) in relation to mean water temperature in the 0-10 m stratum, surface chlorophyll concentration and water clarity at Station 1, between August 1977 and May 1983.

or early autumn. This cyclical pattern of increase and decline broadly matched the seasonal water temperature regime. Chlorophyll concentrations, reflecting algal abundance, likewise waxed and waned with a comparable seasonal periodicity. The broad pattern of planktonic events at Station 1 are shown in relation to one another and to water transparency, in Figure 2.2.11. Less frequent observations at Stations 1 to 5 confirmed the seasonal pattern observed at Station 1 (Figure 2.2.12).

Seasonal increases of specific components (eg Moina brachiata) were sometimes observed to start in the upper reaches of the lake ana[1] progress downstream. It is not clear whether direct physical translocation of organisms themselves, or of progressive environmental changes conducive to their proliferation, was the proximate causal factor involved. The lake nevertheless appeared to be behaving as a 'slow river[1], in keeping with its hydrological characteristics.

In addition to the clear seasonality evident in respect of the global zooplankton community, fairly consistent successional phenomena were observed for specific components in the assemblage. The general successional sequence of species' is summarized in Figure 2.2 13, while the details of year-to-year occurrence are shown in Figure 2.2.14. The copepod M.meridianus consistently led the spring increase of zooplankton, within the remarkably narrow temperature range of 13.2 to 13.7°C in all years.

Subsequent components were far less predictable but in general the spring 'pulse' of M.meridianus was followed in mid-summer, at temperatures of between 16° and 19^{U}C, by various daphnids. M.brachiata generally increased latest in the succession, in late summer or autumn at temperatures of around 21°C, when it often coincided with a second peak of M.meridianus. Predatory components, notably L.excellens and the cyclopoicT assemblage generally

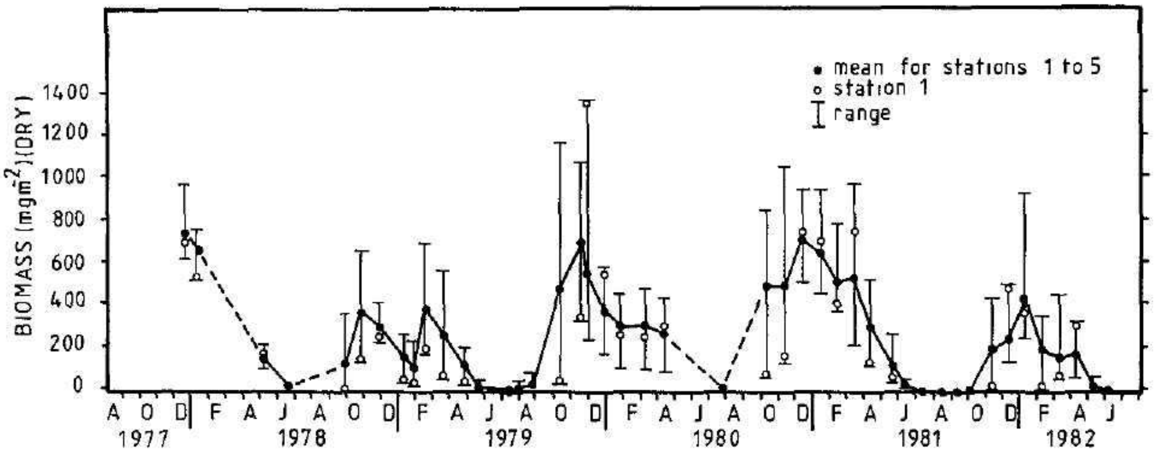


FIGURE 2.2.12. Temporal variations in total zooplankton standing stock at Station 1 (o) in comparison with mean values at Stations 1 to 5 (•). The range recorded on a given sampling date is shown by the bar. Mean values of regular samplings are connected by an unbroken solid line. Linear interpolations between mean values of irregular samplings are shown by a dashed line.

proliferated during the daphnid 'phase', often at temperatures of around 18°C. Changes in density of L.excel lens generally reflected those of M.meridianus, although the relationships were out of phase as is typical of many predator-prey populations.

The above description of successional phenomena in terms of seasonal temperatures should not be taken to imply a direct causal link between temperature and occurrence. Temperature was used to standardize seasonal progression which varied from year to year in terms of calendar time. The control of succession is undoubtedly a much more complex phenomenon, involving inter-specific competition, considerations of food quality and quantity, predation and other environmental interactions.

The specific composition of the daphnid 'phase[1], for example, varied from year to year. Daphnia gibba was abundant in three seasons, while D.barbata and D.longispina only proliferated in single, separate seasons (Figure 2.2.14). The major occurrence of D.barbata was restricted to the period of highest water clarity during the summer of 1977/78. Whether or not factors other than relatively low silt loads favoured the development of this species during this early post-impoundment phase cannot be judged.

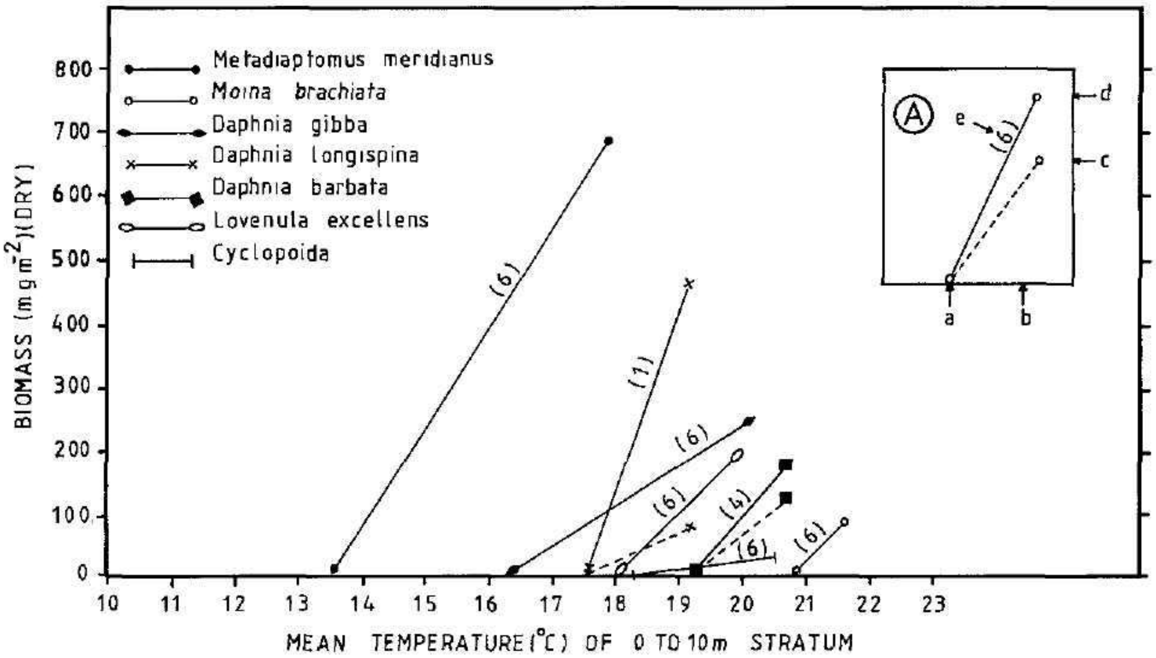


FIGURE 2.2.13. Generalized seasonal succession of zooplankton in relation to mean water temperature in the 0-10 m stratum. For the Key inset:- (a) The mean temperature of annual increase.
(b) The mean temperature of annual maximum biomass.
(c) The overall mean maximum biomass attained.
(d) The mean maximum biomass attained during years present.
(e) Number of years the given species was significant in the plankton.

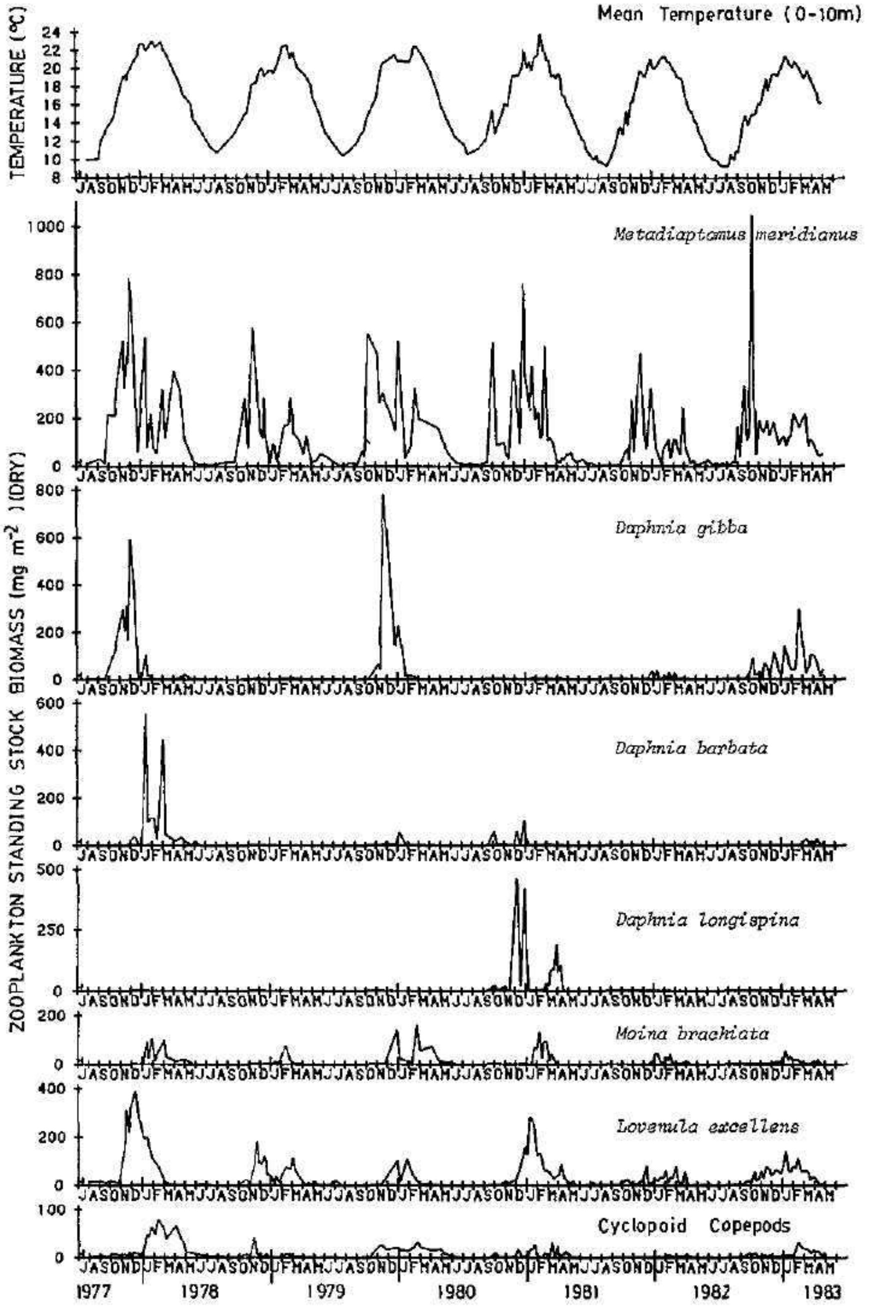


FIGURE 2.2.14. Temporal variation in biomass of the principal zooplankton species or taxa at Station 1 between 1977 and 1983, in relation to water temperature.

Although less obvious., the abundance of both D.gibba and D.longispina was also statistically correlated with turbidity (Table 2.2.8). The positive correlation of abundance; of all daphnids with Secchi disc transparency suggests that the p.ositive influences of increased transparency upon water temperature, food avaiiaoility and the presumed reduction in interference by inorganic particles on the filter-feeding activities outweighed the parallel increase in susceptibility to visual perception and predation.

TABLE 2.2.8. Pearson correlation coefficients between abundance of daphnid species (when present) and concurrent measurements of water temperature, chlorophyll content and water transparency at Station 1. Numbers of observations are given in parentheses.

	TEMPERATURE	CHLOROPHYLL	TRANSPARENCY
Daphnia gibba	$0,133^{ns}$ (115)	$-0,058^{ns}$ (115)	0,195* (112)
Daphnia barbata	0,277** (70)	$-0,060^{ns}$ (70)	0,496*** (70)
Daphnia longispina	$0,217^{ns}$ (30)	$-0,012^{ns}$ (30)	0,493** (30)

* $p \leqslant 0,05$ ** $p \leqslant 0,01$ *** $p \leqslant 0,001$

In addition to cyclical seasonal variation, annual mean standing stocks of the total entomostracon zooplankton varied nearly four-fold over the six year study period, as reflected in Table 2.2.3. Much of this variability was attributable to the daphnid assemblage, while the principal zooplankter, M.meridianus, varied less markedly from year to year. The ecological Implications to planktivorous fish stocks of this variability in food resource are obvious. It will be appreciated that dynamic measurements of production are more informative than static estimates of residual biomass in this regard, but direct productivity estimates could not be obtained routinely. Identification of contributory and causal factors responsible for such inter-annual variation, is obviously fundamental to sound fishery management practices. Some attempts in this direction are provided in a subsequent section.

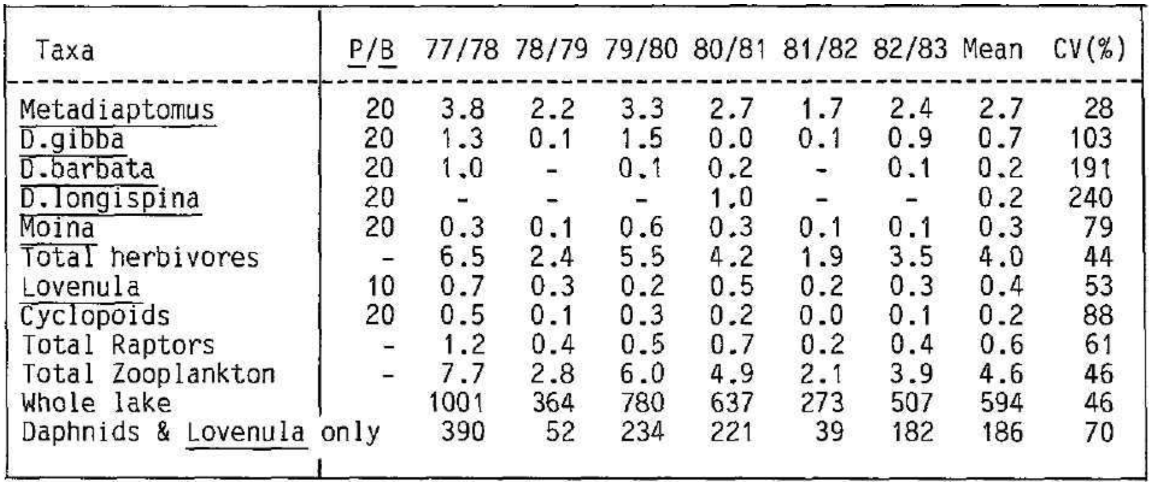
Zooplankton productivity estimates obtained indirectly by multiplying observed annual mean standing stock values (B) by turnover coefficients (P/B) derived from the literature (Waters 1977J are given in Table 2.2.9. TFTe resulting estimates are most probably conservative for two reasons.

Firstly, actual turnover coefficients determined for M.meridianus durin 1977/78 were considerably higher than the values usecT ~7n Table 2.2.9 Similarly, turnover coefficients of the other zooplankton species are likel to be higher. Secondly, the mean annual standing stock values wer determined for Station 1, which generally supports a lower biomass c zooplankton than other regions of the lake (Figure 2.2.12, Table 2.2.7) The estimates given in Table 2.2.9 could accordingly be as little as hal the 'real' values. Detailed studies on zooplankton population dynamic which await completion will provide a more objective basis for correction.

The conservative areal production estimates at Station 1 provide a cruc whole-lake estimate ranging from as little as 270 tonnes (dry weight) durir 1981/82 to 1000 tonnes during 1977/78. Fresh weight equivalents ar approximately 6 times higher (Waters 1977). The indirect estimates provide in Table 2.2.9 suggest that zooplankton productivity declined during tl" study. The validity of this trend needs confirmation based upon direc measurements of production, although it is a trend frequently records during the 'maturation' of reservoirs.

Only a small, variable fraction (1/3 to 1/7) of total zooplankton productic was attributable to species important in the diet of smallmouth yellowfisf But 'good' and 'bad' years for the overall community were 'good' and 'bac years for these major forage species (L.excellens and Daphnia spp.) as wel] OveraJl, the rank order of annual production estimates for the forac species matched those for the total zooplankton. Various limitations i method must be recalled, however. It is likely that standing stocks (J3) c forage species were selectively reduced by fish production. Productivil estimates derived from the expression $\frac{B\ p}{D}$ would accordingly be reduced equally. -

TABLE 2.2.9. Rounded production estimates {g/m^2/yr dry wt) of Lake le Roux zooplankton, based on standing stock (B_) determinations at Station 1 (Table 2.2.3) and published P/J3 values. The whole lake values are tonnes/yr, assuming a constant surface area of 13,000ha.



Taxa	P/B	77/78	78/79	79/80	80/81	81/82	82/83	Mean	CV(%)
Metadiaptomus	20	3.8	2.2	3.3	2.7	1.7	2.4	2.7	28
D.gibba	20	1.3	0.1	1.5	0.0	0.1	0.9	0.7	103
D.barbata	20	1.0	-	0.1	0.2	-	0.1	0.2	191
D.longispina	20	-	-	-	1.0	-	-	0.2	240
Moina	20	0.3	0.1	0.6	0.3	0.1	0.1	0.3	79
Total herbivores	-	6.5	2.4	5.5	4.2	1.9	3.5	4.0	44
Lovenula	10	0.7	0.3	0.2	0.5	0.2	0.3	0.4	53
Cyclopoids	20	0.5	0.1	0.3	0.2	0.0	0.1	0.2	88
Total Raptors	-	1.2	0.4	0.5	0.7	0.2	0.4	0.6	61
Total Zooplankton	-	7.7	2.8	6.0	4.9	2.1	3.9	4.6	46
Whole lake		1001	364	780	637	273	507	594	46
Daphnids & Lovenula only		390	52	234	221	39	182	186	70

The impact of zooplankton on_their_food_resources^_food_limitation

Photosynthetic production is incontestably influenced negatively in silt-laden waters by the severe attenuation of light underwater which restricts the availability of the primary energy source, solar radiation. The relatively low levels of primary production measured in Lake le Roux (see Chapter 2.2.2) imply a potential limitation to subsequent trophic levels. Aspects of this restriction were examined in the context of herbivorous zooplankton, by measuring community grazing rates in *situ* (Haney 1971).

The . impact of the herbivorous zooplankton community upon its food resources appeared rather low. Community grazing rates were linked to zooplankton abundance but seldom exceeded 50%/d in surface waters. They declined vertically with depth in parallel with decreasing zooplankton density (Figure 2.2.15). (A rate of 50%/d implies that only 50% of potential resources are utilized per day; 100%/d implies total utilization per day and values greater than 100%/d imply a 'reworking[1] of the ambient environment within 24 hours). An isolated maximum value of 260%/d was recorded at an exceptionally high density and biomass of zooplankton (375 individuals/^, 800 jjg/J? dry weight) in a particularly warm (26.5°C) sheltered backwater. In passing, it may be noted that no diel pattern in grazing rate was observed.

The grazing profiles shown in Figure 2.2.15 were integrated to provide a mean grazing rate under unit area of lake surface, called the areal grazing rate. This estimate more realistically incorporates vertical structuring within a dynamic stratum (0-10 m for this study) in which physical and biological gradients are fundamental. Areal grazing rates varied seasonally in accordance with zooplankton abundance from virtually 0%/d during winter to c_ 15%/d during summer (Figure 2.2.16). This maximum value implies a daily 'cropping' of only 15% of available food resources and suggests zooplankton is not fully exploiting its food resources. There are certain grounds for understanding how this might arise. The filter-feeding activities of zooplankton, particularly of the 'non-selective' cladocerans, are likely to be adversely influenced by high silt particle concentrations. This can arise from clogging of the filtering apparatus and the associated increased frequency of rejection of food-boluses rendered unpalatable by their high inorganic sediment content. Such disruptions of the normal food-gathering processes would obviously influence energy balances adversely at the individual level, resulting in depressed populations. The correlations which exist between daphnids and water transparency (an inverse correlate of silt load) which were given in Table 2.2.8 could be taken as supportive circumstancial evidence for the interpretations given above. Equally, these correlations could be taken to reflect the beneficial influences of increased water transparency on autotrophic production and hence food availability for the daphnids. It is more plausible that both mechanistic influences outlined above contribute interactively to the same overall result: an inverse relationship between daphnid abundance and silt concentration.

The greater body of evidence and consideration supports the conclusion that the zooplankton is indeed in fine balance with its food resources, and food availability is likely to be a limiting factor in its ecology. Figure 2.2.17 demonstrates the striking decline in brood size of M.*meridianus* as total zooplankton stocks increase seasonally and both inter-

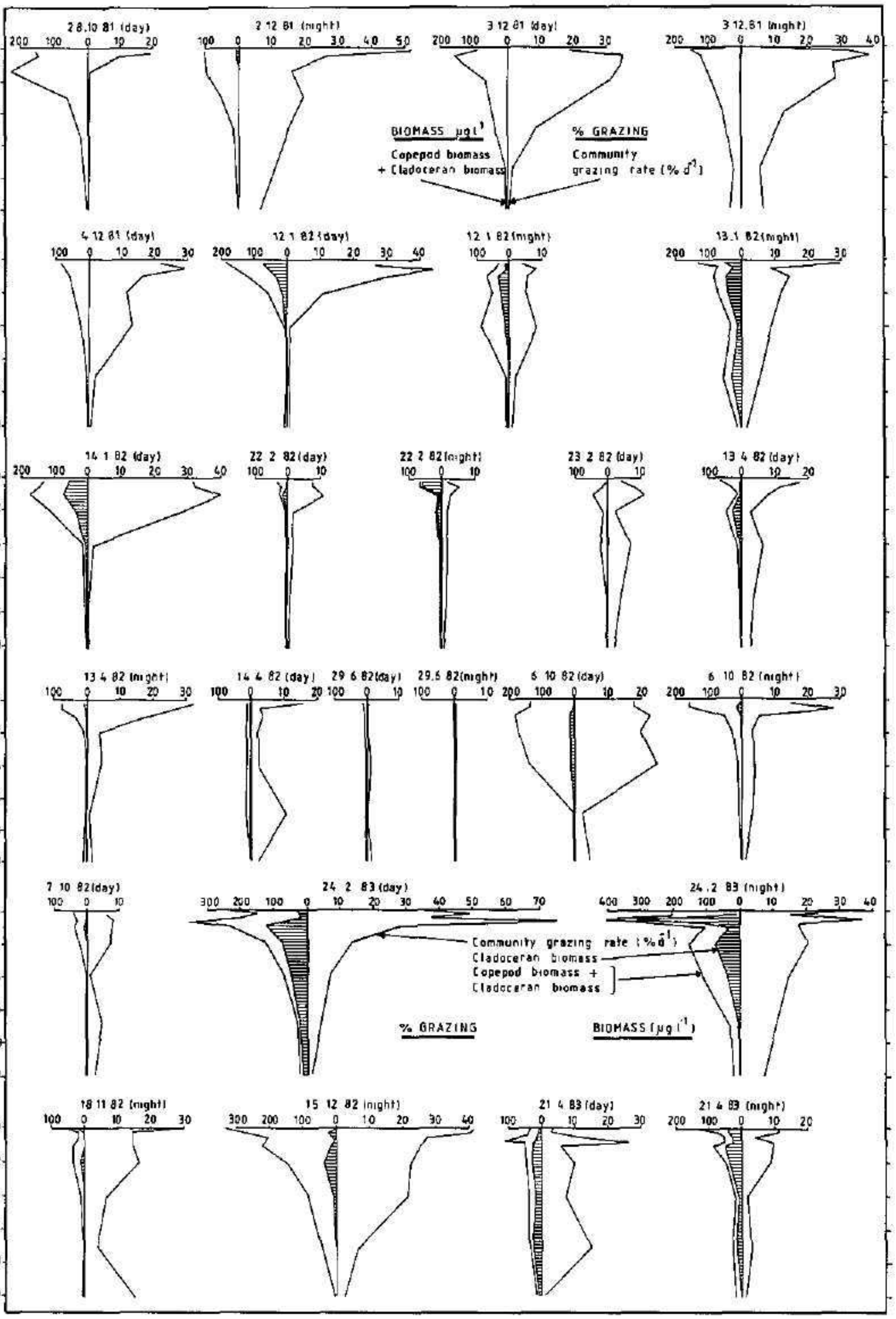


FIGURE 2.2.15. Vertical profiles of zooplankton grazing activity (%/d) in relation to biomass (µg/ℓ) by day and at night, in Croilia Bay.

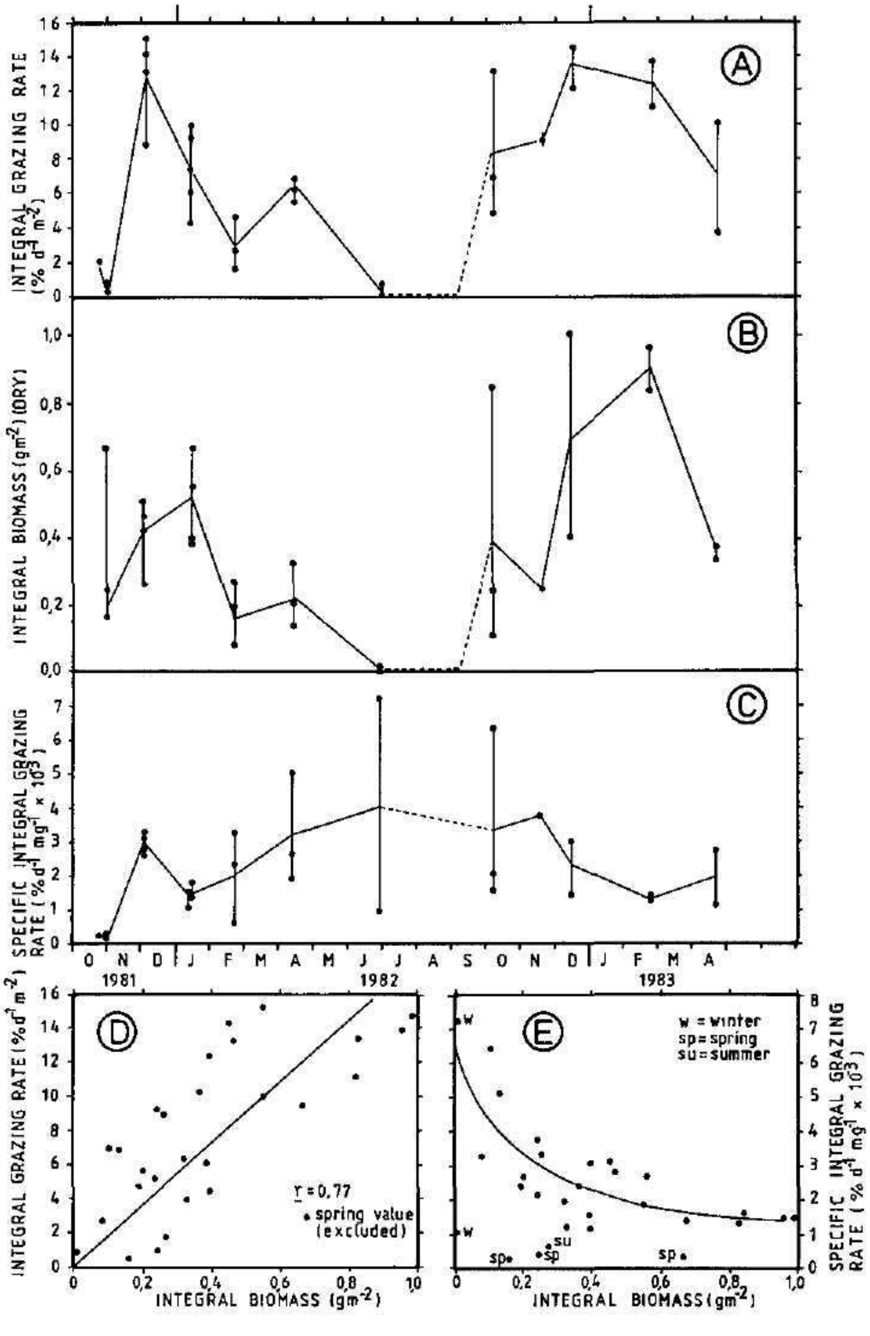


FIGURE 2.2.16. Temporal variations in (A) integral grazing pressure, (B) integral standing stock and (C) specific grazing rates in the water column. Relationships between integral grazing and integral biomass are plotted in (D), while (E) shows the relationship between specific grazing rate and standing stock.

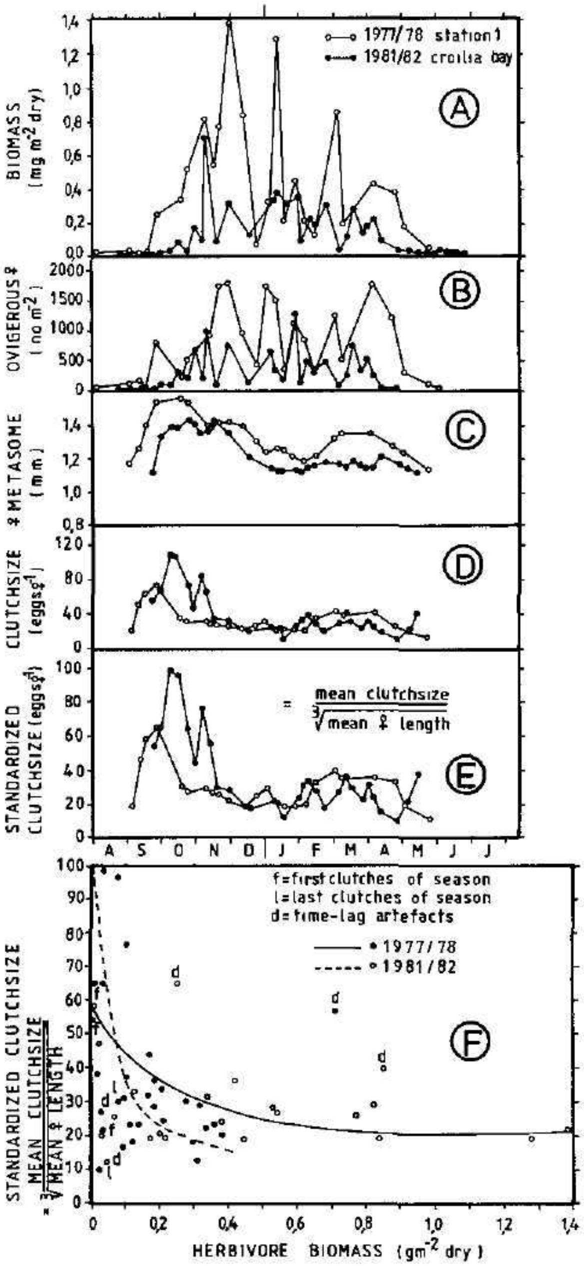


FIGURE 2.2.17. Temporal variations in (A) herbivorous zooplankton standing stock, (B) density of egg-bearing females of Metadiaptomus meridianus, (C) mean metasome lengths of female M.meridianus, (D) average brood size of egg-bearing M.meridianus, (E) average standardized brood size {corrected for body-size) of egg-bearing M.meridianus. (F) Standardized brood size in relation to total herbivore biomass. The 1977/78 observations are for Station 1; the 1981/82 data were determined in Croilia Bay.

and intra-specific competition for food intensifies. Such observations are fairly unequivocal evidence of food limitation.

The overall productivity of Lake le Roux is primarily limited by the constraints of its unfavourable hydro-climatic characteristics on the autotrophic production system. In the turbid, deep-mixing waters of this lake, phytoplankton cells are hard pressed to meet their respiratory energy requirements, let alone increase their population biomass. Such constraints to primary productivity restrict the development of zooplankton stocks. Grazing impacts are accordingly less. The grazing impact of a larger zooplankton population would probably result in resource over-exploitation, and the subsequent destabilization and collapse of both food and grazer populations, to the detriment of both. Seen in this context, the seemingly low grazing rates reflect not resource under-utilization, but rather a dynamic equilibrium between predator and prey. The erratic population fluctuations of virtually all components illustrated in Figure 2.2.14 are often dismissed as being errors of sampling a highly patchy community. 'Overshoots' in the dynamics of predator-prey 'equilibria' undoubtedly contribute to such erratic fluctuations, as has been shown from detailed population dynamic analyses in progress which are not reported here.

Circumstantial evidence detracts from the likelihood that organic molecules adsorbed onto clay particles represent a major food resource for filter-feeding zooplankton. It is possible that they represent an energy subsidy of undefined magnitude. But at present it appears that more conventional autotrophic and microbial heterotrophic organisms (algae, bacteria, yeasts, detritus etc) are required to provide the essential vitamins and amino acids required for the growth and development of zooplankton organisms. If this interpretation is correct, the ingestion of extremely large numbers of silt particles by 'herbivorous' copepods and cladocerans may represent little more than a fortuitous consequence of the structure of their feeding appendages and their feeding behaviour.

2.2.4.2. The zoobenthos

The zoobenthos of Lake le Roux was not studied in any detail. Some determinations were made of standing stock levels of the benthic epifauna (animals living on the surfaces of bottom material) in shallow waters along the shore-line in zone 1 (Figure 3.2.1) during December of 1977 and 1978. Colonization rates of artificial substrata were determined concurrently. The benthic infauna (animals living in rather than on bottom material) was not investigated.

Mayfly nymphs (Ephemeroptera) of the genera Pseudocloeon and Centroptilum and chironomid (gnat) larvae were the principal organisms encountered in the samples taken. Gnat larvae, predominantly tube-dwelling varieties, were more numerous than the mayfly nymphs but weighed considerably less on average. Table 2.2.10 records the standing stocks of zoobenthos encountered on natural and artificial substrata. Steeply shelving, boulder strewn bottom areas supported considerably higher standing stocks than gently-shelving bottoms with muddy or sandy sediments interspersed with pebbles. Several factors plausibly account for this disparity. The first relates to the influence of given changes in water level upon the area of bottom

TABLE 2.2.10. Standing stock levels of zoobenthos on natural and artificial substrata in two types of benthic habitat in Lake le Roux. CV is the coefficient of variation.

HABITAT		YEAR	STANDING STOCK BIOMASS (mg/m^2 dry wt)			
			Natural			Artificial
SLOPE	BOTTOM MATERIAL		mean	CV	n	mean maximum
Steep	Rocks, boulders	1977	279	41%	10	75
		1978				77
Gentle	Mud, sand, pebbles	1977	97	39%	8	90
		1978	95	91%	10	53

habitat. Habitat expansion or contraction is less marked in steeply shelving than gently sloping areas, as is the extent of movement required by organisms to accomodate given vertical displacements in water level. This makes it more feasible for the benthic algae such as certain diatoms which possess limited locomotory powers, to migrate to avoid desiccation or submersion below photosynthetic compensation depth. It likewise reduces the chances of mobile animals being stranded as waters recede. In this regard, steep-profiled bottom habitats provide a more stable environment than flat areas and additionally may provide better and more numerous refugia for zoobenthic animals than exist *over* smoother, soft-bottomed, gently-shelving areas.

Benthic algae, particularly diatoms, were the major dietary items of mayfly nymphs examined. Thus benthic photosynthetic production is likely to be an important consideration in the ecology of this inshore zoobenthos. The light-related constraints to photosynthesis described for the phytoplankton apply equally to the phytobenthos. In this respect, the lateral area available for photosynthesis along steeply-shelving shores is considerably less than along less graded shorelines. However, the bottoms of gently sloping shorelines commonly consist of fine sediment. Under the exceptionally windy conditions of the lake, this is continually resuspended and deposited, further shading and possibly smothering benthic algae and depressing primary production. In contrast, steeper shores are often firm, consisting of coarse material, and less susceptible to this problem.

Serial retrieval of artificial substrata over periods of up to 8 days revealed that colonization by zoobenthos had generally reached its maximum within 3 to 4 days. These peak values are recorded in Table 2.2.10, and were broadly comparable in the two types of habitat, in constrast to the disparate densities observed on natural substrata in these habitats. These exploratory studies suggest a capability of the zoobenthos to respond to water level fluctuations, which is probably not matched by their less motile benthic algal food resources. Variability in food resource may conceivably be of greater importance in determining zoobenthos standing stocks, than is its absolute quantity. Animals can adjust to the latter through the normal biological feedback processes which exist between predator and prey, whereas no such balance can be established with unpredictable, random variations in resource.

The zoobenthos seems to be a relatively minor forage component for fish in comparison to the zooplankton. Assume that the biomass values given in Table 2.2.10 reflect the annual mean standing stocks in a band extending 10 m offshore around the whole lake, and that the estimates for the boulder strewn areas apply to 75% of the total shoreline of 405 km. This gives an extremely crude, and probably greatly inflated, whole lake mean annual standing stock value of about 950 kg (1 tonne) dry weight. Applying a JP/B_ turnover coefficient of 7 gives an annual production estimate of 7 tonnes, about one fiftieth of the minimum zooplankton production estimate of 1981/82, or one two-hundredth of the high 1977/78 zooplankton estimate. These comparisons are based on undeniably crude estimates, but point to the relative unimportance of inshore, epifaunal zoobenthos in the trophic economy of the lake, in comparison with the zooplankton.

2.2.5. An overview of the energy base of Lake le Roux

Various compartments of the biological production system of Lake le Roux have been described above. In Figure 2.2.18 an attempt is made to integrate this information to demonstrate the relative contribution of these compartments to the totality of the lake environment. It must be stressed that the values used in the figure are merely order of magnitude estimates, which differ in their reliability and representativeness. Some were determined from exhaustive spatial and temporal analysis. Others stem from little more than spot analyses. The validity of attempting to integrate data of such variable and disparate quality could be questioned. Nevertheless, provided Figure 2.2.18 is interpreted bearing these serious constraints in mind, it does provide an overview of the lake's energy base. The principal energy source is attributable to photosynthetic production, notwithstanding the light-related constraints which exist in these turbid waters. Allochthonous subsidies are about half the levels of autotrophic sources. Earlier assessments of the importance of these subsidies (Allanson 1982) overlooked losses in the outflow, and were based on observations of abnormally high concentrations and hydrological inflow values.

What is immediately striking about Figure 2.2.18 is the seemingly low transfer efficiency between primary production and invertebrate secondary production, about 3%. Inclusion of transfers directly into the herbivorous fish compartment would elevate the efficiency somewhat. In how far the low efficiencies reflect an inadequate, disparate data base, or real phenomena within these turbid waters cannot presently be judged. But it is pertinent to question the reality of possible interferences in the normal feeding behaviour of filter-feeders by the large quantities of probably unpalatable inorganic suspensoids. In other words, in addition to imposing primary constraints to photosynthetic productivity, suspensoids may influence other pathways in the total production system resulting in less efficiency.

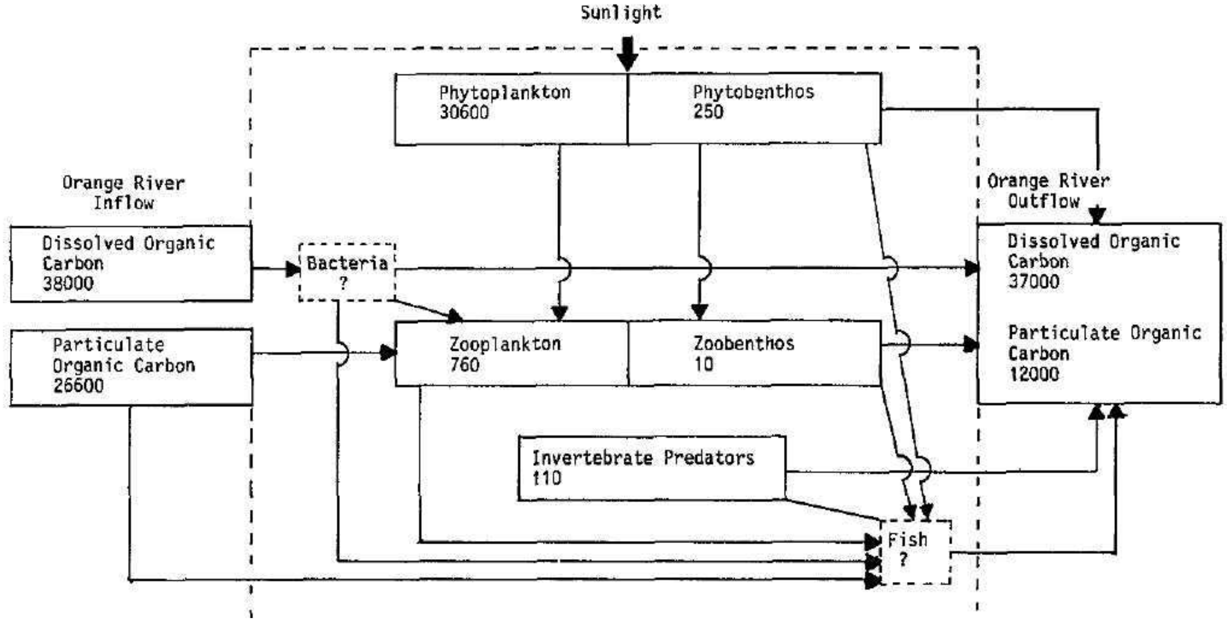


FIGURE 2.2.18. An overview of the energy base of Lake le Roux. All values are given as kg C/day for the whole lake, and at best represent order of magnitude estimates. Respiratory losses are ignored.

2.2.6. Environment-zooplankton and zooplankton-fish inter-relationships

The abundance of zooplankton varied considerably from year to year within the cyclical annual pattern of increase and decline which corresponded broadly to the annual temperature regime (Figure 2.2.11). Factors responsible for differences in magnitude of the annual cycle of abundance of zooplankton from year to year are not immediately obvious, but have great significance to understanding the regulation of biological production in the lake.

TABLE 2.2.11. Correlation coefficients for zooplankton abundance levels and simultaneous environmental conditions. All coefficients are significant at $\underline{p} \leqslant 0.001$ ($\underline{n} = 186$).

	TEMPERATURE	TRANSPARENCY	CHLOROPHYLL
Total zooplankton	0.53	0.45	0.24
Herbivorous zooplankton	0.47	0.39	0.22
Predatory zooplankton	0.56	0.51	0.22

Considering the data base as a whole, significant correlations exist between zooplankton abundance levels and contemporaneous water temperature, water transparency and chlorophyll concentration values (Table 2.2.11). Correlations incorporating time-delays and therefore lag phenomena might plausibly be stronger. Temperature and transparency, but not chlorophyll concentrations, are by themselves significant correlates of zooplankton abundance. This was demonstrated by partial correlation analysis {Table 2.2.12), which controls for the simultaneous interactions of the independent variables.

TABLE 2.2.12. Partial correlation coefficients (and significance levels) for zooplankton abundance levels and one independent environmental factor controlled for the simultaneous interactive effects of co-varying factors.

Dependent	Independent	Controlled	r
Total Zooplankton	Temperature	Transparency and Chlorophyll	0.37 (0.001)
	Transparency	Temperature and Chlorophyll	0.33 (0.001)
	Chlorophyll	Temperature and Transparency	0.09 (ns)

Given the interacting influences of environmental variables, multiple regression analysis (Nie et aj_, 1975) was used to quantify the contribution of each variable to "observed fluctuations in zooplankton abundance. Quadratic (non-linear) and interactive terms were included in the hierarchical analysis which ranked variables in the following order of importance.

(i) Temperature squared (reflecting the importance especially of high temperatures);
(ii) transparency;
(iii) transparency squared;
(iv) chlorophyll concentration;
(y) chlorophyll concentration squared;
(vi) temperature;
(vii) temperature-transparency interaction;
(viii) chlorophyll-transparency interaction;
(ix) temperature-chlorophyll interaction.

The resulting regression equation explains 48% of the observed variability in zooplankton abundance (multiple r = 0.689, £= 0.0001). Exclusion of chlorophyll concentration as an independent variable barely reduces the power of the prediction (_r = 0.667, p_ = 0.0001).

The relationships between zooplankton abundance and two separate independent variables are most effectively visualized by means of response surface plots (Box, 1954). In these figures (Figure 2.2.19) contours are plotted which represent abundance levels of zooplankton over a range of combinations of the specified independent variables as predicted from fitted parameters of the multiple regression. Figure 2.2.19a demonstrates the increase of zooplankton with temperatures particularly at intermediate transparency levels. At the very lowest transparencies, zooplankton is almost independent of temperature; the temperature influence is also reduced at high transparencies. In essence, zooplankton levels increase and subsequently decrease with transparency. The transitional transparency level itself rises with temperature. Considered in relation to temperature and chlorophyll concentration (Figure 2.2.19b), zooplankton increases sharply with temperature at low chlorophyll levels, and less sharply at high chlorophyll levels. It decreases in abundance with both increasing and decreasing chlorophyll concentrations and transparencies either side of an abundance peak at low chlorophyll levels and intermediate transparencies (Figure 2.2.19c).

