

**THE BIOLOGY OF COMMERCIALY IMPORTANT FISH
SPECIES AND A PRELIMINARY ASSESSMENT OF THE
FISHERIES POTENTIAL OF KATSE DAM, LESOTHO.**

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This thesis is dedicated to my mom, 'Maelia, my brothers, Malefetsane and Ramosoeu, for the sacrifice and suffering the endured during the earlier stage of my education.

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ABSTRACT

The construction of the Katse dam was completed in 1996. The dam started filling in 1995 and reached full capacity in early 1998. It forms part of Phase 1A of the Lesotho Highlands Water Project (LHWP). The main aim of the project is to provide revenue to Lesotho, by transferring water from the catchment of the Senqu (Orange) River in Lesotho to South Africa's major industrial and population centres.

During the implementation of the project, an estimated 130 people were displaced. However, the most serious impact has been the loss of the traditional way of life in the form of arable and grazing land as a consequence of inundation. One of the obligations of the project is to ensure that the standard of living of those affected by the project is not impaired. The Lesotho Highlands Development Authority identified a number of rural development projects, which included fisheries development. This study is an integral part of fisheries development in Lesotho.

The aim of this study was to gain an understanding of the biology and the demographics of the fish species in the lake. This information would serve as the basis for the development of a management plan for the sustainable utilisation of the fisheries resources. To achieve this aim, the following specific objectives were addressed:

1. Investigation of the biology of the three principal species.
2. Description of the key population parameters (growth, mortality & recruitment).
3. Investigation of the distribution and relative abundance of the three species.

The three principal species in the Katse dam are rainbow trout, *Oncorhynchus mykiss*, and the two cyprinids, *Barbus aeneus* and *Labeo capensis*.

Sectioned otoliths were used to age *O. mykiss* while both otoliths and scales were used to age *B. aeneus* and *L. capensis*. Marginal zone analysis revealed that slow growth was experienced in winter for the three species. The maximum-recorded age for both *B. aeneus* and *L. capensis* was 12 years while *O. mykiss* reached 4 years. There was no significant difference in growth rates of the different sexes and growth was best described by the 3 parameter Von-Bertalanfy growth model as $L_t = 603[1 - e^{-0.15(t + 0.03)}]$ for *B. aeneus*, $L_t = 526[1 - e^{-0.21(t + 0.9)}]$ for *O. mykiss* and $L_t = 521[1 - e^{-0.17(t + 0.21)}]$ for *L. capensis*.

Male and female *O. mykiss* attained 50% sexual maturity (L_{m50}) at 235 and 275mm FL, respectively. There was no difference in L_{m50} for male and female *B. aeneus* and *L. capensis*. *B. aeneus* reached sexual maturity at 285mm FL while *L. capensis* reached sexual maturity at 244mm. Both cyprinid species spawned in summer (November to January) while *O. mykiss* spawned in winter (May to August). The mean total mortality rate (Z) estimated from catch curves and Butterworth *et al* (1989) equation was 0.72 yr^{-1} for *B. aeneus*, 0.62 yr^{-1} for *L. capensis* and 1.32 yr^{-1} for *O. mykiss*. The estimate of natural mortality was 0.41 yr^{-1} for both *B. aeneus* and *L. capensis* and 0.81 yr^{-1} for *O. mykiss*.

CPUE was used as an index of relative abundance and it revealed that *B. aeneus* was by far the most important and numerically abundant species in the Lake. There was a marked spatial variation in abundance of all the three species with the highest abundance occurring in river mouths. Of the three species *L. capensis* had the lowest catch rates in the main dam (away from river mouths).

Gillnet selectivity analysis showed that the 50mm-mesh size net had the highest catch rate in terms of numbers. The vast majority (83%) of *O. mykiss* were caught in this mesh size. These consisted mainly of sub-adults. In terms of weight the 70mm mesh net had the highest catch rates for *B. aeneus* and *L. capensis*.

Different strategies are required to manage a small-scale commercial fishery and a sport fishery in the Lake. Input control measures were considered to be the most effective for the management of small-scale commercial fishery, while output control measures were considered to be more appropriate for the sport fishery. It has been recommended that the small-scale commercial fishery be initiated with 25 fishing units with 100m of gillnets (50m x 50mm mesh and 50m x 70mm mesh). An adaptive management strategy can then be adopted whereby one or two additional fishing units, over and above the initiated 25 units, can be allowed into the fishery each year during which the response of the stocks to increasing fishing effort can be monitored. Alternatively, depending on the response of the stocks to fishing effort, the number of units could be reduced by one or two per year. This can be effected by way of buy-out. The sport fishery should be

controlled by way of a conservative bag limit (4fish/angler/day) and this should be reviewed annually.

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CHAPTER 1

Introduction and Background

1.1 Background:

Water and the hydroelectric power potential of that water is Lesotho's main natural resource. This is a consequence of high rainfall in the Lesotho highlands. The country receives an average of 780 millimetres of rainfall a year, 85% of it falling between October and April. In the highlands, annual precipitation reaches 1600 millimetres (LHWP 1990). Figure 1.1 shows the summer rainfall pattern from October 1991 to January 1998 in the Katse local catchment. The Vaal River system in South Africa, on the other hand, is deficient in water to meet industrial and urban requirements. This situation resulted in a launch of a multi-million Rand project between the Kingdom of Lesotho and the Republic of South Africa in 1986, which had three main objectives:

1. To provide revenue to Lesotho, by exporting water from the catchment of the Senqu River in Lesotho, to meet the growing demand of water in South Africa's major industrial and population centres.
2. To generate hydroelectric power for Lesotho, in conjunction with the water transfer.
3. To promote the general development of the remote and underdeveloped mountain regions of Lesotho, while ensuring that comprehensive measures are taken to prevent and avoid any adverse effects which the project might have on the local population and their environment.

Phase 1A of the project included the construction of the Katse and the Muela dams, transfer and delivery tunnels, and the Muela hydroelectric power plant. The Katse dam was established by damming the Malibamatso River (see Fig. 1.2). In terms of surface area the Katse dam is small by international standards (Table 1.1) but it is one of the biggest dams in the southern African region. It also has a number of unique features such as being the deepest man-made lake at the highest altitude in Africa. The general characteristics of the lake are summarised in Table 1.2:

Table 1.1 Morphometry of major man-made lakes in Africa at full supply level.

Lake	Altitude (masl)	Area (km ²)	Volume hm ³	Depth (m)	Reference
Kariba	485	5364	156000	93	Balon & Coche 1974
Kainji	142	1280	15800	50	Balon & Coche 1974
Nasser-Nubia	182	6222	157000	90	Balon & Coche 1974
Volta	85	8845	165000	75	Balon & Coche 1974
Cabora Bassa		2739	69000	157	Balon & Coche 1974
Kossou	204	1600	29500	54	Balon & Coche 1974
Van der Kloof		128.1	2930	73	Hart 1986
Katse	2053	35	1950	170	LHWP 1990

Table 1.2: General characteristics of Katse dam (LHWP 1990):

Cumulative catchment area	1866 km ²
Cumulative mean annual runoff	622 hm ³
Total storage	1950 hm ³
Full supply level	2053 masl
Minimum operating level	1989 masl
Dam wall height	180 m
Main inflowing rivers	Malibatso, Bokong and Pelaneng

Reservoirs are created primarily for irrigation, water storage, flood control, or hydroelectric power generation and rarely for fisheries (Lowe-McConnell 1973). Consequently fisheries are seldom considered in the initial planning phase. However the fish populations which occupy these large new impounded waters often prove to be an asset in addition to the benefits for which the dam was originally constructed. Lake Kariba, where millions of dollars worth of fish have been harvested annually without in any way interfering with the primary purpose for which the dam was built, is a good example of multi-purpose use of large impoundment (Allanson & Jackson 1983). The ever-increasing demands for affordable protein, especially in the rural areas, and sport fishing in more affluent society demand better use of Lesotho Highlands Water Project (LHWP) reservoirs for fisheries development. Fortunately the stringent social obligations inherent in the LHWP treaty made it possible for the authorities in this case, Lesotho Highlands Development Authority (LHDA) to consider fisheries development in the initial implementation phase of the project, thus allowing multi-purpose use of the dam. The fact that these people have lost most of their arable land through inundation of the

reservoir means that the situation is unlikely to change through the input from land based food production only. Therefore fish production in the area has the best prospects to address this problem.

Given the high altitude of the lake it is highly unlikely that a large-scale commercial capture fishery in Katse reservoir would be feasible, as the yield will not be sufficient to support it. However, a small-scale commercial fishery and recreational fisheries have a potential in Katse reservoir. The former would mainly address the protein needs for the communities around the reservoir and provide modest but not insignificant income, while the latter would be addressing the requirements of tourists that visit the area. The management of these two types of fisheries has one common objective, which is to obtain long term sustainable yields. For recreational fishing quality of fishing is very important whereas in commercial fisheries quantity is more important as it provides employment. In order to manage the fisheries in Katse dam appropriately, a fine balance has to be maintained to optimise benefits for the two sectors. LHDA has an obligation to ensure that local communities benefit more than anybody else from the developments in the area. With this in mind, one might assume that a fisheries management plan should be tailored to only suit the locals, thus sidelining the tourist based sport fishery. This would however, be a disastrous mistake given that the country and the local residents can benefit substantially from the proceeds of tourism. Therefore, management of the reservoir fisheries should iron out all potential conflicts in these two sectors in order to maximise socio-economic benefits.

1.2 Aims and objectives of the study:

The aim of the study was to examine the biology and relative abundance of the three commercially important fish species in Katse dam and formulate management plans based on this research. The need to formulate fisheries management plans for Katse dam arises from the fact that many people that lost their arable land through the inundation of the dam will engage in fishing to fulfil their subsistence requirements. Appropriate management plans will ensure that the fisheries resources of the lake are exploited on a sustainable basis. The specific objectives of the study were:

1. To describe the reproductive biology of *B. aeneus*, *O. mykiss* and *L. capensis*.
2. To investigate the population parameters (mortality and growth) with which to assess the current status of the stock
3. To describe spatial and temporal variation in distribution and relative abundance.

To achieve these objectives the thesis was divided into seven chapters. Chapter 2 describe the study area and general methodology. Chapter 3 describes age and growth of the three species. Chapter 4 describes the reproductive biology including size at sexual maturity and spawning periodicity. Chapter 5 deals with distribution and relative abundance of the three species. Gillnet selectivity and mortality rates are dealt with in chapter 6. The last chapter (7) deals with general discussion and management recommendations.

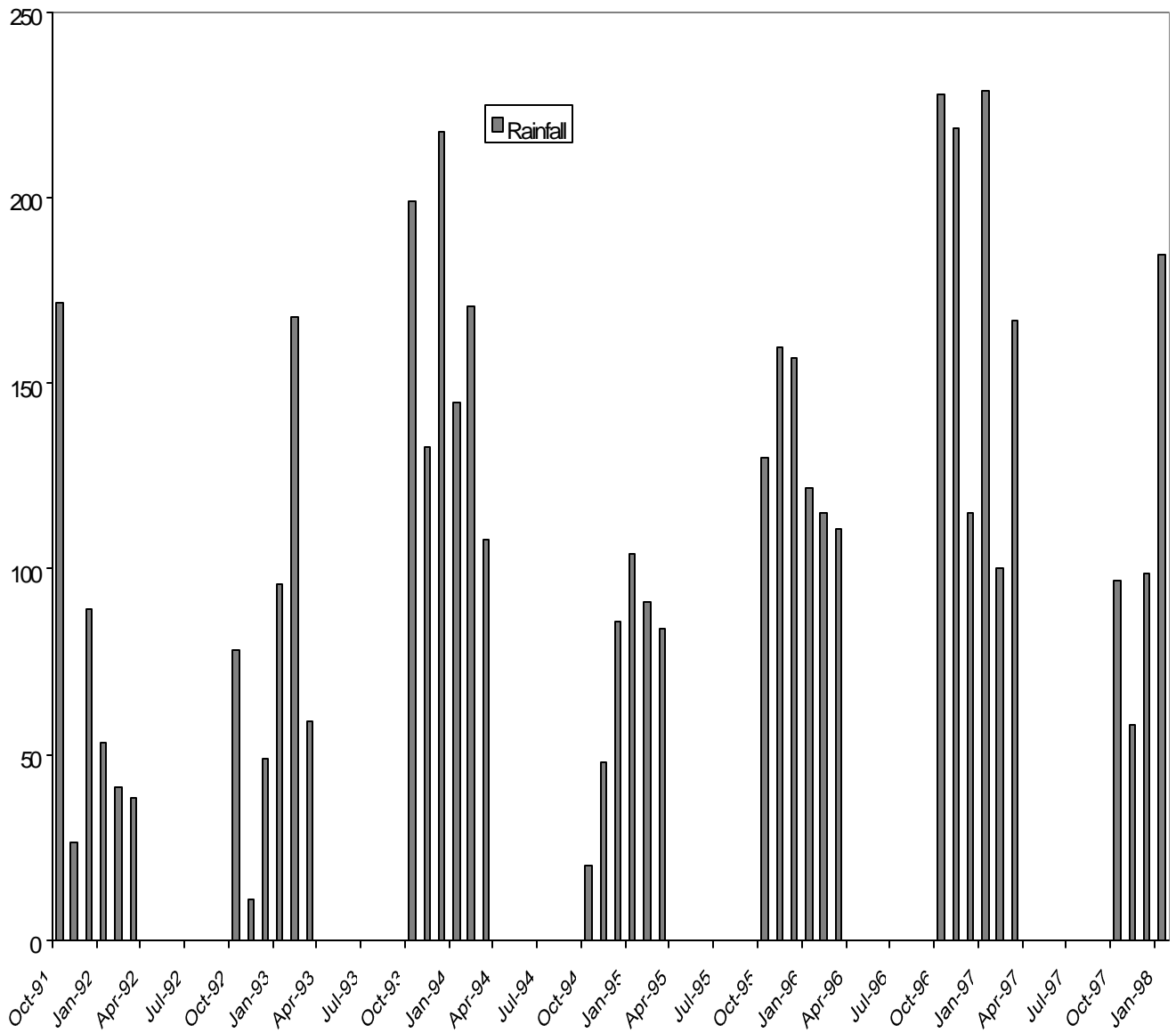


Figure 1.1. Summer rainfall pattern from October 1991 to January 1998 in Katse dam area.

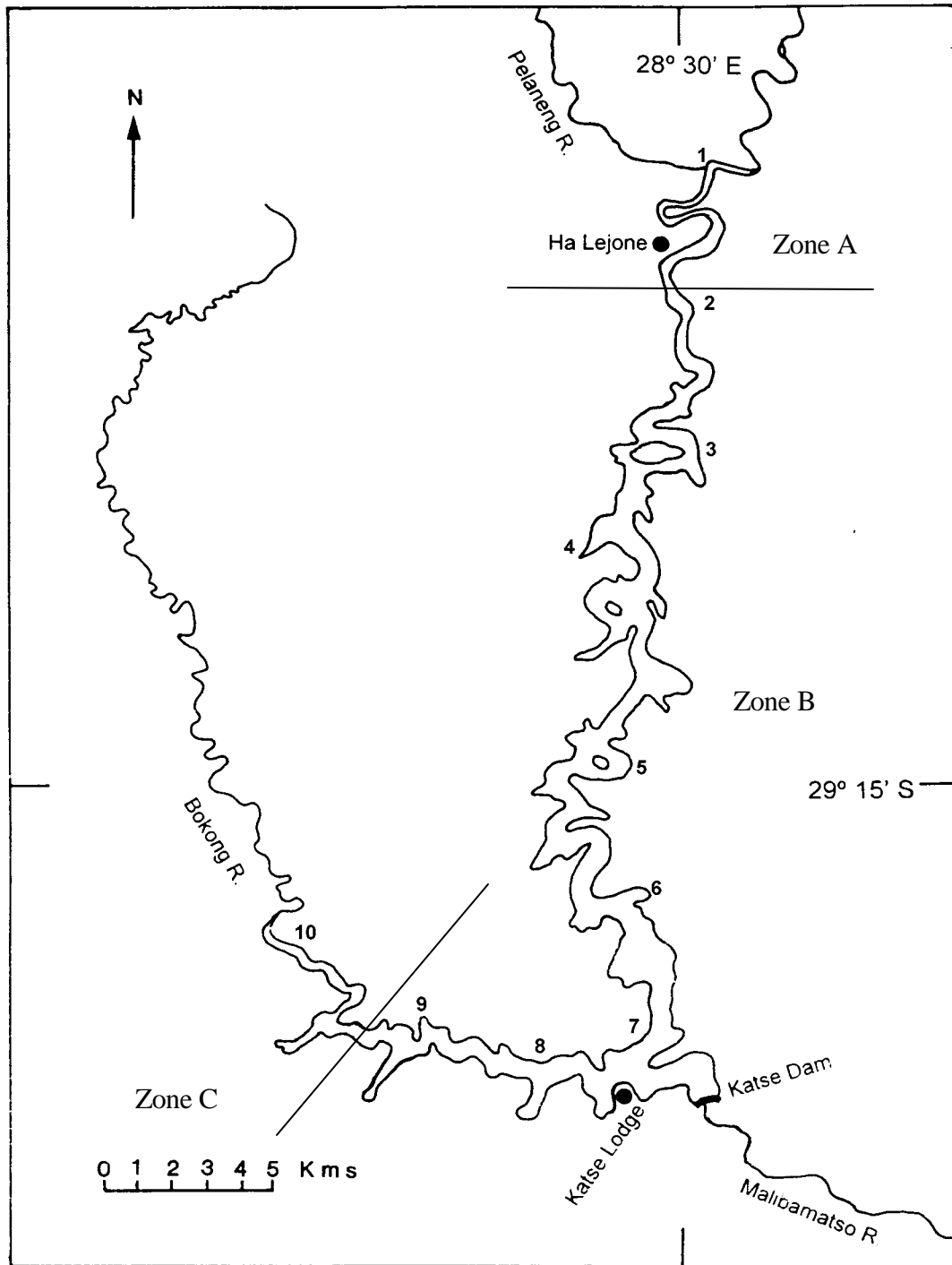


Figure 1.2: A map of Katse dam, Lesotho, showing gillnet sampling sites.

CHAPTER 2

Study Area and General Methodology

2.1 Physico-chemical characteristics of Katse dam.

A clear knowledge of the physical and chemical properties of any water body is necessary for any meaningful conservation and exploitation of aquatic resources (Mwashote & Shimbira 1991). The primary objective of water quality management in regard to fish production is to regulate the environmental conditions so that they are within a desirable range for survival and growth of fish.

Water quality data have been collected monthly by LHDA since 1996. The routine parameters were measured on monthly basis with relevant electronic probes, including oxygen meter, pH meter, conductivity meter, etc. Measurements were made from the surface and at the depth of 30m. The necessary water samples were taken for laboratory analysis. Concentrations of dissolved mineral substances were assessed by the Rand Water board. This database provides an excellent basis upon which to characterise the physical and chemical nature of the Katse dam.

Temperature:

Water temperature in the Katse dam region varies seasonally, ranging from 4° C in winter to mid 20's in summer. Sub-zero temperatures have been recorded in the inflowing rivers but in the reservoir the temperature does not go below zero. Mean maximum summer

temperatures of 20.1 and 20.4 were recorded in January and February respectively. The absolute minimum temperature recorded in the lake during the two years under consideration (1998 & 1999) was 4.1°C and the absolute maximum recorded was 22.5°C. Figure 2.1 shows monthly variation in surface and bottom temperature recorded at the dam wall station. The figure shows that from September to May there was a substantial difference between bottom and surface temperatures with the surface temperature consistently higher during this period. From June to August surface temperatures were virtually the same as bottom temperatures. From this data the following thermal cycle pattern emerges. Total mixing of different layers occurs between June and August at around 10°C. Water tends to get denser with decreasing temperature until it reaches 4°C. Surface temperatures drop in winter due to extremely cold climatic condition and this leads to surface water sinking to the bottom thus causing the lake to become isothermal. Stratification develops in September when temperatures start rising. From October until March a thermocline is formed around 12m depth. From April onwards the thermocline diminishes until it is virtually non-existent in June.

The biological processes such as growth are more rapid at higher temperatures and are often inhibited completely at extremely low temperatures (Eccles 1989). Overall the low temperatures in Katse dam will definitely limit productivity in the lake. This is a common denominator for most high altitude lakes.

Transparency:

Transparency was measured by secchi disc. The average depth visibility varied greatly from month to month. It was generally high between March and September with the highest value recorded in April. In Lake Kariba depth visibility was found to vary between 50cm and 1060cm (Balon & Coche 1974). Water transparency in Lake Kariba is thought to be greater than other African reservoirs where 410cm has been reported as the upper limit (Balon & Coche 1974). Given that water transparency in Katse dam ranges from 100cm to 900cm, the depth visibility of Katse dam should be the second highest in southern Africa after Kariba. This shows that productivity in the lake will certainly not be limited by transparency. The other two man-made lakes (van der Kloof and Gariep) on the Orange River have a very low visibility influenced by the highly turbid Orange River. The depth visibility of van der Kloof dam does not exceed 2 metres (Hart 1986). In these dams productivity is limited by restricted light penetration into deeper waters. In Katse dam light penetration is certainly not a limiting factor.

Dissolved Oxygen:

Oxygen is one of the most significant of all the chemical substances present in natural waters. It regulates metabolic processes of communities and organisms, in particular fish, and it may be taken as an indicator of a lake conditions for their potential production (Balon & Coche 1974). In Katse dam dissolved oxygen was consistently higher than 6mg/L. The lowest mean value of 6.18mg/L was recorded in March. There was a weak negative correlation between dissolved oxygen and water temperature ($r^2=-0.27$). This shows that the amount of dissolved oxygen in the water column is influenced by many

factors other than temperature. But when everything else is equal the concentration of dissolved oxygen in the water column will increase with a decrease in water temperature. In March 1999 when both the thermocline and oxycline were measured, they both occurred at almost the same depth (Fig. 2.2). In general, dissolved oxygen decreases with depth indicating high degree of biochemical activity at the water-mud interface.