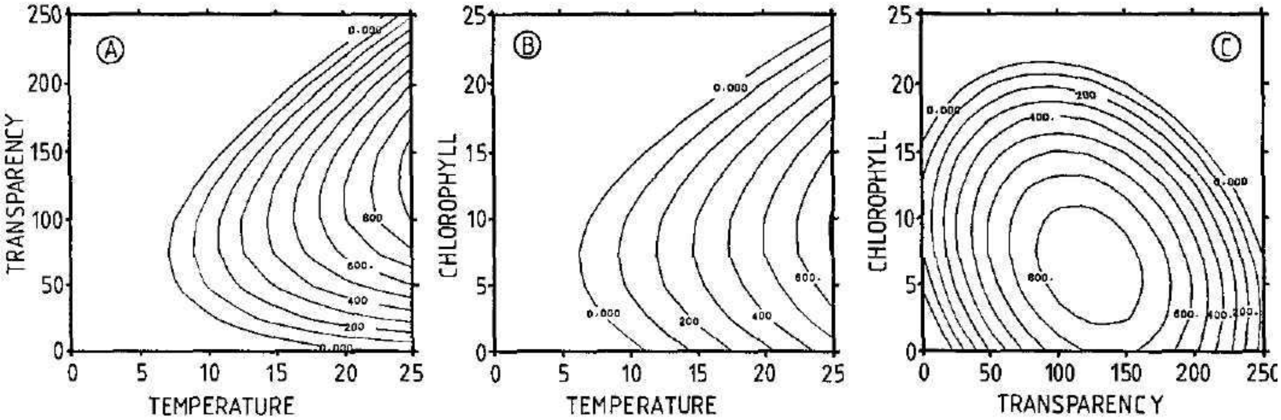


FIGURE 2.2.19. Response surface plots of zooplankton abundance shown as contours (at 100 mg/m^z dry wt intervals) in relation to (A) Temperature (0-10 m stratum) and transparency; (B) Temperature (0-10 m stratum) and chlorophyll concentration; and (C) Transparency and chlorophyll concentration.

On the basis of the overall data set, comprising over 200 determinations, it is clear that zooplankton is related to temperature, transparency and chlorophyll concentrations. These relationships are biologically intelligible. Temperature has an obvious rate influence, and is linked to the primary source of energy, solar radiation, which in turn influences autotrophic production processes and hence food availability. Transparency influences light penetration and hence the vertical extent and magnitude of energy fixation processes. It also additionally influences the feeding ecology of zooplankton in waters of high mineral turbidity and determines their susceptibility to visual predation (see Chapter 2.3). Chlorophyll content is an obvious and immediate correlate of potential food. The relative weakness of the relationship between chlorophyll concentration and zooplankton abundance probably reflects the suppressive influence of zooplankton on chlorophyll as a result of grazing, as discussed earlier. The decrease in zooplankton at high chlorophyll levels (>15jjg/4) is suggestive of the poor quality of food available during Microcystis blooms when chlorophyll concentrations reach such high values.

Having explored the general relationships overall, it is possible to examine the inter-annual variability which exists in zooplankton abundance levels. This variability has an obvious implication to the fishery potential of planktivorous fish stocks, and as will be shown, is translated into measurable effects in populations of smallmouth yellowfish.

Inter-annual variation was assessed by determining mean annual values for the variables of interest, for the hydrological year (August to July). The resulting six 'annual mean[1] estimates are weighted mean values, determined by integrating areas under relevant time-response curves (as in Figure 2.2.11). No meaningful confidence limits can be calculated for these means, but it must be recognised that they are based on over 200 individual measurements over six years.

The correlation of mean annual zooplankton standing stock estimates with a variety of environmental and fish variables is shown in Table 2.2.13. This reveals the striking association of zooplankton standing stock with the number of degree days above 20°C, which confirms the influence especially of 'high' temperatures implied by the significance of the temperature squared term in the multiple regression. There are also strong associations with transparency, but not annual mean chlorophyll levels. Certain of the relationships are illustrated in Figure 2.2.20. Temperature (days>20°C), controlled for the influences of chlorophyll and transparency both separately and together have the strongest partial correlation with zooplankton, underlining its overriding significance. Transparency characteristics and chlorophyll concentrations have progressively smaller effects. In essence, temperature appears to be the most important variable controlling zooplankton abundance, either through obvious direct influences, or more subtle indirect pathways.

Certain attributes of smallmouth yellowfish populations, such as growth rates and catch returns, are correlated with the abundance of zooplankton (Table 2.2.13). Partial correlation analysis suggests that growth rates and relative catches of smallmouth yellowfish are strongly related to zooplankton abundance independently of temperature influences, even though direct relationships with temperature exist (Figure 2.2.20) and contribute to the observed variability in relative growth rates and catch returns.

On the basis of these data, it is quite clear that zooplankton abundance has a measurable influence on attributes of the potential fishery. Zooplankton abundance is itself related to water temperatures and transparency levels. Thus hydrological management aimed at maximizing retention time and hence allowing water to warm up and clear by increasing settling time, is likely to improve the fishery of this lake significantly. There are biological

FIGURE 2.2.20.(a)-(c): Weighted annual mean values of total zooplankton standing stocks (TOTZOO, mg/nf dry wt) in relation to corresponding annual mean temperature (TEMP20, number of degree days above 20°C per year in the 0-10 m stratum), Secchi disc transparency (SECCHI, cm) and algal biomass (CHLORO, *pg/i).* Data are based on the hydrological year August to July following for 1977/78 (1) to 1982/83 (6).

(d)-(f): Interrelationships between annual mean temperature, transparency and chlorophyll values.

(g)-(i): Annual relative growth rate of smallmouth yellowfish, Barbus holubi (BARBGRO, % of mean growth rate of population between 1977/78 and 1981/82) in relation to temperature, transparency and zooplankton standing stocks.

(j)-(l): Annual catch per unit effort, standardized for net selectivity, of Barbus holubi (BARBCATCH, kg per unit effort) in relation to water temperature, transparency, and zooplankton standing stocks.

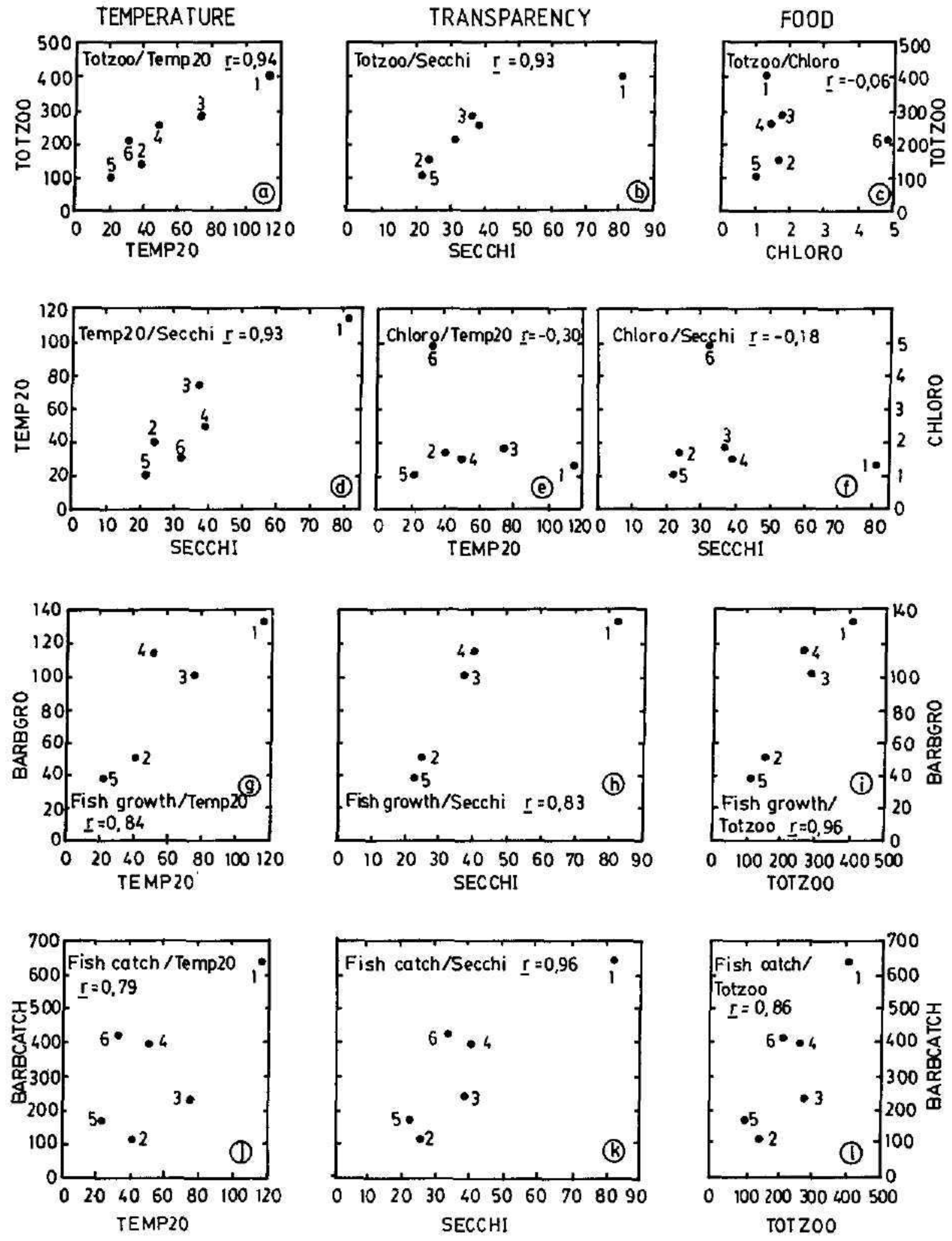


FIGURE 2.2.20. See previous page for legend.

grounds for interpreting certain of these relationships as direct cause-effect phenomena. More unexpected are the 'instantaneous' relationships between annual fish catch and growth rates with contemporary water temperatures and zooplankton abundance levels. Some delayed response would be more intelligible within a cause-effect relationship.

TABLE 2.2.13. Pearson correlation coefficients for mean annual zooplankton standing stocks, environmental variables, and attributes of smallmouth yellowfish populations between 1977 and 1983.

	Zooplankton		
	Total	Herbivorous	Predatory
Mean temperature	0.73*	0.73^{+}	0.65^{+}
Degree-days above 18°C	0.83*	0.82*	0.67^{+}
Degree-days above 20°C	0.94***	0.92**	0.83*
Transparency	0.93***	0.85**	0.95***
Chlorophyll	-0.06^{+}	-0.05^{+}	-0.14^{+}

	Smallmouth yellowfish			
	Growth rate	October catch	April catch	Annual catch
Mean temperature	0.71^{+}	0.50^{+}	0.24^{+}	0.48^{+}
Degree-days above 18°C	0.80*	0.66^{+}	0.80*	0.74*
Degree-days above 20°C	0.84*	0.66^{+}	0.63^{+}	0.79*
Transparency	0.83*	0.49^{+}	0.83*	0.96***
Total zooplankton	0.96**	0.73^{+}	0.81*	0.86***
Herbivorous zooplankton	0.94**	0.84*	0.73*	0.76*
Predatory zooplankton	0.79^{+}	0.27^{+}	0.81*	0.95***

$^{+}$ not significant
* $p \leq 0.05$
** $p \leq 0.01$
*** $p \leq 0.001$

2.3. FEEDING BIOLOGY OF SMALLMOUTH YELLOWFISH

D. H. Eccles.

2.3.1. Introduction

Studies of the fish fauna of Lake Verwoerd had indicated that only five species of fish, the smallmouth yellowfish, Orange River labeo, moggel, sharptooth catfish and carp were likely to be of any importance in potential commercial fisheries in large impoundments. Early studies of the fish of Lake le Roux showed that of these, the last three were relatively less abundant than in Lake Verwoerd, and that only the smallmouth yellowfish and Orange River labeo were likely to be of any major potential value.

The Orange River labeo was known to be a substratum feeder, ingesting large quantities of algae and detritus from the bottom and scraping algae from the rocks, while the smallmouth yellowfish had been shown to feed largely on invertebrates, including zooplankton, for the earlier part of its life history, later becoming increasingly vegetarian. Except in the case of very shallow and clear lakes the production in lacustrine ecosystems is usually dominated by the plankton, as has been demonstrated for Lake le Roux in the previous section. Since it was known to be able to utilise zooplankton, the smallmouth yellowfish was expected to become an important component of the ecosystem, and to form a potential link through which the planktonic production could be harvested. For this reason it was considered important to investigate the efficiency with which it could exploit this and other resources, the factors which limited this efficiency and the degree to which it is dependent on zooplankton.

While the Orange River labeo was also expected to be of potential commercial importance, the fact that it was not known to show a progression in dietary composition with age, together with the absence of any concurrent studies on benthic production, suggested that studies of the diet of this species would be less informative with regard to management practices in comparison with the case of the smallmouth yellowfish. However subsequent findings of the importance of this species indicate that its biomass is greater than would be expected if it was dependent entirely on benthic primary production and suggest that it is probably able to utilise micro-organisms and thus to exploit the detrital food chain.

2.3.2. The diet of the smallmouth yellowfish

The smallmouth yellowfish is a generalised feeder and, of the eight indigenous species in the lake, has adapted the most successfully to lacustrine conditions. While smallmouth and largemouth yellowfish of less than 80 to 90 mm in fork length cannot readily be distinguished from each other on the basis of external characters in the field, the present study showed that the morphology of the gut of the two species is recognisably distinct by a length of 30 mm. The gut of the smallmouth is relatively longer than that of the largemouth yellowfish, and increases in relation to the length of the fish from about 0.7 times the length at 3.0 cm to about 2.3 times the length at 50 cm (Figure 2.3.1).

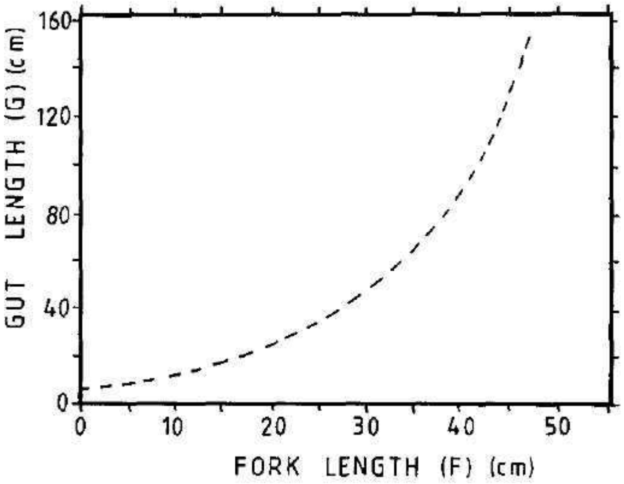


FIGURE 2.3.1.
The relationship between gut length and fork length of smallmouth yellowfish.

Elongation of the gut is characteristic of fish which are able to utilise relatively low-energy food sources such as plant material. In Lake le Roux this species takes a variety of food items, the proportions of which change both with the size of the fish and with environmental conditions, but show a general progression from animal to plant material as the dominant item, although this trend is modified by seasonal effects (Figure 2.3.2). This is consistent with the increase in relative gut length of the larger fish.

Although it lacks specialised adaptations for plankton-feeding, such as a large gape, a protrusible mouth or long, closely spaced gill-rakers for filtering zooplankton from the water, the smallmouth yellowfish is the major consumer of zooplankton in the lake. However, it exploits this resource only during certain phases of its life history. Smallmouth yellowfish of less than 6 cm occur near the shore and feed almost exclusively on bottom-dwelling insect larvae. At lengths above this the fish disperse and spend a greater proportion of the time offshore and near the water surface, where they take increasing quantities of zooplankton. This becomes the major food of individuals between 15 and 30 cm in fork length. Once they exceed 30 cm in length the proportion of zooplankton in the diet decreases progressively, and is replaced by benthic algae and angiosperm material, much of which is of terrestrial origin and is therefore only available in quantity at times when rising water levels inundate marginal vegetation.

In studying the importance of the various dietary items and the factors which affected them the gut was divided into five sections and the first, second and third most important categories of food were recorded for each section. Two measures of the relative importance of different categories in the diet were derived. These were: (a) a preference index (Ip.x), where "x" is the particular food item and Ip is the relative frequency of occurrence of that item in the gut; (b) a dietary index (Id,x) of the mass of a particular category of food item in the gut as a percentage of the total mass of the fish. These gave information on food preferences and on intensity of feeding respectively.

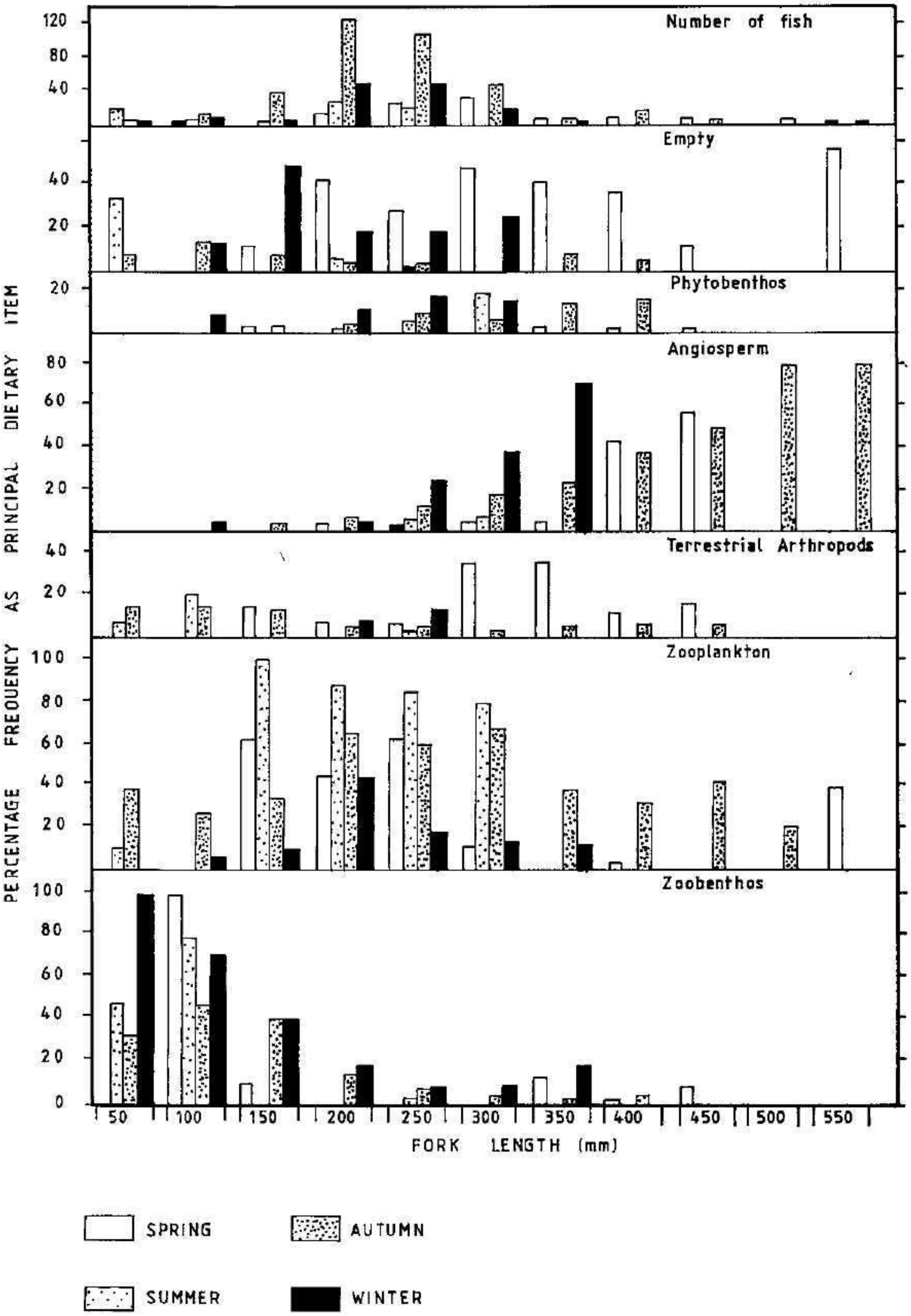


FIGURE 2.3.2. The relation between the principal component of the diet of smallmouth yellowfish and fork length, showing seasonal effects.

Dietary indices for particular food items were derived for those fish which had been caught in gear deployed for no more than two hours. The index is a transformation of the ash-free dry mass of the contents of a section of the gut, expressed as a percentage of the total mass of the fish, in proportion to the relative importance of the dietary item under consideration. It can be expressed as follows:

$$^{]}d,x^{-=M\ *}\ f^{P}$$

where: Id,x is the dietary index for item "x"
M is the ash-free dry mass of contents of the relevant
section of gut. P is the estimated percentage of the
total contents formed
by the dietary item "x";
F is the mass of the fish.

Since in fish shorter than 15 cm the proportion of zooplankton in the diet is positively related to fish length, while in larger fish this relationship is negative, especially in fish longer than 30 cm, only individuals in the size range 15.1-30.0 cm were considered in the analysis of factors affecting the dietary index for zooplankton. In the case of other dietary items all fish were considered since if there was any trend with size it was consistent.

A simple index of incident light intensity, (I 1), derived from clock time, time of sunrise and day length, was used as a correlate of time to derive numerical relationships between time of day and dietary indices or preference indices of various dietary items. The index can be expressed as:

$$I_{l} - {}'' T_{'} - £_{D} -$$

where: T is time after sunrise;
D is length of period of daylight.

A value of zero was assumed for negative values of the index (for times after sunset).

2.3.2.1. ?ooglankton_in_the_diet

Figure 2.3.2 shows that zooplankton is the main component in the diet of smallmouth yellowfish between 15 and 30 cm in length, the range which includes the bulk of the biomass of the species in the lake. Seasonal effects are apparent in the fact that the dominance of zooplankton in the diet is greatest in the summer, when the fish are feeding most vigorously, so that the relative contribution of zooplankton to the energetic balance of this species is greater than is indicated by the figure.

Dietary indices for zooplankton in the foregut were compared with a number of environmental parameters, including the abundance of the main zooplankton species. However, although in winter the predatory larvae of the midge Chaoborus become important in the diet, no estimates are available of the abundance of this species in the plankton.

Multiple regression analysis was used to determine the relative influence of a number of factors on the dietary index for zooplankton (Id_sz) in the foregut. The strongest relationships were with the abundance of Lovenula in all ' samples and of Daphnia during summer, although these were not statistically significant, probably as the result of the high short-term variability of these parameters, both in time and in space (Chapter 2.2.4, Figure 2.2.7). The light index {I 1) was consistently the most important other factor, followed by Secchi-disc visibility, a measure of transparency, both of which were always significant at a level greater than 0,01. A positive relationship was found in the cooler season between Id,z and the distance offshore at which the fish was taken, but this was not the case in summer. Slight negative associations were noted between the index and windiness, possibly as the result of dispersal of zooplankton, and with

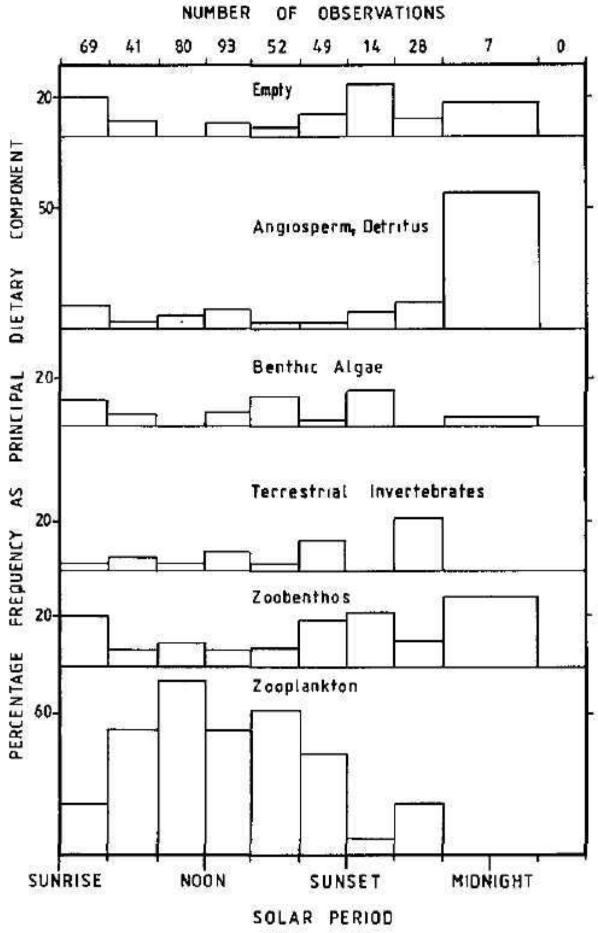


FIGURE 2.3.3. The relation between the 'solar period[1] and the principal dietary item in the foregut of smallmouth yellowfish 15-30 cm long. Day was divided into six equal periods and night into two early periods of one sixth, and two later of one third of the night length. No fish were caught in the last period.

distance from the wall which reflects the greater transparency of the lower basin of the lake (Table 2.2.6). Correlations with the smaller zooplankton species, Metadiaptomus and Moina were not significant, although in summer there was an indication of a marked negative relationship with the former. This may not reflect a direct effect of Metadiaptomus on the diet of the fish, but rather the effect of predation by fish on Lovenula, which is itself the main predator of *Metadiaptomus*.

Although it is the major consumer of zooplankton in the lake the smallmouth yellowfish is not efficient in this role. Examination of the gut contents showed that the species with which the dietary index is positively correlated form major components of the diet. The main zooplankton taken were adults of the large predatory copepod Lovenula excel lens, the large cladoceran Daphnia gibba and larger individuals of DTbarbata and D.longispina. Although it forms approximately 70% of the zooplankton biomass, the small grazing copepod Metadiaptomus meridianus was rarely taken, forming a major component of the diet in only a few individuals, although it occurred as an occasional item in many fish which had been feeding on zooplankton. *Moina*, also, was rare in gut contents.

The high degree of prey selection suggests that the smallmouth yellowfish locates its prey visually. This is supported by the fact that both the relative frequency, Ip,z (Figure 2.3.3), and the dietary index, Id,z (Figure 2.3.4) of zooplankton organisms in the diet are highest about mid-day and lowest before dawn. Further evidence that predation during daylight was largely guided by visual clues was obtained during feeding experiments in aquaria. During daylight the barbels, which are well supplied with taste buds, were carried folded along the lips, but at night they were erected, indicating that in darkness chemosensory clues become more important.

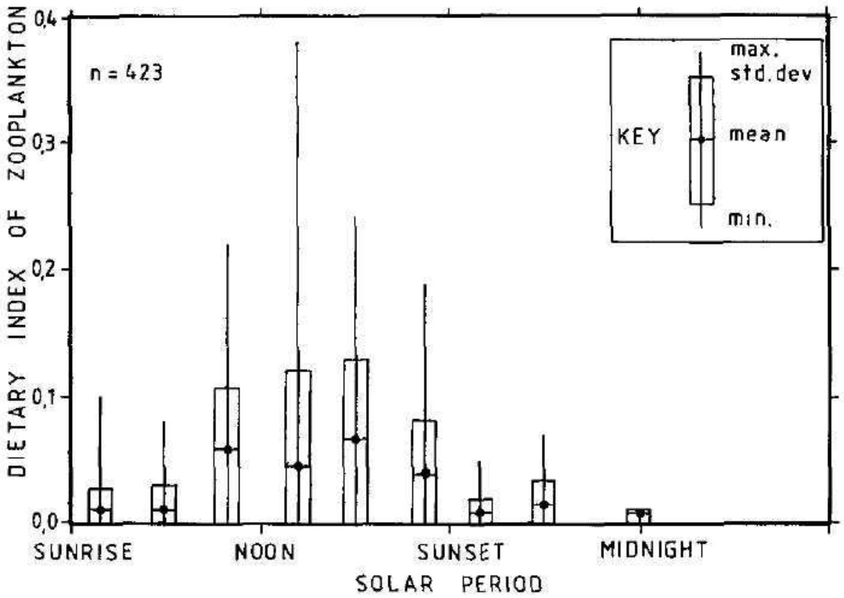


FIGURE 2.3.4. Dietary index (as % of fish mass) of zooplankton in the foregut of smallmouth yellowfish of 15-30 cm length in relation to solar period. Bars show mean, S.D. and range

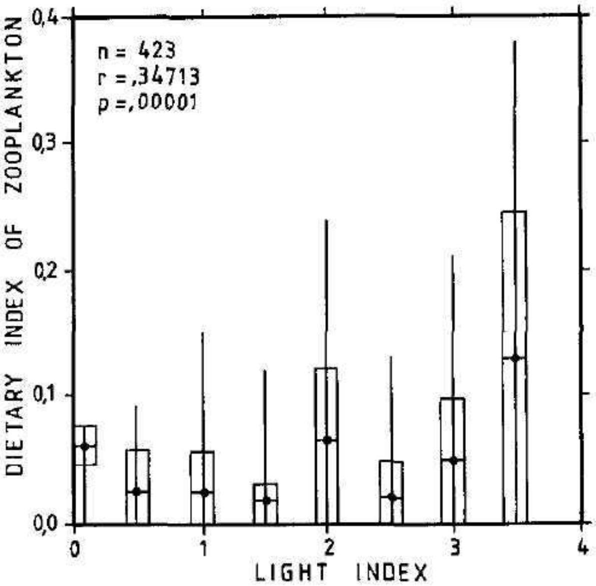


FIGURE 2.3.5. Dietary index of zooplankton in the foregut of smallmouth yellowfish of 15-30 cm in length in relation to the light index.

The relationship between the dietary index of zooplankton in the foregut and the light index is shown in Figure 2.3.5, while Figure 2.3.6 shows a similar relationship with transparency. The fact that the correlation between the dietary index of zooplankton and Secchi disc transparency is greater for the relatively small sample of fish taken during the cool season may be ascribed to the lesser influence at this time of other factors., such as the abundance of zooplankton species, which are very variable over the summer. It may, on the other hand, simply reflect lesser variance due to the smaller number of samples from the winter period.

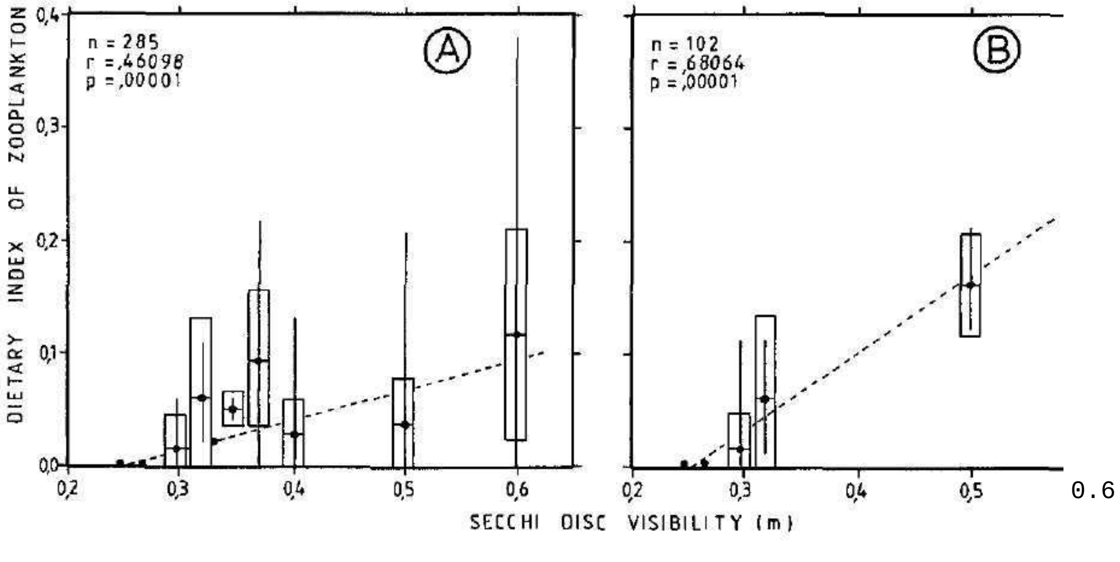


FIGURE 2.3.6. Dietary index of zooplankton in the foregut of smallmouth yellowfish 15-30 cm long in relation to Secchi disc visibility when light index exceeds 1.
A: All fish. B: Fish caught at temperatures below 17.5°C.

2.3.2.2. Other_animal_items_in_the_diet

Because of the varied nature of food items other than zooplankton, and of the fact that they were often second or third order components of dietary importance, dietary indices for these were often imprecise. To compare the relative importance of these items preference indices, rather than dietary indices, were used. The index used was that for the whole gut, obtained by summing the indices for each of the five sections. Since food passage through the gut takes several hours in summer, and much longer in winter, this approach ensured that information on food preference was available for periods away from those of setting and hauling of nets. It could not, however, provide valid information on the importance of time-related factors such as light which was revealed by examination of dietary indices for the foregut. It also allowed the inclusion of a larger sample of fish since there was no need to restrict study to those individuals which had been caught in gear set for a short period. This, however, allowed more time for food to pass along the gut, and thus resulted in an overestimate of the proportion of empty sections.

The factors affecting the preference indices for the various dietary items were investigated by multiple regression analysis. Correlations were poor, and levels of significance usually low. The most significant factor controlling the relative contribution of zoobenthos to the diet was the length of the fish (Figure 2.3.2). The relative frequency of zoobenthos in the diet also showed slight negative correlations with temperature and windiness. While zoobenthos was the main food item of juvenile smallmouth yellowfish it was also relatively important at night for individuals of intermediate size, as is indicated in Figure 2.3.3. The main types eaten are gnat larvae and mayfly nymphs. There is no significant correlation between the dietary index of zoobenthos in the foregut and the light regime (Figure 2.3.7) or Secchi disc visibility. The relative increase of zoobenthos in the foregut at night is largely an artefact, attributable to reduced zooplankton feeding at that time.

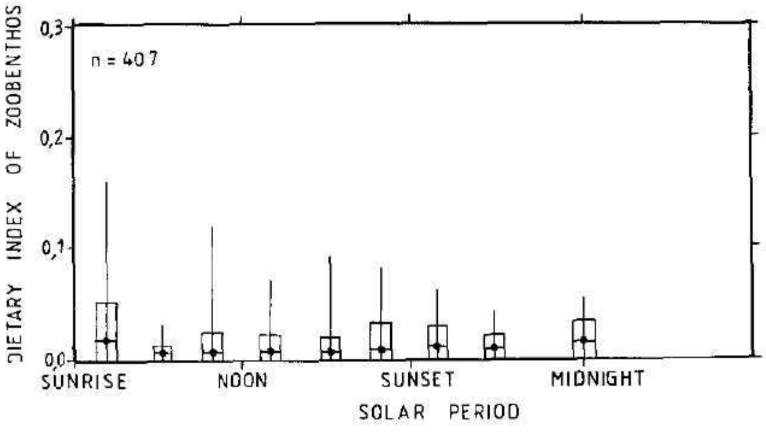


FIGURE 2.3.7. Dietary index of zoobenthos in the foregut of smallmouth yellowfish 15-30 cm long in relation to solar period, all temperatures.

There is no index of the abundance or distribution of offshore zoobenthos in the lake, and time series of abundance of inshore zoobenthos are not available. The few individuals of the smallmouth yellowfish caught in nets set on the bottom at depths greater than 15 m had been feeding mainly on zooplankton, with a minor contribution of terrestrial arthropods. However the low frequency of zoobenthos in these fish may reflect the size of fish selected by the nets used, which was above the length at which zoobenthos is a major component of the diet.

Terrestrial arthropods formed the major constituent of the diet in *8%* of cases, sampled from smallmouth yellowfish below 45 cm in length. It is correlated with transparency which again indicates that this food is detected visually. This is supported by the fact that the dietary index in the foregut for this item is positively correlated with the light index. In contrast to the positive correlation which was found between the dietary index for this item in the foregut and distance from the dam wall, no comparable relation existed for the preference index. This is probably due to the fact that the abundance of this food is low and that feeding on it is opportunistic. However, in its upper reaches the lake is narrow and a greater proportion of the surface area is in proximity with the shoreline, as compared with the situation in the lower basins, so that the chance of encountering terrestrial food items is greater. There are also slight correlations with day length and with rising water levels, although these two factors are probably inter-correlated, reflecting the effect of summer catchment rainfall on the water level.

The remains of juvenile fish were found in the gut of a single individual 20 cm in length, which also contained zooplankton, zoobenthos and terrestrial insects.

2.3.2.3. Vegetablejnaterial

The preference index for fresh angiosperm material was correlated positively with fish length and negatively with the abundance of zooplankton, with temperature and with light index. This suggests that this food item was taken when others were less readily available, and that it was resorted to by larger fish which could no longer obtain sufficient energy from relatively small food particles such as zooplankton.

The preference index for phytobenthos showed no significant correlation with any factor, though it appeared to be negatively related to both temperature and to the abundance of prey species of zooplankton. Much of the phytobenthos taken consisted of filamentous algae, a considerable proportion of which remained apparently undigested, with intact cell contents, even in the hind gut and faeces. Diatoms, when taken, were digested so that only empty frustules were observed. Since the phytobenthos of the lake appears to be dominated by filamentous green algae and cyanophyta, while that of rivers normally consists largely of diatoms, the quality of food available to large B.holubi in the lake is normally lower than that which occurs in their natural environment, the rivers, so that the nutritional stress suffered by these large fish is aggravated relative to the condition in rivers.

Detritus in the diet also tended to be negatively associated with the abundance of zooplankton and with light and temperature and showed its strongest correlation with falling water levels.

The principal factors influencing the occurrence of empty sections in the gut were Secchi disc transparency, wind the previous day and temperature. The correlation with transparency may be spurious, since the significance is low, but the others are highly significant.

2.3.3. Reasons for the change from animal to vegetable foods

The reason for the change from zooplankton to plant material as the major dietary item at lengths above 30 cm is unclear. It reflects a normal progression in the diet of this species, possibly attributable to the declining ability of increasingly large fish to maintain a positive energy balance by feeding on small items such as zooplankton or zoobenthos alone. Such a change is common in large cyprinids and the increasing ratio of the length of the gut in relation to increasing length of the fish is an adaptation to this.

Despite this fact, the timing of the change is probably associated with the ability of the fish to locate sufficient prey by visually directed hunting. This will be affected by the limitations set by turbidity on the volume of water which can be searched effectively, as will be considered in more detail later.

2.3.4. Effects of temperature on feeding rates

Laboratory and field experiments on gut clearance rates show a strong dependence on temperature. In the laboratory the median passage time for marked food items through the gut of fish with continuous access to food was 7.2 hrs at 25°C and 39.3 hours at 11.5°C (Figure 2.3.8), although at this lower temperature a number of individuals had ceased to feed.

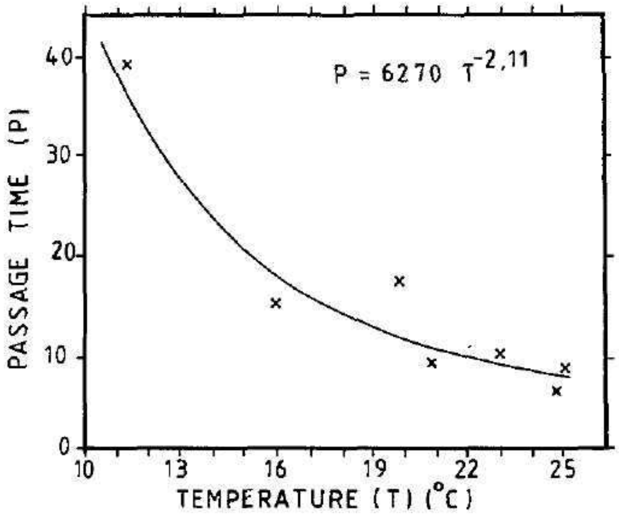


FIGURE 2.3.8. Relation between temperature and mean passage time of food through the gut of the median individual of an experimental group of juvenile smallmouth yellowfish.

The field experiments were not strictly comparable with those in the laboratory, since the field results were obtained in cages from which food was excluded and the quantity of food in the different guts sections was sampled after varying intervals. Under such circumstances the rate of clearing decreases exponentially as the gut empties. In summer, between temperatures of 22°C and 25°C the contents of each of the five sections of the gut were reduced to less than half the original value within 8 hours while in winter, at a temperature of 12°C-13°C, only the first two sections showed significant decreases in contents after 30 hours.

Although many individuals of the smallmouth yellowfish stop feeding at the lowest winter temperatures experienced in the lake, these temperatures are higher than those to which the species was formerly exposed in the river (Figure 3.1.1). The maintenance metabolic requirements at the winter temperatures in the lake may therefore impose a more severe drain on the reserves of the fish than was formerly the case in their natural habitat, and thus contribute to the observed mortality, since the fish would enter the spring period with severely depleted reserves.

2.3.5. Some considerations on the effect of turbidity on zooplanktivory

Fish tend to exploit those habitats and food sources which are the most 'profitable' in. terms of energy budget, and often change from one to another. The basic metabolic requirements of a fish which does not change its shape significantly as it grows will be related to the mass of the fish, which is a function of the cube of the length. Its potential swimming speed, in contrast, follows hydrodynamic laws and is related to the square root of the length.

The maximum distance at which a fish hunting visually reacts to its prey is the 'reactive distance'. In clear water this is affected both by the size of the prey and its optical properties in relation to the visual acuity of the fish, and by the size of the fish since the latter factor affects the maximum speed of the fish and thus the distance it can move in a rush. In turbid systems the reactive distance may be limited to a value below the potential set by characteristics of the predator and the prey item, due to reduced visibility.

In water of limited transparency where the range of visual detection of prey is less than the potential reaction distance of the fish, the latter can be envisaged as forageing in a tube, the diameter of which is defined by the transparency and the length of which is a function of the speed of the fish, and thus of the square root of its length. For each level of transparency up to that where visibility exceeds the reaction distance of the fish, a point will be reached where, other factors being the same, the fish will be unable to visually locate all the zooplankton within its potential reaction distance.

The result of this will be, in the case of visual predators, that as the size of the fish increases the energetic efficiency of foraging will be reduced even further in a turbid system than is the case in clear water, and that the fish will be forced to switch from this to other food sources at a smaller size. In this way the efficiency with which the zooplankton is exploited, and the size at which the fish change to a mainly vegetarian diet will be inversely related to the transparency. Under more turbid conditions the length at which zooplankton ceases to support the energetic requirements of the fish and nutritional stress is experienced will be reduced, and the total production by a cohort of fish will fall.

Support for this hypothesis is found in the fact that although the abundance of zooplankton was lowest in the vicinity of the dam wall, there was a slight, but significant, increase during winter in the dietary index for zooplankton in this area. The ratio of predatory zooplankton, including Lovenula which is a preferred food of the smallmouth yellowfish, to their prey was also generally lower *here* than further up the lake where the turbidity was greater.

2.4. DISTRIBUTION, STRUCTURE AND RELATIVE ABUNDANCE OF FISH POPULATIONS

P.B.N.Jackson, J.A.Cambray, D.H.Eccles, K.C.D.Hamman, T.Tomasson & P.N.White.

2.4.1. Introduction

The above considerations show clearly that Lake le Roux presents an extremely variable environment, while the habitat preferences of many fish change at different phases in their life history. The situation therefore is a dynamic one, changing continuously not only according to the biological needs of the animals themselves, but also as they attempt to adapt to an environment which has changed cataclysmically, and is still undergoing marked changes.

The situation is complex and variable from season to season and year to year in' respect of the various biotic and abiotic conditions described in Chapters 2.1 and 2.2. In general however, each fish species has kept to its own broad breeding b.ehaviour, though individual species have adapted their habitat preferences and characteristic feeding patterns. This introduces an element of predictability into a system which has experienced some extreme fluctuations since impoundment began late in 1976. The absolute result of impoundment has been a great increase in numbers of all species except the rock catlet relative to this stretch of river before impoundment.

2.4.2. The fish community

The fish community consists of nine species (there are no recent records of the trout) dominated by members of the carp family (Table 2.4.1). This is a *very* restricted fauna; Lakes Verwoerd and le Roux have few species in comparison with most other large African impoundments. The brown trout may be ignored since only two records exist, both in the first year of impoundment, of strays from Lesotho mountain streams. Of these nine, the carp was originally from Eastern Europe but is long established, four are endemic to the Orange River, two occur widely in temperate South Africa and two are tropical species at the southern limit of their natural range. Why such a major river should have such a depauperate fish fauna is not fully understood: the reasons probably lie partly in the geological history of the area and partly in the low winter temperatures which prevail over much of the system.