Turbidity, TDS, and TSS:

There was a marked spatial variation in turbidity; total dissolved solid and total suspended sediments. Malibamatso station had by far the highest turbidity and total dissolved sediments. This was almost 10 times higher than the average turbidity of all the stations. The high suspended sediments and silt that create high turbidity in this section of the dam originates from Kao mining activities (LVA 1993, Skelton 1996, *pers. obs*). These suspended sediments influence a variety of physical, chemical and biological properties of the aquatic ecosystem (Hart 1986). They reflect light, making turbid waters generally cooler and less productive than more transparent ones (Alabaster & Lloyd 1982). A more direct effect of increased suspended sediments would be its influence on the spawning success of fish. If silt sediments smother gravel bed habitats in the river, then this would have a serious adverse impact on the spawning success of fish, particularly rainbow trout, which are very sensitive to habitat degradation. Compared to van der Kloof, turbidity and total dissolved solids in Katse dam were much lower. Hart (1986) found that primary productivity in van der Kloof dam was limited principally by turbidity. While it cannot be said with certainty that nutrients limit productivity in Katse

dam the recorded turbidity levels would certainly not limit production. Instead, productivity of the reservoir is most likely limited by low temperature.

Dissolved minerals:

Lakes often differ in productivity because of the amount of nutrients present, particularly nitrates and phosphates (Stickney 1989). These nutrients enter the lake with the runoff from surrounding areas. Lakes that receive runoff from agricultural land or sewage input from cities often contain high levels of nutrients. Concentrations of dissolved minerals measured from 6 different stations are summarised in Table 2.1. In decreasing order of concentration, the following anions were present in the reservoir: nitrites (NO_2), phosphates (PO_4) and nitrates (NO_3). The levels of nitrates were highest in September and October and lowest between January and March. Baijot *et al* (1997) found that concentrations of nitrates in reservoirs increase with decreasing water levels. A similar situation is seen in Katse dam where lowest concentration are found in January to March when rainfall is high and the level of water in dam is correspondingly high. The absolute minimum concentration of NO_3 was 0.05 mg/L in February and maximum was 2.2 mg/L in September. Nitrites levels showed a similar trend to Nitrates with the lowest concentrations recorded during the rain season when the water level was high and higher concentrations recorded in spring when the water level was lowest. The mean monthly NO_2 concentrations were always below 0.05 mg/L even in dry season.

Phosphorus is the most limiting nutrient for plant growth in freshwater environments (Stickney 1989). When large amounts of phosphorus are available, phytoplankton blooms

are encouraged, which lead to reduced water clarity. In Katse dam the highest concentrations of phosphates were recorded in October, but throughout the year the concentrations were lower than 0.5 mg/L.

With regard to cations calcium was the most abundant. The minimum average concentration (5.56 mg/L) was recorded in September while the maximum average concentration was recorded in March. Except for October and March the concentration of calcium was always less than 10 mg/L. The highest mean concentrations were recorded in stations further away from river mouths (stations 4 & 5). Mg^{2+} was found to be the second most abundant cation after Ca^{+} . Monthly variation in mean Mg^{2+} concentrations was very low. They ranged from 2.36 mg/L to 3.59 Mg/L. Similar to Calcium, Mg^{2+} concentrations were higher at station 4 and 5. The absolute lowest concentration of 1.4 mg/L was recorded in April at station 1 while the absolute maximum concentration (5.25 mg/L) was recorded in August at station 5. Another metal cation, which had a mean monthly concentration of more than 1 mg/L, was Na^{+} . The absolute maximum concentration of 3.05 mg/L was recorded in January at station 1 (Pelaneng). The last metal cation with significant concentrations was K^{+} . The highest monthly mean concentration for potassium was 0.76 mg/L, which is almost four times lower than that of sodium. Only traces of the rest of the metal cations were measured in Katse dam. Their mean concentrations were all less than 0.09 mg/L.

The only non-metal cation measured during this period of study was NH_4^{+} . The presence of ammonium ions is usually considered to be an indication of pollution. It exists only in

water containing large quantities of decaying organic matter in which the amount of dissolved oxygen is too small to allow production of nitrates (NO_3^-) (Baijot et al. 1997). In Katse dam the concentrations of NH_4^+ were always very low, with mean value below 0.5 mg/L. This is an indication that anaerobic conditions in the reservoir do not exist all year round.

The concentrations of minerals in Katse dam were generally low and do not pose any danger to fish production. The major concern with regard to dissolved solids in reservoir is the danger of excessive eutrophication and toxicity to fish. Heavy metal toxicity is unlikely to happen in Katse dam given that all heavy metal ions only occur in traces. The location of Katse dam also makes it less prone to industrial and domestic pollution, which are the main sources of toxic heavy metal ions and nitrates and phosphates, which are responsible for eutrophication in many water bodies. A possible source of nitrates in the reservoir would be the agricultural activities in the drainage area of the dam. However, agriculture in this area is not highly commercialised and barely uses nitrate and phosphate fertilisers. As a result NO_3^- and PO_4^{3-} influx from agricultural activities is minimum compared to other reservoirs surrounded by populations engaged in commercial agriculture. The observed nitrates concentration is probably a reflection of the geological nature of the substratum.

The data suggest that the main constraints to fish production in the reservoir would be extremely low temperature and sudden decreases in transparency. Given that one of the most important species (*B. aeneus*) preys mainly on zooplankton which in turn prey on

phytoplankton, any reduction in primary productivity would indirectly lead to reduction in production of *B. aeneus*. Low temperatures and increased turbidity due to high total suspended sediments limit primary production. Low temperature limits primary production by its influence on the rate of photosynthesis while low visibility limits light penetration into the water column, which is also very essential for photosynthesis. The vulnerability of zooplankton to *B. aeneus* is also reduced when transparency is low (Hart 1986). Sudden increases in turbidity may adversely affect *O. mykiss* given that the species require clear unpolluted water to survive.

2.2 A synopsis of the distribution and ecology of the three species:

1. Barbus aeneus

The natural distribution of *B. aeneus* is confined to the Orange-Vaal River system. However, the species is now found in number of rivers beyond its natural range. For instance it has been translocated to large Cape coastal rivers such as the Great Fish River, Gourits and Kei (Skelton 1993). It is more adapted to higher altitudes than any other species found in Orange-Vaal system. It prefers clear-flowing waters of large rivers with rocky substrates and also does well in large dams (Skelton 1993). *B. aeneus* is classified as omnivorous but its diet varies with size. Below a length of 100mm, it feeds mainly on zoobenthos, from 101 to 300 mm zooplankton is the principal but in large fish (> 300mm) detritus become increasingly important (Eccles 1986). The species breeds in spring through to mid-summer after the first substantial rains of the season and are renowned for the upstream spawning migrations (Jackson 1990). They are the most abundant indigenous species in the Orange River and its tributaries in Lesotho.

Table 2.1: Concentrations of mineral substances measured from different stations in
Katse:

Parameter	Station 1 Pelaneng	Station 2 Malibatso	Station 3 Upstream	Station 4 Intake	Station 5 Island	Station 6 Bokong	Average
Conductivity (μS)	6.03 ± 1.31	7.28 ± 1.65	8.48 ± 0.94	8.48 ± 0.51	8.62 ± 0.33	5.66 ± 1.46	7.46 ± 0.64
Hardness ($^{\circ}\text{f}$)	25.41 ± 7.9	35.42 ± 9.44	34.86 ± 6.8	44.67 ± 14.4	44.04 ± 15	29.86 ± 18	36.09 ± 6.8
Turbidity (NTU)	1.3 ± 1.81	31.95 ± 26.1	9.6 ± 17.5	1.92 ± 1.9	1.01 ± 0.5	1.39 ± 1.3	7.90 ± 6.3
pH	7.37 ± 0.16	7.57 ± 0.28	7.69 ± 0.18	7.84 ± 0.40	7.83 ± 0.44	7.45 ± 0.33	7.63 ± 0.20
Alkalinity ($^{\circ}\text{f}$)	24.79 ± 4.4	31.54 ± 7.2	36.42 ± 3.2	36.58 ± 2.4	37.5 ± 2.0	21.27 ± 7.0	31.52 ± 3.2
TDS	51.13 ± 11	62.63 ± 14	64.13 ± 11	67.71 ± 8.1	67.67 ± 6.4	48.18 ± 9.0	60.31 ± 7.0
SS	14.71 ± 14	84.79 ± 148	27.04 ± 35	16.83 ± 26	9.75 ± 2.8	8.95 ± 5.0	27.02 ± 26
Ca (mg/L)	6.54 ± 1.9	9.18 ± 3.0	8.79 ± 2.2	11.62 ± 5.1	11.07 ± 4.6	6.11 ± 1.8	8.96 ± 1.7
Mg (mg/L)	2.0 ± 0.43	2.96 ± 0.63	3.21 ± 0.36	3.57 ± 0.45	3.56 ± 0.61	1.99 ± 0.52	2.9 ± 0.34
Na (mg/L)	1.76 ± 1.22	2.12 ± 1.13	1.67 ± 0.77	2.09 ± 1.22	1.53 ± 0.47	2.17 ± 1.23	1.87 ± 0.69
K (mg/L)	$0.55 \pm .15$	0.63 ± 0.12	0.59 ± 0.25	0.7 ± 0.44	0.64 ± 0.17	0.57 ± 0.12	0.61 ± 0.22
Cd (mg/L)	0.03 ± 0.00	0.03 ± 0.02	0.03 ± 0.02	0.03 ± 0.03	0.03 ± 0.02	0.03 ± 0.03	0.03 ± 0.02
Cr (mg/L)	0.02 ± 0.00	0.03 ± 0.01	0.03 ± 0.03	0.02 ± 0.01	0.03 ± 0.01	0.03 ± 0.00	0.03 ± 0.01
Co (mg/L)	0.05 ± 0.02	0.05 ± 0.02	0.05 ± 0.04	0.05 ± 0.02	0.05 ± 0.02	0.05 ± 0.02	0.05 ± 0.02
Cu (mg/L)	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.03	0.05 ± 0.01	0.04 ± 0.01	0.05 ± 0.01	0.05 ± 0.01
Fe (mg/L)	0.04 ± 0.03	0.1 ± 0.06	0.04 ± 0.03	0.07 ± 0.06	0.06 ± 0.05	0.12 ± 0.20	0.07 ± 0.05
Mn (mg/L)	0.05 ± 0.01	0.05 ± 0.01	0.08 ± 0.12	0.05 ± 0.01	0.05 ± 0.02	0.05 ± 0.01	0.05 ± 0.03
Pb (mg/L)	0.07 ± 0.05	0.07 ± 0.05	0.07 ± 0.05	0.07 ± 0.05	0.07 ± 0.05	0.07 ± 0.05	0.07 ± 0.05
Zn (mg/L)	0.04 ± 0.01	0.06 ± 0.01	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.01
Ni (mg/L)	0.05 ± 0.02	0.05 ± 0.02	0.07 ± 0.05	0.05 ± 0.02	0.05 ± 0.02	0.05 ± 0.02	0.05 ± 0.03
Al (mg/L)	0.07 ± 0.04	0.14 ± 0.13	0.06 ± 0.03	0.09 ± 0.07	0.08 ± 0.08	0.07 ± 0.05	0.09 ± 0.05
Mo (mg/L)	0.04 ± 0.02	0.04 ± 0.01	0.05 ± 0.00	0.04 ± 0.01	0.04 ± 0.01	0.04 ± 0.01	0.04 ± 0.01
NH ₄ (mg/L)	0.18 ± 0.24	0.13 ± 0.16	0.27 ± 0.33	0.21 ± 0.22	0.32 ± 0.61	0.12 ± 0.1	0.21 ± 0.24
NO ₂ (mg/L)	0.04 ± 0.07	0.03 ± 0.02	0.02 ± 0.01	0.02 ± 0.01	0.03 ± 0.03	0.04 ± 0.04	0.03 ± 0.02
NO ₃ (mg/L)	0.2 ± 0.16	0.4 ± 0.34	0.47 ± 0.71	0.37 ± 0.52	0.43 ± 0.58	0.46 ± 0.84	0.38 ± 0.50
PO ₄ (mg/L)	0.04 ± 0.05	0.08 ± 0.13	0.09 ± 0.15	0.06 ± 0.09	0.09 ± 0.12	0.08 ± 0.10	0.07 ± 0.10

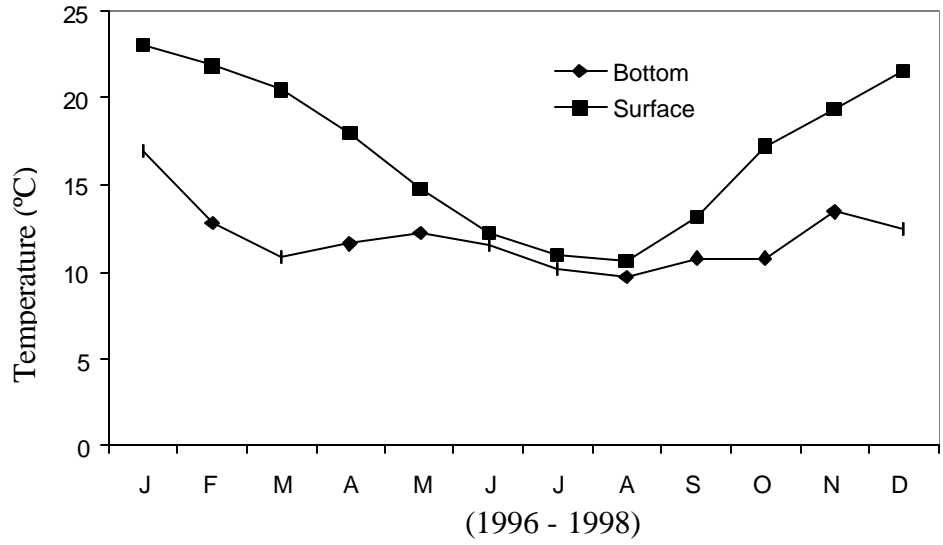


Figure 2.1: Seasonal variation in surface and bottom temperatures in Katse dam

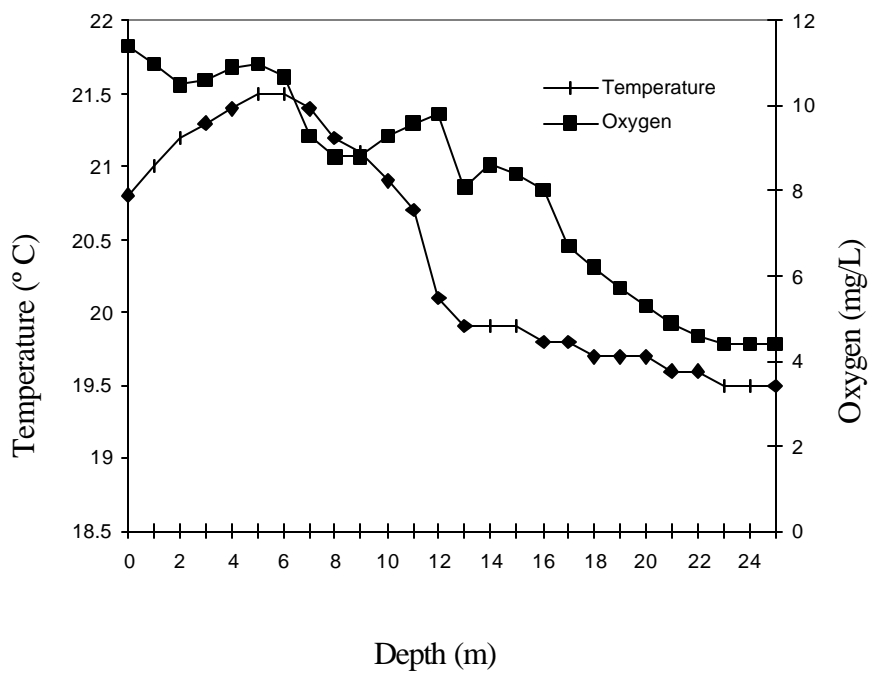


Figure 2.2: Temperature and Oxygen gradient from surface to 25m depth, measured in March 1999 in Katse dam.

2. *Labeo capensis*

The natural distribution of *L. capensis* is also confined to the Orange-Vaal river system. It is the second most abundant indigenous species in the rivers draining into Katse dam. It has also been found to be the most abundant species in the highly turbid Caledon River (Baird 1976). The species prefers running waters of large rivers and also does well in large impoundments (Skelton 1993). It is classified as a substrate feeder and grazes from firm surfaces of the rocks and plants. It breeds in spring or summer after the first substantial floods (Cambray 1985). *L. capensis* attain up to 3.85kg (Skelton 1993), but is not a particularly popular angling fish (Mulder 1973b)

3. *Oncorhynchus mykiss*

Unlike the other two species *O. mykiss* is not endemic to the Orange River system. Its natural range is the rivers of the pacific coast of North America from Mexico to Alaska (Welcomme 1988). It has been widely introduced in temperate and high altitude regions throughout the world (Welcomme 1988). In southern Africa, the species is found in dams and mountain streams of western and eastern Cape, Mpumalanga (formerly eastern Transvaal), Natal, Lesotho, Swaziland, eastern Zimbabwe, and high altitude streams of mount Mulange in Malawi (Skelton 1993). The species was introduced into the highland rivers of Lesotho together with brown trout in 1935 (Shortt-Smith 1963). It has since established itself in the rivers of the Lesotho highlands and it seems to have out competed its sister species (*Salmo trutta*). Its habitat requirements include cool (less than 21 °C), clear and well-aerated waters. Cold flowing water is essential for breeding. Females build redds in which spawning takes place. The species preys on a wide range of animal food

including aquatic insects such as mayfly's nymphs, caddis fly, terrestrial and aerial insects. They also feed on frogs, crabs and fish (Skelton 1993). While it is primarily a predator, it is able to feed to a relatively large size on zooplankton (Eccles 1989).

CHAPTER 3

Age and Growth

3.1 Introduction:

Growth is an important aspect of the ecology and life history of fish, and quantification of growth is frequently a crucial part of fisheries research and management (Pierce *et al.* 1996). Although most fishes have the capacity of sustained though diminishing growth throughout their entire lives, there still exists an ultimate genetic limit to the growth of a species (Lagler *et al.* 1977). Consequently different species have different patterns and rates of growth. Knowledge of growth rate of fish species is important in any fishery development programme (Fagade 1974). It is therefore essential to quantify growth rates and patterns for each species in order to understand the population structure of fish species. Growth rate is influenced by many factors such as food availability, temperature, turbidity, day length, etc. In most cases temperature has an overriding effect due to its influence on the rate of metabolism. This is especially true in cold and temperate climatic conditions such as those prevailing in Katse dam. Rapid growth is experienced in summer when temperatures are high and reduction or cessation of growth is experienced in winter months. Physiological processes such as spawning may also reduce growth. The reduction or cessation in growth rate results in the formation of growth marks on hard parts of the fish such as scales and otoliths. Correct estimation of the age of fish and growth rate is very important for understanding the population dynamics of a species (Pannella 1974, Griffiths 1988).

It is particularly essential in commercially important species where there is a need to put in place control measures such as minimum and maximum size/age limit. Age data in conjunction with length and weight measurements can provide information on stock composition, growth rate, age at maturity, mortality rates and longevity (Cushing 1981).

The general methods of ageing fishes can be broadly divided into direct and indirect methods (FAO 1981). The direct methods of determining age are based on interpreting the layers deposited in hard parts of the fish, paying special attention to interpreting layers that correspond to annual events. These can only be applied to fish species in which changes occur in the rate of growth or metabolism during certain periods of the year, which leave evidence in the hard parts (FAO 1981). The most frequently used structures for age determination are scales and otoliths. Also useful are vertebrae, opercular bones and spines (Royce 1984). Age determination by means of otolith and scale growth rings can be accurate if the patterns can be separated on the basis of seasonal variations from those due to other causes that do not have an annual periodicity.

Scales and otoliths have advantages and disadvantages. The advantage of scales over otoliths is that they are easy to collect, handle, and study. Furthermore, they do not require the sacrifice of the fish for collection (Pannella 1974). Although otoliths require more preparation than scales, validation and verification studies have shown that otoliths have a more distinct zonation, particularly in older fish, and consequently provide more accurate estimates of age (Hecht 1980a, Booth *et al.* 1995). In this study both scales and

otoliths were used for ageing *B. aeneus* and *L. capensis* while in *O. mykiss* only otoliths were used.

3.2 Materials and Methods:

Samples of *B. aeneus*, *O. mykiss* and *L. capensis* were collected monthly from Katse dam between November 1998 and July 1999. Six or more scales were removed from an area immediately below the pectoral fins. They were scraped off using a scalpel and placed in small envelopes. In the laboratory scales were soaked in water containing domestic dish-washing detergent until they were soft, before rubbing gently between fingers to remove any remaining mucus. Scale samples were read with transmitted light using a microfiche reader. The reading of scales was done twice with the second reading taken after two weeks. An age estimate was accepted if the two readings were the same. If they differed by two years or less an average of the two readings was taken as an age estimate. If the two readings differed by more than two years, then the scale was rejected as unreadable. Scales were only used for ageing *B. aeneus* and *L. capensis*.

Sagittal otoliths were collected from the three species by cutting across the head between the opercular and preopercular bones. They were then removed, using a fine forceps. The otoliths were burnt over a low intensity ethanol flame until they turned pale brown. Care was taken not to char the otoliths, as this tends to obscure the internal structure and margin of the otolith (Booth & Merron 1996). The otoliths were then embedded in clear polyester casting resin. They were later prepared for age determination by sectioning

them transversely through the nucleus using a double bladed diamond edged saw. Sections (0.2 – 0.5 mm in diameter) were mounted on microscope slides with DPX mountant and viewed with transmitted light under a Nikon SMZ-2T binocular dissection microscope. The microscope was linked to a video camera and the image was viewed on a TV monitor.

The opaque zones appeared dark under transmitted light. The number of opaque zones was read twice in a space of two weeks. The opaque zones were counted without prior knowledge of the size of the fish or date of capture. If the two readings were the same, the age estimate was accepted. If the two readings did not coincide a third reading was taken and the age estimate was accepted if two of the three readings were the same. If the three readings differed by two years, the mean of the three estimates was taken as a true estimate. However, if the three readings differed by more than two years, the otolith was rejected.

Periodicity of ring formation:

Age validation can be done through several methods. The three most commonly used are the following (FAO, 1981):

1. Observing the timing of ring formation
2. Following a strong year-class through a number of years
3. Using the Petersen method.