A second general point concerns breeding habits. Apart from a few such as the two small species, the chubbyhead barb and banded tilapia which can both breed more frequently, individual fish of all economically important fish breed only once a year, even though the time may occasionally be staggered, i.e., some individuals spawning earlier, some later. This attribute has some extremely important implications.

It means that each year the different species spawn usually in a single short period, generally when floods follow spring or summer rains, a spawning migration often being undertaken by the adults to place the young initially in a favourable locality among inundated vegetation or gravel. Thus each year's crop of young have approximately the same birth date, such

TABLE 2.4.1. Fish species recorded from Lake le Roux

Family	Common Name	Scientific Name	Provenance
Salmonidae	Brown Trout Bruinforel	Salmo trutta Linn. 1758	Exotic: very rare stray.
Cyprinidae	Smallmouth yellowfish Kleinbek geelvis	Barbus holubi Steindachner 1894.	Endemic to Orange River System.
Cyprinidae	Largemouth yellowfish Grootbek-geelvis	Barbus kimberleyensis Gilchrist & Thompson 1913.	Endemic to Orange River System.
Cyprinidae	Chubbyhead barb Dikkop-ghielie mientjie	Barbus anoplus Weber 1977.	Widespread over much of South African hinterland.
Cyprinidae	Carp Karp	Cyprinus carpio Linn. 1758.	Exotic, long established.
Cyprinidae	Orange River labeo Oranjerivier-labeo	Labeo capensis (Smith 1841).	Endemic to Orange River System.
Cyprinidae	Moggel Moggel	Labeo umbratus (Smith 1841).	Widespread over South African interior.
Bagridae	Rock-catfish Klipbaber	Gephyroglanis sclateri Boulenger 1901.	Endemic to Orange River System.
Clariidae	Sharptooth catfish or barbel Skerptand-baber	Clarias gariepinus (Burchell 1822).	Over most of East and Central Africa.
Cichlidae	Banded tilapia vleikurper	Tilapia sparrmanii (Smith 1840).	Central and Southern Africa

fish being said to belong to a single 'year-class[1]. The progress throughout life of each such year-class can be traced. It is normal for fish of each year-class to grow at about the same rate and in a stable environment this rate would vary little from year to year. Thus the older and younger year-classes can be distinguished from one another on the basis of size. Length-frequency analyses are generally used for this purpose: the older the year-class, the longer the modal length. Under the variable and often rigorous conditions of the South African highveld, it can however often happen that the year-class of a favourable year, such as one of early rains and warm climate, can grow faster and overtake or blur the length differences between it and previous year-classes. Conversely, a late-spawned cohort can put on so little growth during the subsequent winter as to be confused with the next cohort hatched the following spring some eight months or so later. This phenomenon of differential growth has caused much confusion in previous fishery studies and may only be overcome by comparing length-frequency data with .growth-rings on scales and otoliths, such as has been done in the present study by Tomasson (1983). The point is very important since it is essential, in commercial and sport fishery management, to know the success (relative abundance) of the various year-classes, and how this may be influenced by environmental conditions.

Each of the nine species in Lake le Roux is therefore a population composed of- a varying number of year-classes some of which are numerous because of, in fisheries parlance, a good recruitment, i.e. a high survival of the young-of-the-year for that year. Others are poor or even absent where there was high natural mortality of young-of-the-year due to cold, drought, rapid draw-down or other causes. It often happens that there is a high natural mortality in later life, e.g. when the year-class is two or three years old. This occurs especially in the smallmouth yellowfish where food shortage leads to starvation and stunting (Figure 2.5.1).

2.4.3. Relative abundance

In the absence of a commercial fishery, it was not possible to estimate the standing stock, or total population density, of the Lake le Roux fish. However, valuable data have been provided by the regular gill-nettings made at fixed stations around the lake since early 1978 by the CDNEC. From these, an index of temporal changes in abundance of the six species generally taken can be estimated by the catch per unit effort (CPUE). Effort was measured by the numbers of fish taken per 100 metres of net in each of seven mesh sizes, of floating nets set overnight for approximately 16 hours. CPUE does not necessarily indicate the relative abundance of species, because they may not be equally vulnerable to capture. Changes in CPUE may thus indicate either changes in abundance or changes in vulnerability to capture (e.g. low catches in some cases in winter caused by some species being more affected by cold than others). However, long term trends over some years, as in the present case, will reflect changes in population abundance and structure. Five-year gillnet catch fluctuations are shown in Figure 2.4.3.

The total CPUE in number for the six species is given in Figure 2.4.1 and MPUE in Figure 2.4.2, being the sum in numbers and mass of all fish caught in each mesh size during the survey. While considerable fluctuations are apparent due to the turbidity increases after the initial closing period, recruitment success in particular years, and natural mortalities due to food scarcities described below, it may be seen that the general trend is for the most abundant fish caught to be the smallmouth yellowfish and the Orange River labeo, all other species being considerably less frequently taken. While openwater trawling was undertaken primarily to discover trends in fish

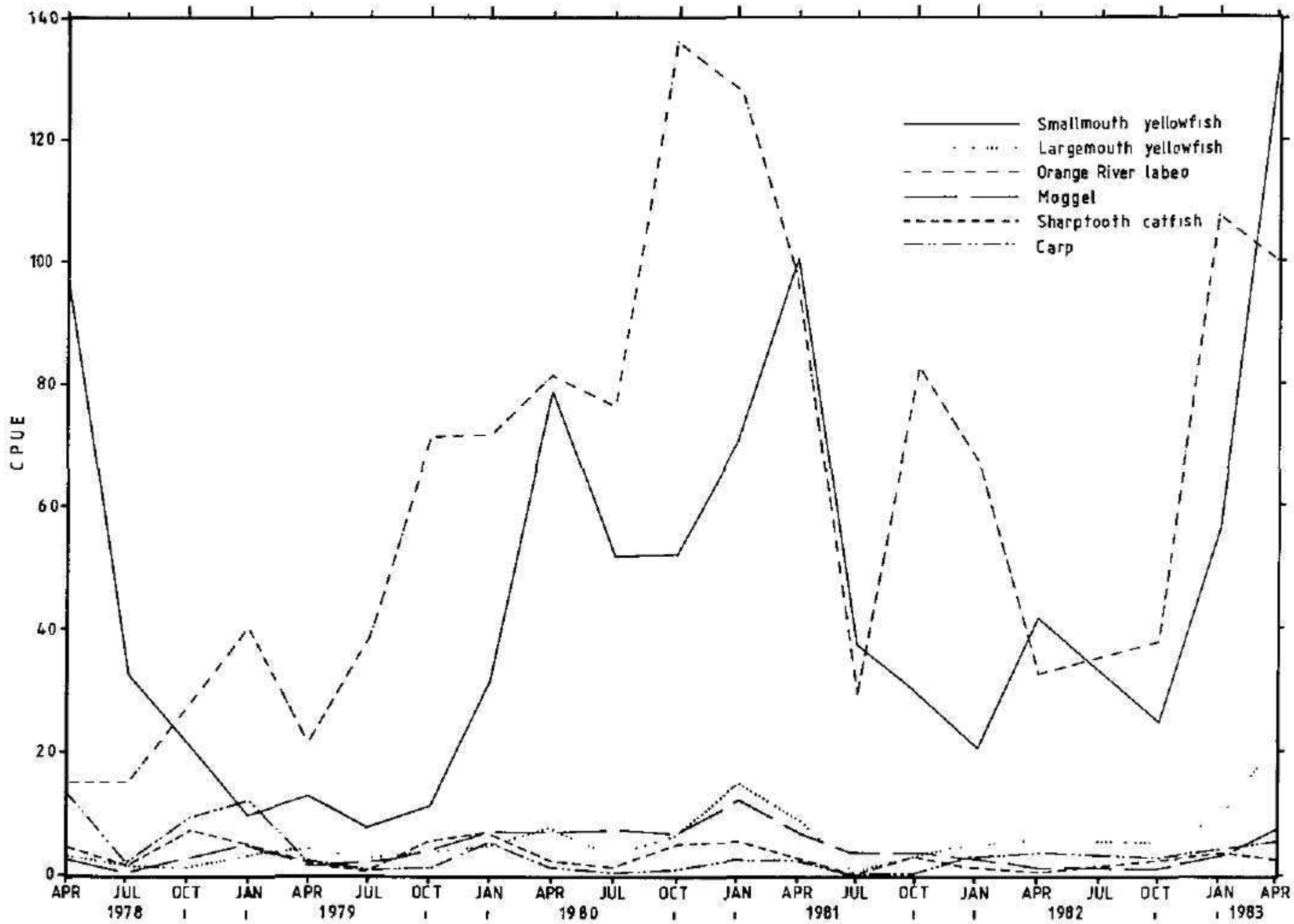


FIGURE 2.4.1. Combined catch (numbers of fish) per overnight set with 700 m multifilament gill-nets (35-150 mm as specified in Table 3.2.2) for six fish species in Lake le Roux for the period April 1978 to April 1983.

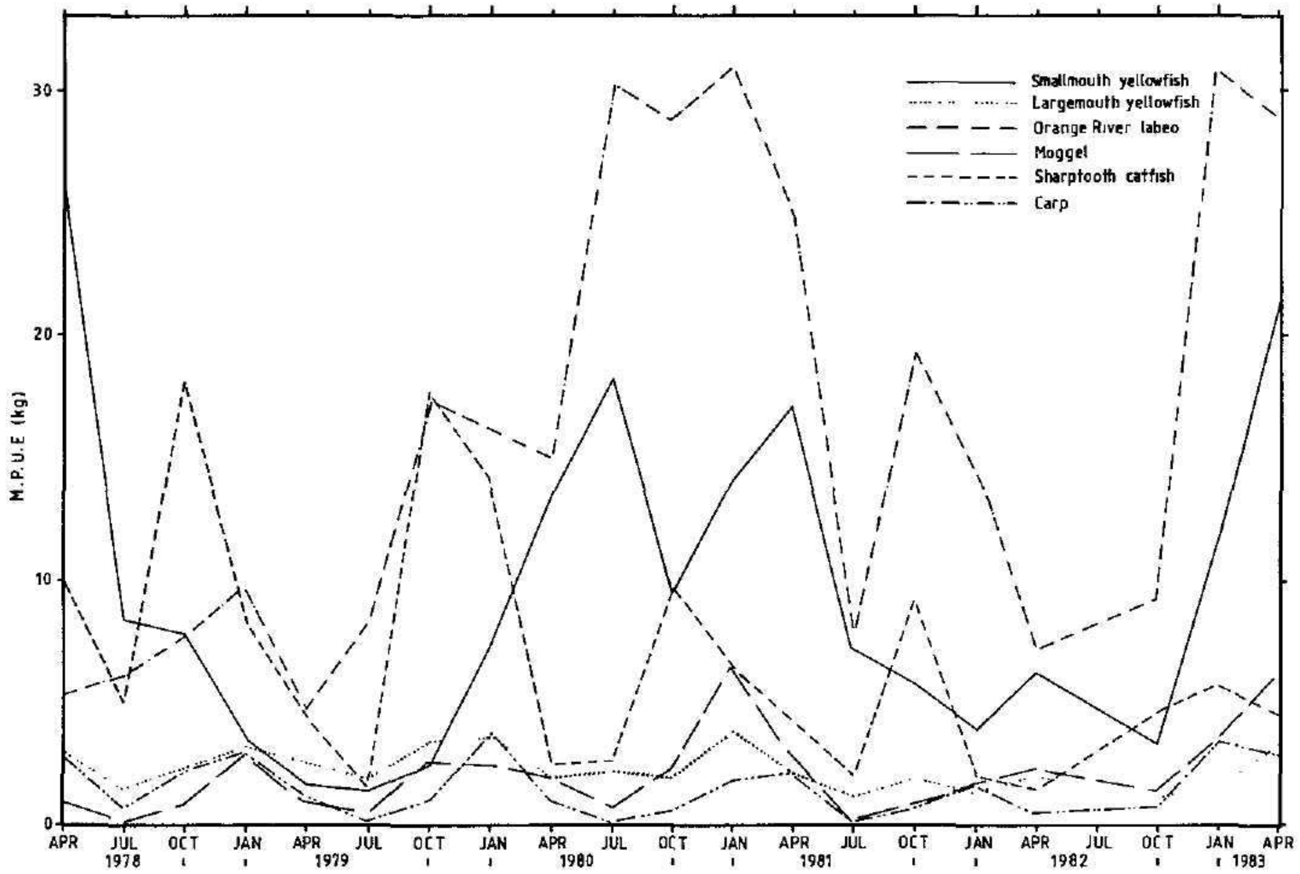


FIGURE 2.4.2. Combined mass per overnight set with 700 m multifilament gill-nets (35-150 mm as specified in Table 3.2.2) for six species at 28 stations in Lake le Roux for the period April 1978 to April 1983.

TABLE 2.4.2. Numbers of fish taken by surface open-water trawling in three main environments in Lake le Roux, Each haul 1 nautical mile in length sampling uppermost 1 metre of water. Three or four hauls at each of several sites as specified.

Species	Uppermost (riverine) dam area above zone 6. (6 sites, 22 hauls).	Flooded river tributaries (7 sites, 25 hauls).	Open waters of main dam (10 sites, 35 hauls).	Total
Smallmouth yellowfish	66	348	56	470
Orange River labeo	21	225	36	282
Moggel	36	214	22	272
Largemouth yellowfish	1	8	4	13
Sharptooth catfish	0	9	3	12
Carp	1	0	2	3
Chubbyhead barb	91	1190	25	1306

distribution, broadly similar relative abundances were noted though only a comparatively small effort of 82 hauls was possible (Table 2.4.2).

A direct comparison of the relative abundance of the nine species involved must take account of the fact that no new species have been introduced, so that all were originally present in the pre-impounded river. As is usual in man-made lakes, some of these have reacted to impoundment more favourably than others. Of the nine, the three most abundant are the three indigenous cyprinids the chubbyhead minnow, the smallmouth yellowfish and the Orange River labeo, all of which have adapted to the new conditions by, in general, increasing *very* considerably in numbers. In all species there are, often, pronounced seasonal variations in catches indicating temporal fluctuations, diminished winter activity, etc, which reflect individual variations in abundance from year to year. Also, in terms of the Eltonian pyramid of numbers it is to be expected that these three, which all include a large vegetarian or invertebrate component in their diet, would be relatively more abundant than top piscivores such as largemouth yellowfish and, to a lesser extent, the sharptooth catfish. Yet in general none of the other six species have become very numerous, though several, especially the moggel, carp and banded tilapia probably occur in fair numbers in particular habitats. These questions of population structure and distribution are examined in the next section.

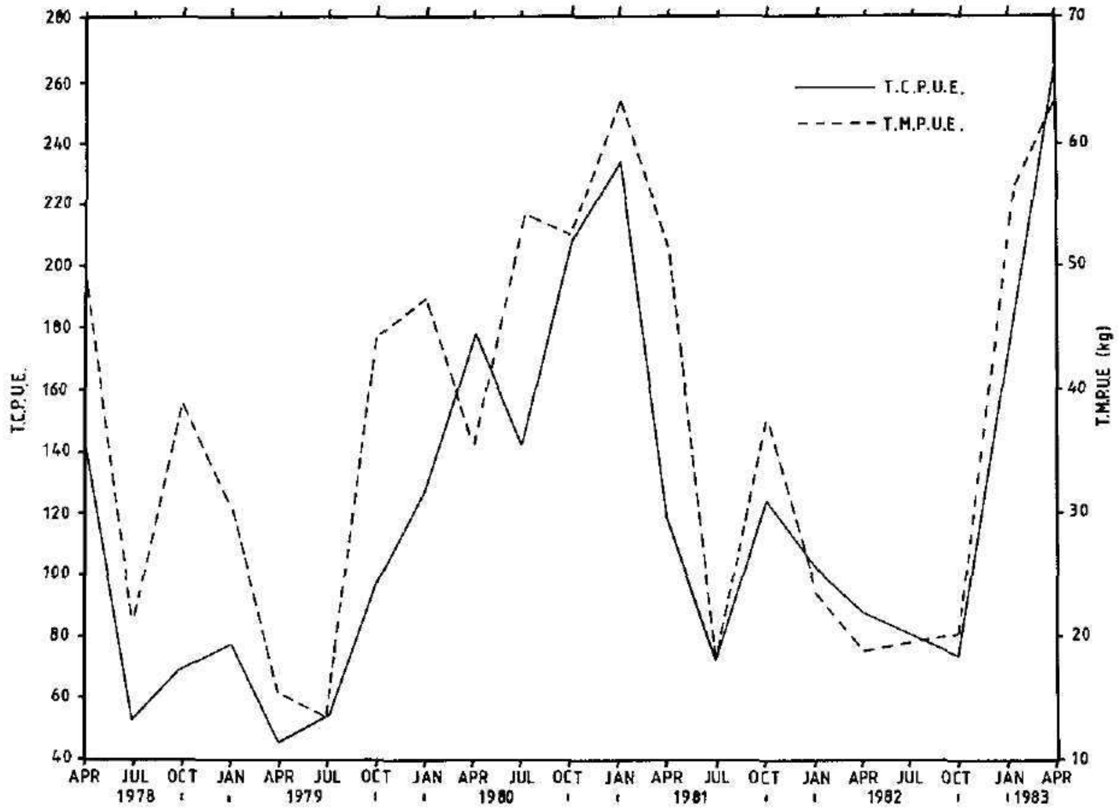


FIGURE 2.4.3. Total overnight catch and mass data with 700 m multifilament gill-nets (35-150 mm) in Lake le Roux for the period April 1978-April 1983.

Distribution and structure of the fish community

Together with this picture of the fish community and the relative abundance of its components, the project obtained considerable information on the habitat preferences, distribution and size structure of the various populations, which are briefly described.

(a) Smallmouth yellowfish. Figure 2.4.1 indicates the CPUE in terms of numbers caught, while the mass per overnight set of the nets is shown in Figure 2.4.2. As is usual with most large impoundments, there was a high survival of the first year-class after closure, followed by rapid growth in the relatively less turbid water of the lake's first year. During the winter of 1978 there was a very high mortality of 2- and 3- year old fish due to high turbidity and relative food scarcity (Figure 2.4.5). Subsequently large temporal variations in CPUE were experienced, reflecting changes in annual rates of growth, recruitment and mortality.

Juveniles are found along the shores of the lake, usually over firm substrate. When a length of approximately 50-80 mm FL is reached, they begin to move away from the shore, taking up a predominantly pelagic way of life and feeding mainly on zooplankton (Chapter 2.2.5). At between 250 and 350 mm yellowfish return to a benthic mode of living. The size at which benthic resources become the mainstay of their diet probably depends on the degree of planktonic food available in the pelagic zone, itself depending largely on water turbidity (Chapter 2).

The main spawning migration of the smallmouth yellowfish is into the Orange River, in this area a regulated stream connecting Lakes Verwoerd and le Roux, near where it enters the lake. Spawning is probably a co-ordinated event for the whole population, so that almost the entire yellowfish population of Lake le Roux is of fish spawned in this particular area.

However, the two main tributaries, the Seekoei and Berg Rivers, harbour resident populations of yellowfish which spawn at times of flood in spring or summer. During the period of study, recruitment from these sources was minor, and had little influence upon the population structure.

As a consequence of the spawning locality, juveniles are most abundant in the upper reaches of the lake (Figure 2.4.4). Catches of 130-150 mm fish are usually highest at zones 5-7 as a new year-class is recruited into the gill-net catches in January or April in its second summer (Figure 2.4.5). In the following season, however, catches of two-year-olds are generally highest in the lower reaches of the lake (Zones 1-3), conforming to the distribution of older fish and reflecting the mobility of the population. General declines in catch abundance with distance from the dam wall, as can be seen in Figure 2.4.5, are associated with an increase in turbidity (Figure 3.1).

The size structure of the population is chiefly influenced by variations in recruitment (year-class strength) and size selective catastrophic mortalities, i.e. when fish of a particular age (size) die off in *very* large numbers due to lack of food. The bimodal length frequency distribution in 1978 and from April 1980 (Figure 2.4.5) is the result of relatively weak

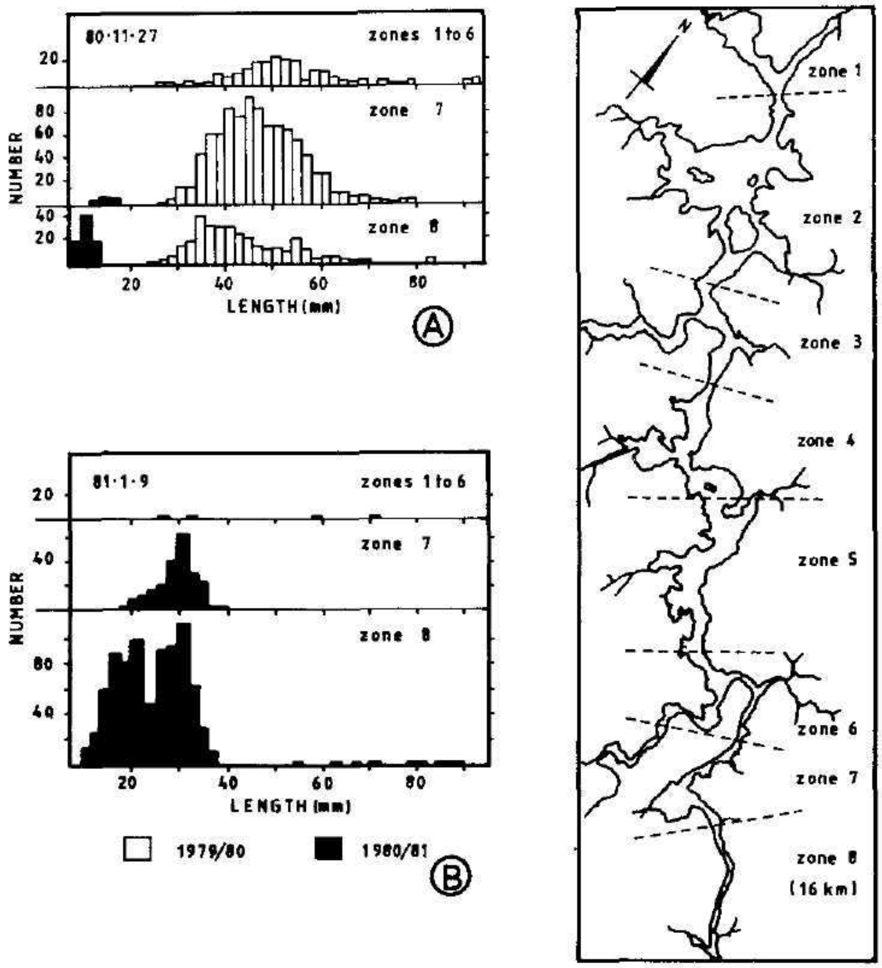


FIGURE 2.4.4. Length frequency distribution of recently spawned and juvenile yellowfish caught by beach seine, (A) on 27 November 1980 and (B) on 9 January 1981, in relation to the lake's several zones. The spawning of the 1980/81 year-class in November 1980, and that spawning took place entirely in the riverine zone 8, is shown. Evidence of two distinct spawnings, though close to each other in time, is provided by the two modes in the 1980/81 year-class in early January, six weeks later. The great preponderance of young fish in the riverine zones 7 and 8 relative to the rest of the lake can be seen; also the disappearance from the seine catches, except for a few individuals, of the 1- or second year-class as these gradually leave the shore and enter the open water. (Data from Tomasson, 1983.)

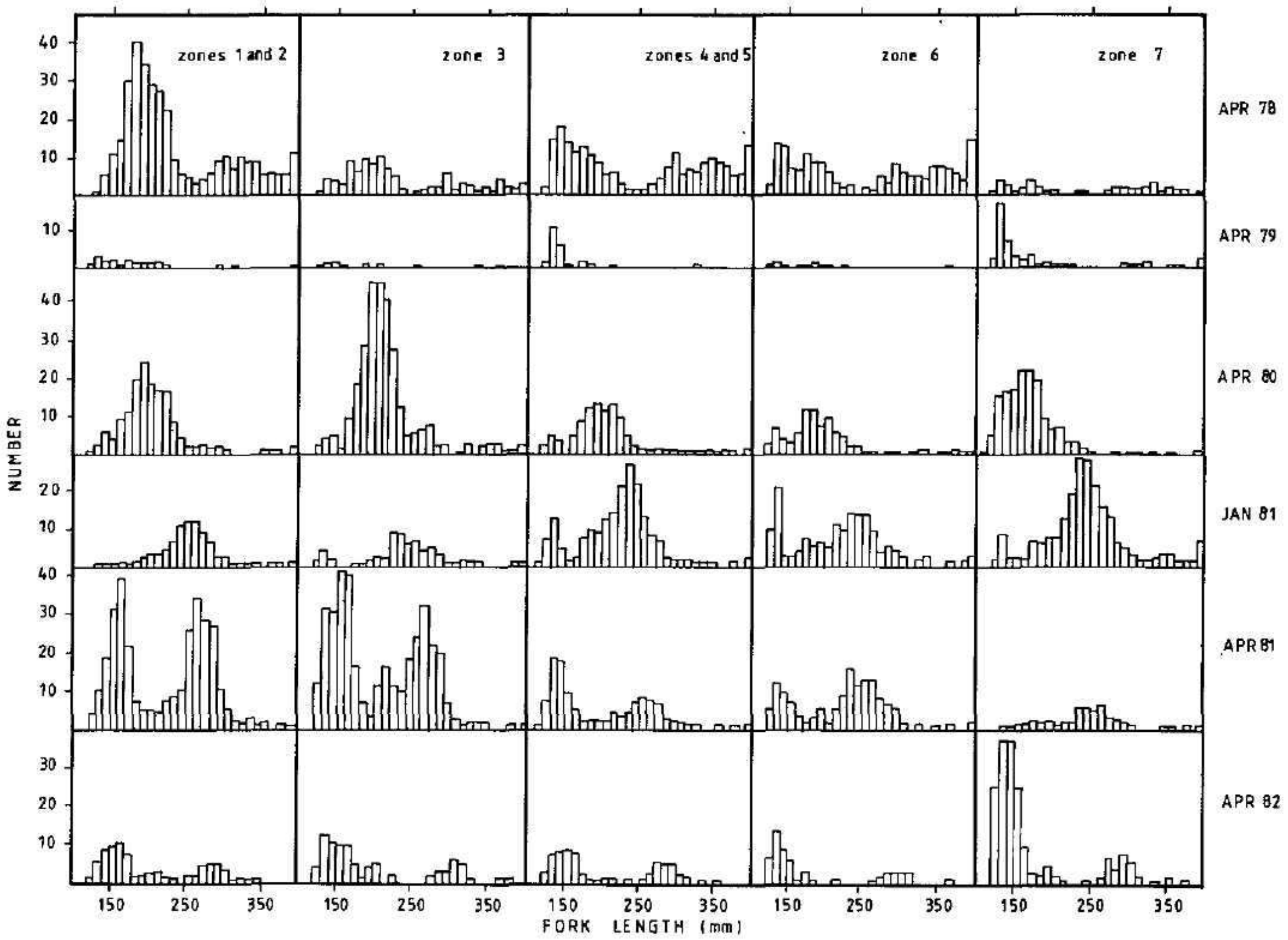


FIGURE 2.4.5. Length-frequency distribution by zone of smallmouth yellowfish caught during CDNEC gill-netting surveys on Lake le Roux. The numbers graphed represent the catch in four settings. All fish 390 mm and larger are combined.

year-classes. In 1978 the bimodal distribution was caused by a relatively weak 1975-76 year class. A mode at 140 mm in April 1980 was relatively small and indistinct. This represented a weak year-class which by January 1981 separated the mode of new recruits at 130-140 mm and older fish (Figure 2.4.5). Reasons for differences in year-class strength are discussed in Chapter 3.1.

Catastrophic mortalities in 1978 and 1981, coincident with sharp increases in turbidity (Figure 2.2.4), did not appear to affect the 1977-78 and 1980-81 year-classes, both of which were relatively strong. Growth rates of smaller fish are relatively less affected than are those of larger fish when overall growing conditions deteriorate (Table 2.5.1). This shows that young fish, less than two years old, are less affected by adversely changing environmental conditions than are older fish, giving rise to size-selective mortality.

(b) Largemouth _y^{e}lI°wQsh. This species does not show the large temporal variations in CPUE as does the smallmouth, and it is numerically a rare fish (Figure 2.4.1). However, it attains a large size, and this is reflected by the relatively much higher MPUE figures (Figure 2.4.2). These variations in population structure and abundance are the result of two major differences in the life histories of the smallmouth and largemouth yellowfish.

Firstly, the largemouth appears to be adapted to relatively warmer temperatures than the smallmouth. This is reflected in later resumption of growth and later spawning for largemouth yellowfish 'probably causing the consistently weak, although variable, year classes. At times when the smallmouth yellowfish suffers high mortalities, the largemouth is much less affected, possibly because feeding activity is normally resumed later in spring/early summer, by which time there has already been a considerable reduction in the smallmouth population. Thus competition for food may to some extent be avoided.

A second major difference between the two large yellowfish species is that the largemouth becomes increasingly piscivorous with size. In Lake le Roux this results in a considerably larger ultimate size being reached by it (Figure 2.4.6).

(c) 0)Cange__River_ labeo. Sharing with the smallmouth yellowfish the distinction of being the most abundant fish in the dam, catches of this species were relatively high in the gill-net catches (Figure 2.4.1). Values show a fluctuating but increasing trend from April 1978 (14,9) to reach the exceptionally high value of 136,3 in October 1980. The effects of increased activity due to feeding and breeding in summer can again be seen. Year class strength is highly variable and related to water level fluctuations during summer (Chapter 3.1). Catch per unit effort, however, is largely influenced by distribution, which in turn depends on turbidity. Increases in turbidity in 1978 and 1981 in both cases caused dispersal of Orange River labeo smaller than 200 mm down the lake, which in the long term led to increases in CPUE. However, short term decreases in CPUE following increases in turbidity are due to increased depth penetration of this species making them less vulnerable to capture in surface set nets.

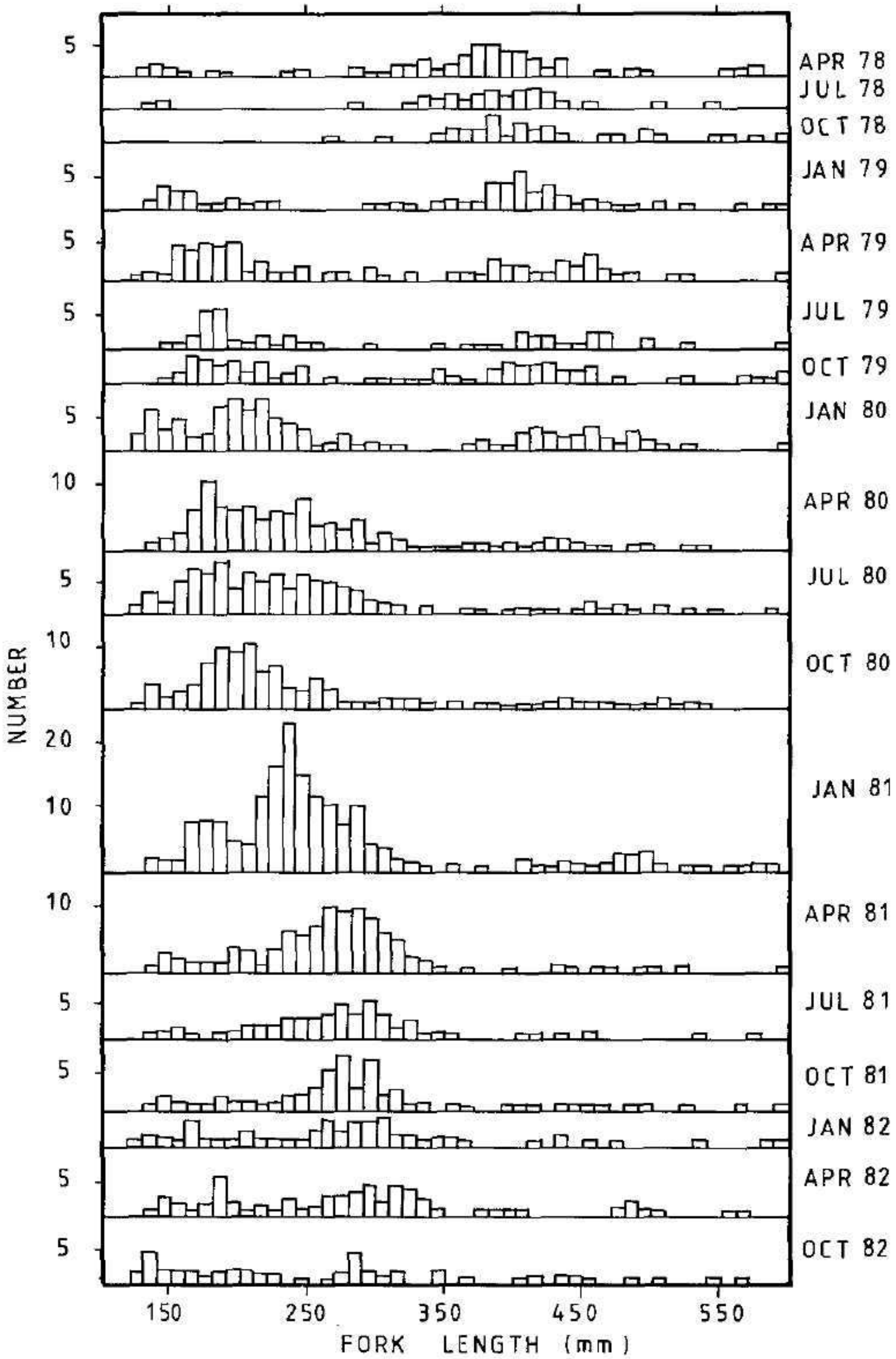


FIGURE 2.4.6. Length-frequency distribution of largemouth yellowfish caught during CDNEC gillnetting surveys on Lake le Roux. The numbers graphed represent catches from 28 settings. All fish 590 mm and larger are combined.

Juvenile Orange River labeo are found along the shores of the lake, and early survival appears dependant on the presence of newly flooded areas (3.1). As they get larger they may move further off shore, but continue to prefer relatively shallow areas where they feed off the bottom. The characteristic marks left by their grazing may be seen on rocks around the water edge at times when water level drops (Figure 2.4.7).

FIGURE 2.4.7 Grazing marks on algae growing on rocks made by Orange River labeo. (Photo: P.B.N. Jackson).

Unlike the large yellowfish, this labeo is capable of spawning throughout the lake in inflowing tributaries, although conditions, for spawning do not occur regularly at any one locality. The population is relatively stationary, and timing of local spawnings in conjunction with different intra-seasonal growth rates in different localities affects the distribution and size structures of labeo in the lake.

Catches of Orange River labeo in April 1978 showed a bimodal distribution at all stations, although the smaller mode was only poorly represented in zones 1-3 (Figure 2.4.8). The two modes are probably caused by good growth of the 1974-75 year-class and older fish during the first year of impoundment, while younger fish did not appear to have benefitted (Tomasson 1983).

Fish in the smaller mode (1975-76 year-class and younger) were well represented at zones 1-3 by January 1979 (Figure 2.4.8). Growth in that

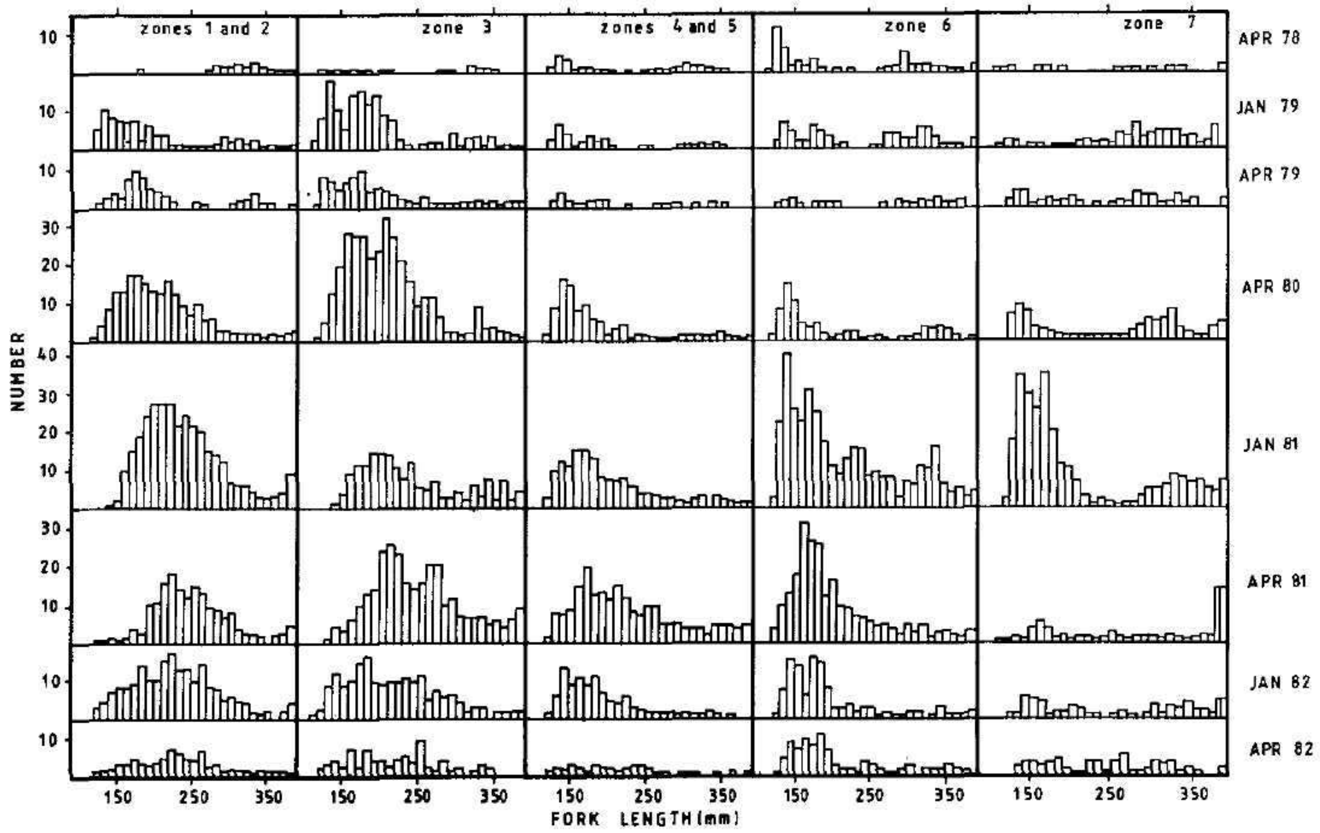


FIGURE 2.4.8. Length-frequency distribution by zone of Orange River labeo caught during CDNEC gill-netting surveys on Lake le Roux. The numbers graphed represent the catch in four settings. All fish 390 mm and larger are combined.

TABLE 2.4.3. Numbers of different fish species taken by one sweep of electrofishing 60 metres of lake shore at various sites.

OPEN BEACHES		FLOODED RIVER VALLEYS			
Cleared beach: Site 73. 03/10/78.		Hondeblaf River 400m from water inflow.		Zeekoei River near inflow near site 35. 04/10/73.	
Chubbyhead barb	150	Chubbyhead barb	51	Chubbyhead barb	16
Smallmouth yellowfish	1	Banded tilapia	1	Orange River labeo	215
Barbel tilapia	3	Orange River labeo	2	Moggel	10
Carp	1	Carp	21	Carp	19
		Sharptooth catfish	1		
Steep shore on south side of open lake mid-way between Stations 31 and 32. 17/01/79.		Berg River above Station 72. 19/01/79.		Zeekoei River long beach. Station 36. 18/01/79.	
Chubbyhead barb	4	Chubbyhead barb	100+	Chubbyhead barb	8
Orange River labeo	15	Banded tilapia	3	Orange River labeo	70
Moggel	1	Carp	28	Banded tilapia	3
Smallmouth yellowfish	1	Orange River labeo	6	Carp	2
		Rock catfish	1	Smallmouth yellowfish	2

season was poor (Tables 2.5.5 & 2.5.6), which indicates that these fish had immigrated to the area. With time, small fish were recruited in all zones. In the 1980-81 season, recruitment in zones 1-3 failed, and fish 120-200 mm were poorly represented in the catches in April 1981. The difference in size distribution in the upper and lower reaches of the lake can to some extent be attributed to reproductive failure in all but the upper reaches of the lake in 1978-79 and 1979-80. The main cause, however, is slow growth in the upper reaches.

In April 1981, small fish disappeared from zone 7 and subsequently small fish (up to 200 mm in length) entered the catches in the lower zones while catches were further reduced up the lake. Growth in 1981-82 was very poor (Table 2.5.6), and can be ruled out as the cause of recruitment of fish up to 200 mm at the lower zones in January 1982 (Figure 2.4.8), which then must be the result of immigration.

Dispersal of Orange River labeo in 1978 and 1981 followed a sharp increase in turbidity, which caused food shortages reflected in deteriorating body condition (Tomasson 1983). The distribution and size structure of this labeo is thus the composite result of erratic breeding, differential growth rates within the lake and finally dispersal when conditions, especially of turbidity, deteriorate beyond a certain point.

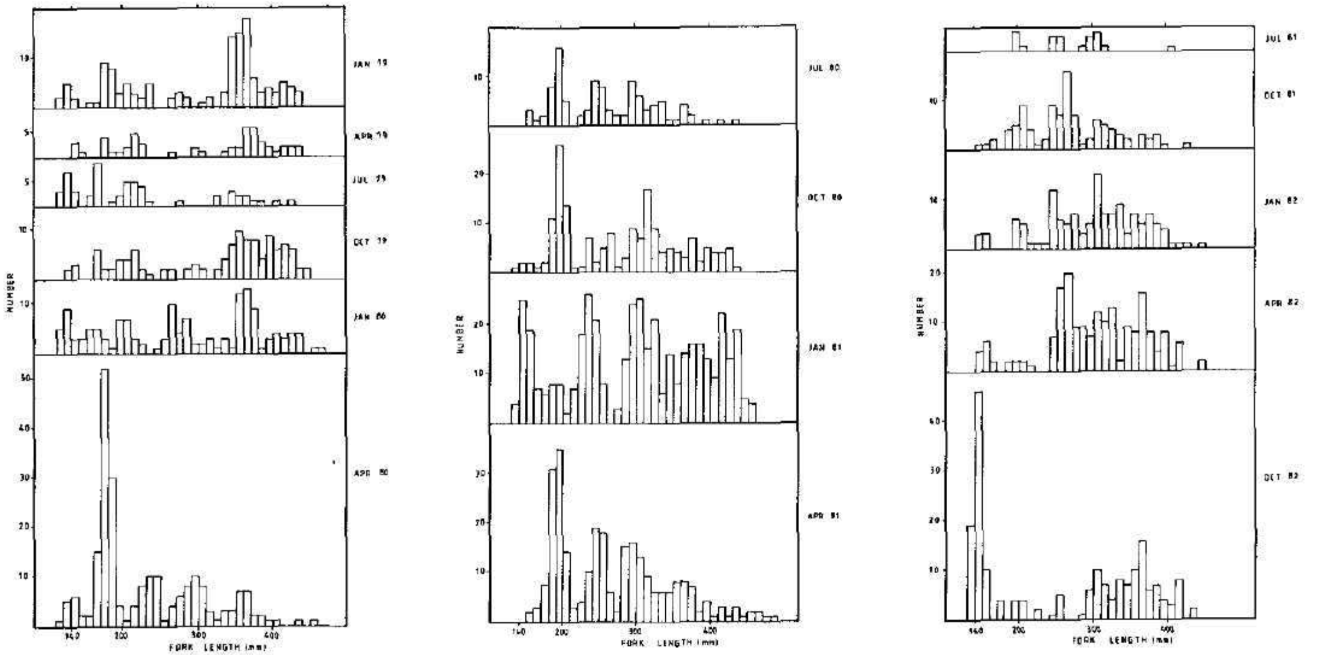


FIGURE 2.4.9. Length-frequency analyses of all moggel caught by CDNEC gill-nets from January 1979 to October 1982.

(d) Moggel. Apart from the usual seasonal abundance fluctuations caused by increased summer activity, few clear trends emerged, and populations remained generally much lower than those of the Orange River labeo (Figure 2.4.1), though with an occasional unusually high catch.