The first method is the most frequently used because it is based on sound assumptions. It requires otolith or scale sample for every month of the year. To validate the periodicity of

ring formation the outer perimeter of the otolith sections was examined on monthly intervals (Horn 1997). In otoliths, growth was reflected as alternating opaque and hyaline zones, and the composition of outer margin was noted and expressed as percentage of the monthly sample (Hecht 1980a, Booth *et al.* 1995)

The rings on scales are formed by an interruption of the regular arrangement of the circuli in the anterior field of the scale. Only those rings, which originated in the one lateral field and crossed the anterior into the other lateral field, were regarded as valid (Bruton & Allanson 1974, Hecht 1980a). The number of circuli between the last ring and the anterior margin was noted and expressed as a percentage of the monthly sample. The examination of the scales for the determination of the periodicity of ring formation was restricted to the single size class (210 –240mm FL) as numbers of circuli between annular rings decreases with increasing size (Hecht 1980a).

To check whether scales and otoliths gave similar age estimates, the number of scales that were assigned the same age as otoliths were expressed as a percentage of the otoliths. This was done to determine the best technique for age estimation for these species.

Growth calculations:

Growth models were fitted according to the recommendations of Punt and Hughes (1992). Variance estimates were calculated using the parametric bootstrap resampling method (Efron 1982) with 500 bootstrap iterations. Standard errors and 95% confidence intervals were calculated from the bootstrap data described by Buckland (1984). PC-

YIELD 2.2 (Punt & Hughes 1992) was used to execute the whole procedure. The selected model was the specialised Von-Bertalanffy growth model of the form:

$$L_t = L_\infty [1 - e^{-K(t - t_0)}]$$

Where t_0 is the age at zero length; L_t is the length at age t ; L_∞ is the predicted asymptotic length and K is the Brody growth coefficient (Ricker 1975, Punt & Hughes 1992).

For fish stock assessment and yield optimisation, it is required that growth be expressed in terms of weight (Ricker 1975, Pitcher & Hart 1982, Gulland 1983). It was therefore necessary to express the Von-Bertalanffy growth model in terms of weight:

$$W_t = W_\infty [1 - e^{-K(t - t_0)}]^b$$

Where W_t is weight at age, W_∞ is the asymptotic weight and b is the exponential value from the length-weight relationship. W was determined by substituting L_∞ into the length-weight equation. The relationship between length and weight for fish from a given population is described by the following equation:

$$W = aL^b$$

Where W is weight in grams, L is length in millimetres and a and b are constants (Gulland 1983, King 1995). A logarithmic transformation of this equation is as follows:

$$\text{Log } W = \text{Log } a + b\text{Log}L$$

The length/weight relationship for each species was calculated by linear regression of log FL (cm) against log weight (g) where a = abscissa intercept and b = the slope.

3.3 Results:

The results presented in Figure 3.1 show that in *B. aeneus* and *L. capensis* one hyaline and one opaque zone is deposited in the otoliths each year. In *O. mykiss* only otoliths were used and similarly one hyaline and opaque zone was formed annually. One hyaline and one opaque zone were considered to be an annulus.

For *B. aeneus* otoliths provided better estimates of age than scales. Generally growth rings on *B. aeneus* otoliths were more discernible than on scales. As a result, errors were more likely to occur in estimating age using scales than otoliths. From an age of 3 up to 6 years more than 50% of *B. aeneus* scales had similar number of growth rings as otoliths (Table 3.1). The maximum age estimated from scales was 11 years compared to 12 years from otoliths. The results indicate that scales may underestimate the age of older fish. Tables 3.1 and 3.2 show that there was no age 1 and 2 fish. This suggests that different collecting gear such as seine nets or smaller mesh gillnets should have been used to fill in this gap.

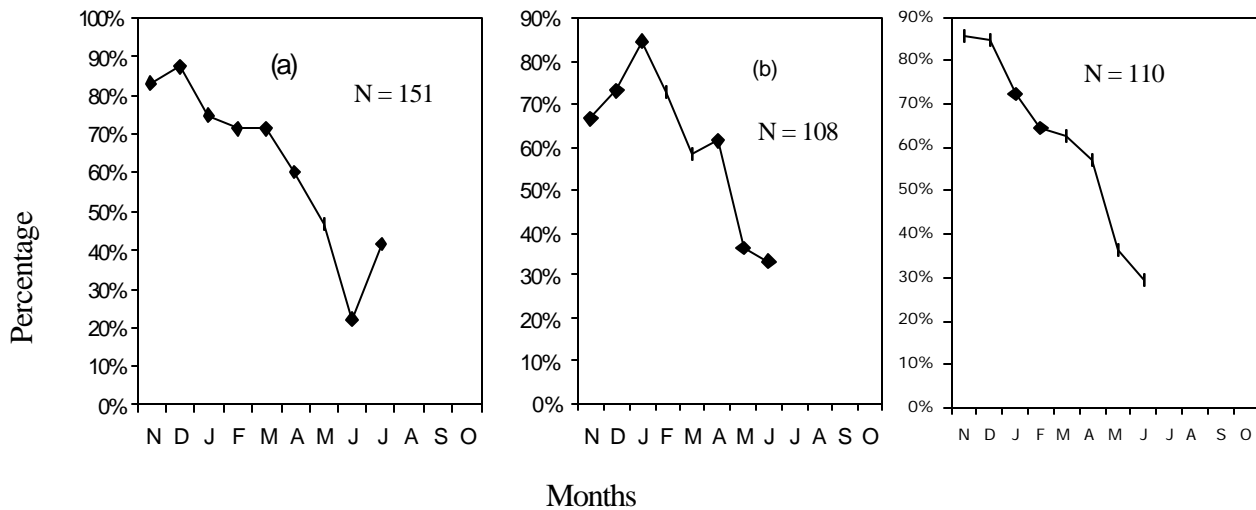


Figure 3.1. The monthly occurrence of an opaque margin in otoliths of (a) *B. aeneus*, (b) *L. capensis*, (c) *O. mykiss* sampled from Katse dam.

For *L. capensis* both scales and otoliths had clearly discernible annuli in all sizes. Except for age 11 and 12 more than 50% of *L. capensis* scales showed similar number of annuli (Table 3.2). The maximum age estimated by both otoliths and scales was the same (12 years). The results show that either of the two techniques can be used to estimate age of *L. capensis* accurately. The proportion of regenerated scales was higher in large size classes of *L. capensis*; therefore caution has to be exercised as the use of these scales could underestimate the age of the fish.

Table 3.1: Percent of *B. aeneus* scales that had the same age as the corresponding otolith.

Age	Number	% Same age
3	20	85%
4	20	75%
5	14	71%
6	19	53%
7	33	42%
8	14	43%
9	13	30%
10	8	25%
11	6	33%
12	3	33%

Table 3.2: Percent of *L. capensis* scales that had the same age as the corresponding otolith.

Age	Number	% Same age
3	18	100
4	32	91
5	27	93
6	11	91
7	2	100
8	7	71
9	6	66
10	7	57
11	7	43
12	5	20

The maximum estimated age for *B. aeneus*, *O. mykiss* and *L. capensis* were 12, 4 and 12 years respectively. Length-at-age for *L. capensis*, *O. mykiss* and *B. aeneus* was adequately described by the Von-Bertalanffy growth model with the calculated length-at-age fitting the observed length-at-age fairly well. This model was selected because its parameters can be used in empirical estimates of natural mortality (Pauly 1980) and in per-recruit modelling (Ricker 1975). The Von-Bertalanffy growth parameters, their associated estimates of variation and confidence limits are presented in Table 3.3 and illustrated in Figure 3.2.

Table 3.3: The Von-Bertalanffy growth parameters, standard error (SE) and 95% confidence intervals for *B. aeneus*, *O. mykiss* and *L. capensis* derived using the absolute error model.

Species	Parameter	Estimate	Standard error	95% confidence
<i>O. mykiss</i>	K	0.21 year ⁻¹	0.0687	(0.054, 0.383)
	L _∞	525.6 mm FL	169.4	(414.6, 1402.06)
	a ₀	-0.904	0.316	(-1.914, -0.436)
<i>L. capensis</i>	K	0.17 year ⁻¹	0.024	(0.12, 0.22)
	L _∞	520.8 mm FL	26.4	(501.43, 616.73)
	a ₀	-0.21	0.31	(-1.043, 0.300)
<i>B. aeneus</i>	K	0.15 year ⁻¹	0.0198	(0.107, 0.207)
	L _∞	603 mm FL	34.99	(563.58, 737.1)
	a ₀	-0.03	0.23	(-0.901, 0.247)

There was no significant difference between length/weight data of males and females in all the three species, hence the length weight relationship was calculated from the combined data. The relationship between fork length and weight of *B. aeneus*, *L. capensis* and *O. mykiss* are presented in Table 3.4. All the three species have b values of less than 3 with *L. capensis* being the closest to 3 of all the species. If b was 3 it would

mean that the fish were growing isometrically (without changing shape) (Wootton 1992). The b values of less than 3 show that all the three species got relatively “thinner” as they grew. Tables 3.5.1 to 3.5.3 show the mean length-at-age and the annual increment in length while tables 3.6 to 3.8 show the age length keys for *B. aeneus*, *O. mykiss* and *L. capensis* respectively.

Table 3.4: Relationship between weight and length of *B. aeneus*, *O. mykiss* and *L. capensis* from Katse dam. Wt = weight, FL = Fork Length.

Relationship	r ²	n
B. aeneus Wt(g) = 0.05 x FL(cm) ^{2.68}	0.93	1900
O. mykiss Wt(g) = 0.02 x FL(cm) ^{2.82}	0.98	1110
L. capensis Wt(g) = 0.024 x FL(cm) ^{2.87}	0.92	973

The growth patterns of *B. aeneus*, *O. mykiss* and *L. capensis* expressed in terms of weight are illustrated in Figure 3.3.

Table 3.5.1: Mean length-at-age for *O. mykiss* and annual increments (mm).

Age	Mean FL (mm)	Annual increment (mm)
1	173 ± 5.41	
2	240 ± 20.86	67
3	294 ± 18.56	54
4	338 ± 76.04	44

Table 3.5.2: Mean length-at-age for *B. aeneus* and annual increments (mm).

Age	Mean FL (mm)	Annual increment (mm)
3	220 ± 10.52	
4	273 ± 22.01	53
5	319 ± 17.34	46
6	359 ± 17.33	40
7	393 ± 22.68	34
8	422 ± 20.68	29
9	447 ± 25.12	25
10	467 ± 15.33	22
11	488 ± 10.07	19
12	504 ± 30.09	16

Table 3.5.3: Mean length-at-age for *L. capensis* and annual increments (mm).

Age	Mean FL (mm)	Annual increment (mm)
3	219 ± 16.10	
4	266 ± 16.18	47
5	306 ± 13.87	40
6	339 ± 25.24	33
7	368 ± 7.07	29
8	392 ± 9.62	24
9	412 ± 9.71	20
10	429 ± 7.35	17
11	443 ± 17.84	14
12	445 ± 16.59	12

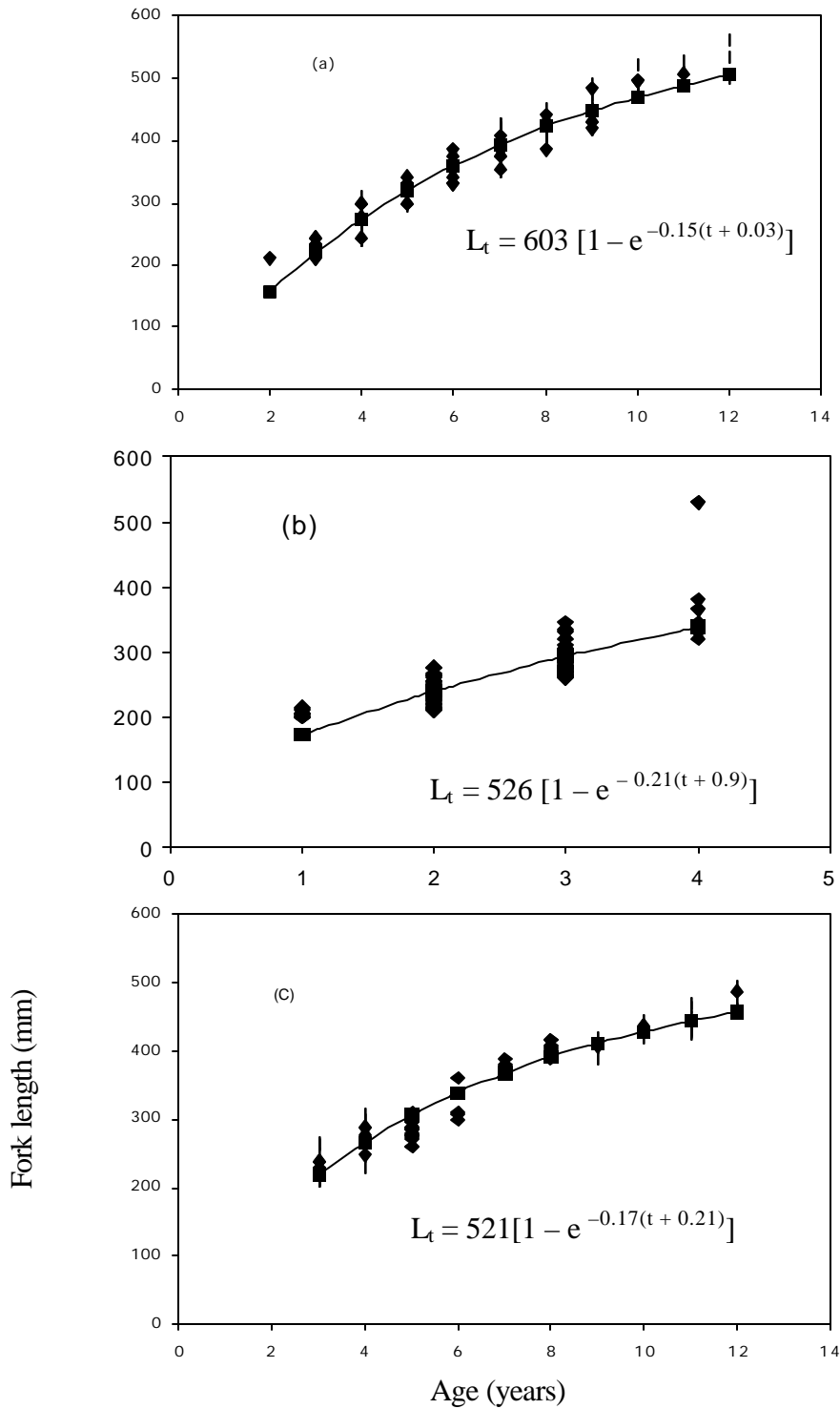


Figure 3.2: Observed and calculated length-at-age of (a) *B. aeneus* (b) *O. mykiss* and (c) *L. capensis*. The growth curve was fitted to combined sex data using the absolute error model of the Von-Bertalanffy growth model.

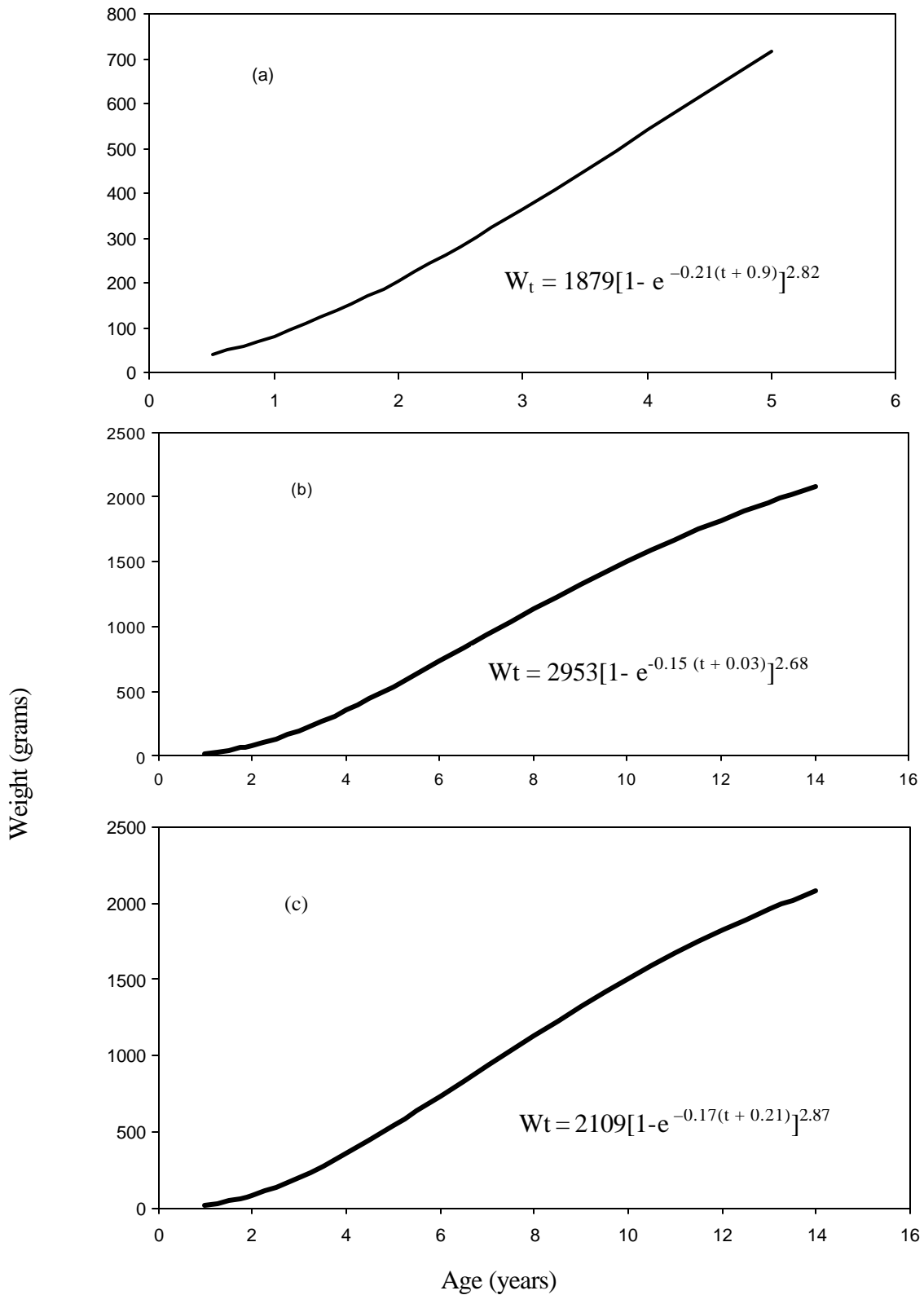


Figure 3.3: Calculated growth in terms of weight for (a) *O. mykiss*, (b) *B. aeneus* and (c) *L. capensis* sampled from Katse dam between May 1998 and June 1999.

Table 3.6: Length-at-age (FL) key for *L. capensis* in Katse dam. Age was estimated from readings of sectioned sagittal otoliths.

Length FL (mm)	Ages									
	3	4	5	6	7	8	9	10	11	12
210 - 219	4									
220 - 229	6									
230 - 239	4	1								
240 - 249	1	2								
250 - 259	1	4								
260 - 269	2	11	2							
270 - 279		7	5							
280 - 289		4	5							
290 - 299		1	5							
300 - 309		2	4	2						
310 - 319			1	1						
320 - 329										
330 - 339										
340 - 349				1						
350 - 359										
360 - 369				1						
370 - 379										
380 - 389					1		1			
390 - 399					1	2	3			
400 - 409						3				
410 - 419						2	1	2	2	
420 - 429							1	4	1	
430 - 439									1	
440 - 449								1	1	1
450 - 459										1
460 - 469									1	1
470 - 479									1	1
480 - 489										1
490 - 499										
n	18	32	27	11	2	7	6	7	7	5

Table 3.7: Length-at-age (FL) key for *O. mykiss* in Katse dam. Age was estimated from readings of sectioned sagittal otoliths.

Length FL (mm)	Age (years)			
	1	2	3	4
200 - 209	6			
210 - 219	2	11		
220 - 229		5		
230 - 239		6		
240 - 249		3		
250 - 259		4		
260 - 269		4	8	
270 - 279		2	17	
280 - 289			13	
290 - 299			6	
300 - 309			4	
310 - 319			1	
320 - 329			1	1
330 - 339			2	2
340 - 349			1	3
350 - 359				
360 - 369				2
370 - 379				
380 - 389				1
390 - 399				
400 - 409				
410 - 419				
420 - 429				
430 - 439				
440 - 449				
450 - 459				
460 - 469				
470 - 479				
480 - 489				
490 - 499				
500 - 509				
510 - 519				
520 - 529				
530 - 539				2
N	8	35	53	11

Table 3.8: Length-at-age (FL) for *B. aeneus* in Katse dam. Age was estimated from readings of sectioned sagittal otoliths.

Length FL (mm)	Age (years)											
	2	3	4	5	6	7	8	9	10	11	12	
210-219	1	4										
220-229		8										
230-239		5										
240-249		3	5									
250-259			2									
260-269			2									
270-279			5									
280-289			1									
290-299			2	2								
300-309			2	3								
310-319			1	2								
320-329				2								
330-339				2	3							
340-349				3	4							
350-359					3	5						
360-369					3	5						
370-379					3	5						
380-389					3	5	2					
390-399						3	3					
400-409						4	1					
410-419						2	2	2				
420-429						4	2	2				
430-439							2	2				
440-449							1	1				
450-459							1	2				
460-469								1				
470-479								1	2			
480-489								1	1			
490-499								1	4	2		
500-509											2	1
510-519											1	
520-529									1	1		
530-539												1
540-549												
550-559												
560-569												1
N	1	20	20	14	19	33	14	13	8	6		3

3.4 Discussion:

Growth rings on hard structures such as scales, otoliths and spines are formed as a response to one or more environmental variables that reduce metabolic rate and result in a slowing of the growth rate (Summerfelt & Hall 1987, Gauldie & Nelson 1990). In tropical and sub-tropical areas growth check formation has often been associated with temporal variation in feeding (Bruton & Allanson 1974) or reproductive periodicity (Booth *et al.* 1995, Booth & Merron 1996). The reason for slow growth rate during high reproductive activity of a species stems from the fact that gonads require energy input for their development and will compete with somatic growth for resources. In temperate regions, abiotic factors play an important role in the growth rate of the fish. Unlike in tropical and sub-tropical regions where reproductive activity induces growth check formation, in temperate areas growth checks are deposited in response to seasonal variation in temperature. Seasonal variation in temperature and other abiotic factors is minimal in tropics and sub-tropics. Consequently biotic factors shape the growth rate of the fish.

The comparison between age estimates using otoliths and scales showed that otoliths in *B. aeneus* were more reliable for age determination. The annuli in otoliths of *B. aeneus* were more discernible than in scales. Consequently in cases where age estimates from scales and otoliths differed, the estimate from otoliths was taken as a true estimate as difficulties in the identification of true annuli in fish scales lead to errors in aging (Bagenal 1974). For *L. capensis* annuli in both scales and otoliths were clearly discernible in all age groups. In Van der kloof dam it was apparent that scales tend to

underestimate age in older age classes of *L. capensis* (Tomasson 1983). Several other authors have also found scales to underestimate age in older fish of different species (Hecht 1980, Booth et al. 1995).

Marginal zone analysis revealed that slow growth in all the three species was experienced in winter. Temperature and reproductive periodicity have been shown to induce growth checks in different species (Bruton & Allanson 1974, Hecht 1980, Booth et al. 1995). In *O. mykiss* reproductive periodicity coincides with the lowest water temperatures in the dam. The mean water temperature in the dam during this time is below 10°C, which is outside the thermal preferendum of the species. This alone should reduce the growth rate of the fish. In addition the high proportion of available energy is used for gonadal recrudescence and is therefore not available for somatic growth. It is therefore safe to conclude that both reproductive periodicity and low temperature are responsible for reduced growth in *O. mykiss*.

For the two cyprinids the two main factors that reduce somatic growth (low temperature & reproductive activity) do not coincide. The fact that experienced was experienced in winter shows that temperature has an overriding effect on all the biotic and abiotic factors that influence growth. Weyl and Booth (1999) found evidence that two growth checks were laid down on scales of *Labeo cylindricus* with one being deposited in winter and another one during the spawning season. The summer growth check was thought to have formed in response to high investment in reproduction and cessation of feeding prior to or during spawning season. Whilst there may be high investment in reproduction for *L.*

capensis in Katse dam there was no evidence to suggest that feeding ceased prior to or during the spawning period. In the van der Kloof dam, Tomasson (1983) concluded that annuli in *B. aeneus* and *L. capensis* are formed when growth resumes in spring. In the Caledon River, Baird (1976) found that annuli in *L. capensis* were deposited in the winter months when the temperature drops and the river ceases to flow. The factors that induce growth check formation in Katse dam and the Caledon River must be similar given the fact that both areas belong to the same river system and changes in climatic conditions follow the same cycle. In the Caledon River growth resumed at the end of August (Baird 1976). Monthly surveys in Katse dam revealed that *L. capensis* only become active in October. This is indicated by the high catch rates of the species from October following non-appearance of the species in the gill net catch from July to September. The increased activity of the fish most probably marks the resumption of intensive feeding which leads to increased growth rate. The extended period of low temperatures in Katse dam as compared to the Caledon River accounts for delayed movement of fish from their refuge areas.

L. capensis in Katse dam reached a maximum age of 12 years compared to 8 years in the Caledon River (Baird 1976). The *L. capensis* population in the Caledon River is subjected to more stressful environmental conditions than in the Malibamatso River (Katse dam). During the dry season the Caledon River ceases to flow completely thus putting a lot of stress on the fish populations which leads to high mortality rates. This probably accounts for the observed low maximum age of *L. capensis* recorded in the Caledon River.

For *B. aeneus* the maximum age recorded in this study was 12 years compared to 10 years recorded by Mulder (1973a) in the Vaal River. The observed difference in longevity is probably due to the fact that fishing pressure in the Malibamatso River before the impoundment had always been low resulting in fish that lived until they reached maximum age. Contrary to the Malibamatso River, in the Vaal River angling has been going on for years (Mulder 1973a). Hook and Line fishing is highly selective. The largest fish are always targeted and caught first. This is probably the reason for the absence of 12 years old *B. aeneus* in the Vaal River.

From the gillnet catches the population age structure of *O. mykiss* consisted mainly of 2 and 3-year-old fish. The 2-year-old fish contributed about 77% of the total annual catch while 3-year-old fish contributed about 20%. This is probably a reflection of high post-spawning mortality of adults. In both *B. aeneus* and *L. capensis* 3 and 4-year-old fish dominated the catches, contributing 50% and 65% respectively. In *B. aeneus* year class 6 and above only contributed 3.89% of the total annual catch compared to 10% of *L. capensis*. There was a dramatic drop in population numbers of *L. capensis* between age 4 and 5 with age 4 making 23% of the total catch while age 5 only made 3%. It is highly unlikely that the observed drop in population numbers is solely a result of mortality. This is probably a reflection of a weak year class or spatial preferences of different size classes.

In lakes fish tend to respond to limitations in food supply by a reduction in individual growth rate rather than a reduction in population numbers (Bryant & Houser 1971). Hence the growth rate of fish in a lake may improve when populations are subjected to heavy fishing pressure or when there is a marked reduction in population density, due to catastrophic natural events. *O. mykiss* population numbers in the dam increased substantially after the filling of Katse dam. During the preliminary survey in 1996 by Tweddle and Davies (1997) the species were in good condition and seemed to be growing well. *O. mykiss* greater than 300mm FL were well represented in the catches (> 85%), giving the impression that trophy size (> 2kg) catches could be common in the area. It has however been observed in this study that the individual growth rate of *O. mykiss* in the reservoir has been very slow. The length frequency distribution for 1998/1999 shows that only few individuals grow beyond 300mm FL.

The mode of population regulation in lakes is particularly important to reservoir fisheries management (Tomasson 1983). During and shortly after filling, reservoirs are usually relatively fertile and this results in an explosion of fish population numbers. As the reservoir matures the productivity is reduced and food supply becomes limiting to high population numbers. This leads to a progressive decrease in individual growth rate and a shift in size structure of the population towards smaller fish (Thompson 1955, Parsons 1958, Jenkins 1970). Although this study did not reveal whether there was any competition for food, it is highly likely that the observed slow growth in *O. mykiss* is a result of a limited food supply for the large population. The effect of reduced productivity in the lake is likely to manifest itself in *O. mykiss* before the other species as it occupies

the highest trophic level of all the species in the dam. Given that a recreational fishery is the primary objective for rainbow trout, large-scale removal of small fish might be necessary to increase the proportion of large fish in the population. However, great caution should be exercised, as there is an alternative explanation for the observed change in size structure of rainbow trout.

The apparent shift in rainbow trout, from a population consisting of large fish in 1996 to that consisting of small fish could also be associated with changes from riverine to lacustrine conditions. Prior to the filling of the dam the rainbow trout was a purely riverine population, whose growth and abundance were regulated by the carrying capacity of the river. The filling of the new dam provided plenty of food and foraging habitats for the fish. The population numbers were very low in relation to the carrying capacity of the dam. The relatively low population numbers combined with the abundance of food and foraging habitats could have resulted in increased growth rate, which lead to a population consisting mainly of large fish. The large spawner biomass and diversity of habitats provided by the new dam ensured good spawning success and reduced juvenile mortality. The increased survival rate of juveniles could have resulted in increased proportion of small fish. Secondly the presence of the dam meant that trout would have to undertake longer spawning migrations than before. This might have resulted in high post-spawning mortality, which further reduced the proportion of large fish in the population.

The Von-Bertalanffy growth curve fitted the observed length-at-age data fairly well. In all species the theoretical asymptotic length differed only slightly with the largest length

recorded for each species. The largest *B. aeneus* recorded in the surveys was 575 mm FL compared to an asymptotic length of 603mm FL. In *L. capensis* the largest specimen sampled was 480mm FL compared to an asymptotic length of 520mm FL. The theoretical asymptotic length for *L. capensis* in Katse dam was essentially the same as that found by Mulder (1973b) in the Vaal River, which was 491mm FL. In the Caledon River the oldest fish (8 years) had an average fork length of 376mm (Baird 1976), but there is no mention of the theoretical maximum length and the length of the largest fish recorded. For *B. aeneus* the asymptotic length computed from Katse dam was much smaller (603 mm FL) than that found by Mulder (1973a) in the Vaal River (765mm FL). The reliability of the growth parameters of *B. aeneus* from the Katse dam and the Vaal River was evaluated using Munro's phi prime test (Sparre & Venema 1992). The phi prime values were almost equal (10.91 and 11.03 respectively) showing that the parameter estimates were reliable. The observed difference in asymptotic length is probably a result of differential growth rates in these two areas. Growth of *B. aeneus* in Katse dam is likely to be slower than in the Vaal River due to extremely low water temperatures experienced in the area during winter. Although the theoretical maximum length for *O. mykiss* was close to the largest specimen sampled (526 Vs 530mm), the 95% confidence limits for this parameter were very wide. This was probably due to the fact that when conditions for growth are optimal, rainbow trout can attain comparatively large sizes. In this case the theoretical maximum length for rainbow trout was calculated based on population consisting mainly of small fish with consequent low precision estimate (Zhao *et al.* 1997). If the age-length data are collected from depressed population in which growth of individuals is slow, the asymptotic length projected by the Von-Bertalanffy growth equation will be an

underestimate compared to maximum observed length of fish in good conditions of growth (Zhao *et al.* 1997). In contrast the growth coefficient (K) is overestimated. Besides yielding low precision estimates this also affects the stock assessment models such as yield per recruit as these model use both K and L_{∞} . The modeling of yield per recruit (Y/R) and spawning stock ratio using an overestimated K value results in an overestimation of optimum fishing levels (Zhao *et al.* 1997).

3. 5 Fisheries considerations:

B. aeneus and *O. mykiss* have potential to support both subsistence and recreational fisheries. On the other hand *L. capensis* can only support a subsistence fishery as this species rarely appears in hook and line catches. From the age and growth studies it is obvious that *B. aeneus* and *L. capensis* are relatively long lived and slow growing species. Much as they may have potential to support a fishery, management should guard against both growth and recruitment over-fishing. If the stocks were to be exposed to overfishing which would result in recruitment failure the fish populations would take a very long time to recover. This may lead to the collapse of the fishery. Contrary to the two cyprinid species, *O. mykiss* is a short-lived species and it grows faster under ideal conditions. However, the results of this study show that the populations in Katse dam have experienced stunted growth. It might therefore be advisable to intensify fishing for this species to fish down populations in order to enhance growth rate. This would in particular benefit the recreational fishermen who mainly target this species and are endeavouring to catch large fish. The intended gill net based subsistence fishery should,

therefore not be viewed as a threat but rather as a benefit to the recreational fishery since it can be used to promote good angling.

CHAPTER 4

Reproductive Biology

4.1 Introduction:

For any organism to be represented genetically in the next generation, it must begin to allocate resources to reproduction at some time in its life (Wootton 1990). Reproductive success is dependent on where and when the fish breed and the resources it allocates to reproduction. Environmental factors play an important role in the reproductive success of a species especially in seasonally variable environments (De Vlaming 1972). There are fish species which have evolved and adapted to certain environmental conditions and can only sustain their populations through reproduction in such conditions. These include fish that have evolved in riverine conditions and those that have evolved in lacustrine conditions. The ongoing impoundment of rivers drastically changes the natural conditions of rivers and in the process affects the reproductive success of certain fish species (Lowe-McConnell 1973).

The fish fauna of a new reservoir depends on the species present in the river prior to impoundment and their response to the changed conditions (Lowe-McConnell 1973). The fish in a new reservoir also face changes in physical and chemical conditions, food availability, and spawning conditions and spawning under new conditions present numerous challenges (Lowe-McConnell 1973). For example, stream spawners have to find tributaries in which to spawn and the young fish have to be able to recruit back into

the reservoir. These challenges are even greater in Katse reservoir as none of the commercially important species are primarily lacustrine fishes (Skelton 1993).

The three principal species, *B. aeneus*, *L. capensis*, and *O. mykiss* are riverine by nature, though they seem to do reasonably well in impoundments (Tomasson *et al.* 1984, Dorgeloh 1986, Skelton 1993). Given the information provided in Chapter 5 it can be assumed that all three have increased their populations since the impoundment. This is an indication that the juveniles have a higher survival rate. However, this does not mean that the impoundment provides ideal conditions for breeding of the three species, as the fish are still basically riverine. Consequently fish production in the lake will arguably not be as high as it would if the three principal species were naturally adapted to lacustrine conditions (Lowe-McConnell 1973).

The onset of sexual maturity represents a critical transition in the life of an individual (Wootton 1990). Reproduction must be timed appropriately for species survival, and an appreciation of the ecology of a species partly depends on understanding its reproductive strategies (De Vlaming 1972). Initially time and resources are only allocated to growth and survival. When sexual maturity is reached these resources are in addition partitioned into reproduction. Patterns of allocation of time and resources to the three essential components (reproduction, growth, and survival) in life, should ensure maximum number of offspring under prevailing environmental conditions (Wootton 1990). Therefore, time and location of reproduction is very important. This is clearly illustrated in species, which undertake extensive seasonal migrations to spawning grounds to ensure optimal

conditions for the survival of the progeny (Wootton 1990, Northcote 1997). Thorpe (1994) regards fish migrations to be “reflections of the major genetic boundaries defining those species within the limitations imposed by their environment”. On the other hand the onset of sexual maturity varies considerably among different species and is subject to considerable variation among different populations of the same species (Nikolskii 1963). Usually the onset of maturity is related to attainment of a particular size by an individual fish (Nikolskii 1963). Size and age at sexual maturity are particularly important in fisheries management. They may be used for the formulation of size limits (Nikolskii 1969), the calculations of natural mortality rates (Rikhter & Efanov 1977) and for the application of spawner biomass per recruit models.

The weight of the gonads has proven to be an important tool in studying gonad conditions. Since gonad weight is closely related to the size of the fish, the influence of the body weight of the fish in analysis is eliminated by the use of a coefficient of maturity, which expresses gonad weight as a percentage of the eviscerated mass (Nikolskii 1963, Marsh *et al.* 1986). Time and frequency of spawning can be deduced from the monthly changes of the coefficient.

The aim of this investigation was to establish the time and duration of the spawning season for the three commercially important species in Katse dam and to determine their age and size at sexual maturity.

4.2 Materials and Methods:

Reproductive studies of fishes, such as assessment of size at sexual maturity, time and duration of spawning season, require knowledge of the stage of gonad development in individual fish (West 1990). The methods employed, range from histology, (which is the most detailed but most time-consuming) to visual staging based on external appearance of the gonad. The most commonly used method for determining gonadal development is the gonadosomatic index (GSI) (deVlammig *et al.* 1982). This method has traditionally been used as an objective support to macroscopical staging, and provides a useful indication of seasonal trends. It may also reflect other aspects of the reproductive cycle such as the spawning strategy of the species (West 1990).

To assess temporal patterns in reproductive activity of the three species, the gonadosomatic index (GSI) was used in conjunction with macroscopic staging (Table 4.1). All fish of maturity stage three (Nikolskii, 1963) and above were considered to be mature. In males this meant that the gonads were clearly larger than those of resting males while in females, eggs had to be visible to the naked eye (Nikolskii 1963), this is stage II in table 4.1.

Table 4.1: The stages of reproductive development as used in this study.

Stages	Description	Appearance of gonads
I	Inactive/Resting	Gonads are very small in size. Testes are transparent while eggs are not visible to the naked eye.
II	Active	Testes change from transparent to pale colour and eggs can be seen with naked eye.
III	Ripe	Gonads are fully developed (covering the whole abdominal cavity) but the gametes do not yet run out when light pressure is applied on the abdomen.
IV	Ripe Running	Eggs or milt are extruded when pressure is applied on the abdomen.

On a monthly basis the mass of gonads from individual fish was measured and the relative gonadal mass was calculated as percentage of total eviscerated mass. Changes in GSI were used to describe the annual reproductive cycle (King 1995). The following equation was used to calculate GSI (Marsh et al. 1986):

$$\text{GSI} = (\text{Gonad Mass}/\text{Eviscerated mass}) * 100$$

Length at sexual maturity was determined for each species and estimated by fitting a logistic ogive to the proportion of reproductively active fish (stage 3 & 4) in 10mm FL classes. The mean length at first reproduction or the length at sexual maturity is defined as the length at which 50 per cent of all individuals are sexually mature (King 1995). The assessment of the proportionality of sexually mature individuals within a population is

normally/advisably done during the peak-spawning period (King 1995). It would be extremely difficult if not impossible to judge whether a fish was mature during a period of lower reproductive activity, as immature fish could easily be confused with individuals in the resting stages. In the case of *O. mykiss* the assessment was done based on samples collected in June and July, while for both *B. aeneus* and *L. capensis* the analysis was done from November to January. The two-parameter logistic ogive to define the length at 50% sexual maturity is described by the equation:

$$P_{(L)} = \frac{1}{1 + e^{-(L - L_{50})/\delta}}$$

where $P_{(L)}$ is the percentage of mature fish at length L , L_{50} the length at sexual maturity and δ the width of the ogive (Booth & Hecht 1997). For both *B. aeneus* and *L. capensis* only male maturity ogives were constructed since there were very few mature females in the gill net catches at that time. For *O. mykiss* both male and female maturity ogives were constructed. Even in larger length classes, the proportion of mature individuals is less than 1, suggesting that, not all-mature individuals are in same reproductive condition at the same time (King 1995). Given that the highest proportion of sexually mature *O. mykiss*, *B. aeneus* and *L. capensis* were 64%, 77% and 56% respectively, the proportions have to be adjusted to represent the number of sexually mature individuals expressed as a proportion of the reproductive population in each size class. The logistic curves for these plots were fitted to data, which were multiplied by correction factors; $(1/0.64 = 1.6)$, $(1/0.77 = 1.3)$ and $(1/0.56 = 1.8)$ for *O. mykiss*, *B. aeneus* and *L. capensis* respectively. An unreasonably high estimation of L_{50} would have been obtained if the logistic curve had been fitted to unadjusted proportions (King 1995). Normalised age-length keys were

used to transform the length frequency distributions to age frequency distribution (Booth & Buxton 1997). Age at sexual maturity was determined by fitting the logistic ogive to age data.

For each species the sex ratio was computed for fish above the size at sexual maturity. Chi-square analyses were performed to ascertain whether the observed ratios deviated significantly from unity (Griffiths 1988).

To establish whether the three species require riverine conditions for breeding and whether they undertake a spawning migration, the proportion of mature (stage 3 & 4) fish in the ripe condition in the Pelaneng and Bokong river interface were compared with the proportion of fish in the ripe condition from the other sampling stations within the reservoir. Chi-square analysis was done to determine whether there was a significant difference between these areas.

4.3 Results:

Sexual maturity:

For *B. aeneus* the onset of sexual maturity is attained at 250mm-fork length. This is achieved after three years of age. The mean length at first reproduction, defined as the length at which 50 percent of all individuals in a population are sexually mature (King 1995) was found to be 285mm fork length (Fig 4.1). The mean age at 50 percent sexual

maturity was calculated to be 4 years. Hundred percent sexual maturity was attained at 330mm-fork length, at an age of 5 years.

For *L. capensis* the onset of sexual maturity was attained at 220mm FL which corresponds to 3 years of age. The length at which 50 percent of all individuals are sexually mature was 244mm FL (Fig 4.1). The mean age 50% maturity was calculated at 4 years. 100 percent sexual maturity was attained at 300mm FL at an age of 5 years.

In *O. mykiss* the length at which 50 percent of all individuals are sexually mature is different in males and females. In males the onset of sexual maturity is attained at 200mm FL and 50 per cent sexual maturity is attained at 235mm FL. This length is attained during the second year of growth. On the other hand, female *O. mykiss* attained 50 percent sexual maturity at 275mm FL, corresponding to the third year of growth. At an age of 4 years 100% of both male and female trout were sexually mature.

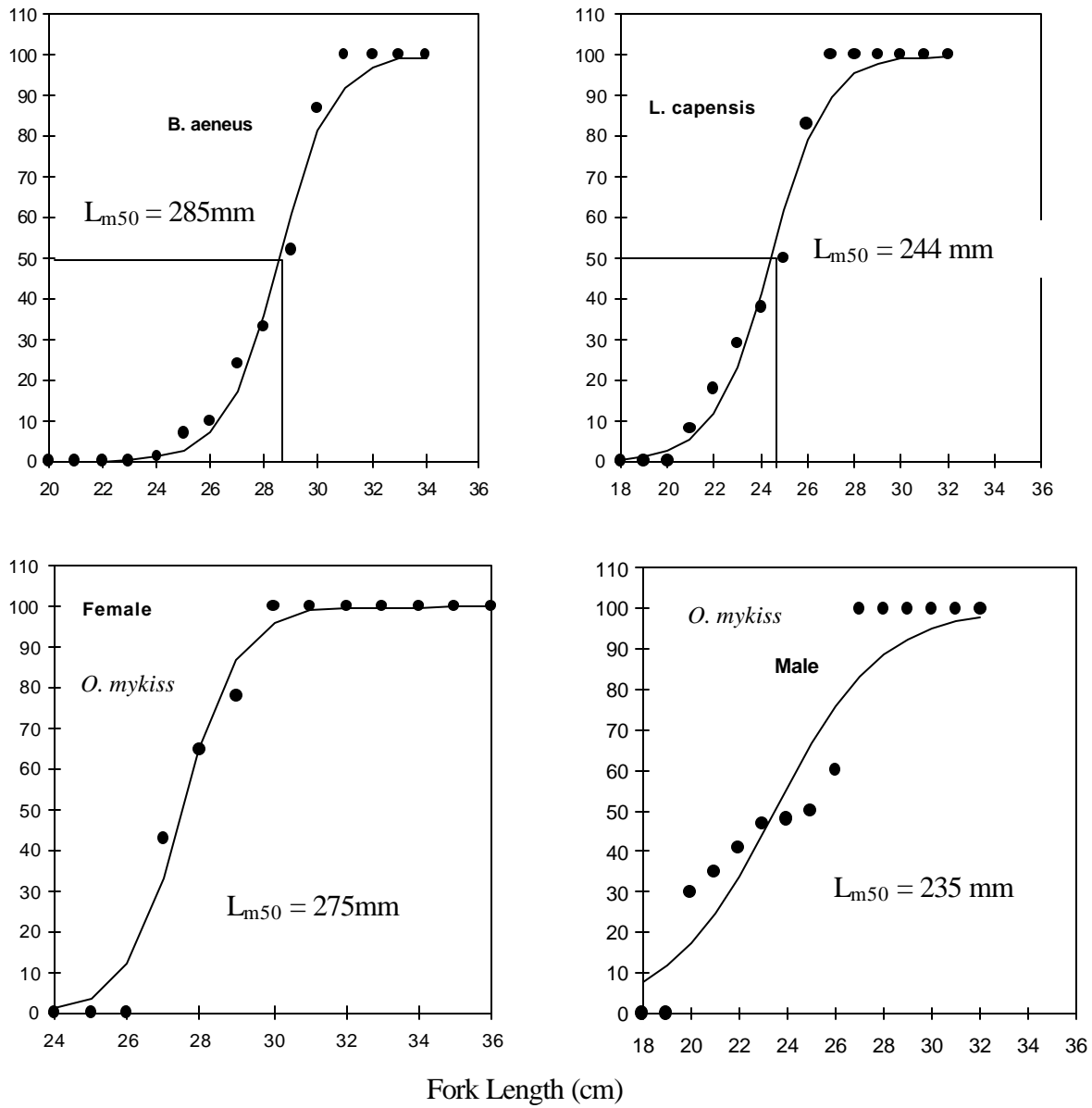


Figure 4.1: Sexual maturity in *B. aeneus*, *L. capensis* and *O. mykiss* Length at 50% sexual maturity was calculated by fitting a logistic ogive to the data.