Juvenile moggel are found along the shores of the lake but are rarely taken in large numbers. They are predominantly benthic feeders throughout their life.

Adult moggel appear to congregate prior to spawning near major tributaries, such as the Seekoei River and also in the top basin where the Orange River enters the lake. They are known often to undertake long spawning migrations. In the lake they appear mainly to spawn in the inflowing Orange River, but evidence of spawning has also been found in the Seekoei River following a flood.

Moggel appear to form a very mobile population and there is no apparent difference in size distribution with locality, but the material upon which these observations are made are small. The size distribution often shows clear modes eg. four distinct modes from April 1980 to April 1981 (Figure 2.4.9), which possibly reflect individual year classes.

(e) Carp. Figure 2.4.1 illustrates the relatively low abundance of carp in the gill-nets and, as well, the decline in abundance from initial comparatively good catches can be seen. The tendency referred to above of gill-net catches being relatively higher in the summer months due to increased fish activity is particularly marked in the case of carp, as the figure shows. The gill-net results also tend probably to underestimate carp abundance since these are bottom-dwelling fish and so less likelytobe caught in the floating gill-nets. Carp are, as well, relatively much more abundant in flooded river estuaries than they are along open lake shores (Table 2.4.3).

An electrofishing study in 1979-80 established that the favoured habitat of carp was shallow sheltered water, still or only flowing very slowly, with a smooth soft bottom of mud or sand, comparatively free of rocks. The preferred depth was a few centimetres to approximately 2 metres. Such conditions are to be found in certain of the shallow sheltered bays and inlets around the dam, but very markedly in the flooded tributaries of the inflowing rivers referred to above. The steep-to rocky shoreline comprising most of the coast of the impoundment carried few or no carp, as can be seen by Table 2.4.3, while virtually all of the 714 specimens of carp examined came from the flooded tributary valleys.

As is to be expected from the carp's known benthic feeding habits, only 3 of the 2355 fish of all species taken from the surface waters with the open water trawl net was of this species (Table 2.4.2). Yet there is some evidence that carp can distribute themselves across open water in Lake le Roux, in spite of mostly living a sedentary demersal existence. A carp, tagged in the Berg River as March 7, 1979 was recaptured by angling at Vanderkloof on April 28, 1979, involving a swim across open water and over one of the deepest parts of the dam of over 7 km in 7 weeks. This is the furthest known record of a carp migration in Southern Africa, though in Europe a marked carp travelled 25 km in one day (Steffens 1958), and one

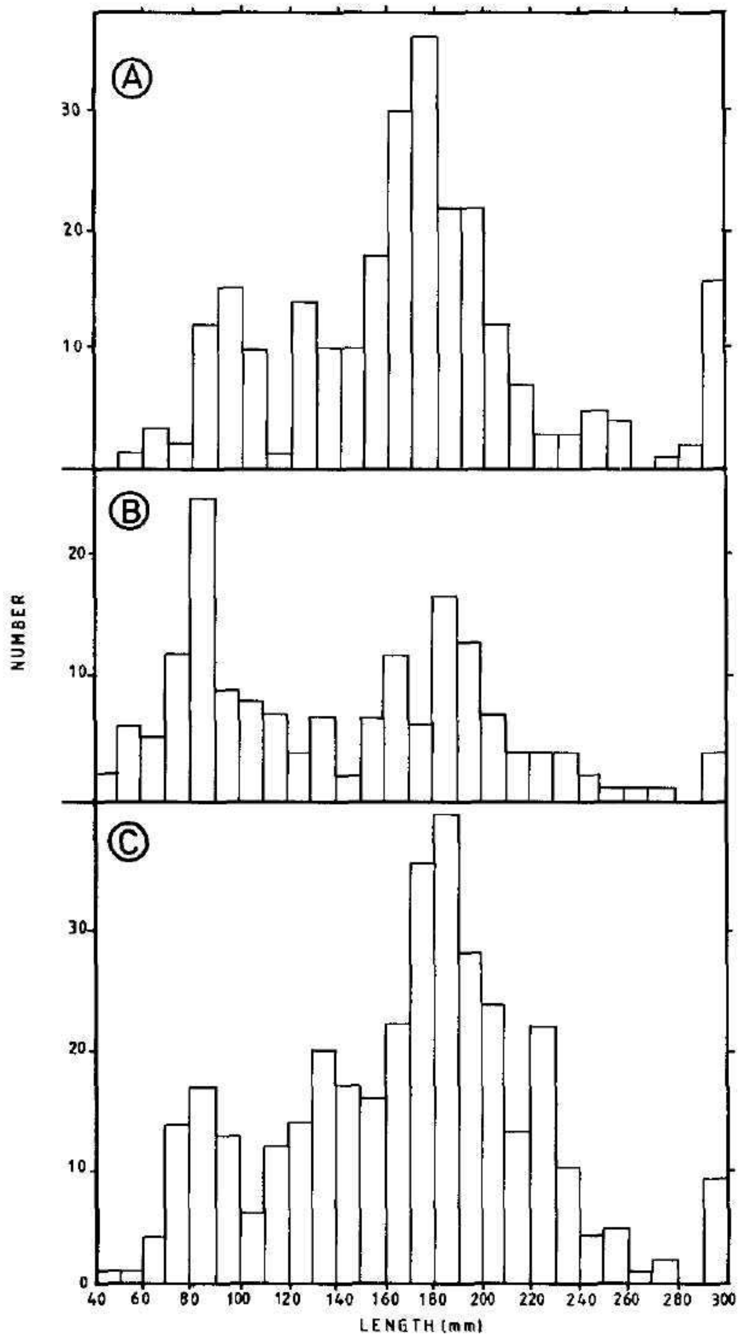


FIGURE 2.4.10. Length-frequency distribution of carp electrofished from the Berg and Seekoei drowned river valleys: (A) 30/11 - 4/12/80; (B) 16/1 - 21/1/79; (C) 6/3 - 11/3/79. All fish 290 mm and larger are combined.

tagged in the Missouri River, Missouri was recaptured in South Dakota, 1085 km away, 28 months later (Sigler 1958). In the summer of 1982-83 small carp were taken by purse seine in the top four metres of water near the dam wall. Size distribution of carp captured by electrofishing during three periods of about a week each are given in Figures 2.4.10, A-C. These were each from the Berg and Seekoei river tributaries typical of the flooded tributary valleys described above, which were found to be favoured carp waters. The size structure of the populations are similar in all cases, and probably a good representation of the population structure of carp during this summer because sampling by electrofishing is essentially nonselective in the smaller length ranges. Two early modes are present at about 85 and 190 mm, the second probably of two-year old fish spawned in the summer of 1976-77 shortly after dam closure, and the first of approximately year-old fish of the second (1977-78) spawning. Older fish were considerably fewer in numbers and 50% of the 754 fish measured were between 160 and 220 mm fork length, indicating, if the presumption that these are two-year old fish is- correct, that the first spawning after closure was a relatively successful one, as is usually the case with fish which spawn among inundated vegetation. Gill-netting by the CDNEC tended to support these results in that the 73 mm mesh caught the most fish, and these had a mode of 190 mm (Gaigher et_ al. 1981). However, these nets were invariably set at the surface, ancT the-numbers of carp caught are probably not a true reflection of the population since carp are most abundant at the bottom and in shallow water of 2 m or'less.

Carp are one of the most commonly caught species by angling from the shore. This is because of their popularity among anglers, while most of the angling activity concentrates in habitats which carp prefer, i.e., soft-bottomed shallow areas. They spawn in spring or summer among newly inundated vegetation to which the eggs adhere until hatching. As a result spawning success may be limited both by lack of vegetation and drawdown exposing the eggs. Feeding is primarily on insect larvae and other invertebrates living in soft bottom muds, a main reason for the preferred habitat being shallow bays and flooded valleys. Carp can grow to a large size and occasionally good catches of juvenile carp are made with beach seines. It is likely that lack of adequate adult habitat primarily limits their abundance. Results of the studies of carp in the lake are given in greater detail by Merron et al (in prep).

TABLE 2.4.4. Total numbers of all species caught by electrofishing, 1979 and 1980.

Year	Chubbyhead barb	Smallmouth yellowfish	Banded tilapia	Sharptooth catfish	Carp	Moggel	Orange R. labeo	Rock catfish
1979	617	243	28	9	456	23	457	1
1980	933	114	81	5	324	4	874	1

(f) The Sharptooth_catfish. The catch statistics (Figures 2.4.1 & 2.4.2)
^^ ^ CDNEC gill-net survey show a relatively poor rate of catch as well as the greatly increased catches in the warmer summer months due to increased activity at this time. In the early years of the dam the highest CPUE (3.5) was recorded from the largest mesh (150 mm) gill-nets (Figure 2.4.11).

To some extent the gill-net data may show a bias due to this species being of mainly benthic habit and perhaps less caught in the top-set gill-nets. But that this is probably not true of this actively ranging predator and is shown by a comparison with the CPUE of long lines (Tables 2.4.5 & 3.2.3, Figure 3.2.9), showing generally higher catches than those of gill-nets, even though the long-lines were also set at the surface. Thus the relative abundance of the barbel is probably accurate relative to the other species taken by gill-net.

As indicated in Tables 2.4.1 & 2.4.4, this potentially important species may not be amenable to capture by gill-netting and electrofishing, and thus may be more numerous than available records indicate. However, it was certainly not abundant.

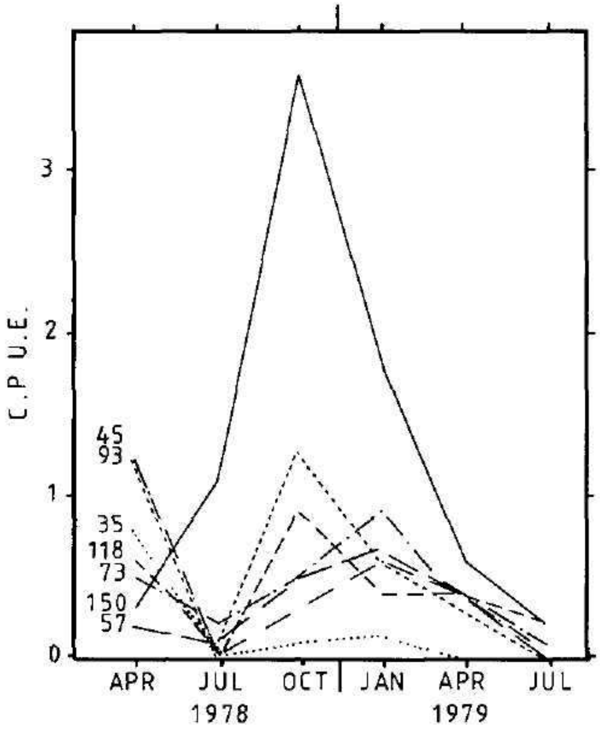
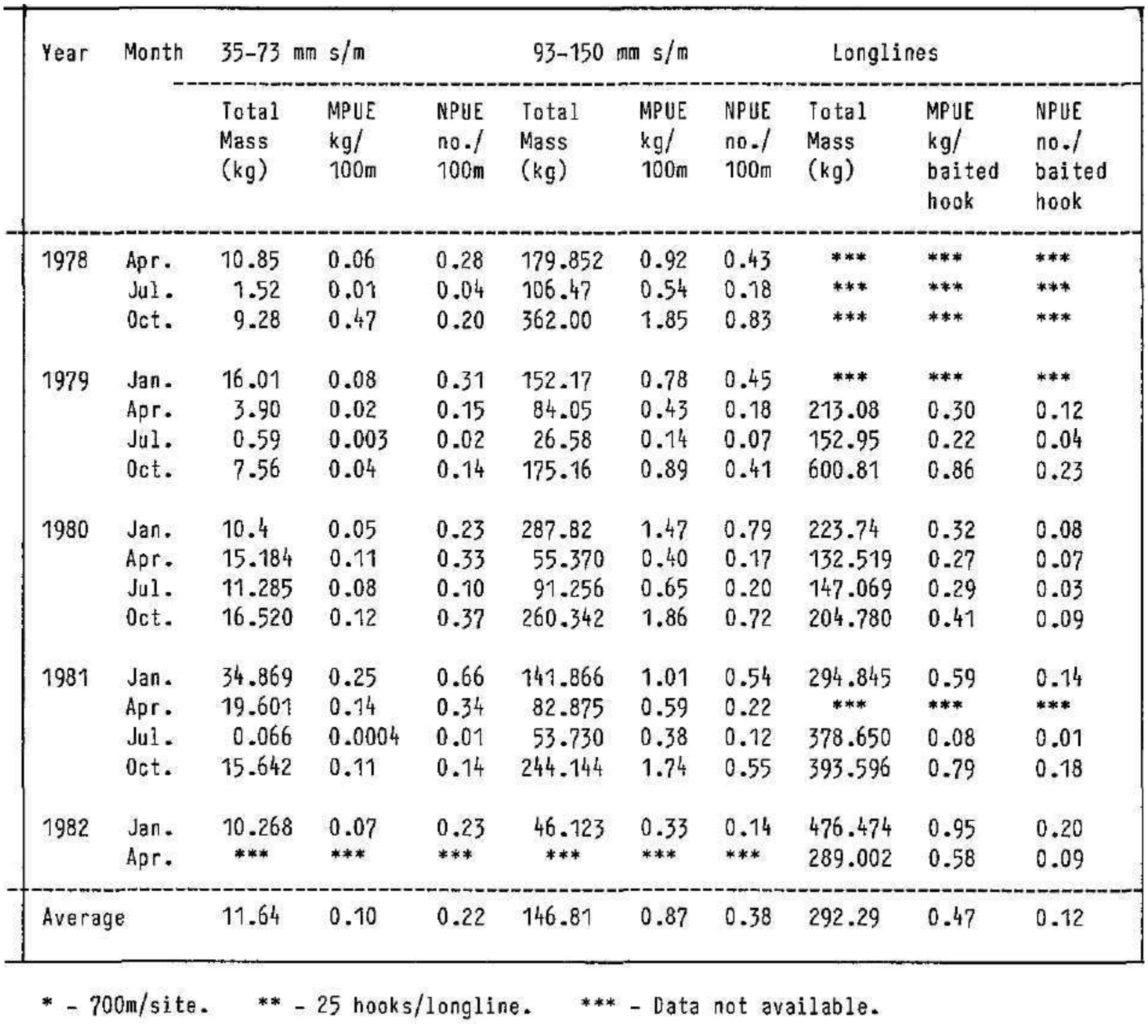


FIGURE 2.4.11. Catch per unit effort of sharptooth catfish collected with seven different gill net mesh sizes from Lake le Roux, April 1978 to July 1979. (Gaigher et al 1981).

TABLE 2.4.5. Comparison of sharptooth catfish data for longlining and gill-netting. (P.N. White, unpublished).
Total Mass (kg) for each 14 day survey of 28 sites (4/78-1/80) or 20 sites (4/80-4/82); Average Mass (kg/100m gill-net*) or kg/baited hook on longline**) and Average Catch (number/100m gill-net or number/baited hook on longline) per 16 hour 'overnight' period for Clarias gariepinus in Lake le Roux.



Year	Month	35-73 mm s/m			93-150 mm s/m			Longlines		
		Total Mass (kg)	MPUE kg/ 100m	NPUE no./ 100m	Total Mass (kg)	MPUE kg/ 100m	NPUE no./ 100m	Total Mass (kg)	MPUE kg/ baited hook	NPUE no./ baited hook
1978	Apr.	10.85	0.06	0.28	179.852	0.92	0.43	***	***	***
	Jul.	1.52	0.01	0.04	106.47	0.54	0.18	***	***	***
	Oct.	9.28	0.47	0.20	362.00	1.85	0.83	***	***	***
1979	Jan.	16.01	0.08	0.31	152.17	0.78	0.45	***	***	***
	Apr.	3.90	0.02	0.15	84.05	0.43	0.18	213.08	0.30	0.12
	Jul.	0.59	0.003	0.02	26.58	0.14	0.07	152.95	0.22	0.04
	Oct.	7.56	0.04	0.14	175.16	0.89	0.41	600.81	0.86	0.23
1980	Jan.	10.4	0.05	0.23	287.82	1.47	0.79	223.74	0.32	0.08
	Apr.	15.184	0.11	0.33	55.370	0.40	0.17	132.519	0.27	0.07
	Jul.	11.285	0.08	0.10	91.256	0.65	0.20	147.069	0.29	0.03
	Oct.	16.520	0.12	0.37	260.342	1.86	0.72	204.780	0.41	0.09
1981	Jan.	34.869	0.25	0.66	141.866	1.01	0.54	294.845	0.59	0.14
	Apr.	19.601	0.14	0.34	82.875	0.59	0.22	***	***	***
	Jul.	0.066	0.0004	0.01	53.730	0.38	0.12	378.650	0.08	0.01
	Oct.	15.642	0.11	0.14	244.144	1.74	0.55	393.596	0.79	0.18
1982	Jan.	10.268	0.07	0.23	46.123	0.33	0.14	476.474	0.95	0.20
	Apr.	***	***	***	***	***	***	289.002	0.58	0.09
Average		11.64	0.10	0.22	146.81	0.87	0.38	292.29	0.47	0.12

* - 700m/site. ** - 25 hooks/longline. *** - Data not available.

Little evidence of good recruitment was noted, either by the taking of young-of-the-year in any of the various gears that were used, or in the entry numbers of young fishes into the smaller meshes of the CDNEC gill-nets (Figure 2.4.8), or in the average size of individual taken by long-line (Table 2.4.4). Indeed the trend apparently has been for larger specimens to be taken, but further work will be necessary to determine to what extent such trends may represent a potential depletion of older stock with the risk of inadequate replenishment through poor recruitment.

Distribution of sharptooth catfish appeared largely to be confined to the flooded tributary valleys (Figure 3.2.8; Table 2.4.3), with the population being considerably sparser along the main shores of the lake or in the open water offshore. Possibly, high mortalities occurred due to food shortages, such as when a prey stock like the smallmouth yellowfish, after first being an easy prey through weakness and emaciation (Figure 2.5.1), later became too reduced in numbers to meet a predator's needs. Large numbers of catfish skulls have been seen along the shore of both Lakes Verwoerd and le Roux, indicating probably a mass mortality.

(g) Chubbyhead _barb. Previous to impoundment this minnow occurred in regular but usually small quantities in shallow weedy pools or among rocks in inflowing tributaries or along the edges of the main river. It increased very rapidly in numbers following impoundment and has colonised all main environments in Lake le Roux, becoming extremely abundant in the process. They occur in shallow weedy pools in inflowing streams and spruits, and among fringing vegetations and rocks in the upper dam where the Orange River enters. From these original habitats this highly opportunistic little ghieliemientjie has colonized the new environments created by the formation of the impoundment. That is the shallow fringing shoreline of the entire perimeter of the new lake, and particularly in the tributaries which used to enter the Orange River more or less at right angles. Near the junction these have often cut steep-sided valleys in the earth's surface, which are now backflooded for distances up to several kilometres as a result of the height of the water impounded by the dam. These 'flooded tributaries' are of considerable importance as being sheltered environments which are away from the main stream of water in the dam, and thus have relatively still calm water. In the case of larger tributaries such as the Knapsak, Hondeblaf, Seekoei and Berg rivers these areas support high populations of minnows, and the greatest concentrations are found there.

The chubbyhead barb is, however, also found in pelagic areas, even in the upper waters of the dam's centre, over a kilometre from any shore. They occur widely in such situations but are nowhere abundant in the open waters. This can be seen from Table 2.4.2, which shows that open water trawl catches of this minnow were far more abundant in the flooded tributaries than in any other part of the dam's open water. However, it is not able to co-exist with similar sized juveniles belonging to the same family, probably failing to compete with them for food and space (Cambray, 1982). This markedly affects distribution; the minnows are as a result, less numerous at the upper end of the dam where most juveniles of the larger cyprinids are, than in the lower section.

Table 2.4.6 indicates the age structure of chubbyhead barb populations; it shows that the general trend for the bulk of the population to be a year old with some entering into a second year, and a very few, especially females, persisting beyond. Females in general grow older and therefore longer than males, their maximum length in the lake being 73 mm as opposed to 60 mm for males. As can be seen there is a wide distribution in lengths in fish of one year-class, accounted for by the fact that the chubbyhead minnow has several spawnings in a year and has initially a rapid growth rate (see next chapter). Figure 2.4.12 indicates the length frequency distribution and sex ratio of barbs taken in water 3-6 m deep at least 15 m from the nearest

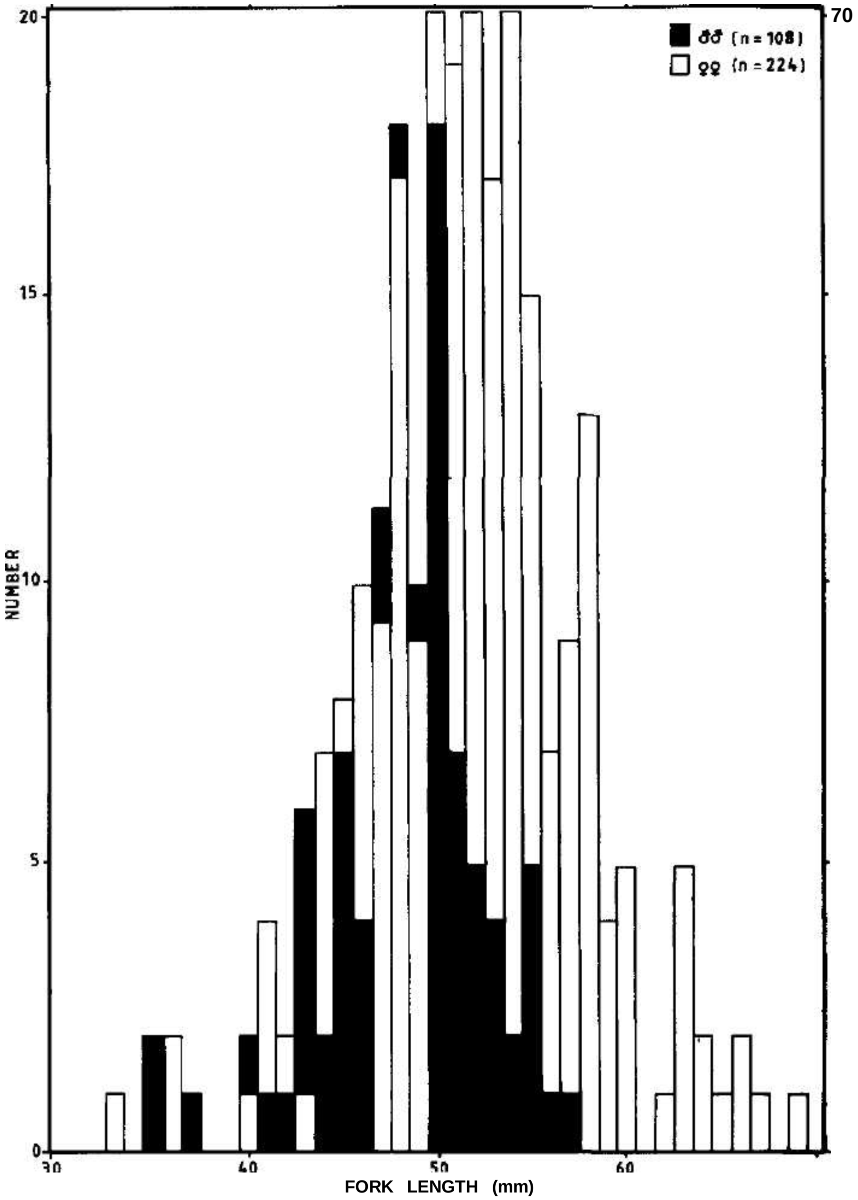


FIGURE 2.4.12. Length frequency distribution of chubbyhead barbs collected by purse-seine 15 m from nearest shore, depth > 6 m, Seekoei River flooded valley, March 1979, showing also relative numbers and size discrepancies of males and females.

shore in the flooded Seekoei Valley, while specimens occur a kilometre or more offshore with bottom well below the thermocline. This probably results from increased abundance forcing a more widespread distribution in search of food and lebensraum, with turbid water acting as a measure of cover from fish and bird predators. But as mentioned above, the chubbyhead tends to be excluded from areas occupied by the juveniles of larger cyprinids. An important attribute of this minnow in new impoundments is that it belongs to that group of fish which is quick-growing, small and able to carry out its life history from birth, growth, reproduction and death within a short time, often only a year. This contrasts with those fish which are slow growing and attain a large size, only attaining maturity after some years have passed, and reach a considerable age. It follows that the first group, of which the chubbyhead minnow is a typical representative, is pioneering and opportunistic in nature, quick to colonize a new environment and increase greatly in numbers.

TABLE 2.4.6. The length distribution of male and female chubbyhead barbs collected from Lake le Roux for different scale ring counts. (From Cambray & Bruton, In press).

MALES				FEMALES				
FL mm	1+	2+	3+	FL mm	1+	2+	3+	4+
24	2			24	2			
26	2			26	2			
28	7			28	7			
30	5			30	9			
32	13			32	16			
34	9			34	11			
36	13			36	17			
38	11			38	22			
40	11			40	17			
42	30			42	20			
44	30	2		44	18			
46	45	4		46	18	2		
48	35	15		48	36	12		
50	21	13		50	24	14		
52	8	9	1	52	10	16		
54	4	3		54	11	28		
56	2	2		56	6	25	2	
58	1	2		58	7	14	1	
60	1			60	1	12	2	
62				62		13	2	
64				64		3		
66				66		2	2	
68				68		2		
70				70		1	1	1

(h) Rock_catlet. This small catfish appears particularly adapted to the flowing waters of rocky sections of rivers, and occurs to a much lesser extent in the static water of an impoundment. Its numbers, therefore, have been very greatly reduced. Small isolated populations still occur in tributary rivers such as the Hondeblaf, Knapsak and Seekoei, where these meet the main waters of the dam but a movement of water still takes place, and in rocky sections of the inflowing Orange where this merges with the lake. As well, it was occasionally taken in small numbers in the CNDEC gill-netting operations (Table 2.4.7).

Even though so much of its original habitat has been inundated, the species seems still to be well established. It remains however, the indigenous species whose status has been most adversely affected by the creation of the big impoundments.

TABLE 2.4.7. Numbers of rock catfish and banded tilapia taken in CDNEC gill-netting surveys: all nets and stations combined.

Date of Survey	Rock Catfish	Banded Tilapia
April 1978	2	5
July 1978	1	0
October 1978	7	1
January 1979	10	11
April 1979	2	7
July 1979	0	1
October 1979	4	3
January 1980	3	5
April 1980	2	1
July 1980	4	1
October 1980	7	0
January 1981	17	4
April 1981	3	4
July 1981	0	0
October 1981	8	1
January 1982	11	0
Total	81	44

(i) Banded__Tilapia. This tilapia was originally described from the Hartz River, in the Orange River system though at a lower altitude, in a considerably warmer area. Prior to the formation of Lake le Roux it was not known to have occurred in the Orange River at this point, having escaped the notice of those who conducted pre-impoundment surveys of the fish populations. Also, it is absent from Lake Verwoerd immediately above, so from these facts it may be assumed to have occurred in extremely small numbers in the river basin before impoundment. It must therefore have increased in numbers very rapidly indeed, especially probably in 1977 during

TABLE 2.4.8. Total number of each species collected with a small mesh seine net, during monthly surveys, and % species composition in Lake le Roux. (From Hahndiek et al, 1978).

Species	November 1977 10 localities		February 1978 24 localities		March 1978 7 localities		May 1978 7 localities	
	No.	%	No.	%	No.	%	No.	%
B.holubi	54	18,7	307	2,8	1	0,03		
L.capensis	8	2,8	7229	66,6	24	0,6		
L.umbratus			492	4,5	97	2,6		
B.anoplus	195	67,5	2369	21,8	3546	95,8	284	95,6
C.carpio	32	11,1	184	1,7	3	0,08		
C.gariepinus								
T.sparrmanii			281	2,6	31	0,8	13	4,4
Totals	289	100,1	10862	100	3701	99,91	297	100

the early stages of filling during the highly productive first year of the dams esistence when turbidity was low and fertility high. In November 1977 none were taken but in February 1978, a bare 14 months after closure, 281 were taken, 2.6% of the total of 10862 fish sampled (Table 2.4.8). From the start of the Rhodes University electrofishing programme small numbers were taken 2-8 at a time, at many sites along the shoreline, particularly where cover in the form of rocks and drowned vegetation was present.

This species is strongly territorial and forms a male/female pair-bond, (unlike related tilapiine groups which are polyandrous), spawning on the substrate with both male and female guarding a brood of young. Although fecundity is relatively low, survival of young is high, due to this parental guarding, but each new pair must move out and delineate a territory of its own. Shoaling is thus a phenomenon of young and unmated fish only. - The distribution and structure of the banded tilapia portion of the fish community therefore, mainly consists of a series of pairs of fish distributed in suitable habitat along the shallow shores of the lake. Shoals of young unmated fish occasionally occur, but are generally small in numbers. Their natural distribution is mostly tropical/subtropical, so that the lake's relatively cold winter temperatures may also limit their numbers. They rarely grow to 80 mm TL, which is less than half the size known from more tropical environments. Reduced tolerances to low temperatures in larger fish may explain this difference in size. Together with their territorial behaviour, this inhibiting effect of cold winters will probably ensure that they will remain relatively unimportant members of the fish community.

Distribution information from offshore gill net catches

No specific study was made of catch rates or distribution in offshore gill nets, but some information was gained in the course of collection of material for dietary studies. This provided some insight into both the distribution in the surface waters, supplementing information from the surface trawl and purse seine, and also in relation to depth. No other information on depth distribution of fish in Orange River impoundments is available.

Surface sampling by gill nets was carried out by the method of drifting, using monofilament gill nets supplied by Messrs Apeldoorn-Lighthouse of Cape Town. Each net was 50 metres long, equivalent to 75 m of unmounted netting, and was so weighted that it would float. The nets hung to a depth of about 2.5 m from the surface. One end was fastened to a drogue, the other end remaining attached to the boat which was at the downwind end of the net. The fleet of nets was held stretched out at the surface by the effect of wind. Sets of these nets were made only during the middle part of the day and were of short duration, varying from 30 minutes to 2 hours. Drift nets were set a total of 14 times, 10 in the lowest basin and four in the Rolfontein basin. A fleet usually consisted of 3 nets of different mesh sizes, usually 47, 57 and 100 mm, although 3 sets included 51 mm nets and one a 65 mm net. The total catches are summarised in Table 2.4.9.

The small-mouth yellowfish formed 82% of the total catch by number and 72% by weight, Orange River labeo being the only other important species. The greater contribution of the latter to the total mass reflects the capture of a few large individuals in the 100 mm net which caught no other fish. The bulk of the catch of smallmouth yellowfish were taken from the upper half of the nets, while the few largemouth yellowfish caught were in the lower part of the net. No moggel were taken in drift nets, although in the summer of 1982-83 many, together with Orange River labeo, were caught in the purse seine when it was towed to capture live smallmouth yellowfish for experimental purposes (Chapter 3.2). This further supports the observation that this species has a patchy distribution, and may indicate a tendency for moggel to avoid the surface, where the other species were caught, and to be found offshore only at depths accessible to the purse-seine used.

The catch per unit effort for most nets averaged above 1kg per hour to 100 metres of mounted net, equivalent to 150 m of unmounted net, and considerably exceeds the catch rates reported from the CDNEC survey gill nets, which were reported for periods of 16h, when these are converted to an hourly basis. The highest average catch rate was for the 51 mm net, but this reflects large catches in early 1980 when a particularly strong year class was present. This net was subsequently used for deep sampling and was not included in later drift settings.

TABLE 2.4.9. Catches in drift nets used offshore. S.y.= smallmouth yellowfish; L.y.= largemouth yellowfish; O.L.= Orange River labeo. *MIX signifies that a fleet of 3 nets of 100, 57 and 47 mm was used but that the catches were not separately recorded. Basins:- V=lowest basin by Vanderkloof; R=Rolfontein basin.

DATE	BASIN	TIME	PERIOD Hr	MESH mm	SPECIES S.y.		L.y.		O.L.		TOTAL		C.P.U.E. (Kg/hr/100m)	
					N	Kg	N	Kg	N	Kg	N	Kg	N	Kg
29.1.80	V	AM	1.3	51	24	2.6	0		0		24	2.6	37	4.0
11.4.80	V	NOON	1	57	3	0.5	1	0.2	0		4	0.6	8	1.2
				51	11	1.2	2	0.3	0		13	1.5	26	3.0
14.8.80	V	PM	1	100	0		0		0		0		0	0
				65	1	0.2	0		0		1	0.2	2	0.4
				57	0		0		0		0		0	0
				51	0		0		0		0		0	0
21.11.80	R	NOON	1.5	*MIX	15	2.3	0		0		15	2.3	6.6	0
11.03.81	V	PM	0.7	100	0		0		0		0		0	0
				57	5	1.1	0		1	0.1	6	1.2	0	0
				47	2	0.4	0		0		2	0.4	6	1.0
12.03.81	R	AM	1.5	100	0		0		2	1.8	2	1.8	2.6	2.4
				57	3	0.6	0		0		3	0.6	4	0.8
				47	1	0.1	0		2	0.3	3	0.3	4	0.4
04.05.81	V	AM	0.5	100	0		0		0		0		0	0
				57	0		0		0		0		0	0
				47	0		0		8	0.6	8	0.6	32	2.2
"	R	PM	0.6	100	0		0		0		0		0	0
				57	1	0.2	0		0		1	0.2	0	0
				47	1	0.1	0		0		1	0.1	0	0
18.06.81	R	PM	0.5	100	0		0		0		0		0	0
				57	0		0		0		0		0	0
				47	1	0.1	0		0		1	0.1	4	0.4
19.06.81	V	PM	0.6	100	0		0		0		0		0	0
				57	1	0.1	0		0		1	0.1	3.2	0.4
				47	3	0.2	0		0		3	0.2	10	0.8
22.10.81	V	PM	0.7	MIX	4	0.7	1	0.1			5	0.8	14.2	2.2
23.10.81	V	AM	1	100	0		0		1	1.1	1	1.1	2	2.2
				57	4	0.8	0		0		4	0.8	8	1.6
				47	2	0.1	0		0		2	0.1	4	0.2
20.12.82	V	PM	1	100	0		0		0		0		0	0
				57	3	0.6	0		0		3	0.6	6	1.2
13.01.83	V	PM	1	100	0		0		1	0.8	1	0.8	2	1.6
				57	8	1.0	0		3	0.4	11	1.4	22	2.8
				47	17	1.8	0		9	0.8	26	2.6	52	5.2
TOTALS			PERIOD		CATCH BY SPECIES								MEAN	
			9.3	100	0		0		4	3.6	4	3.6	0.8	0.8
			1	65	1	0.2	0		0		1	0.2	2	0.4
			9.6	57	28	4.9	1	0.2	4	0.5	33	5.6	6.9	1.2
			3.4	51	33	3.8	2	0.3	1	0.1	38	3.9	22.4	2.3
			6.6	47	27	2.7	0		11	1.0	38	5.8	11.6	1.2
			2.3	MIX	19	3.0	1	0.1	0		20	3.1	5.8	1.0
SPECIES TOTALS					110	14.6	4	0.6	20	5.2				

Two gill nets, each 50 m long and of 51 and 63 mm stretched mesh respectively, were weighted so as to sink. These were set on the bottom in areas which had been identified from pre-impoundment aerial photographs as being clear of obstructions (Figure. 2.4.13). The nets were deployed in a variety of localities at four times of year spanning the cycle of stratification. On each occasion except June 1981 when there was no thermocline, nets were set above and below the thermocline level, although in May and June 1981 no sets were made in water shallower than 30 m.

The results are summarised in Table 2.4.10. On only one occasion were any fish recorded below the thermocline. This was in October, 1981, when nets were set near the level of the thermocline. Two fish were caught in nets set at 26 m overnight on 20 October, when the level of the thermocline was not recorded. The following night 8 fish were caught at 22-23 m. The thermocline level measured at the nearest standard limnological sampling station on 22nd was 20 m, but it is possible that it was deeper at the fishing site which was about 3km downwind. In November 1980, when the

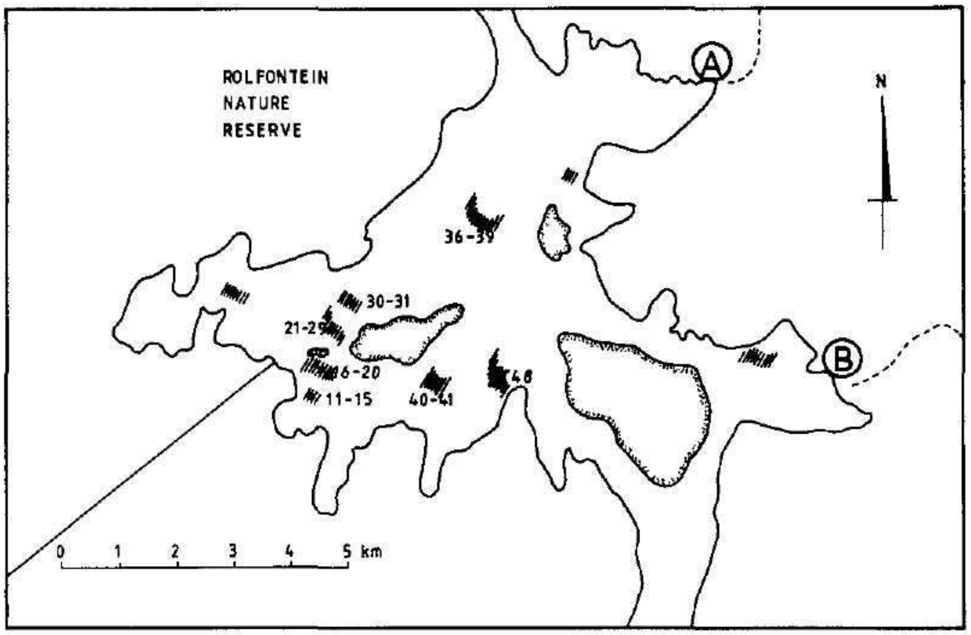


FIGURE 2.4.13. Areas in the Rolfontein basin of Lake le Roux where the bottom is sufficiently clear of obstructions to allow deep gill-netting. Dots indicate localities of experimental deep gill-netting reported in Table 2.4.10. A and B are sites of road access to lake (Chapter 3.4.2, Figure 3.4.1).

DATE		20-21 Nov.1980				10-13 Mar.1981				1-4 May 1981				17-19 June 1981	20-23 Oct.1981		
DEPTH (metres)	PERIOD (hours)	SPECIES:- S.y.	O.L.	C.c.	S.c.	S.y.	O.L.	C.c.	S.c.	S.y.	O.L.	C.c.	S.c.	O.L.	S.y.	O.L.	C.c.
11	3	0	3	4	1												
12.4-13.0	9					9 (2.2)	266 (55.5)	6 (0.8)	4 (0.8)								
12.3-14.8	12	1	0	1	0												
		Thermocline 14-17 m.															
16.5-16.9	14					4 (0.9)	148 (29.3)	2 (0.1)	0								
17.0-18.0	4	NIL												Thermocline absent.			
19.0-20.0	17					0 (11.6)	55 (0.2)	3	0								
21.0-24.0	16	NIL				Thermocline 21 m.											
22.0-23.0	24														2 (0.3)	4 (0.6)	2 (0.3)
26	18														1 (0.3)	1 (0.1)	0
28.0-29.0	23					NIL									Thermocline about 20m on 22 Oct.		
30.4-31.6	20									3 (0.6)	8 (1.8)	0	2 (0.3)				
35.6-39.1	24									Thermocline 30-32 m				6 (1.0)			
40.3-41.3	25									NIL							
48	24													3 (0.4)			

TABLE 2.4.10. Catches in gill nets set below 10 metres (50 m each of 51 and 63 mm stretched mesh). Species: S.y.= smallmouth yellowfish; O.L.= Orange River labeo-; C.c.= carp; S.c.= sharptooth catfish. (Total mass in parentheses). Sets of less than 12 hours duration were in daytime, the others overnight.

thermocline lay at about 15 m, catch rates were low in the depths of 11-13 m, and similar low catch rates were noted in May and June 1981 at greater depths. In March 1981 very high catches were recorded between 12 and 17 metres, although only the Orange River labeo was abundant. This may reflect dispersal of this species from the upper reaches of the lake due to increased turbidity at this time (Chapter 2.5).

On all occasions nets set just above the level of the thermocline caught some fish, as did nets set at 48 m in June 1981 when there was no thermocline. Carp were never recorded below 20 m, but sharptooth catfish and smallmouth yellowfish extended to 30 m while only the Orange River labeo was found below 35 m. In winter, much of the area of the bottom of the lake would be accessible to fish, although only the Orange River labeo appears able to colonise the whole of the area. In summer only that part of the bottom which lies above the thermocline is occupied by fish. Thus there is the possibility that high inshore summer catch rates reflect not only greater activity of the fish, but also their concentration inshore.

2.5. ECOLOGY OF MAJOR FISH STOCKS

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The management of fish populations becomes more species-directed as knowledge of particular populations increase. Thus, in the early stages of a freshwater fishery, resources are often assessed on the basis of general models which predict yield. Such models are based on morphological, edaphic and biological characteristics of the water body and can give an order of magnitude estimate of potential yield (Bhukaswan, 1980). They do not give any guide as to how the fish populations should be exploited for the maximum benefit to the fishery.

When more is known about the fish populations, management may be aided by theories of life history (Adams, 1980), comparative studies in biology (Holt, 1962) and knowledge of environmental influences on the populations (Regier, 1977). Ultimately, management of fish resources for different purposes is best guided through an understanding of the adaptiveness of a population to its environment. The Russion ichthyologist, G-V.IMikolsk.ii stated this clearly (1962, p.277):

> "A knowledge of the forms of adaptive response of populations to changes in the conditions of life, and, particularly, to changes in food supply, is as necessary for a rational organisation of a fishery, as is a knowledge of the changes in living conditions of the population. It is impossible to build up a rational fishery industry, based only on studies of the changes in living conditions, without trying to understand the adaptive response of the population. The fishing industry should be planned in such a way that it becomes a component of the environment of the species exploited, i.e. the rate of the industry's influence should not exceed the range of the adaptations of a species."

Feeding relationships are treated extensively in Chapter 2.3, but here we summarize other features of the ecology, including reproduction, growth and mortality, of the major fish species. All these aspects of their biology largely determine their response to varying environmental conditions. This section forms the basis for the subsequent discussion on the influence of hydraulic manipulations (Chapter 3.1) and exploitation (Chapter 3.3). Biology and ecology of the larger Cyprinidae are treated in Tomasson et _al_ (in prep.), Merron & Tomasson (in prep.) and Merron et aj_ (in prep.).

2.5.1. The smallmouth and largemouth yellowfish

These two large species of yellowfish, indigenous to the Orange River system, are closely related and follow in many ways a similar life-history pattern. They are indistinguishable in the field on the basis of external characters until they reach a fork length of 80 to 90 mm, although they can be separated at lengths down to 30 mm on the basis of gut morphology. Their early life history has thus been inferred from subsequent back-calculation of growth (this study), knowledge of their present geographical distribution

(Jubb & Farquharson, 1965), and from other studies (Mulder, 1973a; Gaigher 1976; Hamman, 1981). The smallmouth yellowfish is of major importance in Lake le Roux while the piscivorous largemouth is by comparison a rare species (Chapter 2.4).

Yellowfish spawn in running water over gravelly beds following a migration, the process being first described in the Orange River by Shortt-Smith (1963) as follows (p.58):

> "When the first rains swell the rivers in spring, the annual spawning migration starts, and they (yellowfish) move upstream in impressive numbers. Waterfalls of five feet and more are negotiated with flashing ease, and in the gravel beds they lay their eggs. Later in the middle of summer, dark shoals of fry can be seen in the calmer shallows".

In Lake le Roux, spawning mainly occurs in spring to summer in the regulated Orange River below Lake Verwoerd. Each species spawns once during a season, with the smallmouth spawning about four to six weeks before the largemouth yellowfish. Time of spawning is variable among seasons and is dependent on river water temperatures. Under a natural flow regime smallmouth yellowfish are ready to spawn during floods in early spring but this can be postponed to late summer if floods are delayed. Thus in the Seekoei River, the largest tributary entering Lake le Roux, a resident population spawned during floods in late March and in late September 1981.

Size at sexual maturity is variable and depends on growth rate. In years following poor growth the population may stunt so that size at sexual maturity is reduced. Smallmouth yellowfish mature at a much smaller size than largemouth in Lake le Roux. The two species have similar fecundities with 350 mm, 400 mm and 450 mm females carrying on average 7500, 11700 and 18300 eggs respectively. The diameter of a ripe unshed egg is about 1.7 mm.