Sex Ratio:

A total of 1372 mature *B. aeneus* were sampled, of which 42% were male and 58 per cent female. The sex ratio was 1 Γ : 1.38E, differing significantly from unity ($\chi^2 = 16.07$, $df =$

1, $p < 0.05$). From the size at 50 per cent sexual maturity (290 mm FL) to 320mm FL, there was no significant difference in the sex ratio ($p > 0.2$). A significant difference only became apparent in fish greater than 330mm FL.

For *L. capensis* a total of 511 mature individuals were sampled of which 56% were male and 44% female. The sex ratio was 1E: 1.27 Γ , differing significantly from the expected 1: 1 ratio ($\chi^2 = 7.684$, $df = 1$, $p < 0.05$).

In the case of *O. mykiss* a total of 963 mature fish were sampled, of which 62% were female and 38% male. The male: female ratio was 1 Γ : 1.63E, differing significantly from unity ($\chi^2 = 28.67$, $df = 1$, $p < 0.05$). Unlike in *B. aeneus* where the sex ratio is only skewed in larger size classes, in *O. mykiss* the ratio (1 Γ : 1.3E) is already skewed from the onset of sexual maturity. At 250mm FL, the male/female ratio was already significantly different ($\chi^2 = 8.19$, $df = 1$, $p < 0.05$).

Spawning periodicity:

A large number of temperate zone cyprinids have been found to initiate oogonial or spermatogonial proliferation under decreasing photoperiod and temperature (Hontela & Stacey 1990). Under the increasing photoperiod and temperature in the spring, the last maturation stages of oocytes or sperm are completed and spawning takes place in the early summer. Both *B. aeneus* and *L. capensis* seem to follow this pattern.

In *B. aeneus* breeding is confined to the summer season. Gonads only start to ripen around September (Fig 4.4). From September to January there was a steady increase in the proportion of ripe fish (stages 3 & 4) in the monthly catches. After January there was a sharp decline in ripe fish until April when no ripe or ripe running fish were caught. The proportion of mature fish in the ripe condition was significantly dependent on season (summer and winter). The highest percentage of mature fish in the ripe (stages 3 & 4) conditions was found in the two sampling stations at the reservoir/river interface. Twenty eight percent of mature fish caught in both the Bokong and Pelaneng river interfaces were in the ripe conditions, while only 10% from the other sampling stations within the reservoir were in the ripe condition.

The GSI values for *B. aeneus* in summer (November to February) were significantly different from those in winter (May to August). From May to September the GSI values were below one percent (Fig 4.2). From then onwards the GSI increased rapidly until it reached a peak in January (5%), after which it declined to less than 1% in April.

L. capensis in Katse dam also breeds in summer, though a little earlier than *B. aeneus*. *L. capensis* are largely inactive from winter until the first spring rains in October. This is reflected in the monthly catch rates. They only appeared in the experimental gill nets in large numbers in October when the first rains started falling. During this time a considerable percent of the fish in the catches were in the ripe condition. However, no ripe running (stage 4) fish were encountered. In November, the proportion of mature fish in ripe running condition had risen from zero to more than 30%. The catches of ripe

running fish declined considerably in December. The situation changed slightly in January when about 10% of mature fish were in the ripe running condition (Fig 4.3)

The percentage of *L. capensis* in the ripe condition was significantly dependent on season. Similar to *B. aeneus*, there was a significant difference in the spatial distribution of mature fish in the ripe and the ripe running condition. The highest proportion was found in the reservoir/river interfaces. For instance, in November, which is the peak spawning period for *L. capensis*, 50% of mature fish caught at the Pelaneng river interface were in ripe running condition. At the Bokong river interface, about 20% of mature fish were in the ripe or ripe running conditions. At the other sampling stations that are not close to the inflowing rivers, not a single fish was caught, which was in ripe or ripe running condition.

Reproduction in *O. mykiss*, unlike in the two cyprinids, is a winter event. The appearance of mature fish in ripe condition (ripe & ripe running) is solely dependent on season. None of the fish caught from October to April were in stages 3 or 4 (ripe or ripe running). Ripe running fish only appeared in the catches in May and their proportion was highest in July. The monthly GSI values also show a similar pattern to the percent monthly composition of gonad stages (Fig.4.2 & 4.3). They increased steadily from January to April, after which there is a sharp increase from May until August with a peak in July. From August onwards the GSI declined until it reached its lowest level in October.

4.4 Discussion:

B. aeneus

As a rule, the onset of spawning in various cyprinids in the temperate zone ranges from early spring to late summer (Hontela & Stacey 1990). *B. aeneus* was no exception to this rule. From the results of the monthly GSI and gonad maturation stages, it can be seen that *B. aeneus* has an extended spawning period from November to February. Although it can be deduced from gonad maturation stages that peak spawning occurred in January, there is evidence to suggest that spawning is continuous from November to February. This is shown by the occurrence of both male and female individuals in the ripe running condition throughout this period. Tomasson (1983) made a similar observation in van der Kloof dam. The spawning time and place can also be inferred from the presence of juveniles in the spawning areas. During this study period, juveniles started appearing in shoals in the shallow margins of the reservoir/river interface on gravel beds around December but were most abundant in January. However, during the previous survey by Tweddle (1997) juveniles were already abundant in many tributaries of the lake in early December. This suggests that peak spawning period for *B. aeneus* must have been in November. It can be concluded that spawning of *B. aeneus* in Katse dam is an extended event, but is intense during the most favourable environmental conditions within this period. This implies that spawning can be delayed for some time if environmental conditions are not ideal (Tomasson *et al.* 1984, Hontela & Stacey 1990). Such a delay may however result in reduced growth and survival rate of the juveniles because they will have a limited growth period before winter sets in. Consequently they will take a

relatively long time to pass through a highly vulnerable stage of life. This could inevitably reduce the strength of the year class (Tomasson *et al.* 1984).

The environmental factors that are thought to influence the spawning time of this species are temperature and seasonal floods. There was a strong positive correlation between the monthly GSI and water temperature ($r^2 = 0.86$). Although gonad maturation is most likely controlled by endogenous mechanisms (Sumpter 1990 & 1992), the strong positive correlation between temperature and monthly GSI suggests that temperature plays an important role in the maturation of gonads. The monthly GSI was high from November to February during which time temperatures were also at their highest level. When comparing temperatures recorded during this study and those recorded in previous years, it was found that they showed a similar pattern, with the highest mean temperature occurring in February. In 1996/97 peak spawning occurred in November while in 1998/99 it occurred in January. This implies that there is a second environmental factor that plays an important role in determining the time of spawning for this species. Because spawning in *B. aeneus* coincides with the start of the rainy season, the most likely event that triggers spawning are seasonal floods. In 1996, during the filling stages of the dam, the floods came earlier and were very frequent, whereas during this study period they were delayed and were not so intense. This in a way explains why peak spawning in 1996 occurred earlier than in the 1998/99 season. This is consistent with a conclusion made by Tomasson *et al.* 1984, in van der Kloof dam, that spawning in *B. aeneus* is ready to take place in spring, but can spawn in late summer if the season's floods are delayed. It appears that the intensity of the floods also has a profound influence in the spawning

success of *B. aeneus*. In 1996, in almost every tributary there were shoals of juvenile *B. aeneus*, whereas during the 1998/99 period the shoals were mostly confined to the major tributaries (Pelaneng, Malibamatso, & Bokong). It is highly likely that during good floods even small streams provide suitable spawning habitats for the species.

As mentioned in the preceding paragraph, the major spawning areas for the species in Katse dam are the Pelaneng, Bokong and Malibamatso rivers. It would seem that *B. aeneus* only spawn in running waters (streams). However, in Katse reservoir there is circumstantial evidence to suggest that spawning may occur in marginal areas of the reservoir, particularly where there are gravel beds. This is inferred from the presence of juveniles in the shallow margins of the reservoir where there are no streams in close proximity. Small juveniles (~20mm FL) were also observed in relatively large numbers (though not as large as in the major tributaries) where the gravel roads, which used to cross the river before impoundment enter the reservoir. The observation suggests that in the absence of ideal spawning conditions, *B. aeneus* may spawn in sub-optimal conditions provided there is a suitable gravel bed to deposit the eggs and wave action.

L. capensis

Nikolskii (1969) explained sexual differences in abundance and size-at-sexual maturity of fishes as adaptations to survival under specific environmental conditions. Based on Nikolskii's theory, Gaigher *et al.* (1980), described possible adaptive significance of sex ratio and differences in size at sexual maturity in *L. capensis*. In their analysis they found that females reached sexual maturity at a bigger size than males. This led to the

conclusion that the success of fertilisation is probably independent of the size of males. However, in Katse dam, it was not possible to test this hypothesis as very few mature females were caught. Consequently size at sexual maturity was determined for males only.

Gaigher *et al.* (1980) also found the sex ratio changes rapidly in favour of females at the length at which females reach sexual maturity. However, the survey in Katse reservoir revealed the exact opposite. The sex ratio changed rapidly in favour of males from 360mm-fork length and above. A chi-square test was performed in different size classes starting from the size at sexual maturity, to establish whether the ratios were significant. The analysis showed that the sex ratio differences were insignificant from size at sexual maturity (240mm) to 350mm-fork length. For the fish > 360mm the ratios were significantly skewed in favour of males. In an attempt to explain why sex ratios in Katse dam are different from those found in previous studies on this species in the same river system, it is hypothesised that sex ratio in *L. capensis* is not genetically determined but is controlled by prevailing environmental conditions. Whether this is indicative of increased mortality of females with size or whether it is a reflection of a spawning migration in which males reach the spawning grounds before the females and hence are caught in large numbers is presently not known.

From the GSI and maturation stages it can be seen that spawning in *L. capensis* mainly occurs in November. It is thought to be initiated by the first floods of the season. Unlike in *B. aeneus* where there was a strong positive correlation between the monthly GSI and

temperature, in *L. capensis* the correlation was very weak ($r^2 = 0.3$), suggesting that floods are more important than temperature in determining the spawning time for this species (Cambray 1985). In van der Kloof dam, inferred from the catches of juveniles, spawning seemed to occur throughout the whole lake (Tomasson *et al.* 1984). In Katse reservoir there was no evidence to suggest this. The highest proportion of ripe running individuals was found in the river mouths of the major tributaries (Malibamatso, Pelaneng, & Bokong). Tweddle & Davies (1997) argued that the species undertakes upstream migrations for spawning. They hypothesised that the males, which are ready to spawn, congregate at river inflows and stay there to mate with ripe females, which migrate from the reservoir to spawn. This was based on the fact that more ripe running males were caught at the river mouths than females, whereas further down into the dam more females were caught. There is very little evidence to support this suggestion from the current survey. The current data shows that the spatial distribution of *L. capensis* in the reservoir is not uniform. The vast majority of mature and sub-adults *L. capensis* are caught in the river mouth all year round. Even in winter when *L. capensis* catches were extremely low, the few that were caught came from sampling stations close to river mouths. Therefore, the observed high percentage of ripe running individuals in these areas is probably a reflection of the spatial distribution of the species in the reservoir.

O. mykiss:

Unlike the two indigenous species discussed in the preceding section, *O. mykiss* is an alien species. It has, however, sustained its populations over many decades in the rivers on which Katse dam is built. Nonetheless, the species has one thing in common with the

indigenous species; it requires riverine conditions to spawn (Skelton 1993). Before the inundation of the dam spawning habitats for the species were in abundance. Malibamatso River, which is the largest of the three perennial rivers feeding Katse dam, was a winding river with approximately 65km of river of which a 35km section is now inundated. This provided ideal trout spawning habitats. To sustain its populations within this new environment the species has to undertake spawning migrations into the major tributaries. This should not pose any problems for the species as spawning migrations are a common phenomenon in salmonids (Northcote 1997). Homing is characteristic of all five species of eastern pacific salmon *Oncorhynchus spp.*, rainbow trout and cutthroat trout as well as Atlantic salmon *Salmo salar* and brown trout (Northcote 1997). In a lake dwelling population of *O. mykiss* maturing adults undertake spawning migration from feeding to spawning habitats. The spawning habitats are in the lake tributaries and feeding and survival habitats are mainly in lakes (Northcote 1997).

The analysis of the male/female sex ratio shows that females are more abundant than males. When Chi-square test was performed on different length groups (50mm interval) starting from the length at sexual maturity, it was found that the ratio of females was significantly more abundant than males in all length groups. As a result, the observed difference in male and female abundance cannot be attributed to differential mortality.

Male and female *O. mykiss* attained sexual maturity at different sizes. Males mature at much smaller size than females. Biette *et al.* 1981 also observed that the average length of female trout was generally greater than that of males. The difference in size at 50%

sexual maturity in this species obviously has an adaptive significance. As fecundity in fishes increases with size, it is more advantageous for females to attain bigger sizes before sexual maturity (Nikolskii 1969, Downs *et al.* 1997). There is a trade-off between current reproduction and the future expected reproductive output. In semelparous salmonids the cost of reproduction is death while in iteroparous species the breeding and immediate post-breeding period is a time of high mortality (Wootton 1990). Rainbow trout belongs to the iteroparous group and it utilises a lot of energy and resources to produce large eggs and undertake spawning migrations. This means that a fairly small proportion of the available energy and resources are channelled to other aspects of life such as growth and survival. It is therefore important that females mature at a bigger size than males as their reproductive effort far exceeds that of males (Scott 1990). The fact that by September/October (immediately after the breeding period) tiny eggs in the ovaries were already visible to the naked eye shows that female *O. mykiss* have a very short rest period during which to partition their energy resources to other important processes rather than reproduction. This explains why it is essential that reproduction in female trout should only be initiated when somatic growth has reached a certain threshold.

Ripe running individuals were found throughout the entire reservoir but similar to the other two species, they were more abundant in river mouths of the major tributaries. During the quarterly electro-fishing surveys of the Pelaneng River, no mature *O. mykiss* were caught in September, December and March (Fig.4.4). However, in June a considerable number of mature ripe and ripe running individuals were caught. This is an

indication that the species migrates into the rivers to spawn during this time of the year. Besides the major tributaries, there are a few perennial streams flowing into the Katse reservoir, but it is still uncertain whether the trout utilise them for spawning. Nonetheless, it is speculated that they can be used for spawning especially during the years in which there are good winter rains or snow to boost their flows. This is based on the fact that these small streams have sufficient gravel beds, which could provide ideal spawning habitats for trout if there is an adequate water flow. Presently the most suitable spawning areas for trout are the Pelaneng and the Bokong rivers. Malibatso River below the Kao confluence has lately become less suitable for trout spawning due to heavy sediment load from Kao mining. It is also uncertain whether the fish on the Malibatso arm of the reservoir migrate beyond the Kao confluence. This section of the river is in a relatively pristine state. In a previous pre-impoundment survey by Skelton (1996) many rainbow trout were caught in this area using electrofishing. The spawning success in this section of the river is unlikely to boost production in the reservoir, as the area is too far upstream. This leaves only the Pelaneng and the Bokong as ideal spawning areas for trout residing in the dam. Therefore, to avert recruitment failure every effort should be made to prevent all possible sources of environmental degradation in these rivers. Given that *O. mykiss* like many other salmonids have low post spawning survival rate (Wootton 1990) any spawning failure could adversely affect the fishery.

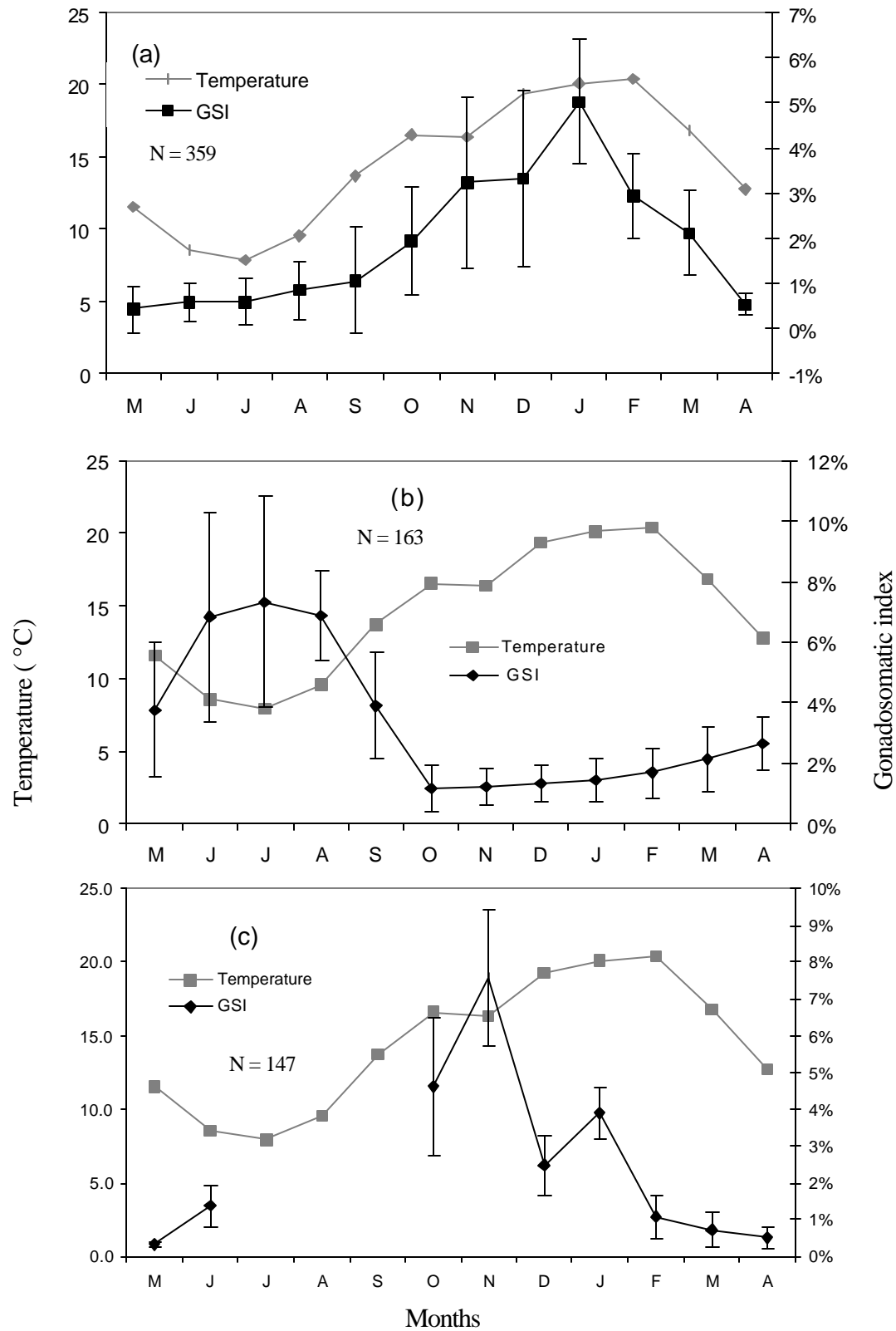


Figure 4.2: Monthly Gonadosomatic Indices (GSI) \pm standard deviation for (a) *B. aeneus*, (b) *O. mykiss* and (c) *L. capensis*

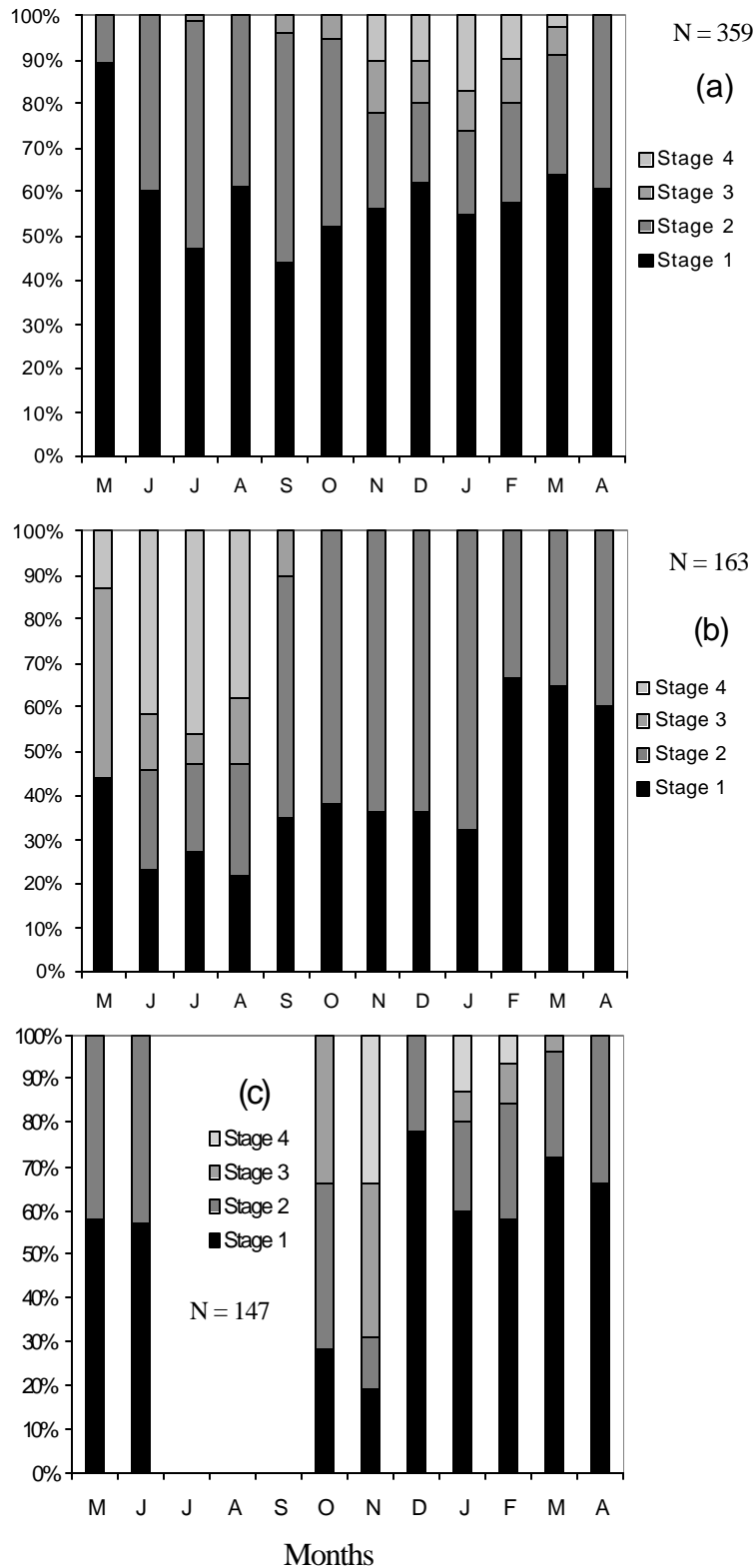


Figure 4.3: Gonad maturity stages for (a) *B. aeneus*, (b) *O. mykiss*, and (c) *L. capensis*.

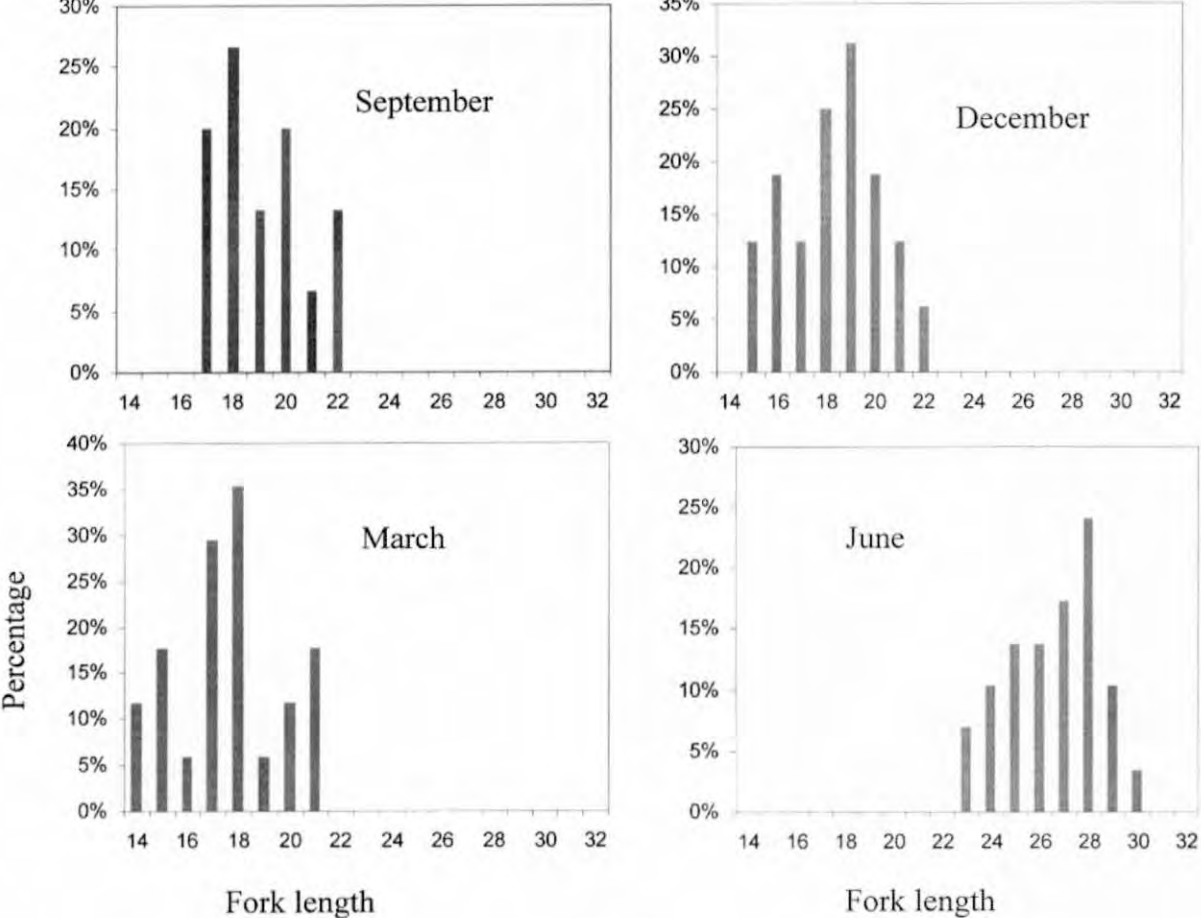


Figure 4.4. Quarterly length frequency distributions of *O. mykiss* taken by electrofishing in the Pelaneng River.

CHAPTER 5

Distribution and Abundance

5.1 Introduction:

The Katse dam started filling in late 1995 and reached maximum capacity in early 1998. Five fish species (*Barbus aeneus*, *Barbus kimberleyensis*, *Labeo capensis*, *Oncorhynchus mykiss* and *Austroglanis sclateri*) were recorded in the rivers before the impoundment of the dam. Four of these species are now caught in the experimental gillnets. However, only three, viz. *O. mykiss*, *L. capensis* and *B. aeneus* have consistently been abundant in the monthly catches.

Fishing in the Lesotho Highlands rivers has always been a part time undertaking especially for herd-boys and fishing effort has been low. Because of the low fishing effort there has been no need for any regulations for fishing. However, since the impoundment of the Malibamatso River the situation has changed.

The establishment of the Lesotho Highlands Water Project (LHWP) led to a large influx of people from all over Lesotho and South Africa, many of whom were employed by construction companies. Those who could not be absorbed in the job market resorted to fishing in the reservoir and rivers. This has resulted in increased fishing effort by several orders of magnitude and therefore necessitates proper regulation. This is also compounded by the fact that most local residents around the new lake have lost their

traditional way of living, mainly in the form of arable and grazing land as a consequence of the inundation. As a result local communities have had to find alternative sources of income, one of which is fishing.

There are two groups of fishermen operating on the reservoir. The first group consists mainly of local fishermen while the second group consists mainly of tourists from South Africa and a few expatriates working for LHWP. Local fishermen fish from the shore using hook and line. Although this group of fishers does not specifically target any species, the bulk of their catch consists of *B. aeneus*. Because most of the shoreline is very steep there are only few fishing spots that are utilised by local fishermen. The highest concentration of fishermen is found near the contractors' camps where job seekers spend most of their time fishing. The most commonly used baits by this group are earthworms, tadpoles and cooked maize meal. Most of their catch is for own consumption and the excess is sold locally. Muth *et al.* (1987) defined subsistence users as people that: consume most of what they produce, sell little in the cash economy, emphasise primitive technology for production and consumption, rely primarily on family labour, maintain a limited economic standard of living, and often must consider individual, family, and group survival in decision making. This group of fishermen can therefore be classified as subsistence fishers as they meet the criteria. The second group of fishermen is recreational fishers. They fish from boats and from the shore. They are highly mobile, fishing the entire length of the reservoir and the in-flowing rivers. They do catch *B. aeneus* but their target species is *O. mykiss*, using mainly artificial lures

including flies and spinners. This group of fishers only fish during their leisure time and they do not normally sell their catch.

The establishment of a small-scale fishery has been identified as one of the alternative sources of income and long-term compensation for seriously affected communities. As mentioned previously local fishers only use hook and line and there are no restrictions on size and bag limit. The plan is to develop small-scale gill net based fisheries for the local communities. This will result in the diversification of fishing gear with its correlate of increased fishing effort on the lake. The end result will be an increase in fishing effort on the fisheries resources of the lake and hence requires appropriate management and regulation of fishing in the area.

The distribution and abundance of commercially important fish species is of vital interest to the fishermen. With data on abundance and weight, the fisheries biologist can make some estimates of production, which provide the basis for developing management strategies (Pitcher & Hart 1982). The abundance of fish species is not a fixed quantity and it varies from one place and one time to another, producing spatial and temporal patterns which fishermen usually learn by experience. Within its area of distribution the abundance of a species will vary with season (Pitcher & Hart 1982). In order to put in place appropriate management plans in the newly formed Katse dam it is essential to determine the distribution and abundance of the fish species that inhabit the reservoir. Knowledge of these aspects will enable the manager to estimate the fisheries potential of the reservoir. The aim of this chapter therefore is to assess the relative abundance of *B.*

aeneus, *L. capensis* and *O. mykiss* and in particular to assess the effect of inflowing rivers on the distribution and relative abundance of these species.

5.2 Materials and Methods:

Catch and fishing effort data are usually collected in all managed fisheries and in fisheries surveys (King 1995). For this study only fisheries independent surveys were used to measure catch and effort because there is no managed fishery in the area and the use of gill nets has not yet started. The use of fishery-independent CPUE data only though limited, still provides good estimates of abundance over time and area, provided a standard gear is used. However, the variability between CPUE's is often very large because catches only represent a small fraction of the total stock (King 1995).

CPUE data were obtained from surveys using multi-filament experimental gill nets between May 1998 to June 1999 at ten different sampling stations. A net-night was taken as one unit of effort. The catch per unit effort (CPUE) was measured as catch in numbers per night. Spatial variation in catch rate was determined by comparing CPUE from different localities. Two-sample T-test was carried out to compare CPUE of each species at different sampling stations with 95% confidence limits. Temporal variation in catch rate was determined by plotting CPUE against time in months. To determine seasonal catch rate, CPUE was calculated separately for four quarters of the year. CPUE's for the three months that make up a quarter were added and divided by three to get a mean CPUE for the quarter. The seasonal variations in temperature and other physical and

chemical characteristics of the reservoir are described in chapter one. The four quarters represented the following months:

1st quarter (winter): June to August; characterised by low temperatures (< 10°C) and receding lake levels

2nd quarter (spring): September to November; characterised by medium temperatures (13 – 16°C) and rapidly receding lake levels

3rd quarter (summer): December to February; characterised by high temperatures (> 19°C) and rising lake levels.

4th quarter (autumn): February to April; characterised by medium temperatures (11 – 16°C) and stable to slowly receding lake levels.

To compare seasonal CPUE data, the non-parametric Kruskal-Wallis one-way analysis of variance (ANOVA) on ranks was applied and Dunn's test (all- pairwise) was used for multiple comparison. A 95% confidence level was calculated for each season.

An index of relative importance (IRI) was calculated to obtain the contribution of each species to the total sample. The IRI (Caddy and Sharp, 1986) was calculated using the formula:

$$IRI = \frac{(\% W_j + \% N_j) * \% F_j}{\sum (\% W_I + \% N_I) * \% F_I} * 100$$

Where %W and %N are percentage weight and number of each species (j) of total catch respectively, %F is percentage frequency of occurrence of each species in the total number of settings and N is total number of species. The index combines the numerical abundance (N), the average size (W) and the commonness (F) of a species and gives the new value as a percentage of the combined value of all species present. This provides a better representation of the ecological importance of the species rather than the weight, numbers or frequency of occurrence alone (Sanyanga 1996).

Shannon's diversity index (H) was used to indicate diversity at different stations. The index is defined as (Begon *et al* 1990):

$$H = -\sum P_i \ln P_i \quad \text{and} \quad H_{\max} = \ln S$$

Where P_i is the number of individuals of each species divided by total number of individuals for all species in each sample.

A total of ten sampling stations were selected and the lake was divided into three zones (A, B & C). The reservoir was zoned in such a way as to determine which of its sections were more productive. This made it possible to compare productivity of different river mouths and the middle section of the reservoir. Zone A and C covered stations 1 and 10 respectively while Zone B covered station 2 to 9. Stations 1 and 10 are in the river mouths while stations 2 to 9 are in the middle section of the reservoir.

5.3 Results:

During the pre-impoundment survey of the Malibamatso River and its tributaries a total of five species were recorded (Skelton 1996). These were *B. aeneus*, *B. kimberleyensis*, *L. capensis*, *O. mykiss* and *A. sclateri*. *B. kimberleyensis* and *A. sclateri* were less abundant than the other three species and hence were not considered candidate species for possible commercial exploitation. In the present study *B. kimberleyensis* has not been recorded and only five *A. sclateri* have been caught in the experimental gill nets. The bulk of the gill net catches in order of importance consisted of *B. aeneus*, *O. mykiss* and *L. capensis*. The Shannon diversity index showed that the species diversity varied from station to station with the highest diversity observed at Stations 1 and 10 and the lowest at Stations 6 and 7.

Relative Abundance:

11612 fish were collected during the study period. Figure 4.1 shows the percent IRI. From this figure it is obvious that *B. aeneus* made the highest contribution by number, weight and frequency of occurrence to the total sample. The combined IRI values for *O. mykiss* and *L. capensis* constituted less than half the IRI value of *B. aeneus* with *O. mykiss* having a slightly higher IRI than *L. capensis*. Figure 5.2 shows the relative abundance by percent fresh weight of each species caught at various stations. From this figure it can be seen that abundance of *B. aeneus* in relation to other species was high in all sampling stations. With the exception of station 9, *O. mykiss* contributed more than 12% fresh weight of the total sample. The highest contribution in weight for *L. capensis* (28%) was recorded at Station (1). Other localities where *L. capensis* contributed more

than 10% fresh weight were Station (4) and (10). In the remaining stations *L. capensis* made a very small contribution to the total catch with less than 1% at Station 6.

The relative abundance of small fish (≤ 210 mm FL) varied seasonally. For *B. aeneus* the proportion of small fish in the monthly samples was highest in August and September and lowest in January and February. For *L. capensis* the proportion was highest in December and January and lowest in October. For *O. mykiss* the July samples had by far the highest proportion of small fish.

Temporal and spatial variation in CPUE:

Total CPUE varied from month to month with the highest catch rates recorded in October and the lowest in July. Total CPUE was consistently higher than 25kg/night except for July when it dropped to 11kg/night (Fig 5.3). With the exception of August, CPUE for *B. aeneus* was higher than that of *L. capensis* and *O. mykiss* combined (Fig. 5.4). In general CPUE for *O. mykiss* was highest from August to October with the August catch rates exceeding those of *B. aeneus*. The lowest catch rates for *O. mykiss* were recorded between January and March. For *L. capensis* the highest CPUE was recorded in November. In January CPUE for *L. capensis* was equal to that of *O. mykiss*. From February to April CPUE for *L. capensis* exceeded that of *O. mykiss* and in May the *L. capensis* catch rate started declining until it was zero from July to September (Fig. 5.4).

Total CPUE also varied from locality to locality. Stations 1 and 10 consistently had the highest catch rates. The analysis of variance showed that CPUE for all the three species at

Stations 1 and 10 was significantly higher than the rest of the other stations (ANOVA, $F = 14.33, 9,110, P < 0.0005$). These stations are situated in the river mouths of the major rivers flowing into the reservoir, namely the Malibatso and the Bokong (see Fig. 1.2). In all the stations sampled *B. aeneus* had the highest CPUE. *O. mykiss* had the second highest CPUE in all the stations except Stations 1 and 10, where *L. capensis* had the second highest catch rates. The lowest catch rates were recorded at Stations 6 and 7, which are in the middle and deepest section of the reservoir. The relationship between depth and catch rate was best described by a power regression (Fig. 5.8). For all the three species catch rates decreased with depth. The decrease in catch rate with depth was highest in *L. capensis* and lowest in *O. mykiss* (Fig. 5.8).

Size distribution:

Having seen that the in-flowing rivers have a great influence on the spatial distribution and abundance of all the three species, the catch data was grouped into three zones (A, B, & C) for size distribution analysis. Two of the three zones were river mouths while the third one was an open water habitat. The two river mouths were not combined so as to allow for comparison, given that they are situated at the extreme ends of the reservoir and are different in size. Zone A comprised of catches collected from Station 1 while Zone B consisted of catches from Station 2 to 9. Finally Zone C comprised of catches from Station 10. Percent length frequency histograms were drawn for each species in each zone to illustrate differences in size distribution. All individuals with fork lengths equal or larger than 400mm were combined and a percent of each size class in the total sample was calculated.

For *B. aeneus* and *O. mykiss* there was no apparent variation in size distribution between zones (Fig. 5.5 & 5.6). The percentage of mature fish (*B. aeneus* & *O. mykiss*) was almost similar between zones, reflecting that of the entire population (Fig. 5.9).

In Zone A all size classes of *L. capensis* were represented (Fig. 5.7). Individuals with 360mm FL or larger contributed more than 22% of the total catch. In Zone B fish smaller than 260mm FL constituted 75% of the total catch and only 0.3% of the total catch were above 360mm FL. In Zone C 66% of the catch consisted of sexually mature individuals (> 250mm FL) compared to Zone B where only 22% of the total catch were above 250mm FL.

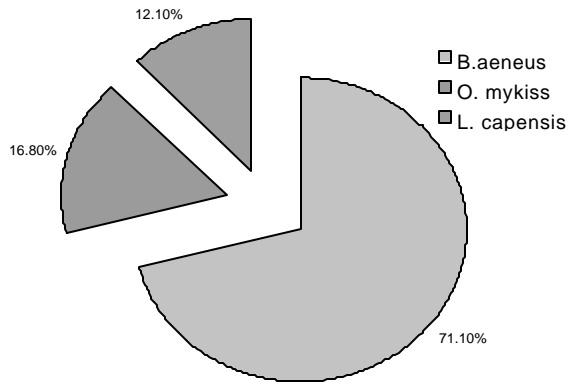
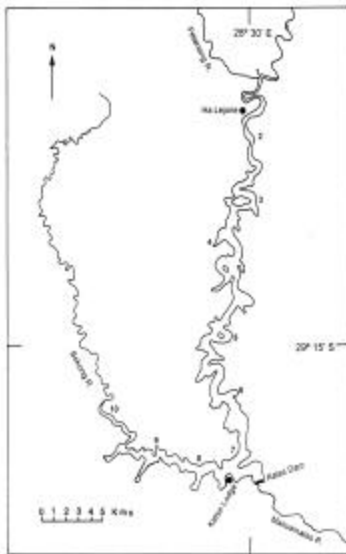


Figure 5.1: Index of Relative Importance (n = 11612)



Map of Katse dam

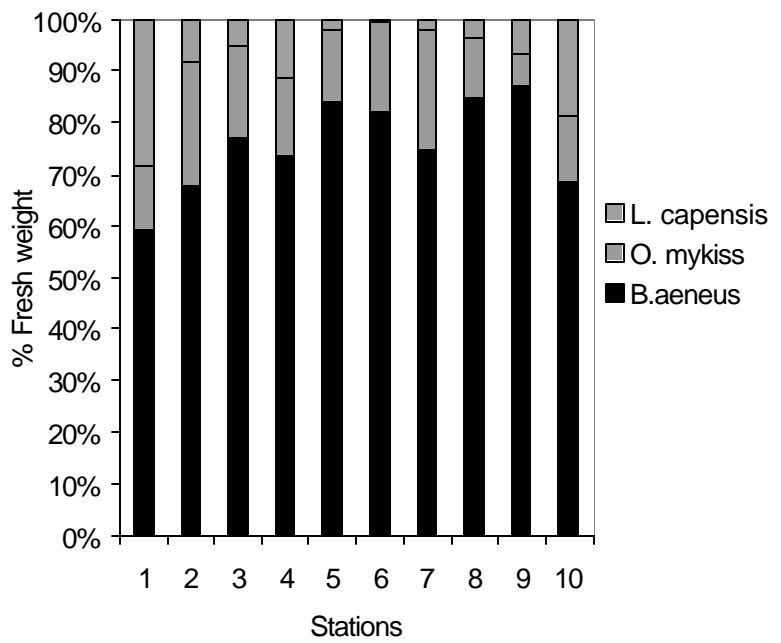


Figure 5.2: Relative abundance by percent fresh weight of species caught at the various stations in Katse dam.