The eggs incubate for several days, depending on water temperature; development is speeded up by increases in temperature (Mulder & Franke, 1973). After hatching the larvae remain immobile for several days in the gravel while the yolk sac is being absorbed. Subsequently the larvae move into the shallows where initial feeding is on micro-fauna, which is later replaced in the diet by benthic invertebrates. In Lake le Roux it was found that at about 50-60 mm length the juveniles begin to leave the marginal areas and assume a pelagic existence increasingly feeding on zooplankton, visually selecting individual prey (Chapter 2.3). Zooplankton density and water clarity therefore determine the upper size limit of yellowfish which can sustain a living on zooplankton in the pelagic zone. When or before this limit is exceeded, usually at between 270 and 320 mm, smallmouth yellowfish return to a benthic mode of living, incorporating a wide variety of material in their diet, including filamentous algae, vascular plants, benthic invertebrates and detritus. The largemouth yellowfish on the other hand turns increasingly to piscivory.

Because of the dependence of smallmouth yellowfish on zooplankton, and the relatively limited benthic food resources, reduced availability of zooplankton was capable of having disastrous consequences. When turbidity in the lake increased sharply, visibility was reduced and the yellowfish

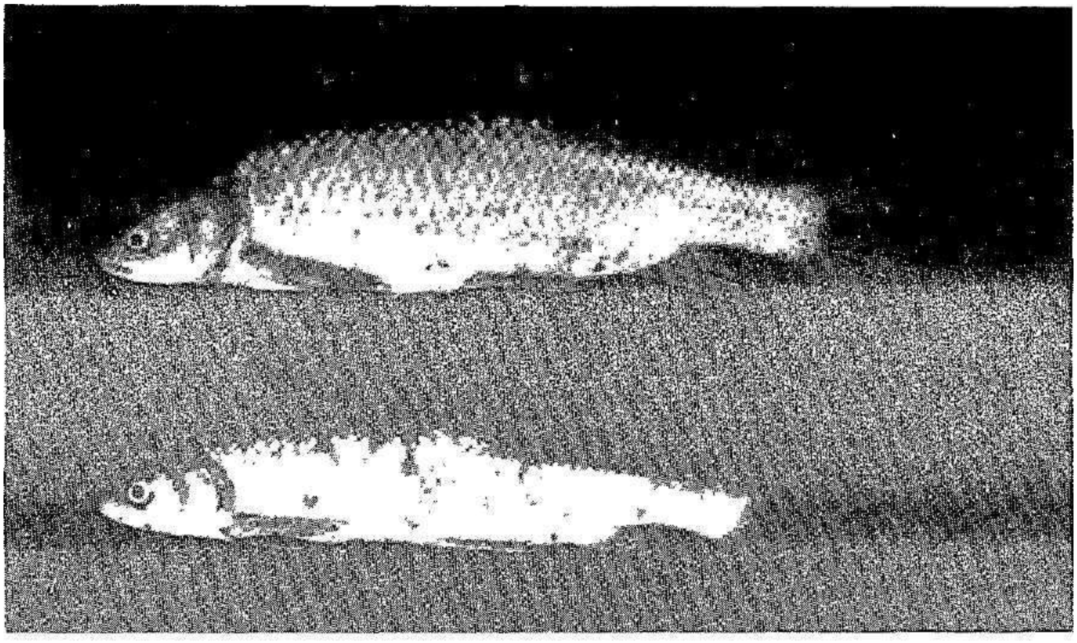


FIGURE 2.5.1. Smallmouth yellowfish caught at Station 5, 16 January 1982, illustrating variation in relative condition. Fish A is 297 mm FL, 346g, C=1.00. Fish B is 276 mm FL, 160g, C=0.58. (Photograph: T.Tomasson).

became a less effective predator on the zooplankton community. This led to food shortages which initially were manifested in generally reduced, but highly variable body condition of individual fish (Figure 2.5.1) and the eventual starvation and death of a large part of the population, particularly those between the lengths of 150 and 350 mm.

The growing season is dependent on water temperatures, but generally commences in October and lasts through April roughly coinciding with pelagic temperatures above 20°C (Chapter 2.1). The smallmouth yellowfish has a slightly longer growing season than the largemouth yellowfish and commences growth earlier in the spring. Rate of growth of individual fish varies markedly within the lake, and shows a general decrease with distance up the lake from the dam wall (Tables 2.5.1 and 2.5.2). However the populations are very mobile and this is shown by the reduction and eventual disappearance in observed differences in growth rate among localities with time (Tables 2.5.1 and 2.5.2).

Rate of growth in early life shows only small variations among years, and at the end of their second growing season, smallmouth yellowfish are 130-150 mm long, while largemouth yellowfish are about 110 - 130 mm. On larger and older fish seasonal differences in growth rate become more pronounced.

TABLE 2.5.1. Length increments of different size groups of smallmouth yellowfish in summer 1979/80, by locality. Length increments were calculated from measurements of growth rings in the scales and the samples were divided according to time of capture. The decrease in back-calculated length increments from samples taken in Zone 1, and an increase in Zone 7 with time, show that the yellowfish are mobile and mix freely within the lake. (From Tomasson, 1983).

Length group	Zone	Growth in 79/80 (mm ±95% confidence interval) as calculated from samples collected in :-			
		winter 80	summer 80/81	winter 81	summer 81/82
50 - 90 mm	2	81(5.8)	68(5.8)	68(5.2)	65(12.1)
	4	66(5.4)	57(7.1)	75(10.0)	68(6.5)
	7	58(5.7)	52(6.3)	60(9.0)	66(15.2)
100 - 149 mm	2	87(3.7)	83(4.5)	76(7.2)	85(6.9)
	4	79(4.9)	80(7.1)	83(5.1)	82(5.0)
	7	63(5.9)	76(5.8)	74(5.0)	75(5.6)
150 - 199 mm	2	77(4.2)	79(6.6)	78(6.9)	78(7.8)
	4	65(7.0)	73(8.3)	76(9.8)	76(6.6)
	7	50(6.7)	68(9.1)	74(8.9)	76(9.1)
200 - 249 mm	2	70(7.1)	76(7.5)	74(11.4)	81(8.3)
	4	63(7.0)	58(13.0)	65(15.0)	66(12.3)
	7	40(17.0)	59(11.3)	69(24.0)	67(38.2)

TABLE 2.5.2. Length increments of different size groups of largemouth yellowfish in summer 1979/80 by locality. (See Table 2.5.1 for further explanation). (From Tomasson, 1983).

Length group	Zone	Growth in 79/80 (mm ±95% confidence interval) as calculated from samples collected in :-			
		winter 80	summer 80/81	winter 81	summer 81/82
50 - 99 mm	2	99(9.2)	71(8.0)	64(8.0)	68(11.3)
	4	81(12.7)	71(8.5)	64(4.6)	65(14.7)
	7	63(8.7)	57(4.7)	62(13.3)	64(11.0)
100 - 149 mm	2	86(19.6)	76(9.0)	70(13.9)	59(6.3)
	4	74(10.8)	72(18.1)	63(9.2)	59(11.3)
	7	57(6.9)	59(6.8)	57(26.1)	62(10.3)
150 - 199 mm	2	81(6.0)	68(7.2)	60(9.4)	74(22.6)
	4	65(8.0)	69(6.4)	63(9.2)	67(9.2)
	7	50(8.0)	59(6.1)	51(8.0)	76(24.7)

Thus growth in the third year of life (age 2) showed 2 - 3 fold differences among seasons, while in fish 4 years and older, up to 10 fold differences in growth were observed among seasons (Tables 2.5.3 and 2.5.4).

Usually a clear trend is seen in deteriorating growing conditions as impoundments age (Lowe-McConnell, 1973; Bhukaswan, 1980). In Lake le Roux no such trend is in evidence (Tables 2.5.3 and 2.5.4), bearing witness to large inter-seasonal fluctuations in environmental variables, to which fish of riverine origin find it difficult to adapt (See Chapter 3.1).

In spite of relatively slow growth rates, yellowfish can reach a considerable size. This is particularly true for largemouth yellowfish. Although relatively scarce, individuals of 400 - 500 mm are occasionally caught. These are at least 10 years and usually more in age. Both species are potentially long-lived, but in the lake, rates of natural mortality vary greatly. In 1978 CPUE of smallmouth yellowfish dropped by over 90% (Figures 2.4.1 and 2.5.2). Some of this was due to reduced catchability but natural mortality, due to starvation as stated above, probably accounted for over 80% of the reduction in catches. In 1981 catches were greatly reduced again although not to the same degree as in 1978 (Figures 2.4.1 and 2.5.2).

TABLE 2.5.3. Average annual length increments of smallmouth yellowfish in Lake le Roux, expressed in millimetres fork length and as percentage of average growth over all seasons. Length increments were calculated from scale measurements. (From Tomasson, 1983).

		Growth of smallmouth yellowfish at age:-					
Season		2	3	4	5	6	Average percentage of 'standard'
1981/1982	mm	42	38	7	6	10	
	%	59	59	15	17	33	37
1980/1981	mm	94	73	52	47	26	
	%	132	114	108	134	87	115
1979/1980	mm	72	67	61	29	26	
	%	101	105	127	82	87	101
1978/1979	mm	46	31	20	16	15	
	%	65	48	42	46	50	50
1977/1978	mm	86	79	59	48	49	
	%	121	123	123	137	163	133
1976/1977	mm	87	98	89	62	57	
	%	123	153	185	177	190	166
Mean increment 'standard'	mm	71	64	48	35	30	

TABLE 2.5.4. Average annual length increments of largemouth yellowfish in Lake le Roux, expressed in millimetres fork length and as a percentage of average growth over all seasons. Length increments were calculated from scale measurements. (From Tomasson, 1983).

Season		Growth of largemouth yellowfish at age:-				Average percentage of 'standard'
		2	3	4	5	
1981/1982	mm	45	32	12	12	
	%	65	53	18	22	39
1980/1981	mm	90	81	54	55	
	%	130	135	83	102	112
1979/1980	mm	69	61	60	*	
	%	100	102	92		98
1978/1979	mm	56	39	38	30	
	%	81	65	58	56	65
1977/1978	mm	69	88	109	78	
	%	100	147	168	144	140
1976/1977	mm	88	60	119	97	
	%	128	100	183	180	148
Mean increment 'standard'	mm	69	60	65	54	

* insufficient data available

Between these periods of drastic decrease, the population does not suffer high rates of natural mortality. Young-of-the-year did not suffer the heavy mortalities of the older fish in 1978 and 1981. In 1980 the good recovery of the population (Figure 2.4.1) was due to a strong 1977/78 year-class entering the catches and similar improvement in 1983 (Figure 2.4.1) was the result of a strong 1981/82 year-class being recruited.

Largemouth yellowfish are not caught in sufficient numbers for changes in CPUE (Figure 2.4.1) to reliably reflect changes in abundance. It appears though, that the larger fish particularly are not as susceptible to catastrophic mortalities as sub-adult smallmouth yellowfish are, and that they are generally long lived.

Smallmouth yellowfish are a very important species in the lake, but population fluctuations are large, responding quickly to changes in environmental conditions. The largemouth yellowfish by comparison is rare, but does not fluctuate in abundance to the same extent.

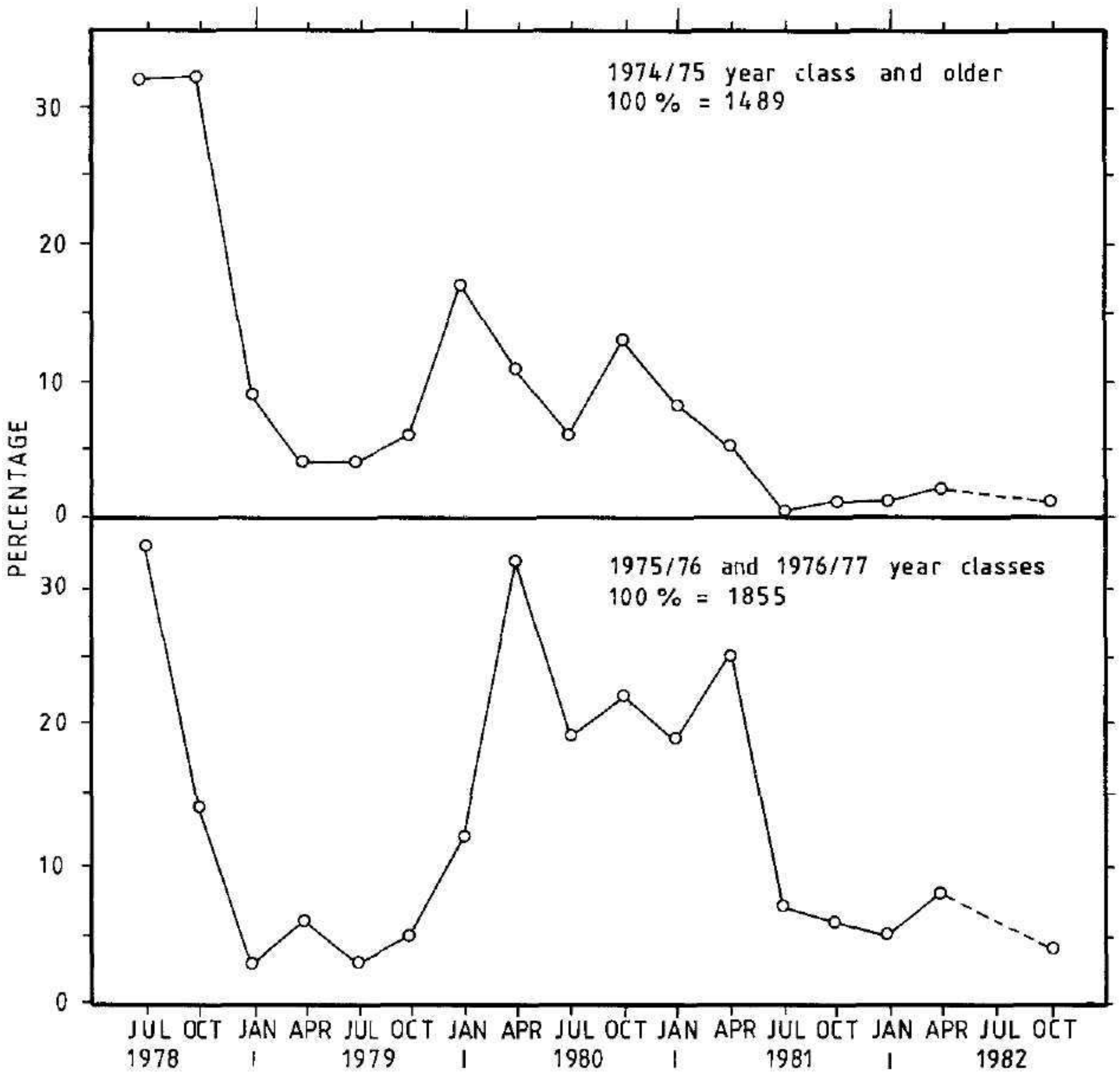


FIGURE 2.5.2. Variations in catch of smallmouth yellowfish in Lake le Roux, spawned in 1976/77 and earlier as a percentage of the catch in April 1978. Catches are from the CDNEC quarterly surveys and have been adjusted for gillnet selectivity (Figure 3.2.2) and reduced effort from April 1982. (From Tomasson, 1983).

2.5.2. Chubbyhead barb

A comprehensive study into the biology of the chubbyhead barb in Lake le Roux was conducted by Cambray (1982) from which the following information has been extracted.

This small minnow spawns along the shoreline of Lake le Roux and also undergoes spawning migrations up inflowing tributaries which are in spate. It has two major spawnings per season, one in spring or early summer and another in February or March. There is also a possibility of minor spawnings throughout the summer because mature ova occur in the ovaries from October to March. Spawning appears to be triggered by periods of steady rainfall at .times when water temperature is at or above 20°C. The multiple spawning behaviour of this short-lived species probably led to the rapid colonisation of Lake le Roux. Fish from the first spawning attain a length of 40 mm FL during their first summer, and they are able to participate in the first spawning of their second summer. The length at sexual maturity for both males and females is between 38 and 40 mm FL.

In multiple spawning species it is difficult to assess absolute fecundity, which may also vary considerably between years. If all yolked ova were counted before the first spawning, counts for 40, 55 and 70 mm FL females were 417, 1396 and 3486 in 1979/80. Corresponding counts were 577, 2317 and 6638 a year later, possibly reflecting improved living conditions. Diameters of the ripe unshed ova range in size from 0.7 - 1.05 mm. When shed, they are demersal and have an adhesive chorionic membrane.- At temperatures between 19 and 21°C the larvae hatch' in 53 hours and at temperatures between 24 and 25°C they hatch in 28 hours. The protolarvae have three adaptations to ensure their survival. Some larvae are pelagic, while others swim to the surface periodically then sink passively, and others adhere to rocks or vegetation with a mucous secretion on the dorsal surface of their head. These adaptations probably evolved to prevent suffocation in the bottom mud.

In Lake le Roux, the chubbyhead barb is predominantly carnivorous, although filamentous algae may also be eaten. It is a highly opportunistic feeder, with the diet chiefly reflecting its habitat (Cambray 1983).

Fish spawned in November reach the sexually mature length of 38 - 40 mm FL by March or April. The second spawn fish attain a length of 21 - 22 mm FL by the end of the growing season, and do not attain a sexually mature length until mid-summer of the following year. However, the longer-lived minnows are usually from the second spawn. This difference in longevity between the two broods enables the spawn from one year to live into an additional year, which would be advantageous to a short-lived species in a harsh environment such as the South African highveld. However, in Lake le Roux this adaptation would aid the rapid colonisation. Females (maximum 4 years) are longer-lived than males (maximum 3 years) with the majority of the population dying off after one year.

In summary, chubbyhead barb underwent a population explosion in the early phases of Lake le Roux, colonising the marginal habitat and extending into the open waters. This species matures within one year and this trait, combined with spawning habits and opportunistic feeding habits, probably led to its successful colonisation of the marginal waters of the impoundment.

2.5.3. Orange River labeo and moggel

The Orange River labeo is an endemic of the Orange system, but since the construction of the Orange-Fish River tunnel, it now occurs in the Fish River (Cambray & Jubb, 1977). The moggel is widely distributed in the Republic. The two species appear to hybridize in some impoundments (Gaigher and Bloemhof, 1975; Hamman, 1981), but no hybrids have been positively identified from Lake le Roux. In this lake, Orange River labeo are common and usually make up over 50% of the gillnet catches (Chapter 2.4), but moggel are poorly represented in the catch.

Labeo species typically spawn on floodplains during the time that these are inundated while rivers are in spate. The Orange River labeo has been found to spawn in suitable inflowing water throughout the lake, and while the subsequent survival of the larvae appears to be related to rising lake levels, spawning is probably triggered by local flooding. The generally short durations and erratic times of occurrence of floods make for variable reproductive success.

Moggel are well known for the length of their spawning migrations up rivers before spawning on floodplains (Jackson & Coetzee, 1982). Aggregations of sexually, mature fish have been found in the. flooded valleys of major tributaries, particularly the Seekoei River, and in the uppermost basin of the lake where the Orange River enters. Reproduction is spatially more restricted in moggel than in Orange River labeo. Both species have a prolonged spawning season, from spring well into summer, during which several spawnings may take place. This is due to large variations in time of maturity within the spawning stock and the influence of local conditions on spawning. Each individual female only spawns once in a season. The lack of co-ordination in breeding indicates that there is little *or* no selective advantage associated with a certain time of spawning. Size at sexual maturity has remained relatively constant since impoundment. In both species males mature at about 330 - 350 mm and females at 370 - 400 mm. However, judging from comparative studies on other populations, size at sexual maturity may be reduced if growing conditions remain unfavourable for a prolonged period of time. The two species are relatively fecund. Female Orange River labeo of 350, 400 and 450 mm carry an average of 47, 110, and 257 x 10^3 eggs. Moggel are slightly less fecund; corresponding figures are 37, 88 and 205 x 10^3 (Hamman, 1981). In populations which mature at a smaller size, relative fecundity is further increased. Average ovum diameter is about 1.2 mm for Orange River labeo and 1.1 mm for moggel, i.e. about 30% of the yellowfish egg size.

The eggs have a short incubation time, usually hatching within 48 hours of fertilization. Soon after hatching the larvae swim repeatedly up into the water column before sinking again (Mulder, 1973b). Juveniles are found in the marginal habitat where they probably are feeding on microscopic invertebrates. Subsequently they turn to herbivory/detritivory and rely on taste rather than sight in sensing food. The Orange River labeo has a relatively longer intestine than moggel (Kruger & Mulder, 1973), reflecting a higher intake of plant matter and indigestable material. The Orange River labeo is adapted to graze algae off rocks, though will eat detritus while moggel favours detritus and mud taken off soft bottoms.

TABLE 2.5.5. Length increments of different size groups of Orange River labeo in summer 1979/80 by locality. Length increments were calculated from measurements of growth rings on scales and the samples were divided according to time of capture. (Tomasson, 1983).

Length group	Zone	Growth as in 79/80 (mm ± 95% confidence interval) as calculated from samples collected in :- winter 80	summer 80/81	winter 81	summer 81/82
50 - 99 mm	2	62(5.0)	54(7.8)	56(8.6)	45(6.7)
	4	51(4.8)	46(5.7)	44(5.7)	45(6.7)
	7	33(5.2)	29(5.1)	44(6.4)	42(5.2)
100 - 149 mm	2	57(5.5)	51(5.6)	58(6.1)	48(5.2)
	4	40(3.8)	47(4.9)	49(5.7)	49(4.0)
	7	36(4.5)	38(5.7)	45(9.2)	45(5.5)
150 - 199 mm	2	56(4.0)	57(4.3)	56(6.0)	57(4.8)
	4	43(4.7)	51(5.8)	53(6.4)	45(4.7)
	7	48(12.2)	35(7.2)	43(8.8)	48(6.3)
200 - 249 mm	2	53(3.5)	51(4.9)	54(4.9)	54(4.1)
	4	42(4.0)	45(4.8)	58(5.8)	50(5.5)
	7	34(7.8)	36(5.8)	45(7.6)	37(8.2)
250 - 299 mm	2	40(4.5)	45(5.5)	51(5.7)	45(5.5)
	4	29(6.1)	37(4.9)	34(9.8)	33(10.6)
	7	31(7.0)	25(5.7)	31(6.4)	24(7.2)

The relatively high abundance of Orange River labeo in Lake le Roux (Chapter 2.4) probably reflects, firstly, its high initial abundance in the river; and secondly, a large favourable feeding area in the long rocky shoreline of the lake (Figure 2.4.7). Moggel was found to be scarce in the lake during the study period, reflecting its low initial abundance and the relatively limited extent of muddy shallow areas favoured by this species.

Growth studies of moggel in Lake le Roux (Merron & Tomasson, in prep.), and other studies (Mulder, 1973b; Hamman, 1981) indicate that it generally grows faster than Orange River labeo during the first few years, though both species eventually reach similar adult size. Generally, the growing season of Orange River labeo in Lake le Roux commences in November and lasts into April. Rate of growth is generally slow, but shows a decreasing trend up the lake (Table 2.5.5), possibly reflecting a decrease of benthic algal food in the increasingly turbid waters. The population is relatively stationary, but fish smaller than 200 mm dispersed in the lake in 1981/82 as seen by the disappearance of observed differences in growth with locality in that summer (Table 2.5.5). This was also shown by changes in size distribution of the population with locality (Chapter 2.4, Figure 2.4.9). Larger fish remained

TABLE 2.5.6. Average annual increments of Orange River labeo in Lake le Roux expressed as increments in fork length, in millimetres, and as percentage of average growth over all seasons. Length increments were calculated from scale measurements.

		Growth of Orange River labeo at age :-						Average
Season		2	3	4	5	6	7	percentage of 'standard'
1981/1982	mm	16	5	1	2	2	0	
	%	33	10	2	5	7	0	10
1980/1981	mm	52	46	42	41	27	16	
	%	106	96	102	111	93	70	96
1979/1980	mm	47	52	49	43	34	26	
	%	96	108	120	116	128	113	113
1978/1979	mm	26	25	19	16	14	13	
	%	53	53	46	43	48	57	50
1977/1978	mm	70	66	60	56	46	47	
	%	143	138	146	151	159	204	157
1976/1977	mm	82	92	78	64	50	34	
	%	167	192	190	173	172	148	174
Mean increment 'standard'	mm	49	48	41	37	29	23	

stationary, and observed differences in growth among localities were maintained throughout the period of study (Table 2.5.5).

There are considerable inter-seasonal differences in growth rate (Table'2.5.6), but growth rates have generally declined, commensurate with the increased intra-specific competition associated with expanding population. The abundance of Orange River labeo increased steadily until 1981 (Figure 2.4.1).

Orange River labeo are generally long-lived and commonly reach a size of 350-400 mm in the lake. Adult males suffer a higher rate of mortality than females, associated with smaller size at sexual maturity. Due to their temporary and unsheltered spawning habitat, there is an increased risk of stranding and predation at the time of spawning. In the lake there was a steady build-up of Orange River labeo until late summer 1981 whereafter there was a general decline (Figure 2.4.1). The increase in CPUE in 1978/79 was largely due to redistribution of the population caused by increase in turbidity and decreased food supply, while the reduction of CPUE in 1981/82 was due to increased turbidity at a time of high population density, leading to an acceleration in mortality rates (See Chapter 2.4).

2.5.4. Sharptooth catfish

The sharptooth catfish, Clarias gariepinus, is common in the warmer parts of Africa down to the Orange River, and is now translocated to the Fish River (Cambray and Jubb, 1977). It is the largest fish species in Lake le Roux with a modal size of 720 mm total length and maximum recorded length of 1185 mm.

This catfish breeds in spring or summer, usually associated with local rains. In Lake Sibaya, spawning took place at night in recently inundated areas (Bruton, 1979). The morphometry of the basin of Lake le Roux affords few ideal spawning habitats. Also, local runoff is insignificant in the water balance of Lake le Roux (Chapter 2.1.2), diminishing chances of rising lake levels at times of local floods. This makes for a.short lived spawning habitat and suitable nursery areas. Reproductive success is thus generally poor, resulting in the scarcity of smaller (younger) fish in the population and a large modal length.

In Lake le Roux, sharptooth catfish becomes sexually mature at about 820 mm TL for males and 740 mm for females. Each mature female spawns once during a season, with a 800 mm female shedding about 110000 eggs. The eggs hatch in about 24 hours at water temperatures of 19 - 24°C, when the larvae are about 4 mm (Bruton, 1979). In Lake le Roux, the smallest juveniles caught were 35 mm. Juveniles were occassionally caught throughout the lake but were most commonly found where the largest tributaries, i.e. the Berg, Hondeblaf and Seekoei Rivers, entered the lake among rocky substrates. .They were however nowhere abundant.

The sharptooth catfish is predominantly carnivorous, and becomes increasingly piscivorous with size. The change in diet is reflected in this growth which around 400 mm enters a second stanza that is a period of increasing growth, approaching a larger maximum length (Figure 2.5.3). This was particularly evident in 1978/79 when there was ample prey available during a mass mortality of smallmouth yellowfish (Chapter 2.5.1). Instead of the typical gradual reduction in length increments with size, increased growth was observed in fish larger than 360 mm (Figure 2.5.4).

High turbidity makes prey more vulnerable, since the catfish rely on their long sensory barbels for the locating of prey, but the prey is more dependent on sight to detect the predator. In spring and summer of 1980/81 when the yellowfish were in good condition and the water was relatively clear, sharptooth catfish suffered higher than average natural mortality and the dead bodies of large catfish were observed along the shores of the lake. This may be associated with successful predator avoidance by the prey in clearer water and the over expansion of the catfish population in the previous years when food was relatively abundant. The process described above is reflected in the catch statistics. MPUE was reduced from 18 kg in the 1978/79 and 1979/80 summers to approximately half that value in the following summers (Figure 2.4.2). Catch in numbers (CPUE) did not show the same distinct trend (Figure 2.4.1), and this is an indication that it was predominantly the large, piscivorous individuals which suffered from the changing conditions. Similarly, evidence of mass mortality of catfish was found during a survey of Lake Verwoerd in December 1980, when large numbers of Clarias skulls were observed along the shores.

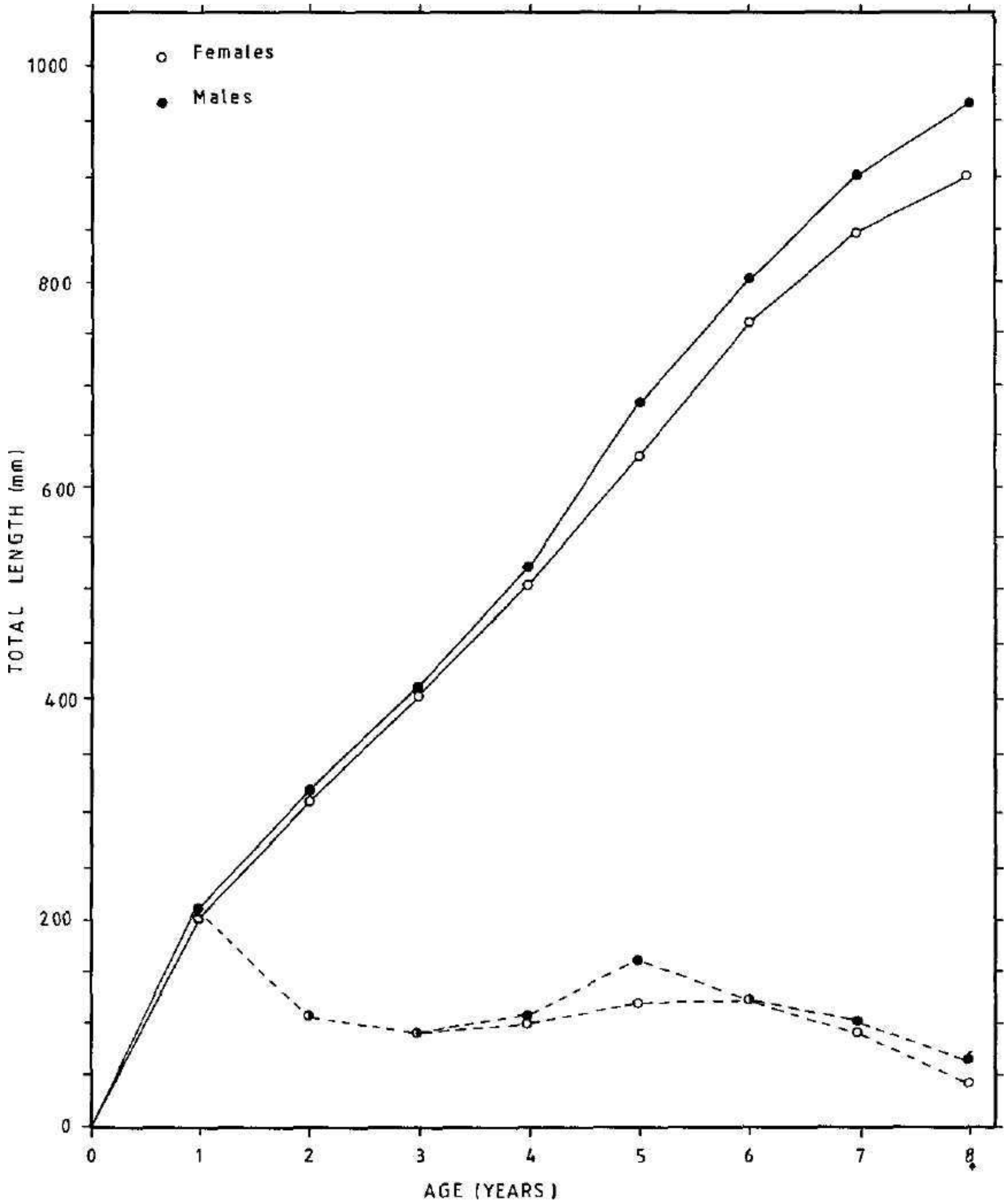


FIGURE 2.5.3. Growth in length of sharptooth catfish in Lake le Roux. Males : solid circles; females : open circles. Growth rates in solid lines; annual length increments in broken lines. (From Quick & Bruton, in press).

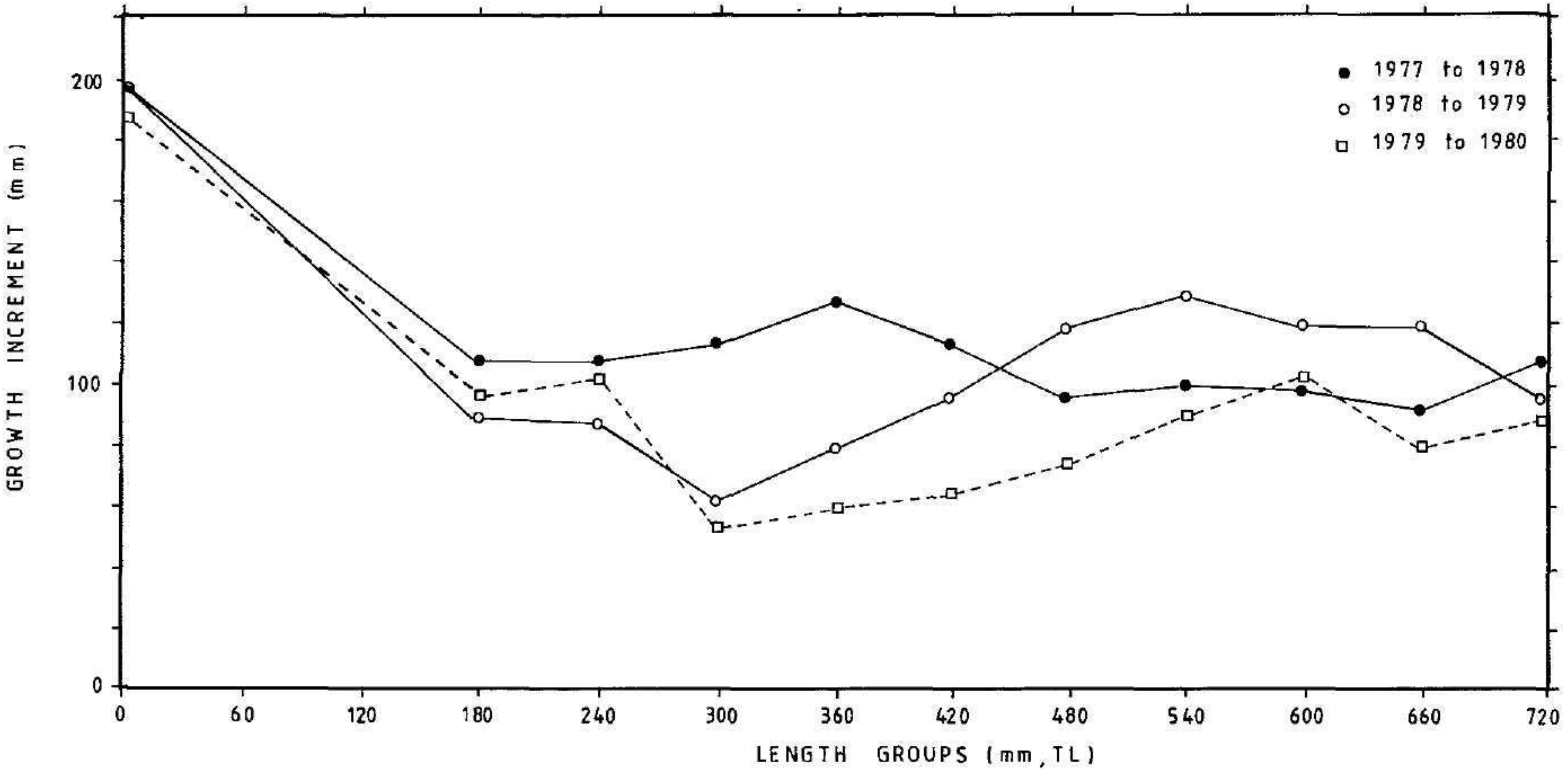


FIGURE 2.5.4. Annual length increments of different length groups of sharptooth catfish during the relatively clear 1977-78 and turbid 1978-79 and 1979-80 growing seasons (n = 468). (From Quick & Bruton, in press).

Chapter 3.

MANAGEMENT

3.1. EFFECTS OF HYDRAULIC MANIPULATIONS ON FISH STOCKS

T. Tomasson & B.R. Allanson

In common with most other large rivers in Africa, the Orange is seasonal in several key physical parameters, such as flow, temperature and turbidity. The fish fauna in the river is adapted to take advantage.of these seasonal changes. Thus in spring the fish generally spawn when the river is in flood, taking advantage of newly inundated river banks and floodplains, conditions which are favourable for the growth and survival of juveniles. In this section, we will summarize the effect impoundment has had on physical parameters in the river connecting Lake Verwoerd and Lake le Roux, and on conditions in Lake le Roux. We also look at the effect which changes in environmental conditions, brought about by impoundment, have had on key biological parameters, i.e. reproduction, including survival of eggs and larvae, dispersal, growth and mortality.

3.1.1. Changes in physical parameters caused by hydraulic manipulations

Temperature

Variations in water temperature are highly seasonal, although the impounding of Lake Verwoerd significantly changed the downstream temperature regime of the Orange River, as shown in Figure 3.1.1. Impoundment raised the winter minima hand lowered the summer maxima, but pronounced seasonal temperature variation was nevertheless maintained. The seasonal temperature range in Lake le Roux (Chapter 2.1) corresponds broadly to that in the inflowing Orange River.

Inter-.seasonal differences in the inflowing Orange River depend largely on rate of water release and lake height in Lake Verwoerd. As in Lake le Roux a thermocline is formed in Lake Verwoerd in early spring at a depth of 22 -25 metres (Stegmann, 1974). Most water from Lake Verwoerd is released through turbines, the intakes of which are cylindrical at a height above mean sea level of 1220.4 - 1227.7 m. Therefore, if lake levels in Lake Verwoerd drop below 1252 m m.a.s.l. in spring or summer, progressively more epilimnetic water will be released, presuming an epilimnetic layer of 25 m. This level is indicated by the line AB in Figure 3.1.2.

Changes in water temperatures in Lake le Roux are largely the result of local climatic conditions, but the upper and lower thermal extremes may be restricted by initial temperatures of water released from Lake Verwoerd.

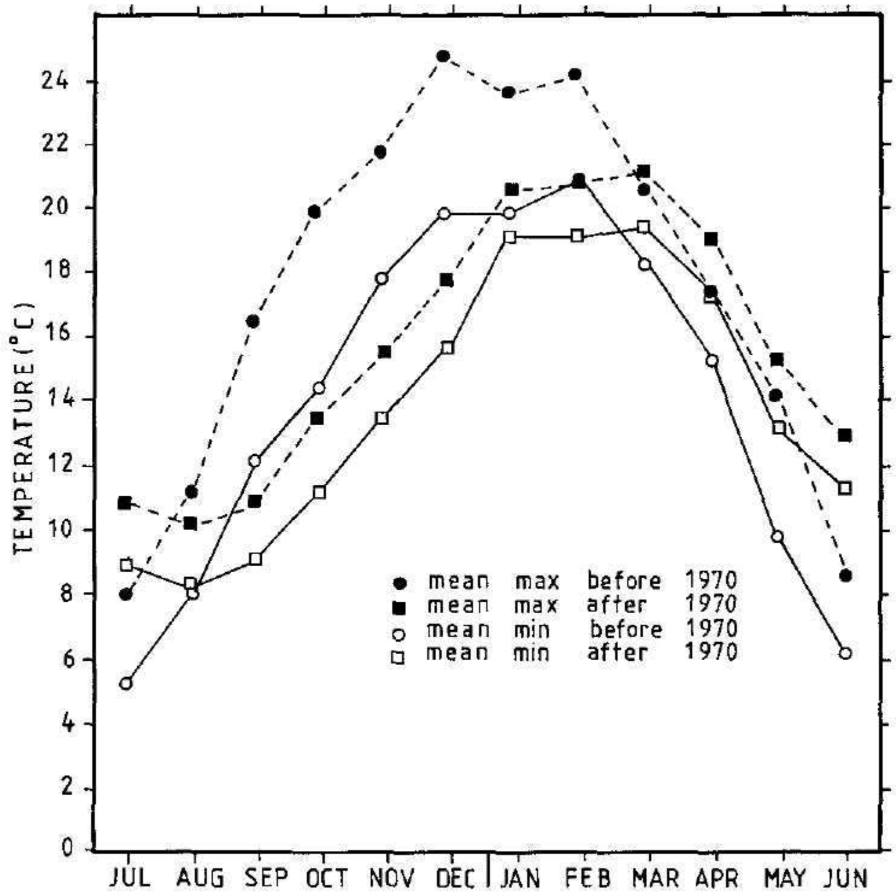


FIGURE 3.1.1 Average daily minimum and maximum temperatures in the Orange River before and after the erection of Verwoerd Dam. (Drawn from data by Pitchford and Visser, 1975).

The upper thermal extreme is further influenced by the high suspensoid load of the water, which attenuates and increases the dispersion of radiant energy in the water column. Thus the more turbid the water, the thinner the surface layer which is directly heated by the sun, and the relatively greater the heat loss will be at night. This is reflected in the relatively low heat content of the lake during the summers of 1978/79 and 1981/82, when the lake was particularly turbid (Chapter 2.1).

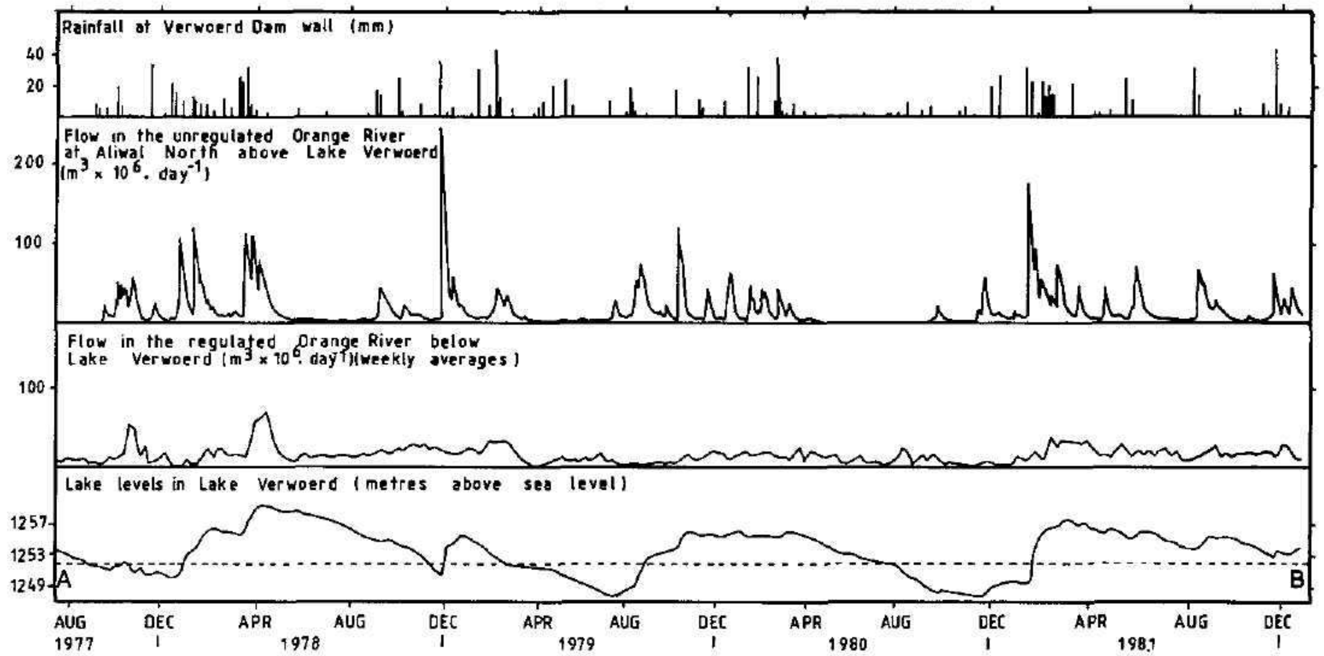


FIGURE 3.1.2. Daily variations in environmental variables in the Orange River system. (Based on data supplied by the Department of Environment Affairs, Pretoria).

Flow_and_water_level fluctuations

In the pristine river where the dams now are, flow and water height were markedly seasonal. In winter time, the river was often no more than a series of connected pools, while from September flow became more continuous, with occasional peaks until end of summer, as can be seen from the flow above the dams (Figure 3.1.2). In the regulated river, however, seasonal trends are absent (Figure 3.1.2), but flow fluctuates in pulses lasting from a few minutes to several hours, depending mainly upon automatically controlled releases by demand for power generation. Lake le Roux receives nearly 99% of its water from the impoundment upstream. Only 1,4% of its water comes from the local catchment. Lake level fluctuations are therefore almost entirely the- result of hydraulic manipulations and no consistent seasonal trend can be discerned (Figure 3.1.2).