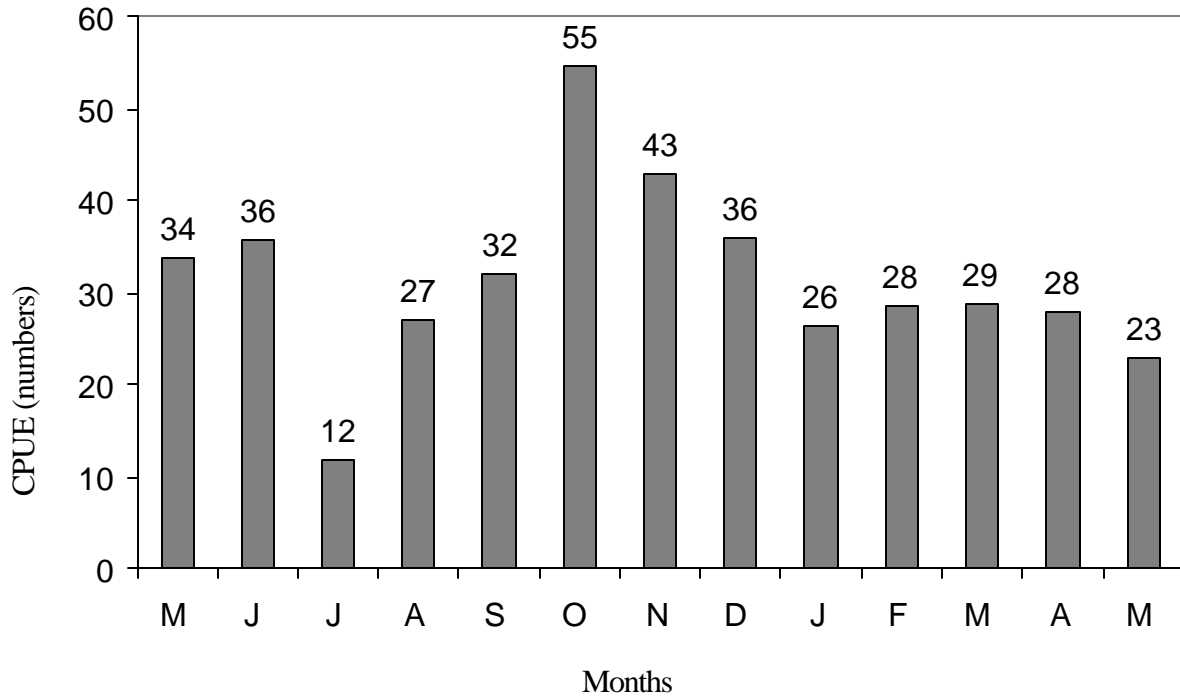


Figure 5.3: Combined total catch per unit effort of *B. aeneus*, *O. mykiss* and *L. capensis* in Katse dam

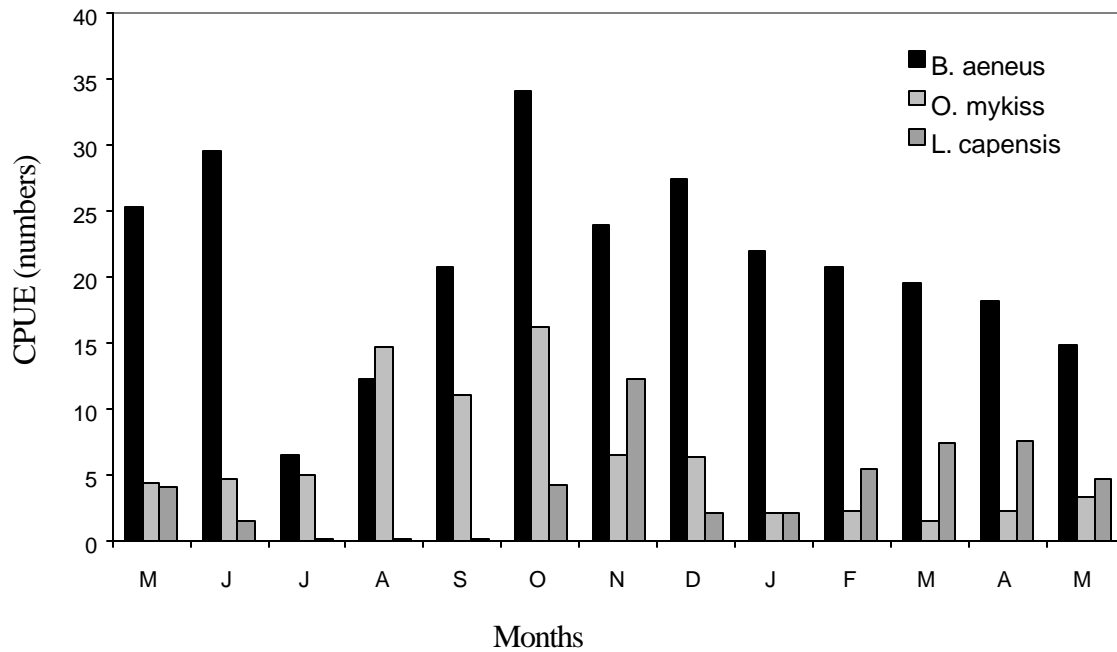


Figure 5.4: Monthly CPUE for the three most important species in Katse dam.

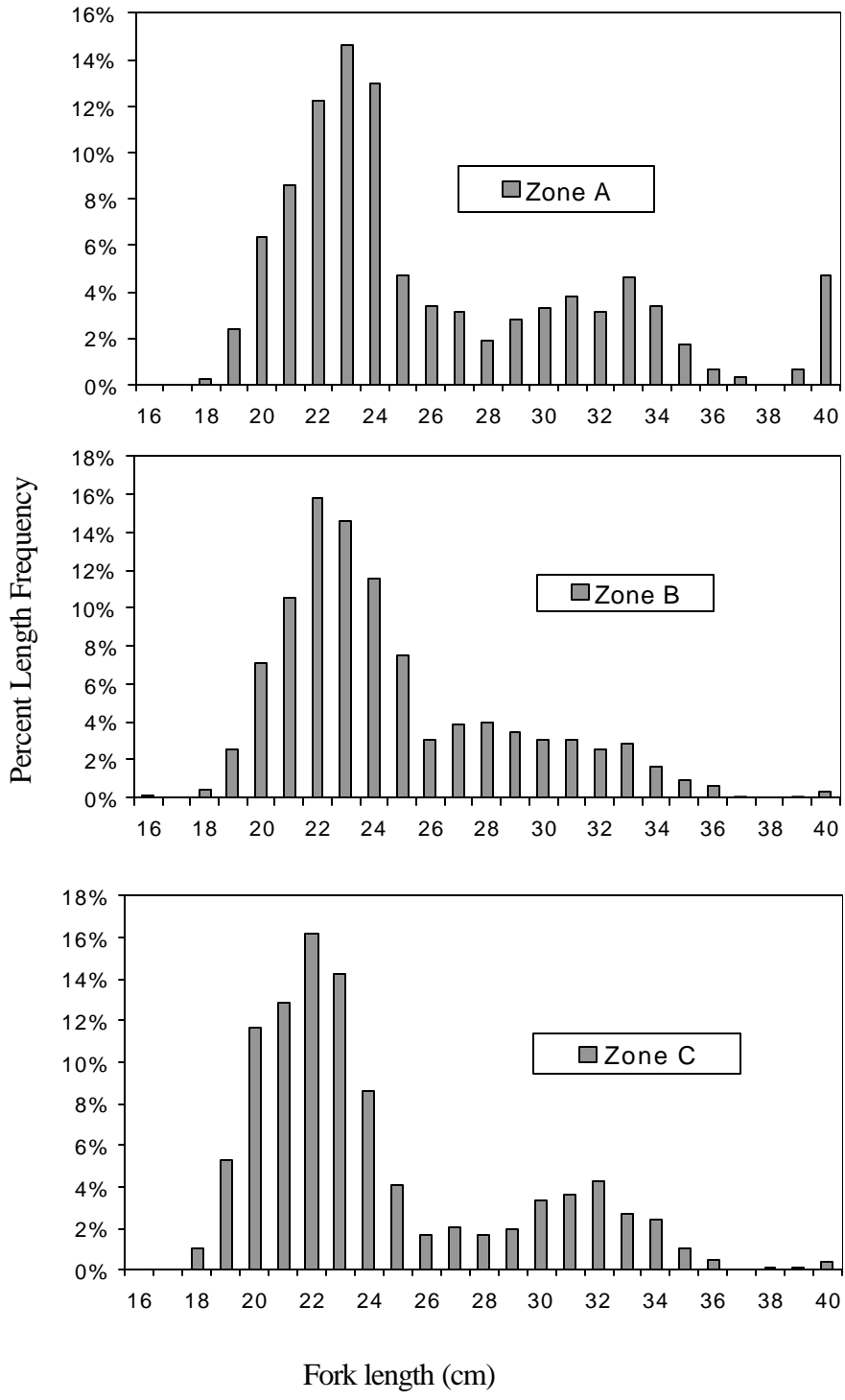


Figure 5.5: Size distribution in zones A, B and C

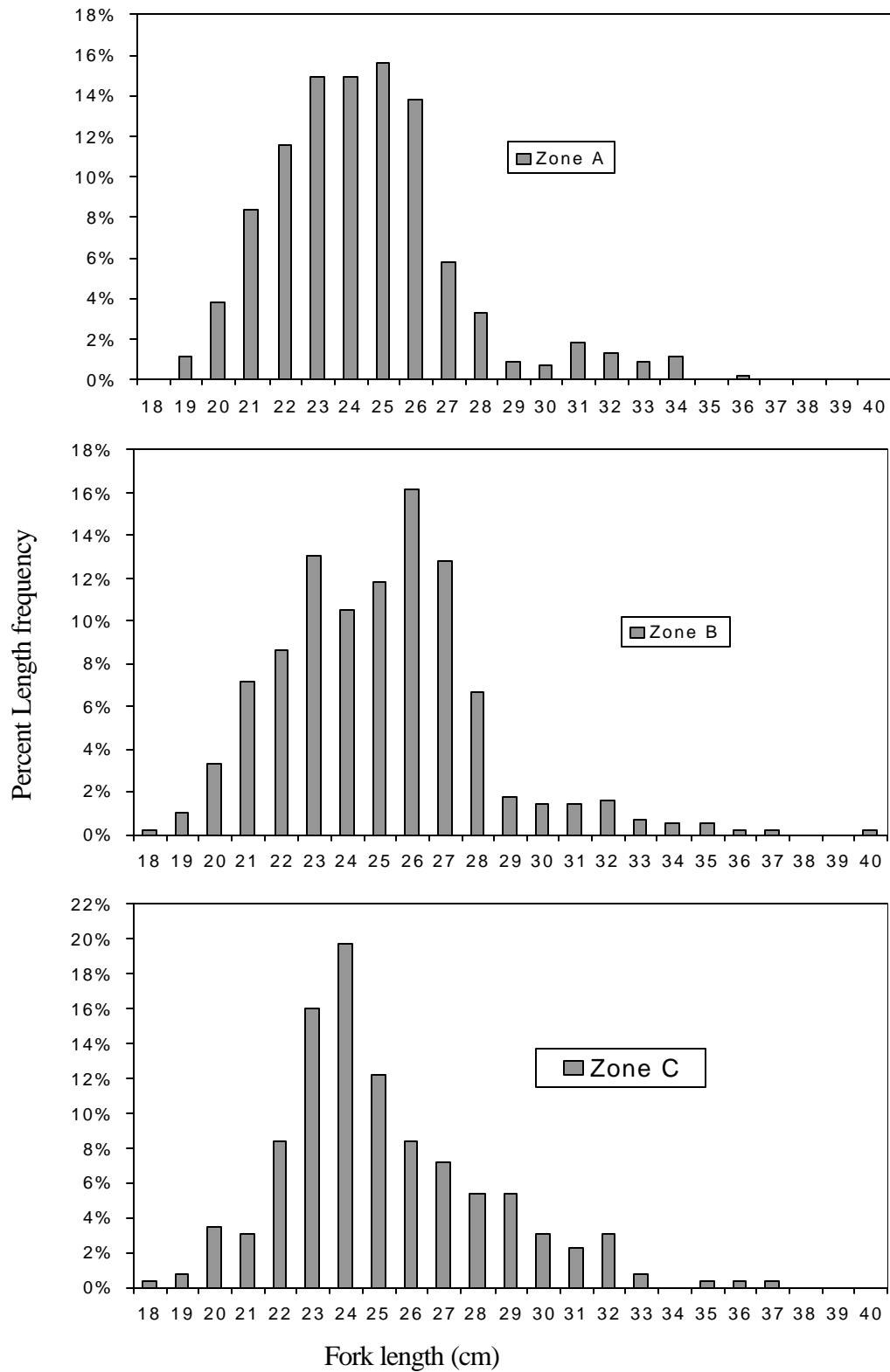


Figure 5.6: Size distribution of *O. mykiss* in zones A, B, and C

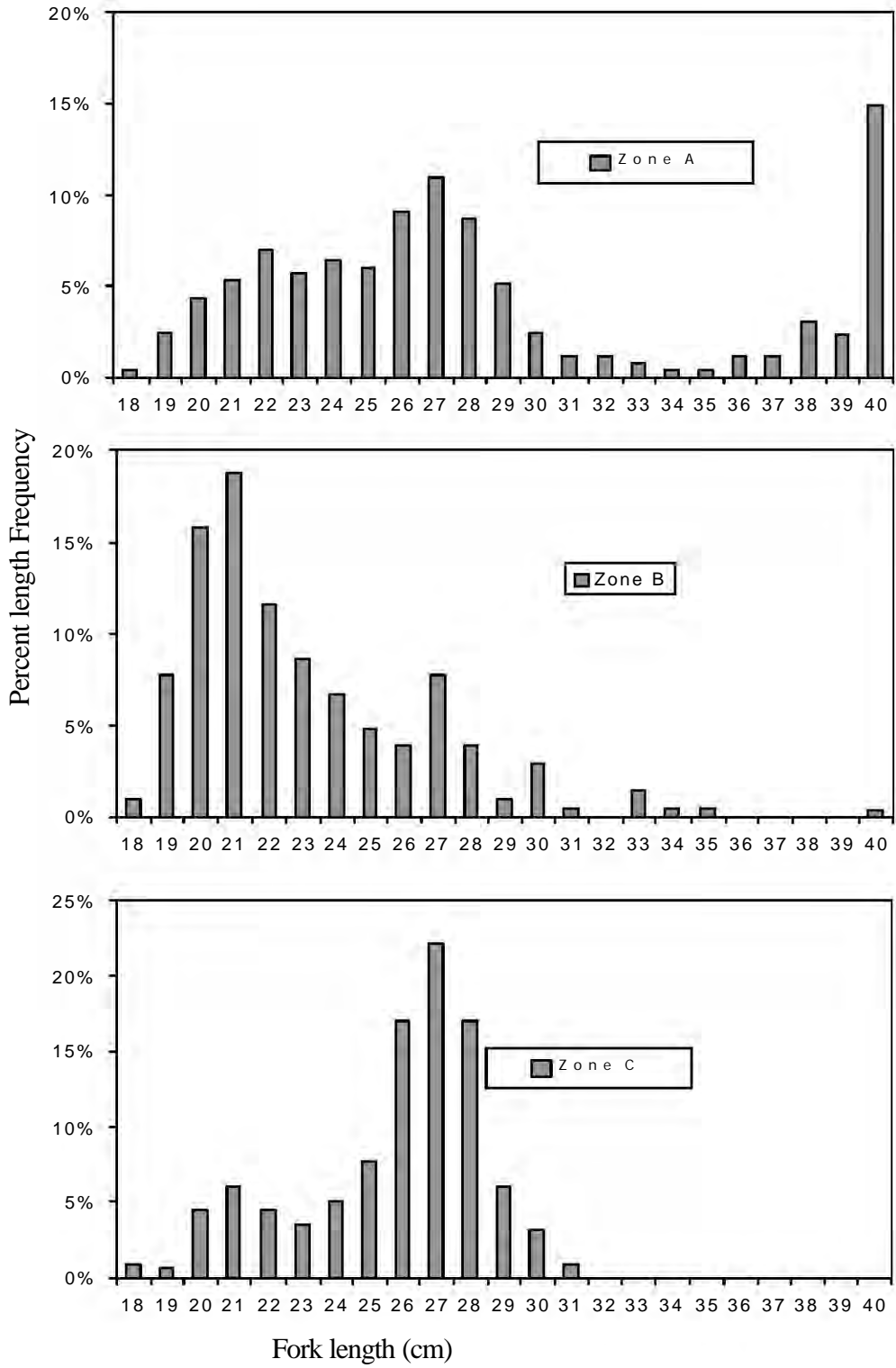


Figure 5.7: Size distribution of *L. capensis* in Zone A, B and C.

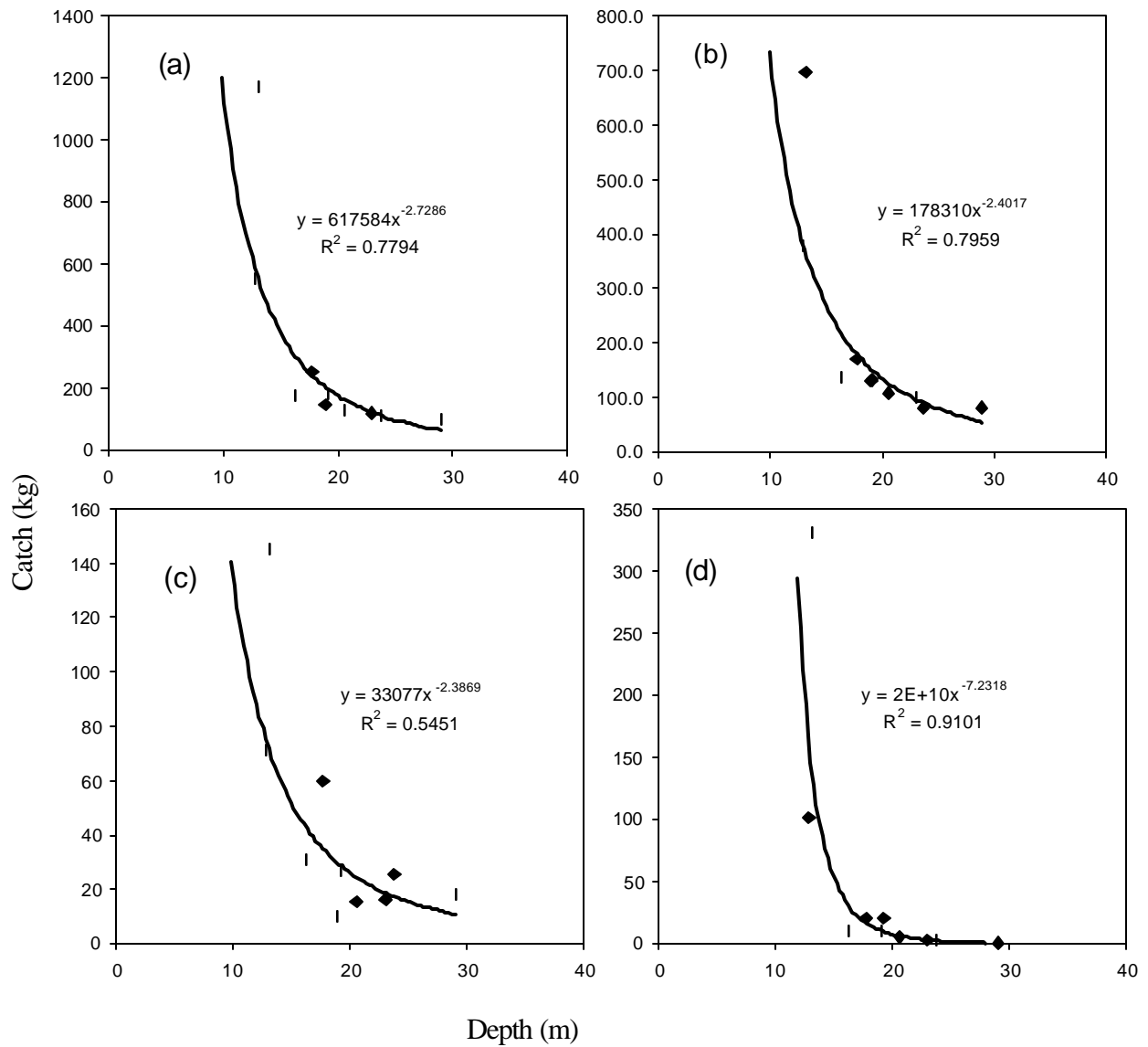


Figure 5.8: Annual catch vs depth (m) for (a) *B. aeneus*, *O. mykiss* and *L. capensis* combined, (b) *B. aeneus*, (c) *O. mykiss* and (d) *L. capensis*.

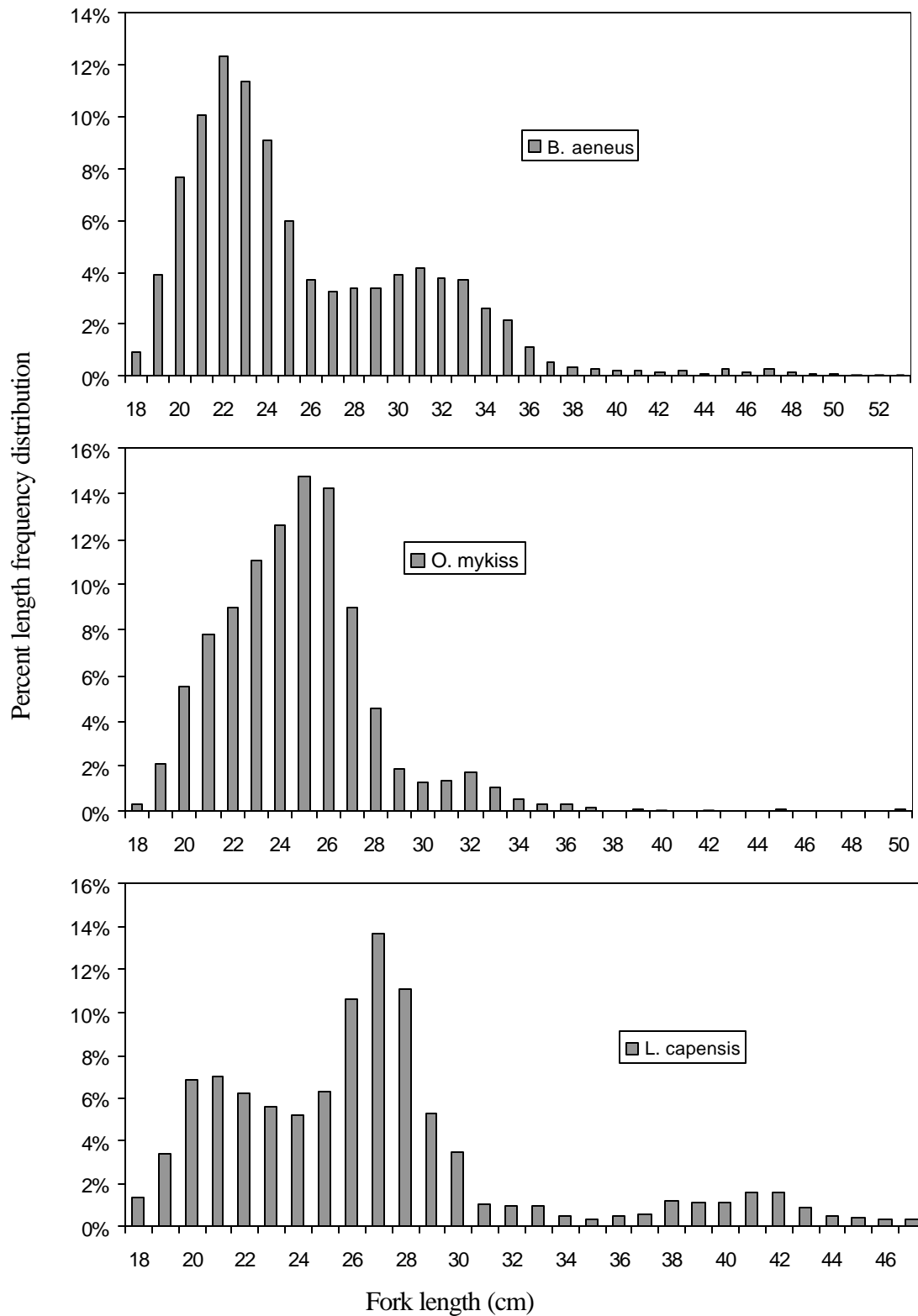


Figure 5.9: Length frequency distribution for *B. aeneus*, *L. capensis* and *O. mykiss* in Katse dam

5.4 Discussion:

In the absence of a commercial fishery, it is often not possible to estimate the standing stock or total population density of a lake (Jackson *et al.* 1983). For Katse dam regular gillnetting made at ten sampling stations from May 1998 to June 1999 has provided valuable data. From these data an index of temporal and spatial change in abundance of the three species was estimated. However caution must be exercised when using this index as CPUE may not necessarily indicate the relative abundance of a species since different species are not equally vulnerable to capture. Although the variability in CPUEs estimated from fishery-independent data is often large (King 1995), there are advantages for using fishery-independent CPUE data over CPUE data collected from an existing commercial fishery. The most important factor that complicates the use of catch rates as an indicator of abundance is the non-random distribution of fishing effort caused by patterns in behaviour of fishers (Worthington *et al.* 1998).