Turbidity

The Orange River, carries heavy silt loads in summer, while in the dry seasons, winter, the suspensoid load is greatly reduced and the water increases in transparency. With the creation of Lake Verwoerd, these seasonal differences have largely disappeared downstream. A large, but variable, amount of silt is trapped in Lake Verwoerd. In spite of this, Lake le Roux is in general turbid, but its water becomes clearer along its hydraulic (long) axis. The difference in turbidity between top and bottom is largest at times when turbidity is increasing. Changes in turbidity occur chiefly during the summer months, but are not cyclical: there are large inter-seasonal variations (Figure 2.2.6). Marked "increases in turbidity are associated with falling levels in Lake Verwoerd. This leads to a short retention time in Lake Verwoerd, reducing the amount of silt trapped there, and the temperature of the inflowing Orange River water where it meets Lake le Roux is very near that of the lake's epilimnion. The silt-laden waters accordingly move down the lake as a surface flow, maintaining low transparencies during the important summer period of plant and animal production.

3.1.2 Effects of hydraulic manipulations on biological parameters

Reproduction, growth and mortality define the dynamics of a population in relation to its environment and accordingly determine how a population will react to exploitation. Reproductive adaptations are the major determinants of the success of a fish species under different environmental conditions (Balon, 1975). We have therefore chosen first to look at how hydraulic manipulations have affected reproduction before discussing dispersal, growth and mortality, which further influence the size of harvestable fish stocks.

Reproduction

The smallmouth and the largemouth yellowfish which previously spawned during the first floods after winter, now breed in the regulated Orange River. In the now almost continuously flowing river, time of spawning is determined by the temperature regime and is usually later than it would have been under natural conditions because of the reduced river temperatures which have been brought about by impoundment. As discussed above, the height of the water

TABLE 3.1. Estimated time of spawning of smallmouth yellowfish in Lake le Roux, in relation to pattern of water release and year class strength. (From Tomasson, 1983).

Season	Time of spawning	Characteristics of water released from Lake Verwoerd	Initial growth rate	Year class
1977/1978	Late October to early November	10-50 x $10^6 m^3$/day epilimnetic		strong
1978/1979	Early to mid-December	15-20 x $10^6 m^3$/day hypolimnetic		weak
1979/1980	Mid- to late November	5-20 x $10^6 m^3$/day hypolimnetic	0.33 mm/day	medium
1980/1981	Late October to early November	5-10 x $10^6 m^3$/day hypolimnetic	0.43 mm/day	strong
1981/1982	Late November	10-15 x $10^6 m^3$/day hypolimnetic	0.25 mm/day	medium-strong

level in Lake Verwoerd and rate of water release affect temperatures in the river below. This has led to annual differences in spawning time of smallmouth yellowfish as shown in Table 3.1. Low temperatures cause late spawning and generally poor initial growth rates, resulting in high mortality and consequently a poor year class. In Table 3.1, a "medium" year class is approximately 50 - 60% of the strength of a "strong" one, while a "weak" year-class is only about 10 - 20% that of a "strong" one. A preliminary analysis indicates that the 1981/82 year-class is probably medium/strong.

The largemouth yellowfish is adapted to higher temperatures than the smallmouth and usually spawns about four to six weeks later. The late spawning causes weak year-classes, and as a result in the lake, largemouth yellowfish is ten times rarer than the smallmouth. The two labeo species, Orange River labeo and moggel, depend on local flooding for spawning. In the riverine section, peaks in flood may be short-lived, leading to the stranding of eggs, larvae and even adult fish. Similarly, local floods in other parts of the lake are usually of short duration. Equally important though is that the peaks in flow in the riverine section or flooding of local tributaries does not necessarily coincide with a rise in lake level. In contrast to the yellowfish, the labeo species have small eggs and the larvae are dependent on external feeding soon after hatching. Newly inundated vegetation provide for good conditions for the initial rearing of juveniles (Jackson, 1960). Thus when the lake was filling, a strong year class of Orange River labeo was formed. In January to April of 1978 and 1981, lake levels rose by seven or eight metres (Figure 2.1.2) contributing to moderately strong year-classes of Orange River labeo. In 1978/79 and 1979/80 seasons, the lake level did not rise and these year-classes do not contribute significantly to the catch of this species.

Lake level fluctuations similarly would be expected to affect the reproductive success of the common carp and of the moggel greatly. However, the lake is steep-sided and the abundance of these two species is further restricted by limited extent of shallow feeding grounds preferred by the sub-adults.

Growth rates vary within the lake and fish distribution therefore has a pronounced effect on population growth. Growth rates of yellowfish show a marked decrease up the lake (Table 2.5.1) although in general there is a decrease in abundance as well (Figure 2.4.5). Figure 3.1.3 shows the relationship between Water transparency and growth rate and illustrates the overriding influence that water clarity has on growth. The yellowfish are visual feeders feeding on zooplankton, and an increase in turbidity reduces their efficiency in procuring food. The Orange River labeo appears to be largely dependent on feeding on "aufwuchs", i.e., benthic algae and associated fauna (Figure 2.4.7), so that decrease in transparency reduces primary production and consequently their food supply. The steepness of the shore limits the area of benthic algae production. As the photic zone is reduced by decrease in transparency, fluctuations in water level will bring about greater changes in food supply than when the water is clearer. This is particularly true for receding water levels, since at times of low water transparency a drop of 30 - 40 cm will reduce the lake level below the previous photic zone.

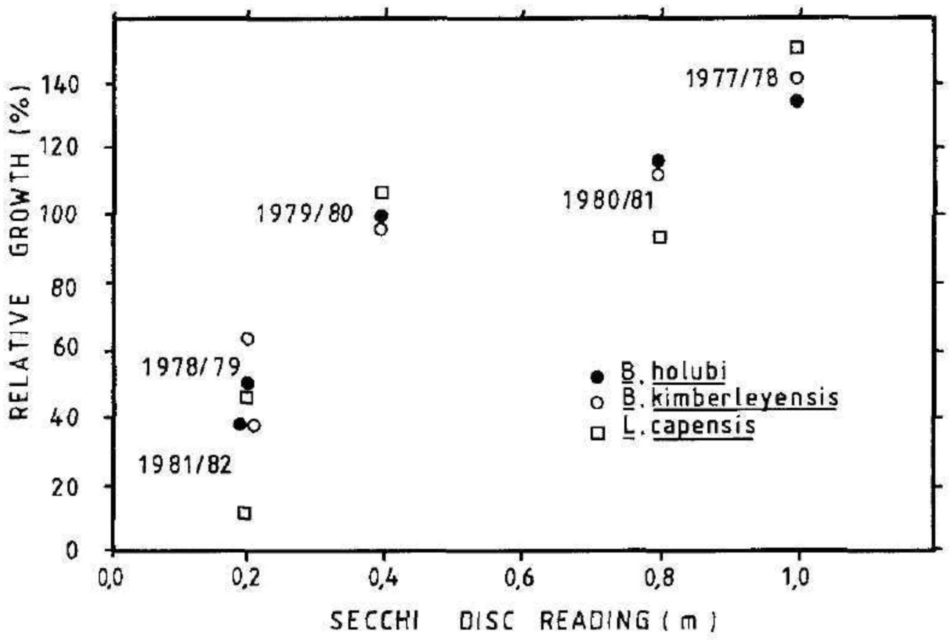


FIGURE 3.1.3. Growth of some large cyprinids in Lake le Roux from 1977 to 1982, in relation to water clarity at Station 1 in January. A season's growth is expressed as a percentage of average length increments in 1976 to 1982.

Yellowfish undertake long spawning migrations (Shortt-Smith, 1963) and their juveniles disperse well. Small yellowfish can disperse throughout this large lake within a single year (Chapter 2.5). The Orange River labeo does not have an extended spawning migration, and eggs and larvae are adapted to disperse with current so as not to become stranded. In a riverine environment, this method is effective for colonizing downstream areas, while in the lake this leads to relatively stationary sub-populations.

Because of the great mobility of yellowfish, their distribution in the lake is indicative of living conditions. They accumulate nearest the dam wall where the water is clearest. Here their growth rates are higher than further up the lake. In contrast, the labeo's are relatively sedentary and their distribution is more likely to reflect their breeding localities than conditions for growth. However, if conditions deteriorate to the point that the fish are losing weight, they will disperse. Thus sharp increases in turbidity leads to a dispersal of Orange River labeo in the lake while dispersal is otherwise restricted in the lotic environment as discussed in Chapter 2.4.4.

Mortality

In general, changes in food supply are primarily reflected in growth rate and maximum size attained in lacustrine fish. Thus the size distribution of these populations is indicative of living conditions. In contrast, changes in feeding conditions in running water usually occasion changes in mortality rate. If, however, the change in food supply is too great, i.e. it exceeds the adaptive range of a species, this general pattern does not hold. In Lake le Roux, natural mortality rate of smallmouth yellowfish was low except in 1978/79 and 1981/82. Both times this was due to a decrease in water transparency in late summer causing a food shortage, the effect of which was particularly felt the following spring when rising water temperatures led to increased metabolism. Insufficient food rations for most individuals then caused large scale mortalities which in the end more than compensated for the reduction in food supply improving the pro-rata level of food availability. In 1978/79 the population of yellowfish was reduced to a level four times lower than in 1981/82, while in 1978, the initial population was twice as large as in 1981 (Figure 3.1.4). Thus the reduction in population size appears to be inversely related to initial abundance.

The temporal pattern in population density of Orange River labeo was quite different from that of the smallmouth yellowfish. Prior to 1978, this labeo population was concentrated in the upper parts of the lake, while large areas further downstream, such as the Rolfontein basin (Zone 2) were sparsely populated. Therefore, dispersal lead to the exploitation of large new areas when food supply had been reduced and large scale mortality was averted.

In 1981 however, the Orange River labeo was abundant in all parts of the lake. Therefore the dispersal of individuals within the lake did not bring them into contact with fresh resources, and starvation ensued. This resulted in accelerated mortality, as indicated by the declining trend in catches of labeo from April 1981 to October 1982 (Figure 3.1.4). The rate of decline was not as abrupt as in the catches of the smallmouth yellowfish.

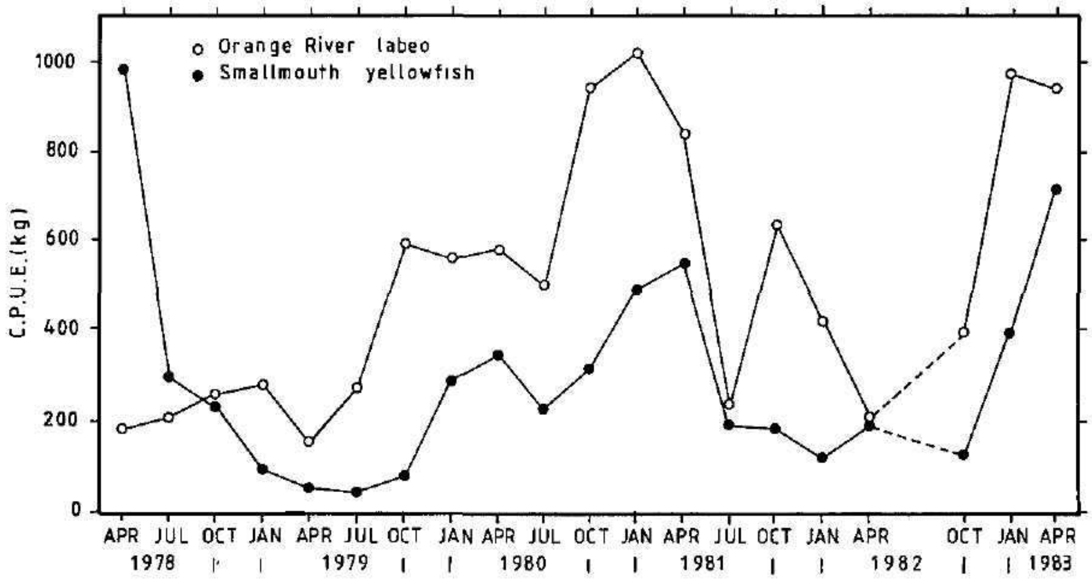


FIGURE 3.1.4. Temporal changes in catch per unit effort (CPUE) of smallmouth yellowfish and Orange River labeo in Lake le Roux. Unit effort represents the catch in 700 m of multifilament gillnets at 28 sites. Catches were adjusted for gillnet selectivity and reduced effort from April 1982. (Adapted from Tomasson, 1983).

There was about 60% reduction in catches of Orange River labeo from April 1981 to October 1982, while a similar reduction in catches of yellowfish occurred between April and July 1981. It therefore appears that adult Orange River labeo are better "buffered" against negative changes in the environment than the yellowfish.

3.1.3. Conclusion

Changes in the environment brought about by hydraulic manipulations greatly affect the fundamental biology in smallmouth yellowfish and Orange River labeo, the two dominant fish species in the lake. These are shown schematically in Figures 3.1.5 and 3.1.6. The sensitivity of the fish populations to man-induced environmental changes also suggests various ways in which a fishery should be managed to optimize yields. This will be dealt with in a later section.

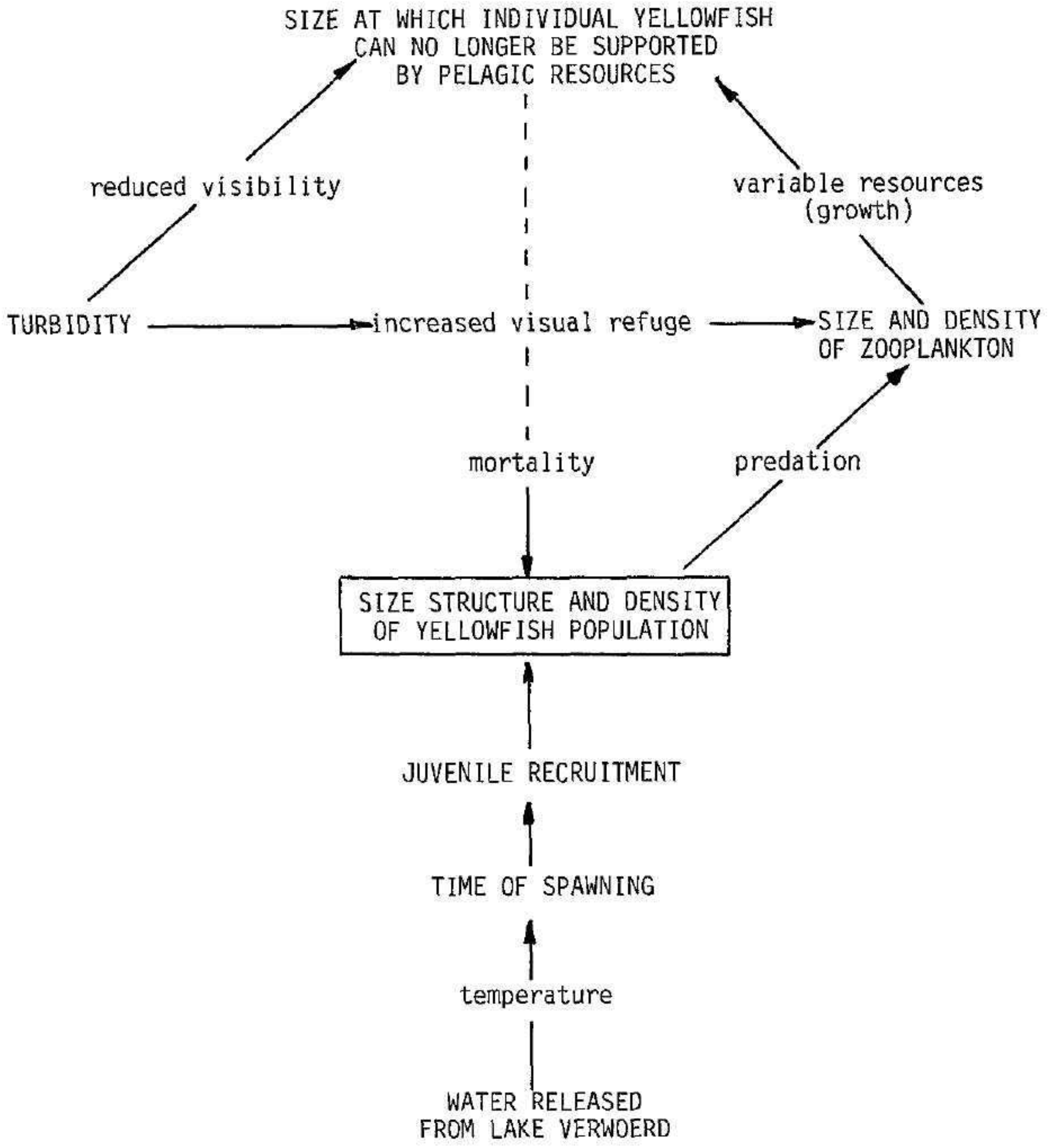


FIGURE 3.1.5 Major functions affecting size and structure of the smallmouth yellowfish population in Lake le Roux. (From Tomasson, 1983).

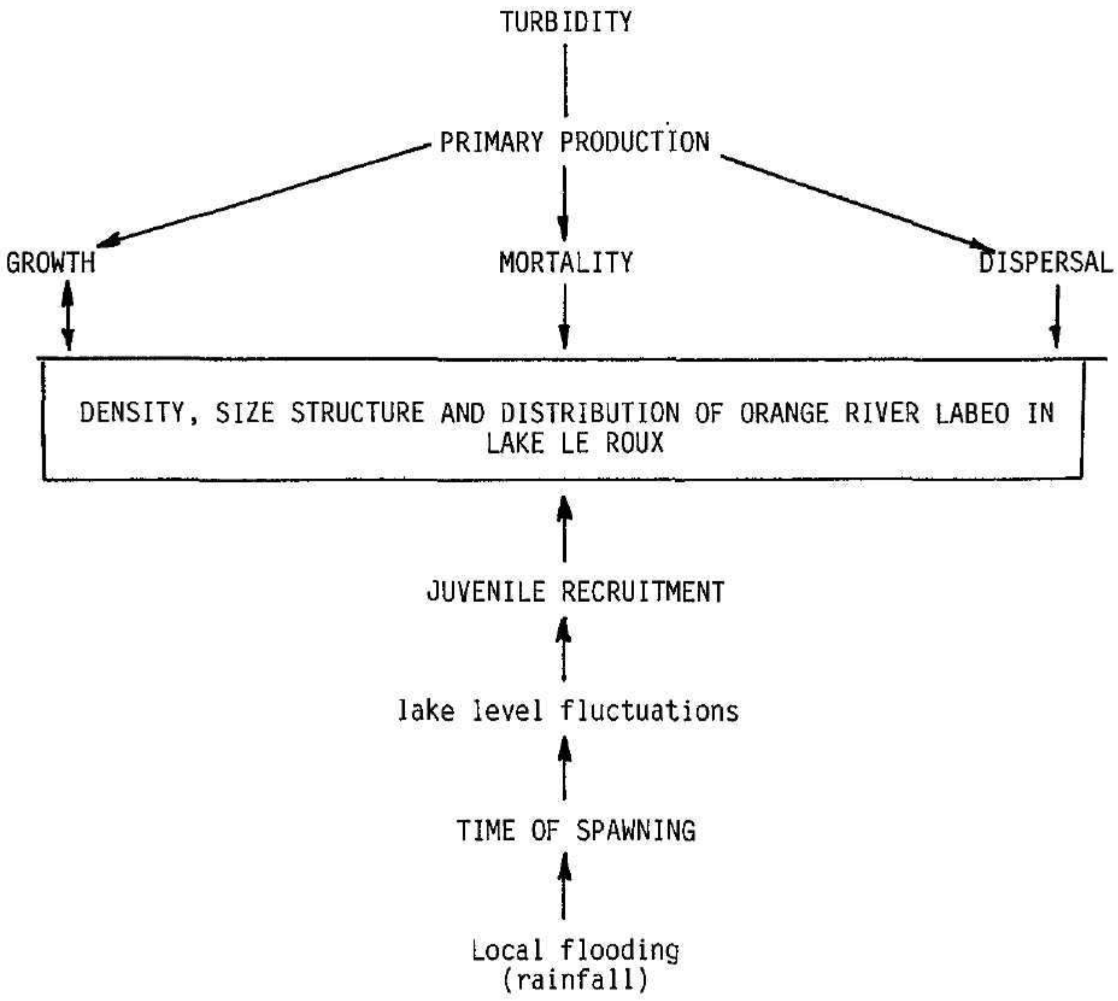


FIGURE 3.1.6 Major factors affecting size structure, density and distribution of Orange River labeo within Lake le Roux. (Adapted from Tomasson, 1983).

3.2. THE CHOICE AND EFFICIENCY OF FISHING GEAR

P.B.N. Jackson, D.H. Eccles & K.C.D. Hamman.

3.2.1. Introduction

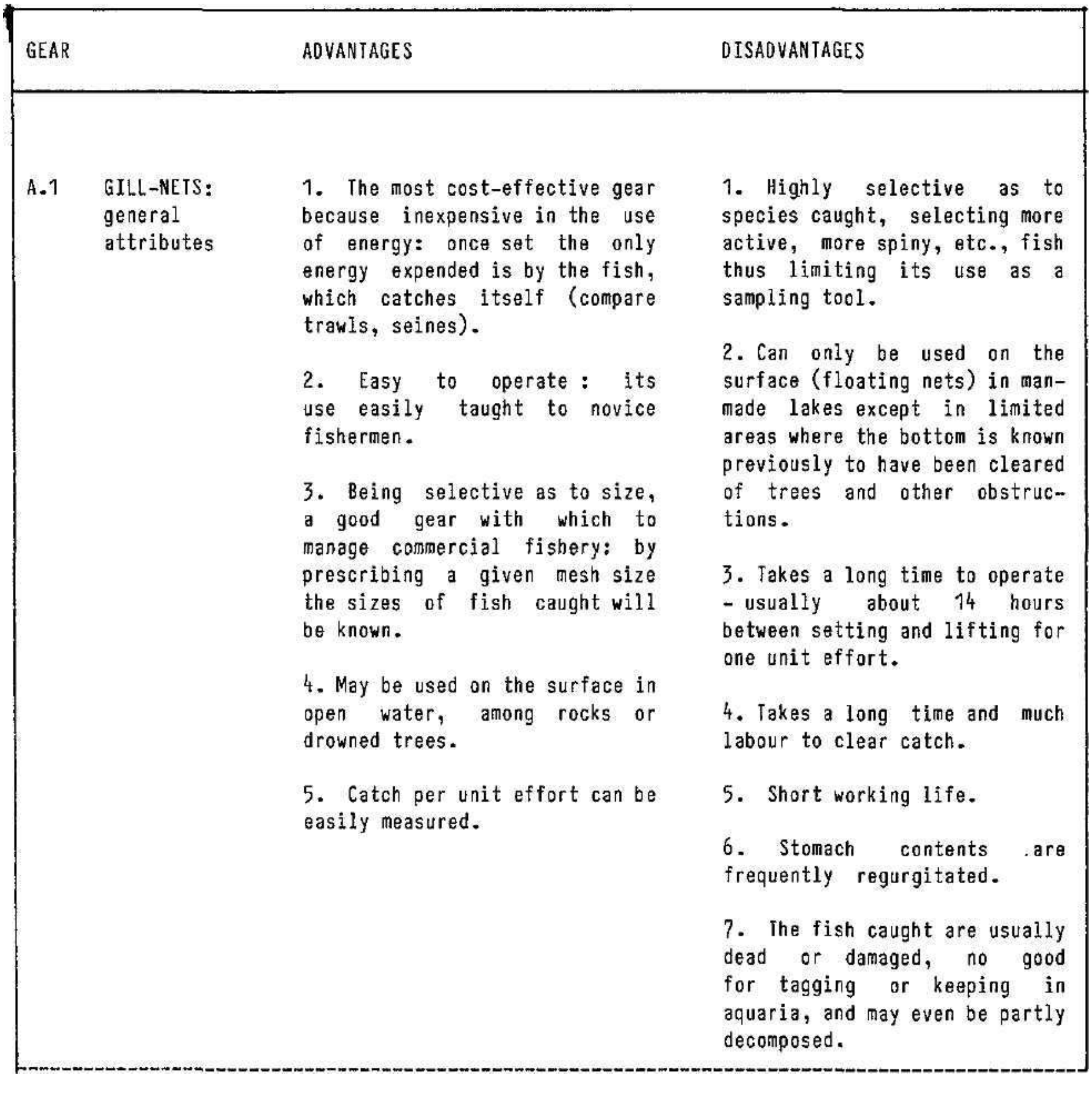
One of the team's specific mandates was to evaluate various types of fishing gear with a view to to assessing their efficiency for both commercial and scientific sampling purposes. Of those employed, the open-water trawl and purse seine, neither previously used in South African freshwater, proved effective in establishing, also for the first time, the penetration into open water of several species, especially the smallmouth yellowfish during its subadult, plankton-feeding stage. Monofilament gillnets were also extensively used for the first time.

No one item of fishing gear is ideal and universally applicable for all purposes. Gears differ in their effectiveness for capturing various species and sizes of fish. Fish are large elusive animals, and are frequently aware that they are being pursued, so make efforts to escape by swimming round or jumping over a net. To capture sufficient for either sampling or commercial purposes therefore usually involves the expenditure of a great deal of time and effort. In this way fish differ from small planktonic animals such as copepods and cladocera of which sufficient, once the initial infrastructure of nets and boat is available, may quickly be caught for adequate analysis. In addition the choice of fishing gear will depend considerably on the purpose for which the fish are required. For a commercial fishery the most cost-effective gear for the taking of the desired species in the required size-range will usually be chosen, while for stock assessment and other scientific research representative samples of all size-groups of the species in all habitats will be needed. This requires the use of several different types of fishing gear, and a detailed knowledge of the selective properties of each.

3.2.2.. A comparison of fishing gear used in the survey

Table 3.2.1 sets out the advantages and disadvantages of various types of gear, as experience has indicated them particularly in the context of the Lake le Roux.

TABLE 3.2.1. Fishing gear used in Lake le Roux and advantages and disadvantages of each.z



GEAR		ADVANTAGES	DISADVANTAGES
A.1	GILL-NETS: general attributes	1. The most cost-effective gear because inexpensive in the use of energy: once set the only energy expended is by the fish, which catches itself (compare trawls, seines). 2. Easy to operate : its use easily taught to novice fishermen. 3. Being selective as to size, a good gear with which to manage commercial fishery: by prescribing a given mesh size the sizes of fish caught will be known. 4. May be used on the surface in open water, among rocks or drowned trees. 5. Catch per unit effort can be easily measured.	1. Highly selective as to species caught, selecting more active, more spiny, etc., fish thus limiting its use as a sampling tool. 2. Can only be used on the surface (floating nets) in man-made lakes except in limited areas where the bottom is known previously to have been cleared of trees and other obstructions. 3. Takes a long time to operate - usually about 14 hours between setting and lifting for one unit effort. 4. Takes a long time and much labour to clear catch. 5. Short working life. 6. Stomach contents are frequently regurgitated. 7. The fish caught are usually dead or damaged, no good for tagging or keeping in aquaria, and may even be partly decomposed.

A.1.1 Multifilament gill-net.	1. Relatively cheap to purchase. 2. Easy to make up.	1. Easily torn: mending is a laborious and never-ending job for many personnel.
A.1.2 Monofilament gill-net.	1. Catches fish even more readily than multifilament. 2. In the smaller mesh sizes catches more small fish than multifilament.	1. Expensive to buy. 2. Does not fold up as readily as other nets, therefore much more bulky to stow in a boat and catches on protuberances more readily. 3. Very easily torn and very difficult to mend. 4. Very short working life.
A.2 Set lines or trot-lines (long lines with series of many hooks).	1. Relatively cheap. 2. Easy to make up. 3. Easy to operate. 4. Easy to quantify catches. 5. Fish usually alive.	1. Only effective against fish which will take a bait such as catfish and carp. 2. Bait must be bought or provided. 3. Takes a long time to operate - usually overnight.
B. MOVING GEAR	1. Unlike gill-nets which are highly selective and have a bell-shaped selection curve (Figure 3.2.2) limiting the net's catch to one part of the population, moving gear has a one-sided curve, enabling the fishery to select all fish above a given size.	1. Gear is usually fairly elaborate and expensive to operate.

B.1	Beach seine	1. Where conditions suitable will, if large enough, take a very good sample of fish present, down to the limit of the smallest mesh size. 2. Takes a sample relatively quickly. 3. Small two-man seines useful for sampling juvenile fish, small minnows, etc. 4. Captures fish alive and unharmed, useful if fish needed for tagging, keeping in aquaria, or accurate examination of stomach contents.	1. Expensive to purchase, needs professional skill in making up large nets. 2. Can only be used on a substrate and onto a beach. 3. Substrate must be clear of rocks, drowned trees, vegetation. 4. To sample completely all fish present in the seined area, must be of large size but with the centre portion of small mesh, needing a large labour force to pull it. 5. Like all moving gear is expensive to operate because energy is constantly required to catch fish. 6. Catch per unit effort difficult to quantify due to varying length of haul etc.
B.2	Purse seine or ring net	1. Properly handled will take an almost complete sample, i.e., remove nearly all the fish in the area fished, down to the limit of smallest mesh size. 2. Just as effective in open water, against vertical cliffs or steep banks, etc. 3. An effective year in Lake le Roux because the turbidity makes it invisible to the fish. 4. Takes a sample quickly. 5. Delivers the fish alive and unharmed to the operator. 6. Catch per unit of effort can be easily measured.	1. Expensive and fairly difficult to make. 2. Somewhat difficult to operate until experience is gained. 3. Expensive to operate needing a good deal of hard work or a large labour force. 4. After the net has been 'pursed' i.e., the drawline has pulled all the bottom rings together, it is difficult to pull the rings equidistantly apart along the rope again without going ashore. 5. Often time-consuming to get good results because operation is largely at random: it is impossible to locate shoals or concentrate fish under a light.

B.3	Open-water trawl.	1. Relatively inexpensive to construct. 2. Surface water sampling possible anywhere in the dam. 3. Sample can be taken quickly, 10 - 15 minutes to cover one nautical mile depending on speed of tow. 4. Takes fish down to limits of mesh size. 5. Delivers fish alive to the operator.	1. Very expensive to operate, needing boat with 2 outboards of 35 hp or more to tow. 2. Probably biased in that larger fish (Ca 20 cm FL) can often avoid it due to small size and low towing speed. 3. Samples top 1 m of water only.
B.4	Electrofisher with hand-held anode.	1. Works well on any kind of substrate. 2. Works well in water of the conductivity of Lake le Roux. 3. Works well in water of the high turbidity of Lake le Roux since fish cannot see the anode. 4. Collects very good non-selective samples of cyprinid and cichlid fish. 5. Collects a sample quickly. 6. Needs a team of 2 only though a third is desirable.	1. Very expensive in initial purchase, and costly in petrol to operate. 2. Limited, or at least best suited, to shoreline or shallow water (wader depth) sampling. 3. Sampling probably biased as catching siluroid fishes (catfishes) less frequently. 4. Captures probably only a small sample of the fish in an area. 5. Can be dangerous if not carefully used.
B.5	Electrofisher with anode on trawl towed behind a boat.	None.	1. Caught no more fish than trawl without electrofisher. Use discontinued.

3.2.3. Gill-nets

The advantages that gill-nets have over all other gears, particularly those of cheapness and ease of operation, may readily be seen from Table 3.2.1. As is usual in African freshwater fishery surveys, therefore, most of the fishery information in this work on Lake le Roux was obtained with the aid of gill-nets. Multifilament nets were operated by the Cape Department of Nature and Environmental Conservation (CDNEC) and the Institute of Freshwater Studies while monofilament nets were used by the J.L.B. Smith Institute of Ichthyology (R.U.S.I) and Institute for Freshwater Studies (I.F.W.S).

Extensive sampling was done quarterly by CDNEC from April 1978, using a fleet of seven floating multifilament nylon gill-nets (Table 3.2.2), set at 28 sites (Figure 3.2.1) over a period of 14 days. They were usually set between 15h00 and 17h00 always parallel to the shore and taken up the following morning usually 07h00 - 09h00. In all cases nets were made up locally by C.P.A. fishermen using net blanks (unmounted webbing) imported from Taiwan and hung by the half (i.e. a length of webbing 100 m long was mounted on ropes 50 m in length). Sufficient floats were added to allow the net to float at the surface in view of the high probability that nets set on the bottom would catch on snags. Different twine thicknesses and colours were used from April 1980 (Table 3.2.2). In April 1982 C.P.A. discontinued sampling at eleven sites and three new ones were added (Figure 3.2.1).

TABLE 3.2.2. Specification of gillnets used by CNDEC during quarterly surveys on Lake le Roux.

Mesh size (mm stretched mesh)	Black nets April 1978-January 1980		Brown nets April 1980-October 1982	
	Depth (m)	Twine thickness (denier)	Depth (m)	Twine thickness (denier)
35	2.50	210/9	2.22	210/4
45	2.49	"	2.20	"
57	2.46	"	2.19	210/6
73	2.46	"	2.22	"
93	2.46	"	2.23	210/9
118	2.46	"	2.17	"
150	2.52	"	2.16	"

Gill-nets are normally highly selective in the size of fish they catch. Since fish are usually held at certain parts of their bodies, a net will select those individuals whose circumferences at those points is close to that of the meshes. In fishes such as catfishes, carp, etc., possessing spines, serrations, prominent teeth, etc., this selectivity is less marked since such fish are often tangled. In Lake le Roux this usually occurs with the catfish and the carp. Relatively few of these, however, were caught in the gill-nets since most are bottom-dwelling, thus avoiding the surface-set gillnets. The big yellowfish and labeo which at once formed the bulk of the catch and represented the greatest commercial potential are relatively less spiny and, being fusiform in shape, are most often caught by wedging. Selectivity curves for these are therefore likely to be fairly accurate, and are given in Figure 3.2.2 for nets of 35, 45, 57, 73, 93, 118 and 150 mm stretched mesh.

The relative abundance of the various species caught in the multifilament gillnets at the different stations and their fluctuations throughout the period are discussed in Chapter 2.4. Complete specifications of all multifilament gill-nets used by CDNEC are given in Table 3.2.2.

Monofilament nets

Because of the fine twine with which they are made, monofilament nets are far more efficient in the capture especially of small and young fish than are multifilament. The facility with which a fish gets wedged in a gillnet is generally a result of its momentum which is in turn the product of the velocity and mass of the fish. As both these parameters are progressively reduced with decreasing size of fish, it follows that momentum is reduced until a size is reached where a fish is too small to gill itself at all and must be captured with moving gear or by electrofishing. However, this size is significantly smaller with a monofilament rather than a multifilament net. Therefore, while the minimum size of multifilament net used was 35 mm stretched mesh, monofilament nets of 20 mm and 24 mm were consistently used with success. It is possible that the highly turbid conditions result in generally slower swimming, which would intensify the above considerations.

The monofilament nets used in this study were imported from Messrs Netzweberei Rudolf Vogt, Itzehoe, West Germany. They were initially factory made in one piece, i.e., with a polythene float line (head rope) and weighted perlon lead line (foot rope) ready incorporated on to the netting. Later, replacement netting was hung on the original line by project fishermen. They varied from 20 to 110 mm stretched mesh with twine thickness of 0.15 - 0.25 mm. These were sinking nets, 1.5 m deep, 30 m long, green in colour, and were fished systematically close to the shore in shallow water 1 - 3 m deep. Figure 3.2.3 shows high catches obtained in small mesh sizes.

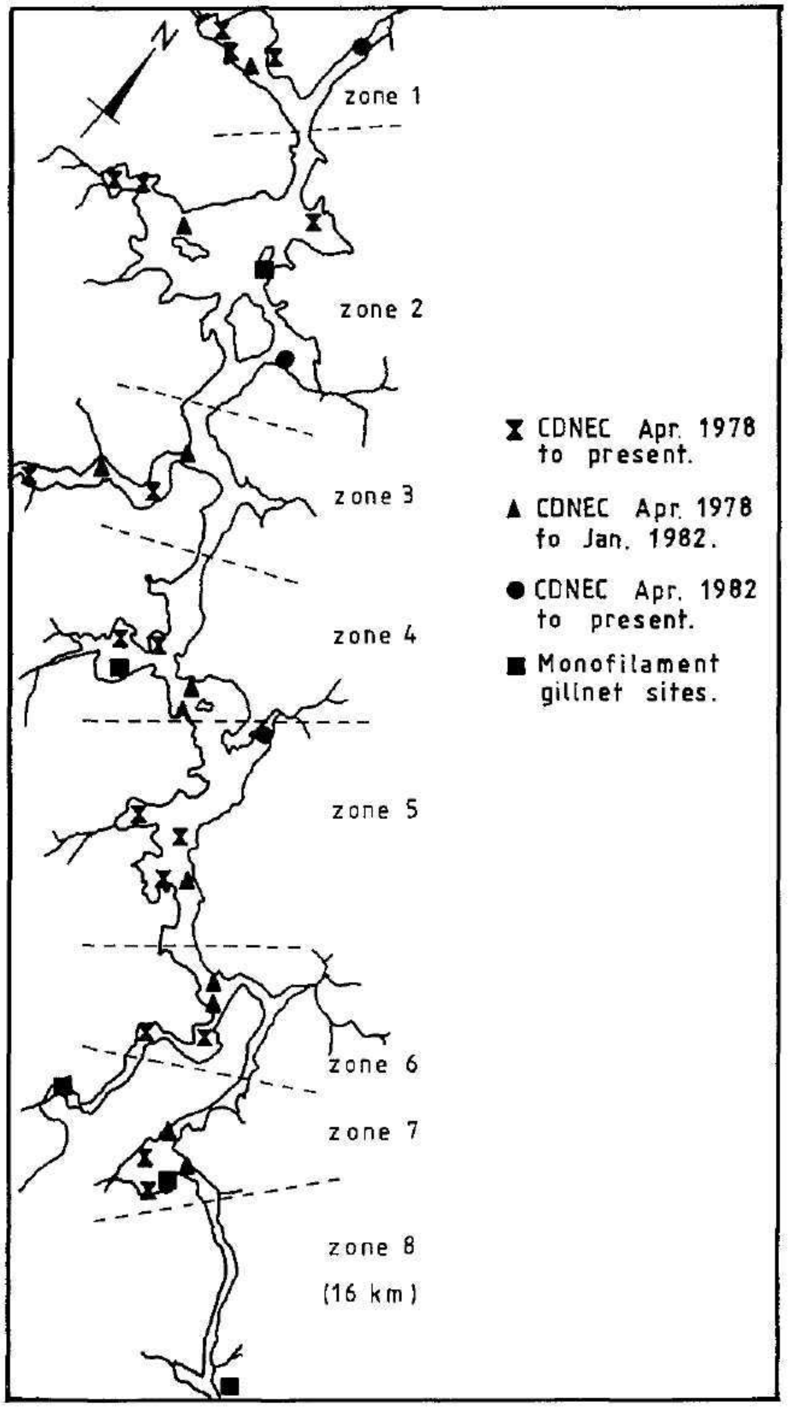


FIGURE 3.2.1. Gillnet sites in Lake le Roux and the division of the lake into zones. (Tomasson, 1983).

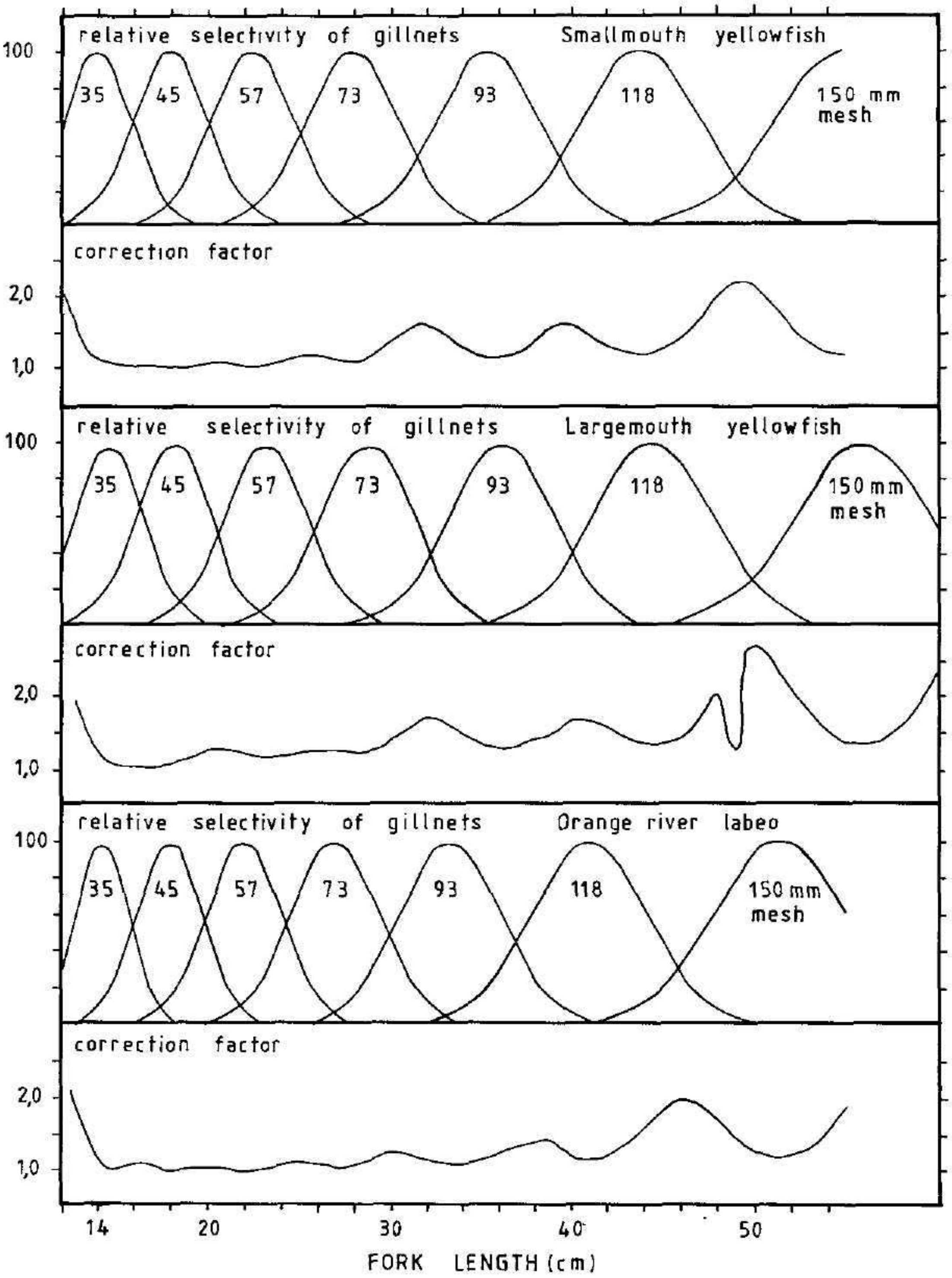


FIGURE 3.2.2. Relative selectivity of CNDEC gillnets of different mesh sizes for different length fish, and the correction factor used to adjust catches of different size groups to actual relative abundance. (From Tomasson, 1983).

FIGURE 3.2.3. A large catch, mainly 2+ Orange River labeo, from shallow water of the Seekoei flooded river tributary, in the 30 mm monofilament gillnet. (Photograph: R.E. Stobbs).

3.2.4. Beach seine nets

After some trial and error the use of large seine nets, needing to be set in a wide sweep at a distance from the shore and then pulled in, was abandoned. The main reason was the very few areas in the dam with a substrate smooth enough to allow the pulling of such gear. A large labour force was necessary and much damage to the gear caused by snagging on drowned trees or rocks, or picking up loose stones. This also biassed samples by causing the escape of fish.

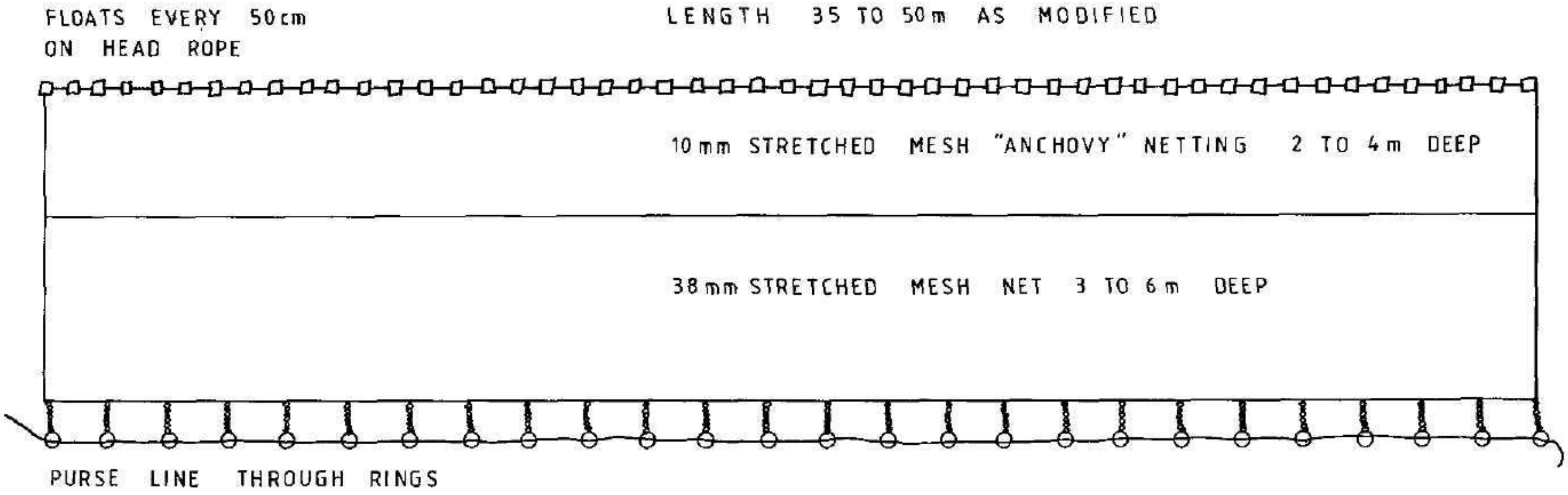


FIGURE 3.2.4. Diagram of the purse seine net used during the survey.

Small two-man beach seines proved, however, to be extremely useful for the sampling of small fish, particularly the chubbyhead minnow, as well as juveniles of larger species.

Since 1978 CDNEC has conducted a quarterly 3 day survey of the juveniles and small fish populations along the shores of the lake. Depending on lake levels, 30 - 40 sites were sampled covering a variety of habitats. The main gear used was a beach seine net made out of monofilament shade cloth with a stretched mesh size not exceeding 2 mm. A small (30 m) seine net made of 'anchovy mesh[1], a braided webbing of 10 mm stretched mesh size, was also used during the survey, though the smaller juveniles are not retained by a net of this size. (Cambray, 1982).

3.2.5. Purse seine nets

The ability to take quick samples of the fish population in open water or where a rugged environment prevents the use of a conventional beach seine is very useful in man-made lake situations. For this reason a small purse seine was constructed, its design based on one used by the International Biological Programme on Lake George, Uganda (Gwahaba, 1978). This is the first time that such a purse seine has been used in South African freshwater, though purse seines have for many years been used for commercial and research purposes on the African Great Lakes and Kariba.

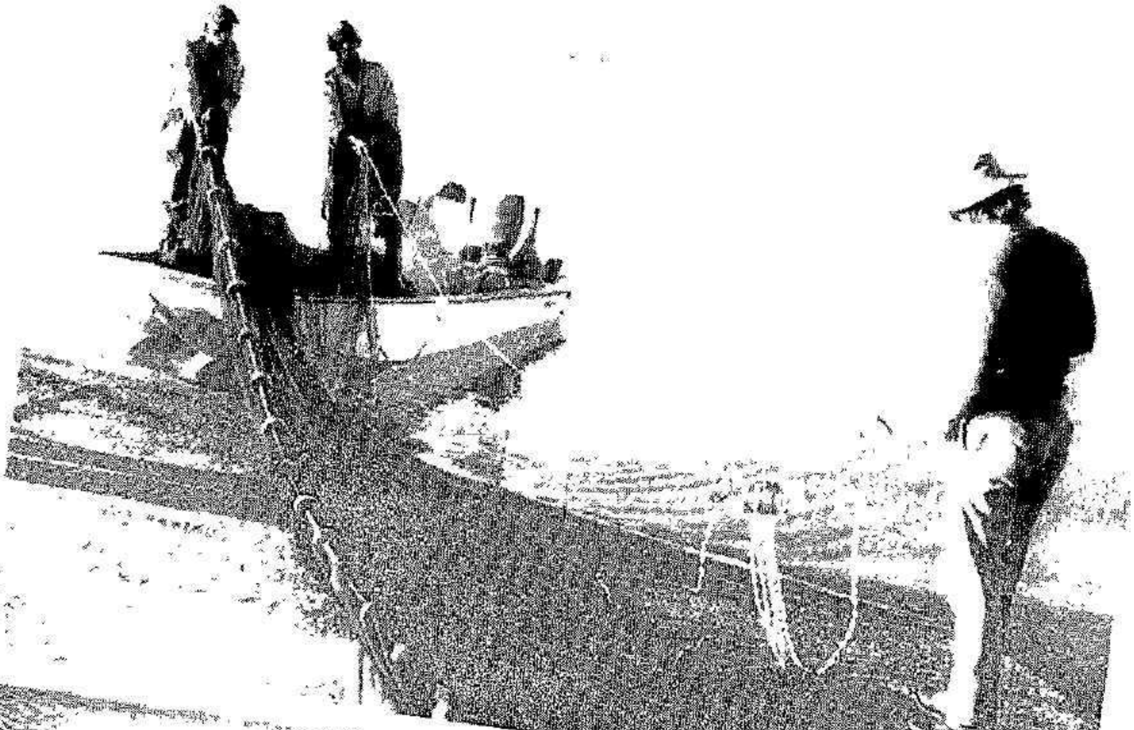
This net is illustrated in Figure 3.2.4. As originally designed, it was 34 m in length with an upper netting strip of braided net of 10 mm stretched mesh and 2 metres deep, and a lower strip of knotted net of 38 mm stretched mesh, and 3 metres deep. Both were hung to about 80% on head and foot ropes.

Plastic floats of 90 mm x 45 mm were mounted on the head rope at every 50 cm, while 4.8 mm chains, 50 cm in length and with a 15 cm diameter ring of 4.8 mm building rods were specified for the other end.

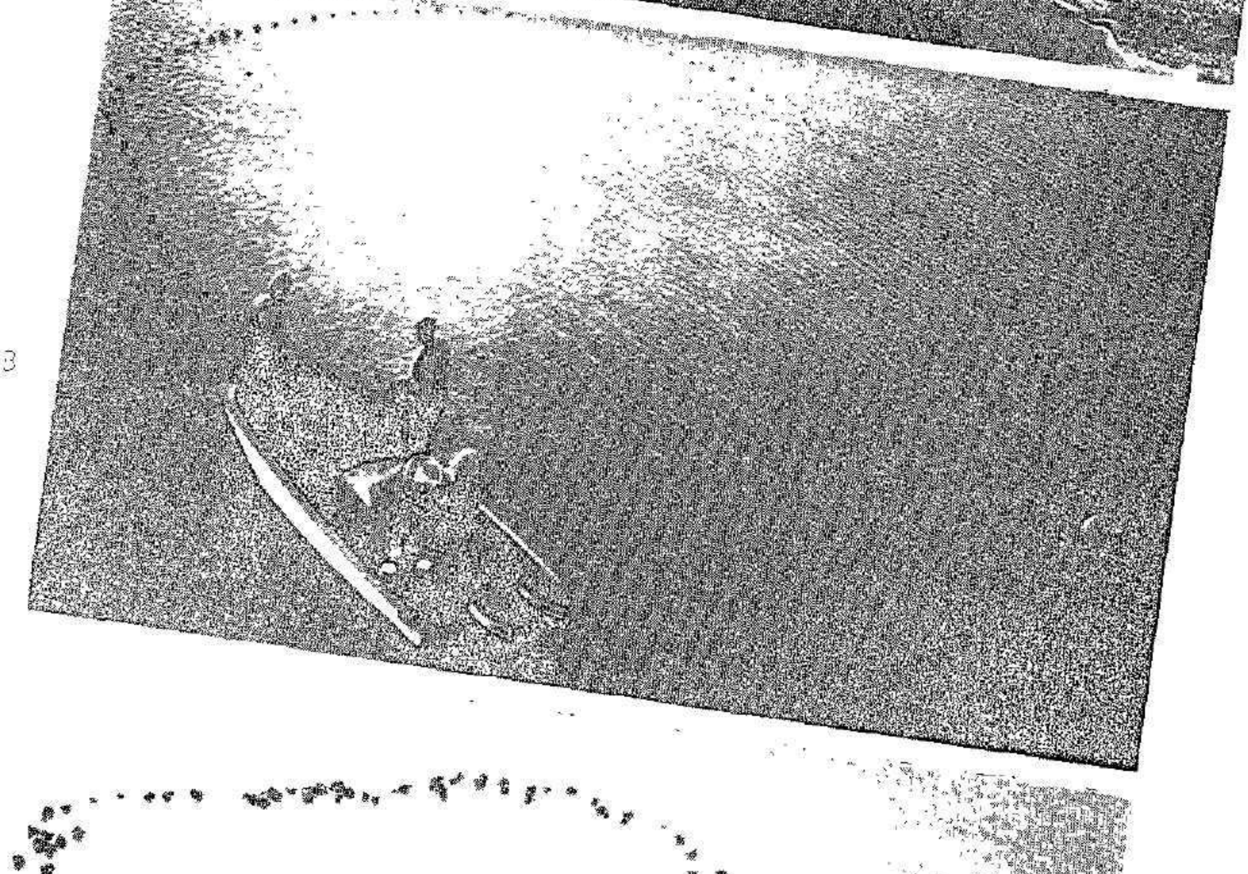
Purse seines belong to the class of 'surround' nets set in a circle (Figure 3.2.5 A,B), the bottom being after setting, 'pursed' by the rings being brought together by a rope passed through them. As later modified the purse seine was lengthened to 50 m, giving a circle of some 16 m in diameter, and the chains reduced in length to avoid tangling. In use, after pursing the ropes, chains and bottom large mesh section of net were brought onto the fishing boat first, so that the encircled fish were left in the upper, small-mesh, net section. In this way catfish of 85 cm and chubbyhead minnows of 4 cm or less may be caught in the same haul. Figure 3.2.5 E,F illustrates this non-selective sampling attribute of the purse seine.

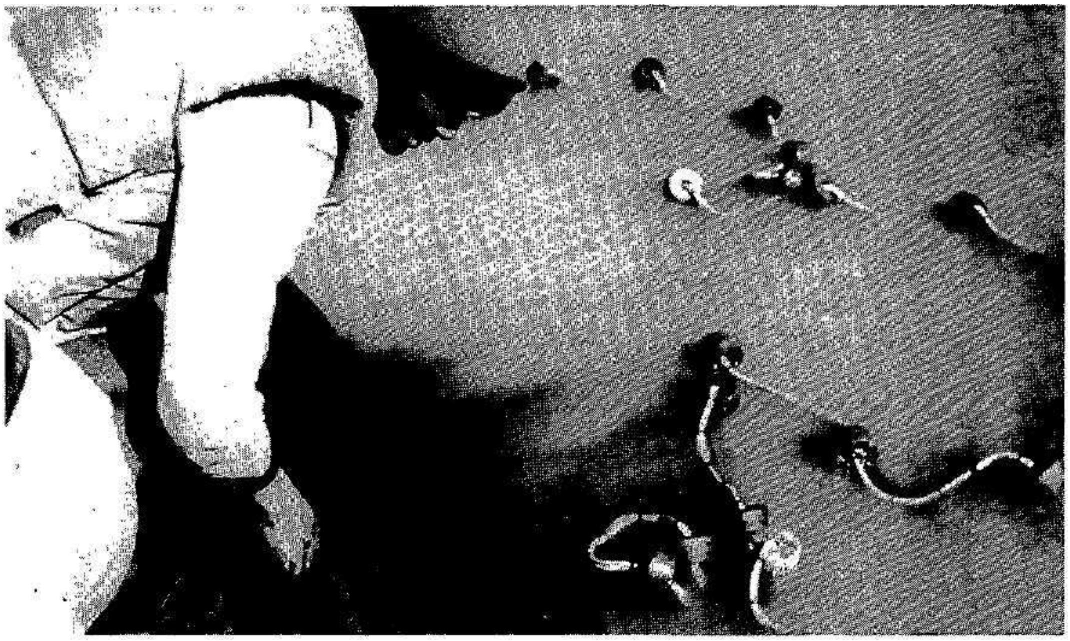
FIGURE 3.2.5. Sequences in a purse-seine operation on Lake le Roux. A : Stacking the net on the boat. Note purse line and rings equally spaced along it, on right. B : The net is set in a circle.
C : The net is 'pursed' by pulling the rings together, then hauled from the bottom, rings first.
(Photographs: R.E.Stobbs). (next page)

A



B






40 EV

FIGURE 3.2.5. Sequences in a purse-seine operation on Lake le Roux.
D : The fish concentrated in the upper small-mesh net, and floats.
E and F : Larger and smaller fish *are* removed and counted. (Photographs: R.E.Stobbs).

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In another modification of its use the purse seine was extensively used in open water by Mr D. Eccles of I.F.W.S. in order to take yellowfish from the pelagic zone for feeding studies. Here effective results were obtained by towing the net for a distance in the manner of a lampara or trawl before bringing the ends together and pursing the net.

Among other new information gained the purse seine proved the existence of the chubbyhead minnow in open and deep water, away from the shore, for the first time.

3.2.6. Open water trawl

The experience gained from preliminary work with gillnets, electrofisher and purse seine indicated the importance of the open water to certain species and the need for a relatively rapid method of assessing abundance in pelagic areas. To this end a frame trawl for towing in open water was constructed, modified from a design used on large freshwaters in America.

The gear is illustrated in Figure 3.2.6. It consists essentially of a rectangular wooden frame, the leading edge of each side rounded and the trailing edge tapered so as to give a hydrofoil shape, 260 cm in length and 100 cm in depth. A net of several mesh sizes, the final being braided webbing of 10 mm stretched mesh, is attached.

Such a net lends itself well to a quantitative sampling of fish distribution in an impoundment, such that geographical locations can be accurately known, at each location, or 'station' a constant effort can be applied and catch in each case accurately measured. Figure 3.2.7 illustrates the various stations on Lake le Roux which were thus quantitatively samples in the fish distribution study. At each station the net was towed such that its upper edge was fishing just below the surface, so that at all times the upper 1 metre of the dam's surface was fished (Figure 3.2.6 b). The gear was towed for 1 nautical mile at a constant speed of 4.5 knots, so that a

FIGURE 3.2.6. Open water frame trawl.
A : View of trawl and bridles. Note chains in foreground to adjust bridle lengths. B : The net towed at the surface behind two 40 hp outboard motors.
C : Catches in open water consist mainly of 2-3 year old smallmouth yellowfish.

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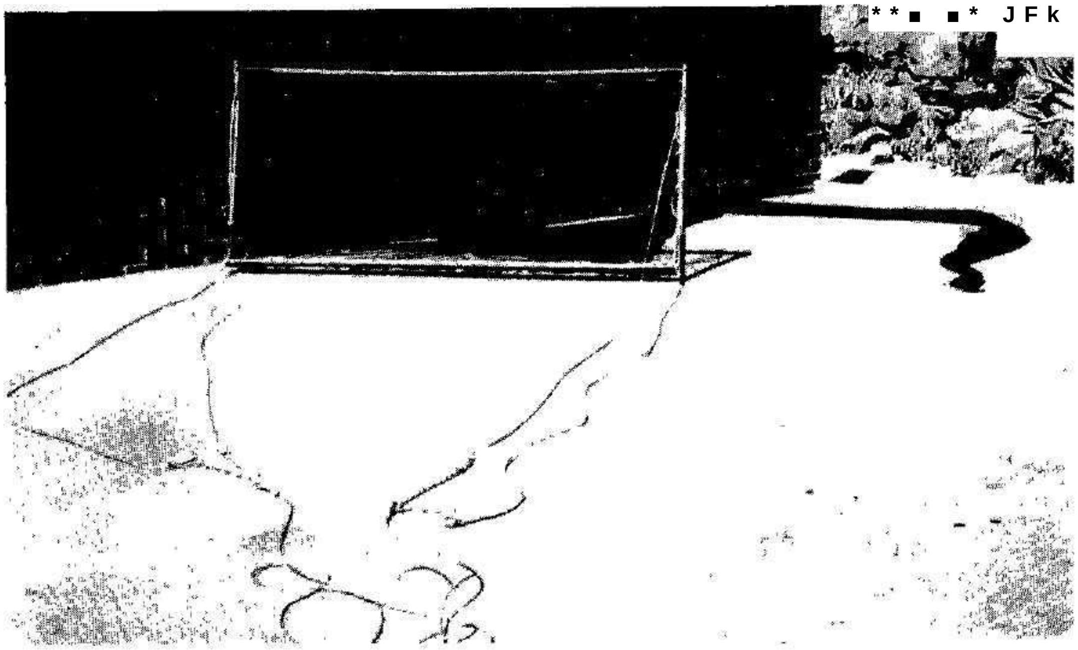

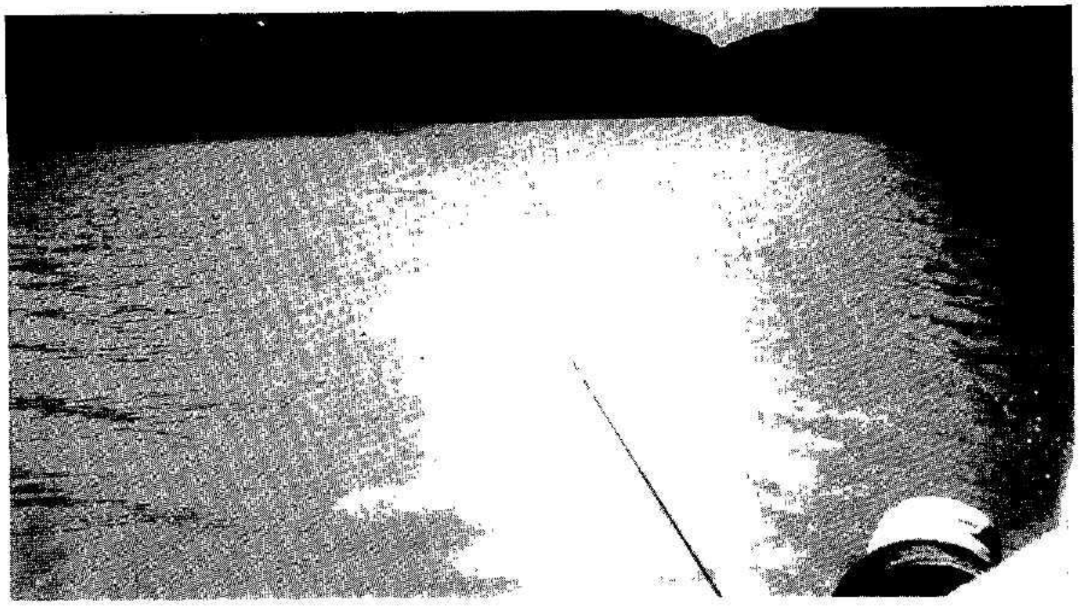

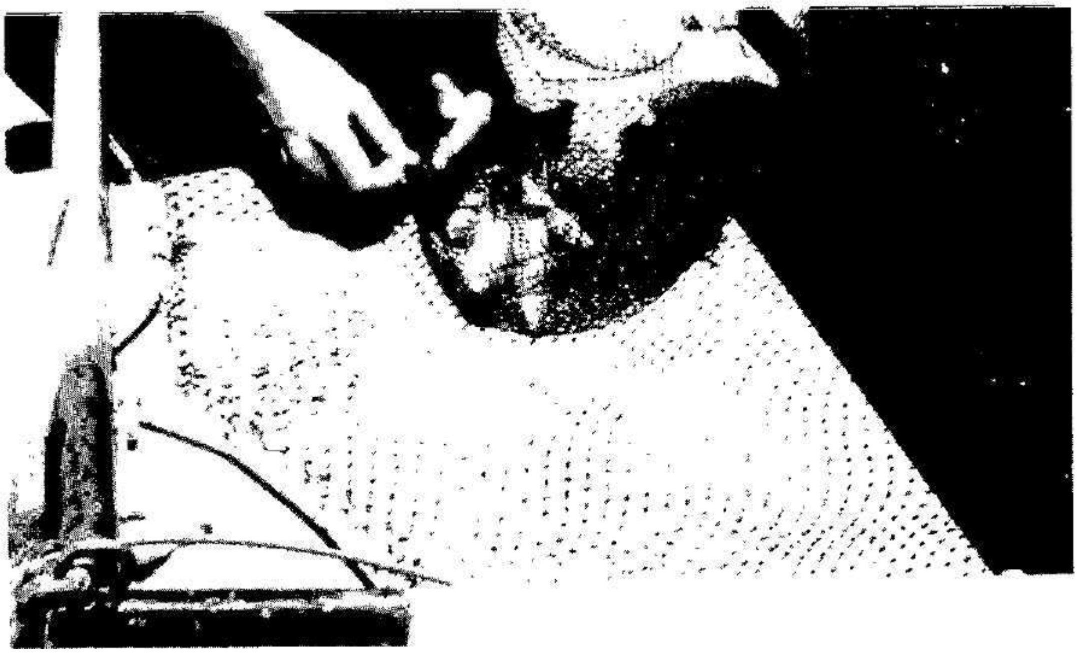

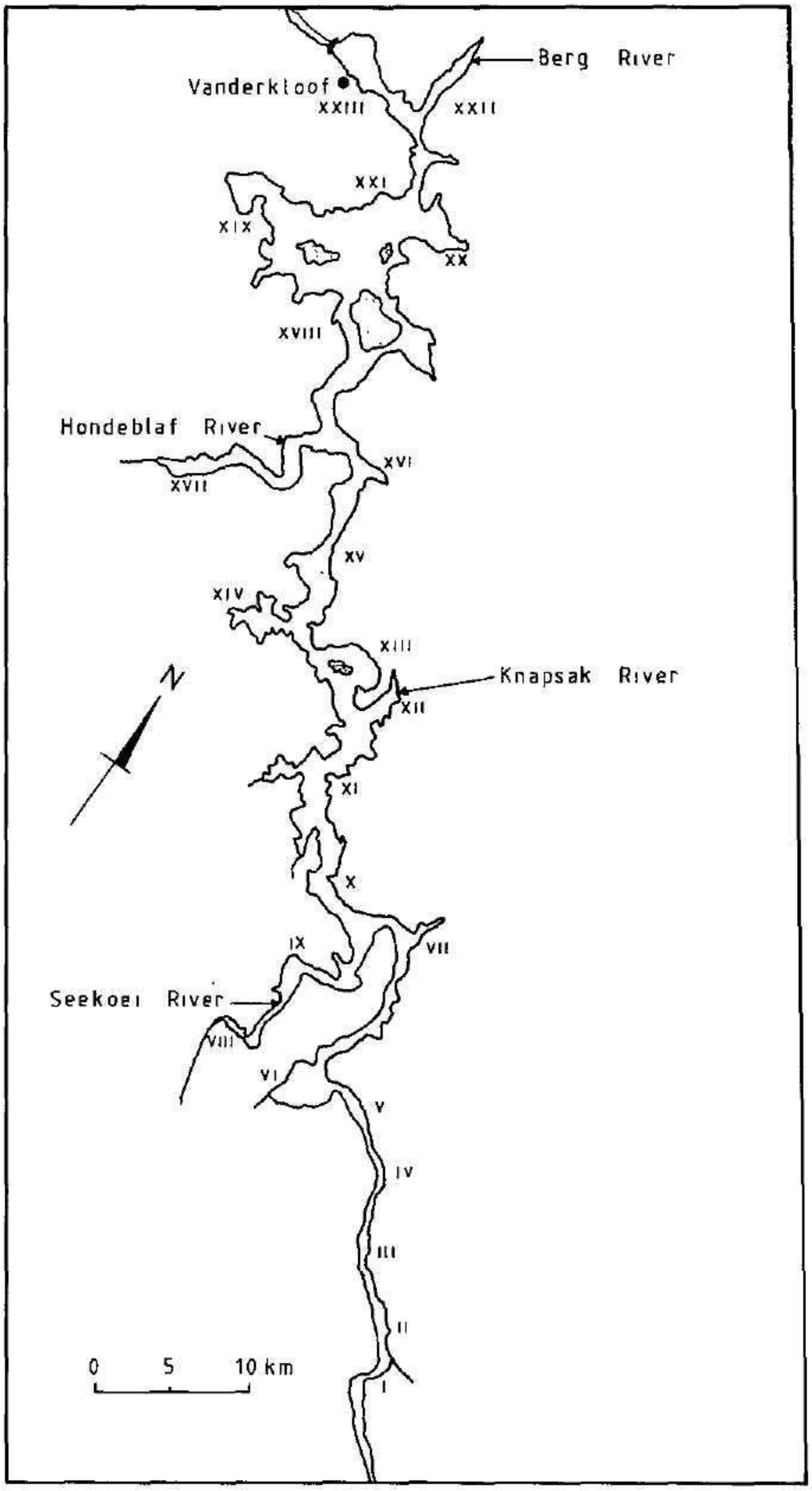

FIGURE 3.2.7. Map of Lake le Roux indicating open-water trawling stations (Table 2.4.2). Stations numbered in roman numerals to avoid confusion with gill-netting stations and limnological zones.

standard fishing effort was maintained at all stations. Table 2.4.2 shows the catch and species composition at each station from which it may be seen that no part of the lake is devoid of fish, the greatest abundance occuring in the flooded valleys. However, the generally low catches call for a much higher effort to map accurately the distribution and abundance of fish in the pelagic zone. While a constant unit effort was maintained, sampling bias may occur by larger fish being able to avoid the gear.

3.2.7. Electrofishing

Though the disadvantages listed in Table 3.2.1 impose severe limitations in the use of the electrofisher, this gear proved invaluable in the preliminary stages of the work in assessing fish distribution and abundance. Little or nothing was initially known of the habitat preferences and relative abundances of the different species on the various types of shorline. Without the electrofisher, such information would have taken far longer to acquire.

The electrofisher used was the 'Heron' model of Messrs Mecanique Electronique de Montfermeil, giving either a pulsed or a direct current of up to 3 KVA, 3 phase 4.3 amps, 50Hz. The voltage output is adjustable in five steps, and power is provided by a 4.5hp generator.

The anode (catching pole) is hand-held, mounted as a 60 cm diameter hand-net with 60 m of cable. The electrofisher, with the operator in waders, operated very well in the shallow waters of the dam to about 1.25 m regardless of any submerged trees or rocks (Figure 3.2.7). Ionic concentration (conductivity) is well within the optimal range for the apparatus. However the highly turbid water has both advantages and disadvantages. The pulsed current induces fish to swim into the net when within 1 to 1.5 m from it. At about 0.5 m fish are made rigidly immobile when the current is switched on and, in the still water of a dam, then sink (usually) or float. So in these turbid waters the net can be brought within these ranges without the fish seeing it, while the operator cannot see the fish, so cannot in any way select the fish caught. He often finds later that fish, frequently of large size, have swum into his net without his being aware of it. Conversely he cannot recover those immobilized fish that have sunk deeper than about 20 cm, only those at the surface being visible. It resembles a game of blind man's buff, and is a highly stochastic sampling situation. However only such random sampling is possible. A complete capture of all fish in an area is not possible. Figure 2.4.10 illustrates the length frequencies of carp caught with the electrofisher.

3.2.8. Long-lining

Together with the quarterly programme of multifilament gillnetting referred to above, sets of longlines were made at the same stations. These were made up with 25 hooks, Mustad No 6/0, per line, each on a gangline of 1 m and mounted 1.5 m apart. Lines were buoyed with floats so as to float at the surface. Thus the hooks, which were mainly baited with fishheads, were approximately 1 m down in the water. This was a depth similar to that of the gill-nets, the bottoms of which were 1.5 - 2 m below the surface. Fishing period was similar, 14 - 16 hours per set.

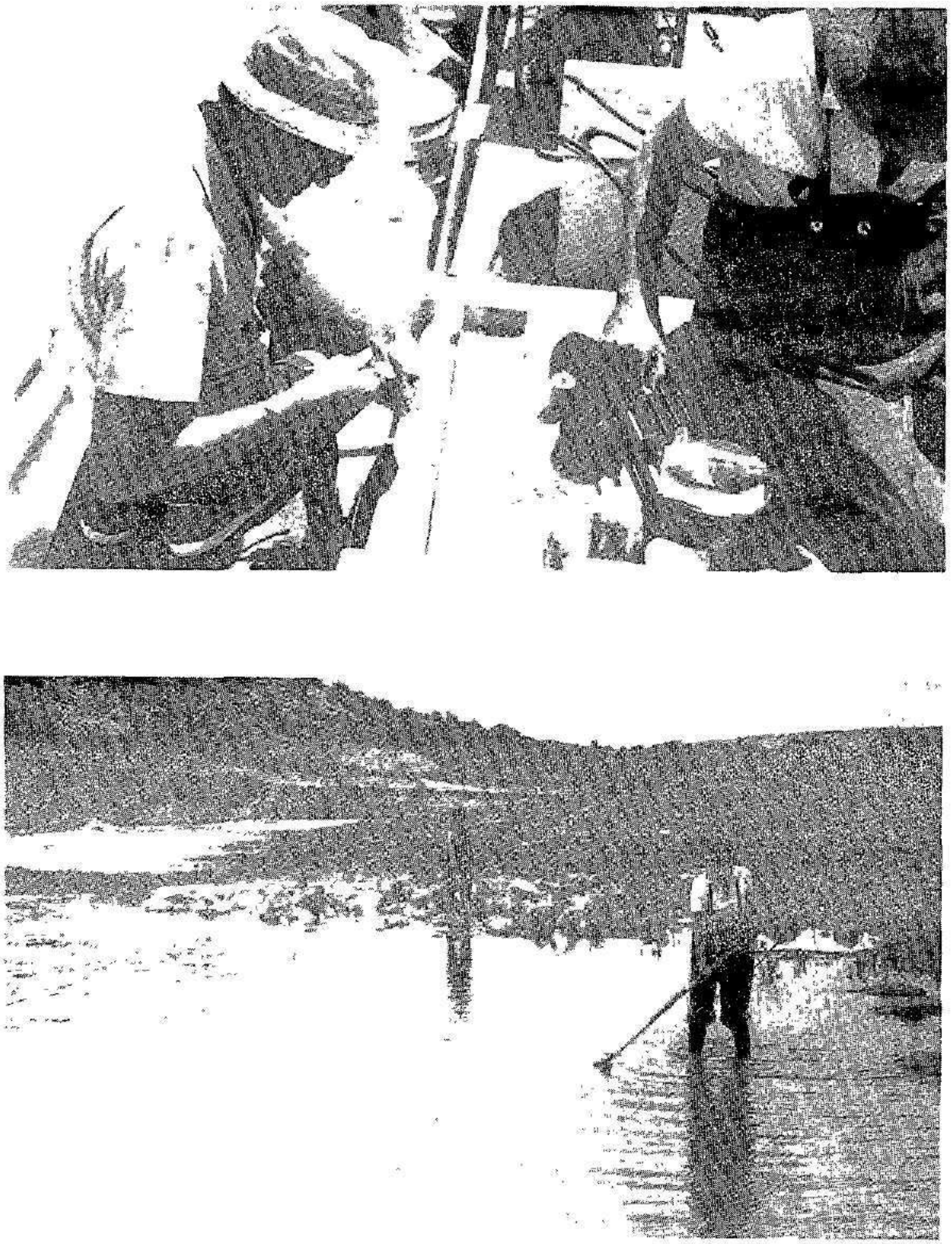

FIGURE 3.2.8 Electrofishing. A : Weighing, measuring and tagging living carp caught by electrofishing. B : The electrofisher being used in typical 'carp water[1] in a flooded valley, calm and shallow with muddy and rocky bottom suitable for invertebrate production. (Photographs: P.B.N.Jackson).

As may be seen from Table 3.2.4 and Figure 3.2.8, catches were good, even allowing for the selective nature of the fishing, and compared favourably with the gill-net catches. Table 2.4.4 indicated the selectivity of the longlines as compared to that of the gill-nets (multifilament), from which it can be seen that the modal size if the line-caught catfish exceeded that selected by the largest-meshed gillnets in use. From this data it may be deduced that the longline is an effective method of fishing for barbel in Lake le Roux. Virtually no fish other than catfish (C.gariepinus) were taken by longline.

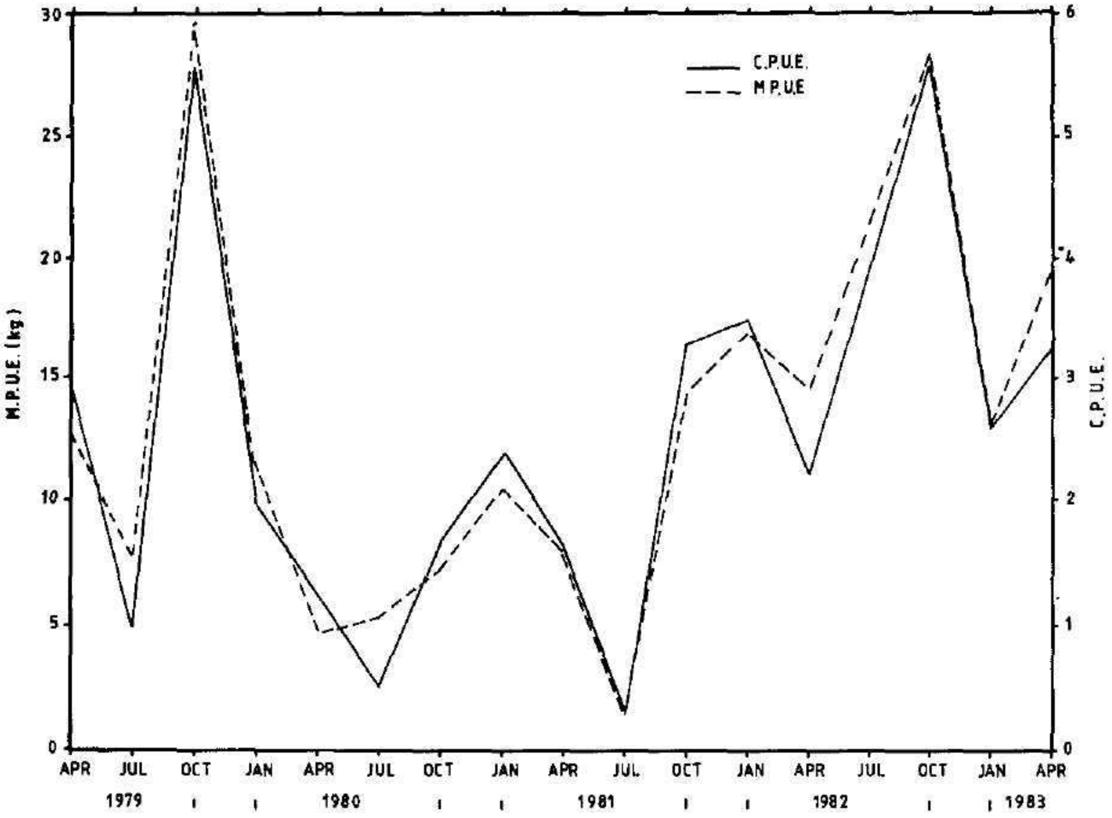

FIGURE 3.2.9. Average overnight catch and mass data for sharptooth catfish with a 25-hook baited long-line of hook size Mustad 6/0 at 28 stations in Lake le Roux for the period April 1979 to April 1983.

TABLE 3.2.3. Sharptooth catfish catch statistics as collected with baited longlines (25 hooks) at 28 stations in Lake le Roux for the period April 1979 - January 1982.

	Total catch	% females	Total mass (kg)	Average catch per line	Average mass per fish (g)
Apr.1979	84	40.5	-	3.0	-
Jul.1979	29	51.7	-	1.0	-
Oct.1979	158	44.8	-	5.6	-
Jan.1980	56	41.1	-	2.0	-
Apr.1980	34	32.4	132.5	1.2	3 898
Jul.1980	14	35.7	147.1	0.5	10 505
Oct.1980	47	36.2	204.8	1.7	4 357
Jan.1981	68	42.6	294.9	2.4	4 336
Apr.1981	46	28.3	218.2	1.6	4 744
Jul.1981	7	28.6	37.9	0.25	5 409
Oct.1981	92	44.6	401.0	3.3	4 358
Jan.1982	98	37.8	476.5	3.5	4 852

3.3. FISHERIES OF LAKE LE ROUX

T. Tomasson, J.A. Cambray, D.H. Eccles, P.B.N. Jackson & P.N. White.

3.3.1. Introduction

The potential of a fishery is defined by two limitations, biological and economic. Total yield and production varies depending on the desired quality of the catch (size of individual fish and species composition) which can be selected for by applying different management strategies. Economic considerations usually dictate which combination of yield and quality is chosen. Thus the expense of capturing the fish, unit price of the catch and yield determine the feasibility of different types of fisheries. However, social considerations may at times outweigh economic ones. In this chapter we discuss the biological factors contributing to the fishery potential; socio-economic considerations are treated in Chapter 3.4.

The commencement of a new fishery is analagous to starting a new business. In both cases, capital expenditure is necessary before profits appear. There is an element of uncertainty to begin with. Before embarking on the venture the businessman assesses this risk in broard terms. Later, when experience is gained, the Managing Director can report to his Board with a much more precise estimate of profits and management needs. Similarly the starting of the new fishery is based upon approximate appraisals from which the risk can be judged. Gulland (1974) gave details and pointed out- the need for accuracy and precision increasing as the fishery develops. As he puts it (Gulland 1969 p.99): "In an undeveloped fishery all that is generally required is a rough measure, say within a factor of two or three, of the magnitude of the resource and the potential yield from it... Later, better eestimates will be required."

Preliminary appraisals are used here since the lack of commercial fisheries precluded more precise estimates. These *err* on the conservative side but even so amply justify a commerciasl fishery. Bruwer and Claasens (1978) estimate 430 tons based on the morpho-edaphic index of the lake. This, though probably largely correct in the relative assessment of yield compared with other dams, had no correction factor for turbidity so was perhaps on the high side. But an arbitrary figure of 50% of this corresponds closely to the rule-of-thumb estimate of 1000 kg per annum per kilometre of lake shore used by Jackson (1977). The figures are 215 and 192 tons respectively. Extrapolation of the total mean catch of 700 m of gillnets set quarterly by CDNEC (Figure 2.4.3) are also not at variance though probably giving a higher figure. In Chapter 2.2.4 (p.49-50) annual dry-mass zooplankton production is estimated to have varied from 270 to 1000 tonnes. While only part of this is exploited by fish, other resources are used, particularly by the labeos. A minimum total annual fish yield of 150 tonnes live mass is not inconsistent with zooplankton production of this magnitude. From all these an initial appraisal of 150 - 250 tons per annum was arrived at. For reasons given in Chapter 3.4.6, a price of R1/kg is anticipated, giving a minumum value of the fishery as R150 000 per annum.

3.3.2. Biological considerations

One of the main limitations of the study is that no absolute estimate of population density could be made. If a commercial fishery had been in operation, the decline in catch per unit effort of a given year-class combined with the landing statistics would have given us this valuable information.

There are several so-called first generation models, such as Ryder's morpho-edaphic index, available to assess potential yields in lakes and reservoirs, which are reviewed by Ryder (1978) and Bhukaswan (1980). Most of these, however, are based on regression analysis of selected variables known to affect or reflect the productivity of a water body, (e.g., total dissolved solids, depth, transparency, chorophyll concentration etc- against yield in lakes of similar types (origin) and geographical location. In short, these estimates are derived from a framework of references. Unfortunately, South African freshwater fisheries are both poorly developed and poorly monitored. Thus no framework of references was available on which to base prediction of fish yield from Lake le Roux.

Studies of the energy base of the system (Chapter 2.2) of the adaptations of the fish populations to their food resources and of other environmental conditions (Chapter 2.5) provide a basis on which to assess possible yield. The main source of energy in Lake le Roux is through autochthonous primary production, but this is severely limited by the turbidity (Chapter 2.1). Source energy subsidy is derived via the input of organic compounds from adjacent systems, but in terms of availability as fish food, this source is of minor importance, especially to the most important commercial species in the lake. This is shown by the loss in relative condition of fish, their dispersal and accelerated mortality rates when there is a reduction in water transparency. The relative unimportance of the allochthonous food source is probably partly due to the deep lake acting as a 'sink', and partly to little of the allochthonous organic carbon being such a form that it can readily be used by herbivorous (detritivorous) fish which are predominantly the two labeos. Therefore, in addition to the inter-seasonal fluctuations in fish growth resulting from changing light and temperature regimes, harvestable stocks may be further reduced due to an increase in natural mortality rates in years of foor primary production.

Although size of harvestable stocks may vary considerably among years, inter-annual fluctuations in yield can be reduced by adopting certain management measures. Depending on the objective, fishery management in general can be aimed at increasing yield, increasing the proportion of large fish in the catch (recreational fisheries) reducing or eliminating certain species (rough fish) etc. These and other considerations inevitably lead to the question of augmenting existing stocks by artificial propagation and the introduction of new species, which will be explored later in this section. First, however, the consequences of the two main aspects of exploitation, i.e., the intensity of the fishing and size composition of the catch and how these will affect yield will be examined for the species presently inhabiting the system.

3.3.3. The effect of exploitation on population structure and yield

Two major population parameters, reproduction and growth, can be greatly influenced by population density. When growing conditions are poor, a relatively larger proportion of available resources is allocated to maintenance and reproduction than when food is in ample supply. Therefore, fish production is reduced to a greater extent than might be expected when there is a reduction in primary production. Accordingly, one of the most important facets of fisheries management is the determination of how much should be harvested and which size groups should be fished. In a variable environment, such as Lake le Roux, optimal yields can only be approached if regulations are flexible and adjusted to changing environmental conditions.

(a) Smallmouth yellowfish. The population of smallmouth yellowfish shews, ^^ periods of time, a considerable variation in abundance (Chapter 2.4, 3.1) and size composition (Chapter 2.4); both are closely related to turbidity and density.

In 1978/79 the index of population density was reduced from 1000 to 50, and in 1981/82 there was a second major reduction from about 550 to 200 (Figure 3.1.4). These reductions in catches were brought about by a decrease in transparency which reached the same level in 1979 and 1982 (Figure 2.2.3). Although some of the reduction in CPUE could be attributed to reduced vulnerability of the fish to capture, for the reason that fish will swim more slowly in turbid water, and so will firstly have relatively less chance of encountering a net, and secondly of becoming entangled if they do, it mainly reflected reduced population density caused by mortality. In 1978/79 reduction in catches was 95% as opposed to 65% in 1981/82, when the density of the survivors was about four times that of the previous occassion. This shows the effect of 'scramble competition[1] (Pitcher & Hart, 1982), which leads to a mortality of excess of the reduction in carrying capacity. The excess mortality is positively related to initial abundance, which in 1978 was about twice that of 1981 (1000 vs. 550; Figure 3.1.4). Therefore, exploitation of smallmouth yellowfish could have a stabilizing effect on the population. In order to attain maximum yields the largest size groups in the pelagic zone should be exploited. If there is a desire to retain larger individuals for recreational fisheries, an upper size limit of fish caught in commercial or artisinal operations should be imposed. This could be achieved by regulating mesh size of nets used in fishing operations (Table 3.3.1). Furthermore, the exploitation of yellowfish would increase the size and numbers of large fish which could be maintained in the pelagic zone (Figure 3.1.5).

Year-class strength of smallmouth yellowfish is variable and can be weak depending on hydraulic management (Chapter 3.1). If fishing pressure is light, variations in year-class strength will only have a moderate effect on total catches, while changes in turbidity are likely to have an overriding effect on population changes. Depending on initial abundance, up to 90% of the population may be lost through natural mortality, leading to a decline in CPUE which would make a small-time fishery (light fishing pressure) less stable than a more intensive fishery. However, if the population is being exploited heavily, a fishery might be more affected by variations in year-class strength than by variation in production due to changes in turbidity.

TABLE 3.3.1. Modal lengths and mass of smallmouth yellowfish and Orange River labeo caught in different sized gill-nets.

Mesh size mm. stretched mesh	Smallmouth yellowfish		Orange River labeo	
	length/cm	mass/grams	length/cm	mass/grams
35	13-15	28-44	13-15	27-43
45	17-19	64-90	17-19	64-92
57	21-24	122-182	21-24	128-197
73	26-30	233-360	25-29	225-363
93	33-38	480-738	31-36	451-732
118	41-48	929-1500	38-45	873-1510
150	52	1900	49	1990

Yellowfish form highly mobile populations (Chapters 2.4 & 2.5). Thus fishing in one area of the lake is unlikely to deplete local sub-populations. Catches are usually highest where the water is clearest, i.e., near the dam wall (Chapter 2.4). In spite of this mobility there are enough areas inaccessible to fishing to ensure adquate spawning stocks, even in the face of relatively intensive exploitation.

The major population parameters of smallmouth yellowfish such as growth, recruitment and mortality are sensitive to environmental fluctuations which are largely the result of hydraulic management (Chapter 3.1). If hydraulic management cannot be adjusted to meet the needs of a future fishery, predictions of changes in environmental conditions will be indispensable for the planning and optimal use of such a fishery. Predictions should be based on an understanding of hydrological principles and envisaged water-use practices.

There is a drop of 24.5 m between the river bed at the H.F.Verwoerd Dam and the full supply level of Lake le Roux. The construction, between the Verwoerd Dam and the upper reaches of Lake le Roux, of a dam with relatively low-head turbines, such as are installed in many of the navigation dams of the Mississippi River, would extract additional energy from the river at relatively low cost. This energy would otherwise have to be supplied by increasing discharges from one of the existing dams, thus reducing the volume of water available for other uses. Such a barrage would also increase the passage time of water between the lakes, allowing additional warming in the summer, with reduced siltload, and a possible consequent reduction of the tendency for inflowing water to enter the hypolimnion of Lake le Roux. The possible consequences of such warming are complex, and while productivity would increase, the present balance in relative species abundance could be upset. Higher temperatures might favour expansion of banded tilapia, which could adversely affect growth and mortality of juvenile cyprinids which favour the shallow inshore areas. Furthermore, it is important that such a barrage be sited so that as great a distance as possible of flowing water, several kilometres at least, exists below its outflow and the highest retention level of Lake le Roux, since this area contains the spawning grounds of the yellowfish, on which a potentially very valuable fishery is almost completely dependent.

(b) Orange River labeo. This species is not readily caught with hook and j_ne ^ .^ ^^^ ^ potential angling species. In Lake le Roux it does not show as large a fluctuation in CPUE as smallmouth yellowfish (Figure 3.1.4). A moderate fishing effort might have reduced natural mortality in 1981/82 and left the survivors in a relatively better condition. Although this species is relatively sedentary, there was a considerable movement of fish smaller than 200mm associated with increases in turbidity (Chapters 2.4 & 2.5). If the population of Orange River labeo in zones 1 and 2 had been reduced prior to the increase in turbidity in 1981/82, a situation similar to the one in 1978/79 might have arisen. When turbidity increased sharply in 1978, a redistribution of labeo into relatively vacant areas at zones 1 to 3 accounted for a considerable increase in CPUE of this species (Figure 3.1.4) and survival appeared to have been good.

A major problem associated with the exploitation of Orange River labeo is the reproductive uncertainty of this species, which in the lake is greater than in the pristine river. It requires floods to trigger spawning and elevated water levels to ensure good survival of the young. When reproductive success is variable, multiple spawning and numerous breeding year-classes allow for a population to maintain a high abundance even if reproductive success is poor in consecutive years. A heavy and sustained fishery reduces the number of year-classes in the breeding population and may therefore cause a collapse of the population in a relatively short time. It appears that labeos in general, are similarly adapted to variable reproductive success and virtually all the large labeo populations of tropical Africa have collapsed due to intensive exploitation (Tomasson, 1983).

An intensive fishery on labeos would lead to a reduction of repeat spawners and a simple age structure of the populations. Increased exploitation (reduced density) is also likely to lead to an increase in growth rate, which is usually accompanied by a narrower size range for each year class. A high yield can only be sustained for as long as reproductive success remains good, but may decline rapidly, particularly when reproduction fails in successive years. Once reduced, it may take the population a long time to recover. Therefore, a continuous large-scale fishery in labeos in Lake le Roux should not be contemplated, although catches could be relatively good in the short term. Instead, selective short-term fishing effort with long periods between should be applied, and this fish regarded as a reserve for times when catches of other species fail.

(c) Largemouth yellowfish. This species is not abundant in the lake and is unlikely to play an important role in a commercial or artisanal fishery. However, it is a prized angling fish and since it is long-lived it might be useful to impose an upper mesh size limit to protect large individuals, which then would contribute to the excitement of angling. It would be impossible to fish selectively for smallmouth or largemouth yellowfish because of the similar habits of these two species. The prohibition of large-mesh gillnets will protect big individuals of both species, but the abundance of largemouth yellowfish will remain low. In Lake le Roux, largemouth yellowfish is near the upper range of its distribution, which appears primarily to be limited by low temperature. The relatively low temperature in Lake le Roux for this species results in late spawning and therefore its year-class strength will remain weak in comparison to that of smallmouth yellowfish.

(d) Catfish. Gillnet catches show that this is not an abundant fish in the lake, and that the population is largely made up of relatively old (large) fish (Chapter 2.4) indicating low rates of natural mortality and poor reproductive success. This species is readily caught on long-lines (Table 2.4.5) and catches are likely to be good initially, but are probably not sustainable and will decrease to a lower level in the event of a heavy exploitation.

The large size reached by this species in Lake le Roux, as compared to many other populations, is probably chiefly due to abundance of prey (cyprinids) and their vulnerability to capture by catfish because of the turbid waters (Chapter 2.5). Thus if an intensive fishery on the cyprinids took place, living conditions of large catfish might deteriorate, although the fishery would mainly take fish of 20 cm and above, too large for most catfish. It is possible that effects of poor reproductive conditions are further aggravated by cannibalism with adults preying on their own young. However, exploitation will inevitably reduce MPUE and the modal size of the population will be reduced.

(e) Other species. None of the other species in the lake are likely to contribute importantly to commercial fisheries, whichever way they are managed. The relative scarcity of moggel and carp is primarily due to the lack of suitable habitat, and their reproductive success is likely to be affected adversely in a manner similar to that of the Orange River labeo. However, carp is at present one of the more important angling species in the lake.

3.3.4. Supplementary stocking and introduction of new species

It would be possible to enhance the spawning success of many of the species in the lake by the technique of artificial propagation in hatcheries, although the success of such an enterprise would be difficult to guarantee since survival between spawning and recruitment to the fishery would be dependent on conditions in the lake, and may not be improved by the provision of additional juvenile fish. The main limitation to augmenting the existing populations is that these are all of riverine origin and are poorly adapted to live in lentic waters, a problem commonly encountered in reservoir fish communities (Fernando & Holcik, 1982). There is not one specialized plankton feeder in the lake, and while smallmouth yellowfish does exploit zooplankton, it selects mainly the largest individuals of the largest species present (Chapter 2.2.6), virtually ignoring the smaller species which form the bulk of the zooplankton. Thus the small zooplankter Metadiaptomus comprises over 60% of the zooplankton population (Figure 2.2.14) but is rarely taken. The introduction of a specialized phytoplankton feeder to the lake would undoubtedly increase fish production markedly. A suitable feeder could be expected to exploit the plankton resource much more effectively than the yellowfish.

The great rivers of temperate North and South America and of Asia differ in character from those of South Africa in that they have considerable dry season flows, so that plankton-feeding species have evolved there. It is in these areas that exotic species suitable for introductions to the lakes might be found. Since the indigenous ecosystem has already been fundamentally altered there can be little objection to the introduction of a specialized plankton-feeding fish on the grounds that it would disturb the natural regime. Any species proposed for introduction would have to be carefully seclected. A generalised species might be able to compete successfully with indigenous fauna and replace them in relatively undisturbed riverine parts of the system. A highly specialised planktivore would be unlikely to be successful except in areas where there is an adequate supply of plankton and thus could only live in those parts of the system which have already been substantially altered, so would not be a threat to indigenous species. The choice of species would be dependent on the probability that they would be able to exploit the currently under-utilised resources, and have a significant market value, either commercial or sporting, and so benefit the fishery.

A further possibility for introductions is to supplement indigenous fish with more desirable species, after careful consideration. The Cape authorities are currently investigating the suitability of various mullet (haarder or springer) species for introduction into farm dams. These fish appear to use similar resources to those used by the labeo species but are know to digest bacteria in detritus, an ability suspected, but not yet demonstrated, for some labeos. They are valued both by anglers and as a food fish. The flesh is firmer than that of the Orange Rive labeo, and appears to have better keeping qualities. One species is familiar to the market in the dried form as 'bokkoms'. Since these fish do not reproduce in fresh water their survival would depend on regular introduction of artificially spawned fry from a coastal nursery, and this may be feasible at some future date when such a facility is able to provide a source of fry for general distribution. The inability to reproduce in the lake would mean that any such introduction would be reversible and the fish could be eliminated within a few years by natural mortality in the absence of further stocking.

3.3.5. Conclusion

Unless new species are introduced, smallmouth yellowfish and Orange River labeo are likely to form the backbone of any commercial fishery. Catfish may also play a small but important role, while carp, yellowfish and catfish will be most important in a recreational fishery.

Smallmouth yellowfish in Lake le Roux appears to have the potential to sustain a fishery on a continuous basis, particularly if hydraulic management can be adapted to avoid exceptionally weak year-classes. The intensity of the fishing should be guided by predictions of changes in the turbidity regime of the lake. If a recreational fishery becomes a primary objective, large scale removal (netting) of small fish or hydraulic management aimed at reducing spawning success would be necessary to increase the numbers of larger fish (Chapter 3.1). A commercial fishery should, therefore, not be seen as a threat but rather as a benefit to recreational fisheries, since it could be used to promote good angling.

The Orange River labeo is not an angling species and does not have the potential continually to sustain a large fishery. This species does not react as quickly to environmental changes as smallmouth yellowfish and has a relatively fixed size at sexual maturity. Therefore, it might be best exploited on an 'accumulated stock' basis, i.e., the population would be exploited intensively for relatively short periods of time but left to recover for long periods in between.

In the event of a commercial fishery being established, the best procedure might be to mainly exploit labeo at times when catches of yellowfish are low. This differentiation could be achieved to some extent by setting floating gillnets well offshore to catch yellowfish while setting in shallower water or near the shore to catch Orange River labeo.

Catches are generally highest near the dam wall. If a fishery was concentrated at Zones 1 and 2 (Figure 3.2.1) these would be 'seeded' from other areas, although labeo would only disperse when conditions deteriorated. If an even supply of catches was desired, a fishery which could switch from yellowfish to Orange River labeo would be essential. In a commercial situation, a rotational fishery, based on several impoundments (there are four reservoirs in the Orange-Vaal system larger than 100 km^2), might be the most efficient. In that case a monitoring programme could be established to decide when each reservoir is to be exploited to see to the interest of commercial and recreational fisheries alike.

3.4. POSSIBLE DEVELOPMENT OPTIONS FOR FISHERIES

D.H. Eccles, R.C. Hart, P.B.N. Jackson & T. Tomasson.

3.4.1. Possible management options

There are several possible options for the exploitation of the potential fishery of Lake le Roux, subject to a variety of constraints. Based on the understanding of the factors controlling the productivity of the lake gained in the present study, a number of recommendations can be made with regard to the management of a fishery. These take into consideration both the potential fish production and the physical, biological and socio-economic factors which would affect the fishery. The options available are listed below. They are, to a large extent, complementary, and the benefit available from the resource could be maximised by adopting a combination of them.

a. Develop a resident commercial fishery with the general, though not exclusive, aim of producing a low-priced product aimed at the immediate local market and at lower income urban markets nearby. Such a fishery would be based primarily on harvesting those sub-adult fish which would otherwise die of starvation each year, and would not compete with angling.

b. Develop a fishery exploiting a number of lakes in rotation and geared mainly to catching adult fish to produce a high-quality product aimed at the major urban markets.

c. Manage the fishery primarily for the benefit of anglers.

d. Adopt a combination of the above options.

e. Leave the fishery essentially unmanaged and open to whoever wishes to use it.

3.4.2. General management considerations

A number of management features, or the lack of them, apply to freshwater fisheries development in Lake le Roux. Firstly, the lack of information on the marketing of freshwater fish in South Africa engenders a degree of uncertainty as to expected financial results. Secondly, the steep nature of the shoreline of most of the lake, and the paucity of roads leading to the shore limits the choice of areas at which a fishery could be based. Ideally these should allow ready access to the main areas of the lake, and also offer ready communication with the general road system.

Contrary to the situation in marine fisheries, overfishing is unlikely to pose a threat to the stocks in Lake le Roux. The lake has a very long shore line, most of which is inaccessible by land and much of which is rendered unsuitable for netting or angling by the presence of drowned vegetation or by the rocky nature of the bottom. This would ensure the survival of adequate breeding stocks unless heavy exploitation were to take place at the upper reaches of the lake or of the major drowned tributaries at the time of breeding migrations. Survival of breeding stocks would be guaranteed by prohibiting fishing in these areas.

Land ownership also imposes constraints on the development of fisheries in so far as any enterprise attempting to exploit the resource would require to base its operations at a site with road access to the lake shore. The Water Affairs Division of the Department of Environment Affairs controls the land between the estimated high flood level and a height of 6 m vertically above this, or a distance of 50 m horizontally from this, whichever is the lesser. The land above this was purchased by the State, but is now under a variety of controls. Some has been handed over to Provincial Administrations. The rest, with the exception of that falling under the Vanderkloof Municipality, is administered by the Department of Agriculture, which currently leases some of this to farmers although it will probably eventually be re-sold. On the Cape Province shore much of this land is controlled by the provincial Department of Nature and Environmental Conservation and is administered as nature reserve, with which a commercial fishing settlement would probably be incompatible.

There are ten sites with road access to the shore but three of these are in nature reserves while three others are situated too high up the basin or drowned tributary valleys (Figure 3.4.1). Only the site on the north side of the lowermost basin (G), two sites on the east side of the largest basin (A and B), one at Elandskloof (E) on the Cape shore and one on the Knapsak River (C) on the eastern side of the upper reaches of the lake appear suitable for fishery bases.

Finally, financial considerations impose restraints on the development of a fishery. These can be divided into Governmental and investment oriented aspects. The first applies to the need for an administrative framework to control the fishery, the basis for which already exists in the Cape Provincial Department of Nature and Environmental Conservation. The second requires that there should be a prospect of a reasonable return, either monetary or, in the case of angling, subjective, to capital and labour invested in the enterprise. This return cannot be assured in the absence of an administrative framework which allows for control of entry into the fishery so that potential excessive fishing effort, with consequent diminishing returns, is avoided. Running costs of administration can be offset to a greater or lesser degree by the imposition of licence fees or of taxes on production. The latter method of revenue collection is, however, expensive to administer and also encourages the falsification of catch data which renders the estimation of accurate stock statistics impossible. The imposition of a pre-paid licence fee, on an annual basis, is therefore recommended.

3.4.3. Angling

Only four of the species which occur regularly in the lake are attractive to anglers. The most important of these from the angling point of view is the carp which favours the *very* shallow inshore areas and therefore may have been under-represented in the catches in gill-nets, which needed a minimum depth of 2 m (Chapter 3.2). Although the lake has a very long shore line, the steep nature of much of this limits the area suitable for carp and may set a limit to the total population of this species (Chapters 2.4, 3.2).

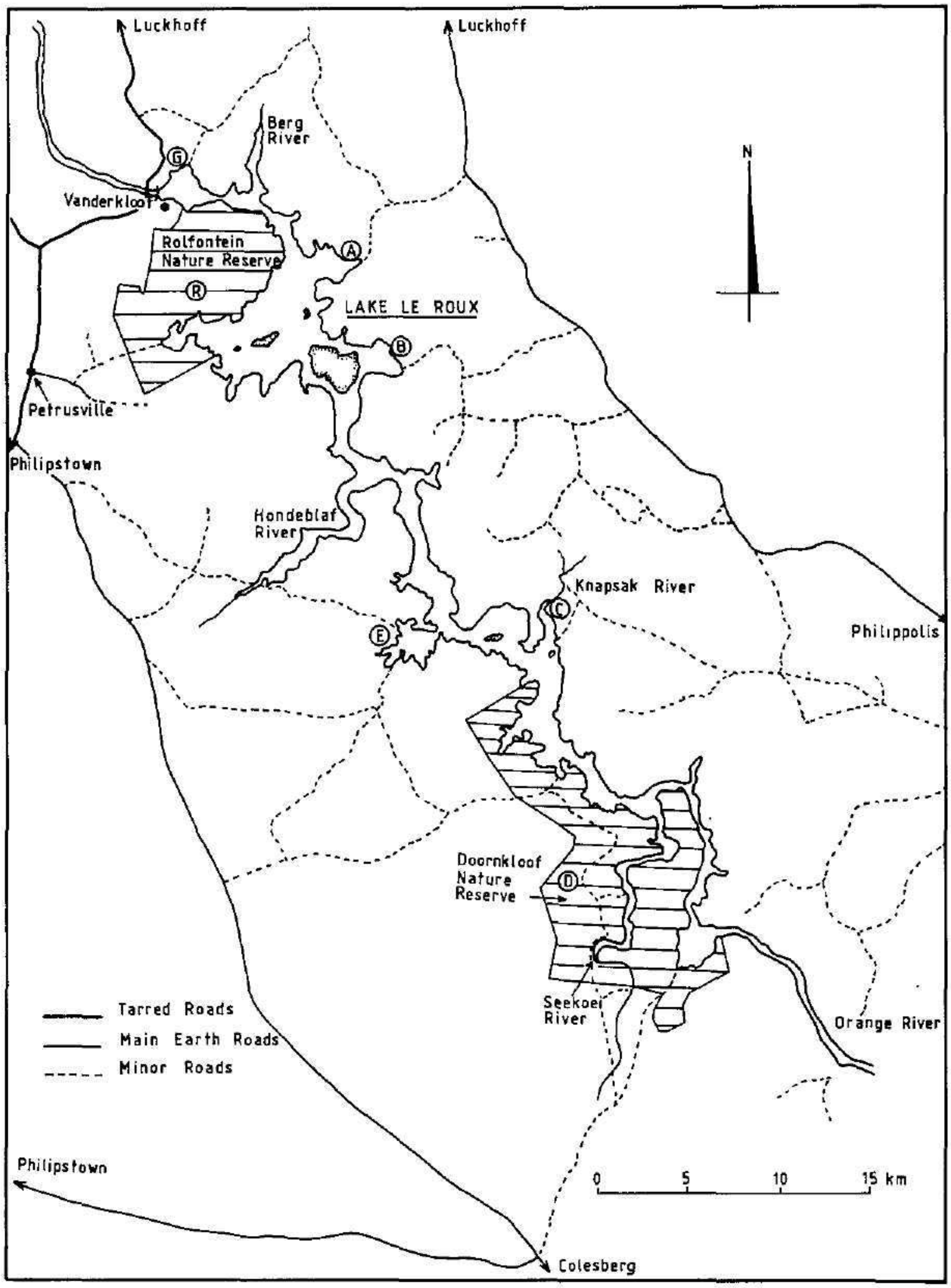

FIGURE 3.4.1. Road access to Lake le Roux. Hatched areas are CDNEC nature reserves, Rolfontein (R) and Doornkloof (D). Other letters refer to possible sites for fishing bases mentioned in text.

The other species sought after by anglers are the yellowfish and the sharptooth catfish. The smallmouth yellowfish, though not normally a predator of fish, has fairly good angling potential and takes a variety of baits (Bruton et aj_., 1982). The largemouth yellowfish is at the top of the food chain ancTTs a *very* good angling fish, but is relatively rare in this lake. The natural scarcity of largemouth yellowfish may be further enhanced by the effect of turbidity in making the detection of prey or a bait more difficult. The sharptooth catfish grows to a large size and readily takes many kinds of bait so is popular with anglers. It detects its food by taste so that its ability to locate a bait is not seriously affected by turbidity. It is also favoured as a food fish by the local Coloured population.

Since only a small proportion of the total fish fauna is susceptible to angling, the great bulk of the potential fish yield would not be exploited by this method. The abundant Orange River labeo would scarcely be utilized, and *very* few smallmouth yellowfish would be caught. However the economic value of angling is considerably greater than the monetary value of the fish caught if total expenditure by anglers is considered. Cadieux (1980) estimated that the total expenditure by anglers in the Transvaal in 1977-1978 was of the order of R 32 million. Accordingly, an angling fishery would be economically desirable so long as it could be managed to provide sufficient satisfaction to the participant anglers. It would complement, rather than compete with, a commercial fishery.

3.4.4. Commercial fishing

Economic considerations are of prime importance in commercial fisheries which must yield a return to capital invested and also cover running, labour and management costs. Except where the product is *very* highly priced, commercial fishing must use methods which will allow a large throughput of fish. This is especially true in South Africa where meat is, by world standards, relatively cheap. Freshwater fisheries must also be able to compete with sea fish, of which there is an abundant supply of high quality close to our shores. Although the cost of transport of this to inland markets adds appreciably to the price, it still remains a relatively cheap food. Fishing methods which *are* suitable for commercial use include such gears as traps, gill nets, trawl and seine nets and multi-hooked long lines.

In Lake le Roux the existence of obstructions in the form of boulders and remains of vegetation render the use of moving nets, such as seines and trawls, impractical except in certain restricted areas, and would probably preclude their commercial use. Commercial fish traps, such as are used in the American great lakes, are not practicable in a system where the water level fluctuates considerably under the influence of other users. Thus only gill netting and long lining appear to offer much prospect of commercial success. (Chapter 3.2).

Gill nets can be set at any level in the water column and any distance from the shore, though in practice they are usually set at the surface or on the bottom. Over 70% of the catch of surface-set gill nets away from the shore consists of smallmouth yellowfish. This species is also common in catches taken inshore, although here Orange River labeo is often the predominant species. In the case of gill-nets set on the bottom in relatively deep water, Orange River labeo usually dominate the catch (Chapters 2.4.4, 2.5).

The major problems with gill-netting are that if the nets are set for extended periods the quality of the fish is often adversely affected, while the nets themselves are very susceptible to damage if used in areas with many obstructions. There are few areas along the shore line or on the bottom of Lake le Roux where nets can be set without risk of damage from rocks or from drowned vegetation. While some areas of formerly cleared or open ground have been identified from pre-impoundment aerial photographs, these are small and are mostly in a single basin (Figure 2.4.13), so that they are unlikely to support an extensive bottom fishery. A fishery based on bottom-set or inshore gill nets would therefore have to include greater provision for replacement nets and for repair costs than would be the case for a fishery using surface nets. A surface fishery would, however, exploit only a certain proportion of the available stocks, and would have a substantially lower catch per unit effort than an inshore fishery.

Little research has been done on the acceptability of fresh-water fish in the markets near the lake, or on the prices that such fish can command. Roode (1978), using fish from Lake le Roux, found a minimum price of R 0.60 to be feasible at that time. Another of the few available studies of freshwater fish prices in South Africa was carried out in January 1983 in conjunction with fish-cultural experiments at the University of the North. The fish, prepared in a variety of ways, sold readily. Carp, Labeo species and Barbus marequensis (yellowfish) fetched R 1.30 ancT TT.mattozi (papermouth) R 1.50 for whole fish. Whole catfish fetched R 1.00 per kilo fresh and R 7.00 smoked. These prices appear high and it should be noted that they were obtained in that part of the country furthest from supplies of fresh sea fish which, in that area, is rendered less competitive by-the cost of transport from the coast.

Some further information is available from commercial harvesting of moggel from Lake Mentz. Here the fish were first marketed fresh in the Uitenhage and Grahamstown areas, but were later being dried for sale elsewhere. However the latter product fetches only a low price, equivalent to about R 0.40 per kilo for the fresh fish, and much of it is exported since, being close to the coast, it comes into competition with low-priced sea fish and does not find a ready local market.

3.4.4.1. Potential_for_a_fishery_for_a_high_griced_product

In the absence of reliable market information a detailed appraisal of the potential for a commercial fishery cannot be made, but .consideration of a number of factors allows some realistic comments to be offered.

The fish fauna of both Lake le Roux and Lake Verwoerd is dominated by the carp family {Chapter 2.4) which includes the carp, yellowfish and labeos. These are characterized by the possession of numerous fine, forked bones in the flank muscles which require special preparation before cooking. In smaller fish these bones can be broken up by filleting and then scoring the fillets for almost their full thickness at intervals of about 1 cm. The short lengths of fine bone are then not noticed after the fish is fried or roasted. They can also be broken up by mincing, or softened by pickling in vinegar or canning. In large individuals the bones can be removed individually after cooking, but such specimens form a small proportion of the stocks in the lake. These considerations militate somewhat, at the present time, against the ready acceptance of cyprinids in the sophisticated urban markets unless the fish are large enough for the bones to be readily removed or if they have been softened in a canning process. Further work on processing of freshwater fish and on the market acceptability of fish processed in a variety of ways, such as drying, smoking, pickling and filleting is required. It is unlikely that a fishery confined to Lake le Roux, taking only the largest individuals, and requiring refrigerated storage and distribution facilities, would be economically viable. A fishery based on the exploitation and canning of the more abundant individuals between 25 and 35 cm in length might be more successful, but would still involve large capital costs and would be competing for markets with established marine products which are caught in much greater quantities and thus benefit from economies of mass handling.

A long-line fishery for sharptooth catfish, producing a high-quality smoked product for the urban market might possibly be feasible, although market research into the acceptability of such a product would be required before any substantial investment could be made. It is questionable whether the population of this species is sufficient to sustain a fishery on its own, although it might supplement a gill-net fishery for other species. These catfish are sufficiently hardy for individuals caught over much of the area of the lake to be returned alive to a central plant, where they could be held until there were enough to justify batch processing.

The cyprinids, by contrast, are relatively delicate and usually die soon after removal from a gill-net, so that without the use of fast transport, or of refrigerated storage on fishing boats, the quality of fish delivered at a central processing plant may suffer. This is particularly so in the case of Orange River labeo, where gutting in the field might be necessary. Both fast transport and refrigeration or storage on ice involve expenses which would reduce the potential commercial viability of a fishery geared to supplying fresh fish.

3.4.4.2. Potential_for a_fishery_for a_low^griced_product

During surveys there was no difficulty in giving away the catches to the fishermen or to local farmers who gave it to their labourers. The fish" were acceptable fresh, but chilling or refrigeration facilities would probably be required if a commercial fishery, handling relatively large quantities of fresh fish on a regular basis, were to be established. While little is known of the market acceptability of dried *or* smoked fish, it is likely that such a product would be the major outlet for any commercial fishery on Lake le Roux. In many African countries the main method of preparing fish for the market is sun-drying, and cyprinid fish prepared in this way are very popular. The possibility exists that an export market could be developed for such a product.

If the product is to be dried, the relatively simple processing and storage facilities required will involve less capital and running expenditure than would be the case if the product were to be refrigerated. Thus a fishery based on a dried product would be viable at a lower level of turnover than one based on the sale of fresh fish, unless the latter were sold direct from the landing site.

The climate at Lake le Roux is ideal for air-drying, although the quality of the product would be improved by brining prior to drying or smoking. There are considerable numbers of Coloured (Griqua) and Black people resident in towns or employed on farms in the vicinity of the lake. The Coloured people are familiar with dried salted fish in the form of "bokkoms[11] and it is possible that lake fish prepared in a similar way might find a ready market. Most Coloured and Black households in the area lack refrigeration facilities, and a dried product would have the advantage that it could be bought in quantity when money was available and kept for later consumption.

A fishery based on the most abundant and fastest growing size classes of the stocks, on which the effects of natural mortality are not yet severe (Chapter 3.4), is more likely to be economically viable than is one based on the largest individuals, which form only a small part of the stock. It would involve relatively low processing and distribution costs and provide local people with a product they can afford, Its financial viability would be enhanced by the absence of a need for frequent refrigerated or insulated transport to relatively distant urban markets.

The smallmouth yellowfish and Orange River labeo, due to year-to-year differences in food availability or in hydraulic management, are subject to great changes in annual recruitment to the fishery (Chapter 3.3). In most years there is some spawning of yellowfish, although success is reduced in years with low river temperatures, while poor feeding conditions lead to stunting and breeding at a size below the normal. Orange River labeo are not subject to stunting, so that starvation results in a failure to breed, while breeding itself is dependent on ephemeral floods in tributaries and can fail completely in some years. Labeo are also relatively slow-growing in comparison to the yellowfish. These factors, especially their inability to breed below the normal adult size and their dependence on ephemeral meteorological events for spawning, render them more vulnerable to over-fishing. In a fishery based on these two species the optimum strategy would be to exploit the smallmouth yellowfish when it is abundant, and in years when this is scarce to harvest the accumulated stock of Orange River labeo.

In addition to the desirability of adopting such a management strategy to maximise the long-term benefit, running costs of such a fishery could be kept low if smallmouth yellowfish were exploited mostly by gill nets set offshore at the surface, either anchored or used as drift-nets from a boat. Although yields per net would be lower than those to be expected from inshore nets, labour and replacement costs would also be less than for nets set close to the shore. When a greater proportion of Orange River labeo is needed to supplement the catch, nets should be set inshore.

It would be possible to combine a line fishery for sharptooth catfish with such a small scale gill net fishery. A further supplement to the value of a fishery would be to process the offal to recover fish oil, although the price for this is unlikely to exceed R 300 per tonne and the annual yield would be less than 5 tonnes.

3.4.5. Socio-economic considerations

Although the need for economic data had been recognized by the team at the beginning of the investigation, the present study did not involve any socio-economic input. However some comments in this field are pertinent to the question of the management of any potential fishery.

It is unlikely that a fishery based on a high priced product would have sufficient throughput to justify full-time fishing for the season. A more successful strategy would be for the operator to exploit a number of lakes in rotation, moving his equipment and crews from one to the other, as is done at present in the case of venison cropping. While such an approach might be economically viable it would be inherently expensive, particularly in respect of fuel. The employees would be likely to reside outside the neighbourhood so that there would be little economic benefit to the local area, although the need for development opportunities for the local Coloured communities was stressed as long ago as 1963 in the report of the Orange River Development Conference in Bloemfontein (Biesheuvel 1963).

A further complication of this type of rotational fishing is that control of the fisheries of Lake Verwoerd and Lake le Roux is the responsibility of different administrations, in this case the CDNEC and the Orange Free State Department of Nature Conservation, which might adopt different criteria of management. This might be further complicated if such a fishery were to include such water bodies as the Grassridge Dam and the lakes on the Vaal system.

A fishery based on adult fish would be wasteful in that it would concentrate on that part of the fish population which offered the best price and would leave the sub-adults un-harvested. Under the peculiar ecological conditions prevailing in the lake these sub-adult fish are subject to a 50-70% natural mortality and few would survive to become available to the fishery (Chapters 2.4, 2.5). This contrasts with most fisheries where mortality of sub-adults due to fishing has a major effect on the number of adults and breeding stock.

A fishery based on producing salted and dried fish for local sale could be carried on at a relatively low level of effort on an almost year-round basis, and need not involve great capital expenditure. Fast outboard-driven boats would not be necessary as the fish could be gutted in the field and stored in brine on the boats until they could be returned to the base for drying. Such a fishery could consist of a number of small units working for a single company, or of a number of independent units. In the latter case the individual units would probably have too small a turnover to attract White entrepreneurs, but might still be suitable for operation on a family basis by local Coloured people. The fishery would exploit the bulk of the available stock and, because of the relatively low capital investment and running costs compared with a fishery for a fresh product, would be profitable at lower levels of catch per unit effort. It would therefore be able to operate for much of the year so that local people could be employed in it. This would be valuable in an area where there are limited opportunities for employment.

The questions of the viability of a hatchery and of the desirability of introductions cannot be answered until catch data, by which the probable effects of enhanced spawning and recruitment can be assessed, become available. The capital costs would be considerable and, in the case of a hatchery, significant running costs would be incurred even if the facility were operated only in the breeding season. These costs would only be economically justifiable if there was a good prospect that they would be covered by a substantial increase in the value of fish produced. No decision should therefore, be taken until the lake is exploited at a level which would enable the potential economic benefits to be assessed. This consideration need not apply to the possible introduction of mullet if supplies of fry become available as the result of other programmes.

Should the decision to construct a hatchery be taken, the ideal site would be at the H.F.Verwoerd Dam, where fry could readily be introduced to both lakes. It could possibly be integrated with the existing hatchery and fish-farming operation of the Orange Free State Department of Nature Conservation. However the existence of laboratory facilities and housing at Vanderkloofdam may make the latter the site of choice for a hatchery.

It might be possible, as a pilot project to assess the possible effects of such stock enhancement, to translocate field-caught fingerlings of Orange River labeo from nursery areas to lower, more productive, parts of the lake where they could be released after marking. A similar evaluation would be possible if ripe fish were caught in the field and induced to spawn under laboratory conditions.

3.4.6. Conclusions

1. An appreciable'stock of fish exists in Lake le Roux and an annual yield of the order of 150-250 tonnes might be expected from the system as it exists at present with little governmental expenditure and with minimal prejudice to other users of the lake. Although the fish is of somewhat low quality compared to sea fish, a market for it was found in 1978 at a price of R 0.60 per kilogram. At current prices (1983) it is not unrealistic to anticipate a local price of the order of R 1.00. Exploitation of this would add an additional R 150 000 annually to the local economy at the cost of a relatively small capital input. Should higher yields or prices be realized, there would be corresponding increases in the local economic benefit. Various options are available by which yields or quality might be enhanced.

2. The nature of the fish fauna of the lake, and the available fish stock, is such that an extensive fishery for the more sophisticated urban markets, based on Lake le Roux alone, is unlikely to be economically viable. Viability might be attained if such a fishery could be rotated between a number of lakes, although this would introduce difficulties of management where the lakes fall under the authority of different administrations.

3. A sport fishery exists at present for four of the nine species in the lake. Large specimens may be caught with a variety of baits, but those species with the greatest angling potential are the carp and sharptooth catfish. Angling resources are unlikely to be improved by the

introduction of additional predatory fish species since the hunting success of these will be limited by the high turbidity of the water.

4. The productivity of the system is restricted by high turbidity and also by relatively low water temperatures. The outflow from the Verwoerd Dam could be regulated so as to attain the highest possible water temperature downstream while optimising flow for yellowfish spawning (Chapter 3.1). This would reduce the possibility of weak year classes resulting from low water temperatures at the natural spawning time (Chapters 2.4, 2.5). If, at some future date, the wall of the Verwoerd Dam is raised, it is likely that the turbine and compensation water intakes would be always below the thermocline and downstream conditions would be less favourable for yellowfish spawning than they are at present. Such a deterioration of spawning conditions could be compensated for by the construction of a hatchery or by using the existing hatchery at Lake Verwoerd to supplement stock for both lakes.

5. The type of fishery which is most likely to succeed is a small labour-intensive fishery, using gill nets of 50 to 75 mm stretched mesh, and exploiting 2- and 3-year old sub-adult yellowfish and labeo for the local market. It should produce mainly a dried salted or smoked product which could be stored and distributed relatively economically. This fishery should be based on employing locally resident Coloured fishermen. Such a fishery would not compete with angling, which would be expected to benefit by the removal of stocks which compete to some degree for the same resources. The restriction of mesh sizes to a maximum of 75 mm would ensure that the larger individuals were not vulnerable to capture in gill-nets (Table 3.3.1), so that the fishery would not exploit these fish which are the prime target of anglers. From time to time when deemed desirable by the managing authority, this fishery should be augmented by the use, for short periods, of larger mesh gill nets, seine nets or long lines operated either by the existing fishing concern(s) or, on a rotational basis among several lakes, by another company.

6. There is no need to impose quotas on a fishery for sub-adult fish. Because of the high mortality experienced after a length of about 30 cm is reached, such a fishery would cease to be economically viable long before it would adversely affect recruitment to the stock of adult fish. The effect of physical obstructions in preventing effective fishing in large parts of the lake, combined with the closure of certain areas to commercial fishing will ensure that sufficient sub-adults survive to maintain the breeding stock.

7. The fishery production potential could be enhanced by the introduction of suitable species. These could be exotic specialized plankton feeders which would pose little threat to the indigenous fauna outside the lakes and would increase the overall efficiency of energy flow in the ecosystem. Alternatively the value of the resource could be enhanced by the introduction of species such as mullet (haarders and springers; Family Mugilidae) of which several species native to South Africa are able to grow in fresh water, although they need salt water for breeding. These would compete directly with indigenous fish such as labeos and would be unlikely to result in increased production, but would be more readily marketable. The introduction of mullet would be

reversible since they would not reproduce in the lake. It would however be contingent on the availability of ample supplies of artificially spawned juveniles. Although the CDNEC is currently interested in such a project there is no immediate prospect of large scale propagation of mullet.

8. An investigation into the marketing aspects of freshwater fish in South Africa, and its value in local economies* is urgently needed to provide the necessary background information to enable rational decisions to be made. The construction of dams or the abstraction or diversion of water from rivers effects considerable changes in the quantity of fish obtainable. In many cases, such as the present, the result may be the enhancement of available fish stocks. In others, such as the construction of the Jozini Dam on the Pongolo River, the disruption of the flooding regime has led to the loss of local fish supplies (Heeg & Breen, 1982). Such potential effects should be considered during the planning stages of a project, when their economic impact should be included in the cost/benefit analysis. If necessary, ameliorating or enhancing structures such as fish ladders or hatcheries should be included in the initial planning and be constructed at the same time as the main structure, thus effecting eventual savings by avoiding the necessity to bring in plant and equipment at a later date. Simultaneous provision of fish-enhancing measures would also ensure that their benefits were available without an intervening period of actual or potential loss.

9. Too little is known of food utilization by Labeo species, of depth distribution of fish species in the lake and its variation in time, or of the immediate effects of weather, particularly wind, on fish distribution.

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GLOSSARY

Abiotic. Descriptive term for characteristics without the attribute of life.

Algae. A general term for relatively simple autotrophic plants with little cellular specialization and reproducing by simple fission or by spore formation. In fresh waters they may be single-celled or filamentous and are often responsible for the bulk of autotrophic production in the system.

Allochthonous. (Material) produced elsewhere, in a different system; of extraneous origin e.g. terrestrial (dry land) matter coming into a water body.

Anaerobic. (adj.) Capable of living in the absence of oxygen, or living processes performed in the absence of oxygen.

Anoxic. Lacking oxygen.

Aquatic. Pertaining to water, especially living in water.

Angiosperms. Complex plants with seeds and woody fibres, e.g. grasses, trees, herbs.

Arthropods. Jointed legged animals, e.g. insects, spiders, shrimps.

Autochthonous. Organic (material) produced within the system; of intrinsic origin, e.g. matter produced within the water body, (cf. allochthonous).

Autotrophic. Self-nourishing, dependent upon photosynthesis, e,g. green plants. (That production) which arises photosynthetically.

Biomass. A quantitative estimation of the total weight of living material found in a particular stated area or in a stated volume of water. Expressed as live weight or as some derived measure such as dry weight, or weight of a specific chemical (e.g. carbon).

Benthic. Bottom-living.

Biotic. (Factors) which relate to the living environment (cf. abiotic).

Catch per unit effort. Catch obtained in a standard amount of effort (q.v.); e.g., in a gillnet of standard size set for a fixed period, or plankton net of standard size towed for a fixed distance and speed. Used to obtain estimates of relative abundances of stocks at different places or times of year.

GLOSSARY

Cohort. A specific sub-group of a population, eg. a group spawned at the same time, such as a year class or geographicallyt separate section of a year-class.

Community. A well defined assemblage of plants and/or animals of various species living in the same habitat and clearly distinguishable from other such assemblages.

Condition factor. A measure of the relationships which exist between length and weightoOf fish. If growth is isometric the model is

$$W = cd$$

$$C \times 10^{\circ} = CF$$

The condition factor varies with fish species depending on the shape of the fish. It also varies within species depending on reproductive or nutritional state and can be used as an index of the latter.

Density-dependence. The condition where growth, survival, food availability, etc. for a population is related to and influenced by the numerical abundance of the population.

Density-independence. Factors such as temperature, floods, drought, pollution, etc., which affect populations independently of their numerical abundance.

Detritus. Organic debris from decomposing plants and animals with the associated microflora of decomposers.

Diatoms. A class of algae with distinct pigments and siliceous cell walls which can be planktonic or benthic.

Drogue. A structure, usually collapsible, which is attached to a rope and deployed in air or water to spread out and produce drag.

Effort. The amount of work done in capturing aquatic animals, usually measured in units, e.g., the haul of a net of known size for a standard distance.

Environment. The totality of physical, chemical and biotic conditions surrounding an organism.

Epilimnion. The upper warmer water layer in a stratified lake, which is usually well oxygenated by wind-induced mixing.

Fishing mortality. Death of fish due to human fishing operations.

Fork length. The length of a fish measured in a straight line from the tip of the snout to the fork of the tail. All fish in this report are measured to the fork length (FL) except the sharptooth catfish and the banded tilapia. (cf. total length).

Genus. A group of closely related species of common ancestry. Habitat.

The specific place in which an organism lives, cf. Niche.

Heterotrophic. Dependent (for nutrition) upon organic material initially synthesized by autotrophs.

Holomictic. A water body in which a seasonal overturn mixes the entire water column.

Hypolimnion. The deepest layer of a stratified lake. Usually cold, and with little temperature difference from top to bottom of the layer. Unaffected by wind, usually with lower oxygen concentration than epilimnion and often becoming anoxic.

Lentic. Still or standing water, as in lakes and reservoirs.

Littoral. Along the edge; inhabiting the shoreline or nearshore waters.

Lotic. Flowing water, as in rivers and streams.

Mass per unit effort. The mass of all animals caught in one unit effort.

Microbial. Pertaining to single-celled microscopic organisms.

Modal. Pertaining to a mode, or point of greatest abundance, on a frequency distribution. Several separate modes can be exhibited in a single distribution, (eg. modal length).

Monomictic. Water body which overturns once a year.

Morphometry. Physical dimensions such as shape, depth, width, length etc.

Mortality. Death. In fish, mortality can be ascribed to fishing or natural causes.

Natural mortality. Death due to all causes other than those directly related to Man's activity, eg. starvation, disease, predation, old age, etc. (cf. fishing mortality).

Natural recruitment. also Recruitment into the fishable population, ie. that supply of fish which each year becomes vulnerable to the gear used in the fishery.

Nekton. Larger, motile pelagic organisms which apart from their motility are planktonic.

Niche. The role of an organism in its environment, or that part of its environment which provides the conditions necessary for the existence of an organism.

GLOSSARY

Omnivorous. Eating both plant and animal foods.

Overturn. The periodic process whereby stratified waters become vertically mixed and lose their layered structure.

Pelagic. Living in the open water, away and apart from the shore.

Plankton. Microscopic plants or animals which float or drift passively in the water.

Plankter. Any individual member of the plankton.

Phytoplankton. Plant components of the plankton.

Population. A defined set (number) of individuals, eg. all members of one species present in a community.

Primary production. Elaboration of organic matter, using sunlight and inorganic compounds (autotrophic production) or on the basis of the consumption of pre-formed organic matter (heterotrophic production).

Production. Total elaboration in given time of tissue regardless of its fate, ie. irrespective of whether it is eaten, caught, dies naturally, survives to the next year, etc.

Pyramid of numbers. A diagrammatic representation of the relative numbers of carnivorous (predatory) and herbivorous (plant-eating) animals in the community, showing that the herbivores, occupying the base of the pyramid, are very much more numerous -than the predators which occupy the apex.

Recruitment. Converse of mortality, ie. "the addition of new members to the population under consideration". See Natural recruitment.

Species. Groups of actually (or potentially) interbreeding natural populations which are reproductively isolated from other groups. The species is intended to indicate a single kind of organism and is designated by a specific name (<u>plural</u>: species).

Stock. That group of fish or other animals under consideration usually qualified as 'total stock^1, 'fishable stock^1, stock in open water^1,etc.

Stratification. Situation in a lake where the water is divided into three regions or layers: the epilimnion, thermocline and hypolimnion.

Suspensoids. Fine particulate material suspended in water.

GLOSSARY

Thermocline. Region of rapid temperature change between the epilimnion and hypolimnion in a stratified lake, where the temperature has a drop of at least 1C per metre of depth.

Total length. The length of a fish in a straight line from the tip of the snout to the tip of the tail, usually measured in those fish which have no fork but a round or square tail (banded tilapia, sharptooth catfish).

Trophic. Pertaining to nutrition.

Water column. The layer of water between lake bed and lake surface; the vertical extent of a water body, functionally synonymous with depth.

Year-class. All the fish of a specific age, eg. spawned at approximately the same time.

Yield. That portion of fish tissue which may normally be taken by fishing methods, ie. that portion of production which is used by man.

Zooplankton. Animal components of the plankton.

ABBREVIATIONS and ACRONYMS (which are not explained in the text)

CDNEC	Cape Department of Nature and Environmental Conservation.
CPUE	Catch per unit effort.
ESCOM	Electricity Supply Commission.
FL	Fork length.
FSL	Full supply level.
IFWS	Institute for Freshwater Studies.
MPUE	Mass per unit effort.
RUSI	J.L.B.Smith Institute of Ichthyology, Rhodes University.
TDS	Total dissolved solids.
TL	Total length.

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