Various physical and biological processes may contribute to the observed variation in CPUE and relative abundance (Underwood *et al.* 1996). Given that the sampling gear (gill nets) used in this study is categorised as passive the factors that will affect CPUE of a species are those that influence the movement and migration pattern. The results show that the CPUE of all the species combined was lowest in winter and highest from spring to autumn. This is an indication that fish were more active when temperatures were high (> 18°C) and less active in winter when temperatures were extremely low (< 10°C). *B. aeneus* and *L. capensis* had lower CPUE in winter than *O. mykiss* and this can be

explained by the fact that trout are more adapted to cold climatic conditions than the other two species. Jackson *et al.* (1983) also found pronounced seasonal variations in catches on van der Kloof dam, which indicated temporal fluctuations and diminished winter activity. The catch rates for *L. capensis* in Katse dam were lower than those of *B. aeneus* during this time. *O. mykiss* on the other hand had the highest CPUE during this time. The explanation for the observed variation in seasonal CPUE is twofold. For the two cyprinids, the low winter temperatures seem to retard their movement and *L. capensis* in particular seem to hibernate hence are rarely caught during winter. Increased movement/migration is resumed as higher spring temperatures set in and this is reflected by the higher catch rates. The movement is further intensified during the spawning period of the species. This is inferred from the fact that CPUE for both *L. capensis* and *B. aeneus* were highest during the peak spawning months from November to January (see Chapter 4). *O. mykiss*, on the other hand, is by nature a cold water species, hence it has a greater tolerance for low water temperatures than the other two species. It is therefore not surprising that trout CPUE was higher in winter than in summer. This period (winter) also coincides with their breeding season and the effects of increased activity due to breeding are again illustrated by the higher catch rates.

Although no indices of abundance were measured prior to the impoundment of the dam, it can be reasonably assumed that the abundance of the three principal species has increased since the inundation of the reservoir. A similar trend was observed in van der Kloof dam where *B. aeneus*, *B. kimberleyensis* and *L. capensis* populations expanded rapidly after the filling of the dam (Tomasson 1983). *B. aeneus* and *L. capensis* made up

over 90% of the catches in the experimental gill nets (Tomasson *et al* 1985). Given the recorded catch data it can be concluded that the three species, particularly *B. aeneus* and *O. mykiss* have succeeded in colonising the entire reservoir. Both CPUE and IRI value for *B. aeneus* were higher than those of *L. capensis* and *O. mykiss* combined. This would suggest that the species has the highest potential for small-scale commercial exploitation. The relatively high abundance of *B. aeneus* in Katse dam may be due to its initial abundance in the river and a greater ability to adapt to the new conditions.

For all the three species CPUE was highest at Station A followed by Station J both of which are at the river mouths of inflowing rivers. This is not too surprising as all the species are of riverine origin and hence are more adapted to riverine conditions than lacustrine conditions. Prior to and immediately after the impoundment of Lake Kariba cyprinids particularly *Labeo altivelis* formed a major component of commercial catches (Kenmuir 1994). However, cyprinid catches soon declined with *L. altivelis* restricted in distribution to the three major affluent rivers of Sanyati basin (the Naodza, Gache Gache and Sanyati) (Kenmuir 1984). It can therefore be seen that cyprinids, particularly *Labeo* species do not readily adapt to lacustrine conditions. This partly explains why the two cyprinids (*B. aeneus* and *L. capensis*) tend to concentrate in the river mouths as opposed to the middle section of the reservoir. It is further hypothesised that the higher CPUE at Station 1 in comparison to Station 10 is because there are two inflowing rivers near this station (see Fig. 1.2), thus providing ideal conditions for *B. aeneus* and *L. capensis*. Another factor that seems to influence catch rates at all the stations is turbidity (chapter 1). There was a strong positive correlation ($r^2 = 0.83$) between total CPUE and turbidity.

Though not tested it can be hypothesised that when turbidity is low fish tend to see the gill nets and can therefore easily avoid them. There was also a negative correlation between depth and CPUE. This can be explained by habitat preferences of the different species. *L. capensis* is by nature a bottom feeder (Skelton 1993, Tweddle & Davies 1997). It is hypothesised that the species is found in large numbers in shallow areas as opposed to deep open waters for two possible reasons. Firstly, the fish stay near the bottom and are therefore less susceptible to floating gill nets in deep waters. The second, and most likely scenario, is that the preferred habitat (bottom) for *L. capensis* is too deep and is most likely unsuitable for the species. This partly explains why CPUE of *L. capensis* at Station 5, 6 and 7 (Fig 5.4), all of which are deep, was almost zero. The other two species are opportunistic feeders and their distribution and abundance are less likely to be influenced by depth. This is reflected in their size distribution within the reservoir (Fig. 5.5 & 5.6) which was similar throughout the entire reservoir.

As mentioned earlier *L. capensis*, unlike the other two species were rarely caught at stations close to the dam wall. Tomasson (1983) postulated that the relatively high abundance of *L. capensis* in van der Kloof dam might be due to its initial abundance in the river and the long rocky shore of the lake. Katse dam, unlike van der Kloof dam, has a very steep shoreline and a limited littoral zone. As a result *L. capensis* is only found in abundance near the river mouths where the depth is < 20m. Another observation of note was that the *L. capensis* catches at Station 1 in November were even higher than those for *B. aeneus*. The increased catches were due to the presence of large breeding aggregations in the area at that time. Tweddle and Davies (1997) made a similar observation in the

survey of fish populations during the initial filling stages of the reservoir. It is possible that the catchability of the species increases during spawning, as they are highly active in shallow areas. Breeding in *L. capensis* coincides with the spring run-off thus increasing turbidity, which in turn increase the probability of capture by a passive gear as it impairs vision (Leggett & Jones 1971, Hamley 1975).

The size distribution of *B. aeneus* and *O. mykiss* was almost similar at all stations. This is an indication that the populations of these species move extensively throughout the reservoir. Only sub-adult *L. capensis* were caught in Zone B while in Zones C and A both adults and sub-adults were caught. In contrast large *L. capensis* were caught at Stations 1, 4 and 10 and their absence at all the other stations supports the hypothesis that the large individuals remain in these areas all year round. The relatively high abundance of *L. capensis* at Station 4 is attributed to the fact that the station is situated near a perennial stream. This provides ideal conditions for their benthic habits.

CHAPTER 6

Mortality and Gillnet Selectivity

6.1 Introduction:

It is well known fact that every fishing gear is selective to some degree. For instance very small fish are less likely to be retained than large ones in a trawl net, whereas in gill net both very small and very large fish are unlikely to be caught depending on the mesh (King 1995). The only gear currently in use by both local and recreational is hook and line. No assessment of the hook and line fishery was done, instead gear selectivity studies were only done for the fishery independent experimental gill nets.

Studies of fish populations depend on equipment and methods that provide a representative catch of all length classes of interest (Jensen 1986). A net of a certain mesh size is highly selective and its efficiency varies with fish of different lengths. Gill nets are popular for sampling inland waters because of their versatility, low cost and ease of operation (Hamley 1975). They can be used in lakes of any size and on large or small-scale fisheries. Hamley (1980) identified a number of problems of sampling with gill nets and the most important one being that the amount of gillnetting effort cannot be related to the volume of water or area of the bottom fished. With some active gear like trawls, one can calculate what proportion of a lake has been swept and, from that, what proportion of its fish has been subjected to the fishing gear. Unlike trawls, gill nets are passive gear and fish have to swim into the net to be caught. Gillnets are highly size selective and great

care has to be exercised to ensure that the mesh size used in any assessment catch a representative component of each size or age class of the population.

To assess the selectivity of gillnets a range of mesh sizes have to be used (Hamley & Regier 1973), otherwise the catch will not be a representative sample of each size or age class. Factors that affect either of these probabilities will affect net selectivity. Based on this Rudstum *et al.* (1984) concluded that the size selectivity of gill nets is best considered as a characteristic of the entire fishing operation. It is therefore essential to consider all these factors when estimating gear selectivity as proper estimates of gear selectivity are crucial for any population dynamics study. A precise description of gillnet selectivity per species is needed to obtain accurate predictions on the results of mesh size regulations (Reis & Pawson 1992). Accurate estimates of selectivity are also necessary for interpretation and analysis of gillnet catch statistics in population studies (Spangler & Collins 1992, Pet *et al.* 1995).

Population dynamics embraces birth, growth and mortality (Nikolskii 1969). In any exploited fishery causes of fish mortality can broadly be divided into two classes: natural mortality and fishing mortality. The total mortality is defined as the total loss of part of the population by fishing and natural mortality, while natural mortality is defined as death due to all causes other than fishing (Nikolskii 1969).

The most common method of estimating mortality rates involves plotting the natural logarithms of the numbers of fish surviving by age as a curve. A line that best fit through

these data has a slope equal to the instantaneous mortality rate (Z). In contrast to the relative ease and accuracy with which the total mortality rate (Z) can be determined it is not easy to accurately estimate the division of the total mortality rate into fishing mortality rate (F) and natural mortality (M) when both are occurring (Royce 1984). Natural mortality is equal to total mortality during periods when there is no fishing, but when fishing is occurring the simultaneous natural mortality must be estimated mathematically.

There are a number of empirical equations that are generally used to estimate natural mortality. These equations invariably give different estimates of natural mortality and as a result some may not be suitable for certain situations and data sets. Because of uncertainties surrounding the estimation of natural mortality some authors tend to take a mean value of all the empirical equation as an estimate of natural mortality (Wely & Hecht 1998). Given that the dam Katse has only recently filled and the local populations are only starting to take fishing seriously, fishing effort is not that high. It is therefore assumed that fishing mortality will be lower than natural mortality and the value of natural mortality will be estimated from the equation that best suits this assumption.

6.2 Materials and Methods

Mortality:

The total instantaneous mortality rate (Z) was estimated by two different techniques. First, from the slope of the descending limb of a catch curve by regressing natural

logarithm of age frequency against age to all fully recruited ages. The age corresponding to the top of the catch curve was assumed to be the age at 50% capture (Butterworth *et al.* 1989). However, for *O. mykiss*, age data points were not sufficient for fitting a regression line, therefore a regression line was fitted to a length converted catch curve (Sparre & Venema 1992). In addition, further estimates of total mortality were obtained from the following equation (Butterworth *et al.* 1989).

$$Z = \ln[1 + 1/(t_m - t_f)]$$

Where t_f is age of fully recruited fish and t_m is mean age of fully recruited fish sampled. To construct a catch curve a normalised age length key was prepared from age length data and the length frequency data was transformed into age frequency using this key.

The estimation of instantaneous natural mortality rate is ambiguous. However, values of this parameter are needed for most of the models presently used in stock assessment models. Consequently the estimation of natural mortality often relies on empirical relationships. These relationships are derived from correlating natural mortality with biotic and abiotic parameters pertaining to the fish population (Rikhter & Efanov 1977, Pauly 1980, Hoenig 1983, Gunderson & Dygert 1988). The instantaneous mortality rate for the three species was estimated by four different empirical equations, namely:

(1) Pauly's (1980) empirical equation:

$$\ln M = -0.0152 - 0.279 \ln L_\infty + 0.6543 \ln K + 0.463 \ln T$$

This requires estimates of the von Bertalanffy growth parameters (L_{∞} , K) and the mean temperature (T) over the distribution range of the species.

(2) the Rikhter and Efanov (1977) equation:

$$M = 1.521/a_m^{0.72} - 0.155$$

This equation requires an estimate of age at 50% sexual maturity (a_m).

(3) the Gunderson and Dygert (1988) equation:

$$M = 0.03 + 1.68 \times \text{GSI}$$

This equation uses GSI of ripe female as the input parameter.

(4) the Hoenig (1983) equation:

$$\ln Z = 1.46 - 1.01 \ln (a_{\max})$$

This requires an estimation of the maximum age sampled (a_{\max}). Although the Hoenig (1983) equation was developed to approximate total mortality, it was derived from empirical data that pertained to unexploited or lightly fished stocks. Since fishing effort in Katse dam is relatively low the value derived from Hoenig's (1983) equation is

probably closer to M than Z. To use this equation for estimating M, every effort must be made to sample all age groups present in the population.

Given an estimate of Z and M, the instantaneous fishing mortality rate was obtained by subtraction ($F = Z - M$).

Gill net Selectivity:

Gillnetting was carried out on monthly basis from May 1998 to June 1999 in Katse dam. A set of gill nets was made of white multi-filament twine with four different mesh sizes ranging from 50mm to 110mm stretched, with a depth of 2 metres.

The selectivity estimates were calculated according to Holt's (1957) model. This model is based on the assumption that the selection curve can be described by a normal distribution:

$$S_{(ij)} = \exp - (L_j - L_{opt})^2 / (2\sigma^2)$$

Where $S_{(ij)}$ is the selectivity for length class (j) in mesh (I), L is fork length, L_{opt} is optimum length (cm) and σ is the standard deviation. The optimum selection length (L_{opt}), which is the most efficiently retained length in a certain mesh size and the standard deviation (σ) were estimated from the total catches of each mesh size. The input data for analysis were the numbers caught per length class and the mesh sizes. Fish of certain size frequencies were caught in different mesh sizes and the catches of such mesh sizes were compared. To estimate the overall selection factor (K) plots of $-2a/b$ against $(M1 + M2)$

were made for each species and a regression line passing through zero was drawn. where a and b are parameters in Holt's model for gillnet selectivity while $M1$ and $M2$ are mesh sizes with overlapping selection ranges. The slope of the regression line being the overall selection factor (K) (Hamley 1975).

6.3 Results:

Mortality estimates:

Age based catch curves for *B. aeneus*, *O. mykiss* and *L. capensis* are illustrated in figure 6.1. The estimates of total mortality (Z) from catch curves and the Butterworth *et al.* (1989) equation are presented in Table 6.1. The Z estimates for each estimation technique differed only slightly in *B. aeneus* and *O. mykiss*. However, in *L. capensis* the Z value estimated by the Butterworth *et al.*(1989) equation was almost double that estimated by the catch curve. For all the three species the Butterworth *et al.*(1989) equation gave higher estimates of Z . The mean Z values from the two estimation techniques were $0.72 \pm 0.03 \text{ year}^{-1}$ for *B. aeneus*, 1.32 year^{-1} for *O. mykiss* and $0.61 \pm 0.2 \text{ year}^{-1}$ for *L. capensis*. The point estimates for natural mortality (M) calculated from Pauly (1980), Rihkter & Efanov (1977), Gunderson & Dygert (1988) and Hoenig (1983) equations are shown in Table 6.1. The M estimates differed substantially for each estimation technique hence it was not advisable to take the arithmetic mean of the four estimates. For instance Pauly's (1980) equation, which is considered to be the most suitable (Amarasinghe & De Silva 1992), yielded an unreasonably high M estimate for *B. aeneus* ($M > Z$). It would therefore not make sense to incorporate such an estimate in the computation of natural

mortality. As fishing has only recently started in Katse dam, the assumption is that mortality due to fishing should be lower than natural mortality. Therefore the computation of natural mortality was based on the method that yielded an estimation which was in line with this assumption.

As mentioned for *B. aeneus* Pauly's (1980) equation provided unrealistic estimation of the natural mortality rate (M). On the other hand Gunderson and Dygert's (1988) and Hoenig's (1983) equations estimated natural mortality to be less than half of the total mortality (Z). This means that fishing mortality was higher than natural mortality. Such a situation is highly unlikely given that fishing has only recently started in the reservoir and it is not very intense. Therefore Rihkter & Efanov's (1977) equation provided a better estimate of natural mortality as its in line with the underlying assumptions pertaining to fishing and natural mortality in the lake. The same argument stands for *L. capensis*. For *O. mykiss* the natural mortality rate estimated from Pauly's (1980) and Gunderson and Dygert's (1988) equations was too low compared to the total mortality. Hoenig's (1983) and Rihkter and Efanov's (1977) equations provided natural mortality estimates which were slightly higher than fishing mortality. Therefore a mean of Hoenig's (1983) and Rihkter and Efanov's (1977) estimates was taken as an approximation of natural mortality for rainbow trout. Finally, fishing mortality (F) was estimated as $(F = Z - M)$, 0.31 year^{-1} for *B. aeneus*, 0.51 year^{-1} for *O. mykiss* and 0.2 year^{-1} for *L. capensis*.

Gill net selectivity:

Gillnet selectivity results are presented in Figure 6.2. These estimates were based on lumped monthly gill net catches with the assumption that the selectivity of the gill nets did not change during the study period. Plots of $-2a/b$ on $(M1 + M2)$ show how the selection factor K can be calculated from catches in the multiple mesh sizes (Pet *et al.* 1995). This is graphically illustrated in Figure 6.3. Holt's model of estimating gill net selectivity also assumes a constant coefficient of variation for selection curves. This is validated by plots of sum of standard deviations ($\sigma_1 + \sigma_2$) on sum of optimum lengths ($L_{opt1} + L_{opt2}$), which approximate straight line through the origin with the overall coefficient of variation as the slope (Fig 6.4).

B. aeneus and *L. capensis* were always caught wedged or gilled in all mesh sizes while only few *O. mykiss* were caught in meshes 90 and 110. And the few *O. mykiss* that were caught in these mesh sizes were small in size and often entangled in the net by their teeth. This led to selection curves of the two mesh sizes moving to the left of the smaller mesh sizes instead of right (Fig 6.2). As a result plots of $(\sigma_1 + \sigma_2)$ on $(L_{opt1} + L_{opt2})$ for *O. mykiss* did not pass through the origin. Therefore the assumption of constant coefficient of variation was violated. When the selectivity curves of each species were compared with length frequency distribution, the estimated selectivity curves showed a close fit with recorded catch length frequency distribution.

Table 6.1: Estimates of the instantaneous rate of total mortality (Z) and natural mortality (M) for *B. aeneus*, *O. mykiss* and *L. capensis* in Katse dam. Estimates of Z were obtained from catch curves and the Butterworth *et al.* (1989) equation using age frequencies from experimental gill net in Katse dam. Estimates for (M) were obtained from Pauly (1980), Rihkter & Efanov (1977), Gunderson & Dygert (1988) and Hoenig (1983).

Species	Total mortality (Z)		Natural mortality (M)	
	Catch curve	Butterworth et al. (1989)	Method	M
<i>B. aeneus</i>	0.69 year ⁻¹	0.74 year ⁻¹	Pauly (1980)	1.023 year ⁻¹
			Rihkter & Efanov (1977)	0.406 year ⁻¹
			Gunderson & Dygert (1988)	0.114 year ⁻¹
			Hoenig (1983)	0.35 year ⁻¹
<i>O. mykiss</i>	1.09 year ⁻¹	1.55 year ⁻¹	Pauly (1980)	0.213 year ⁻¹
			Rihkter & Efanov (1977)	0.77 year ⁻¹
			Gunderson & Dygert (1988)	0.153 year ⁻¹
			Hoenig (1983)	0.85 year ⁻¹
<i>L. capensis</i>	0.41 year ⁻¹	0.81 year ⁻¹	Pauly (1980)	0.186 year ⁻¹
			Rihkter & Efanov (1977)	0.406 year ⁻¹
			Gunderson & Dygert (1988)	0.157 year ⁻¹
			Hoenig (1983)	0.35 year ⁻¹

6.4 Discussion:

Mortality Estimates:

Of all the species *O. mykiss* had the highest instantaneous total mortality rate (Z). This was expected given that the species is comparatively short lived. Another observation of note was that fishing mortality was also highest in rainbow trout. The comparatively high fishing mortality for rainbow trout is due to the fact that recreational fishermen specifically target this species, while it is also caught by locals though in lower numbers than *B. aeneus*.

B. aeneus had the second highest fishing mortality. Local fishermen mainly exploit the *B. aeneus* populations in Katse dam. These people do not necessarily target this species. However, its high relative abundance in the lake and its omnivorous mode of feeding makes it an easy target for local fishermen who use less sophisticated and non-target specific tackle than their recreational counterparts. *L. capensis* had by far the lowest fishing mortality.

The estimation of natural mortality of *L. capensis* from Rihkter & Efanov (1977) equation yielded the same value as total mortality (Z) estimated from catch curve ($M = 0.406$, $Z = 0.41$). This is a true reflection of what is happening in Katse dam. Reports from fishermen on the lake indicate that no *L. capensis* is caught with hook and line. The only catches of *L. capensis* reported came from rivers and only a small percentage are caught with hook and line. They are mainly caught by herdboys in winter when water

levels are low. However the fishing gear in use is not hook and line but spears. Because of their sedentary nature *L. capensis* seem to be more vulnerable to this kind of fishing, which is particularly common in Malibamatso River below Katse dam. The non-appearance of *L. capensis* in the hook and line catches may be explained by the benthic feeding habits and the inferior mouth of the species, which makes them relatively invulnerable to hook and line. With the exclusion of experimental gill nets, hook and line is the only gear used in Katse dam at the moment. Therefore the observed total mortality rate of the species should be solely due to natural mortality.

The data show that 6 and 7-year-old *L. capensis* were relatively few compared to older year classes. Such a situation is not common, as population numbers tend to decrease with age due to mortality. This is an indication that there might have been a spawning failure prior to the inundation of the dam which resulted in a weak year class. Tomasson *et al.* (1983) also found year class strength of *L. capensis* to be highly variable. The strong year classes were correlated with optimum spawning such as rising Lake Levels in spring or summer. The reason for the observed weak year class strength for age 6 and 7 might be that less ideal environmental conditions prevailed which lead to a spawning or recruitment failure. The most likely cause of spawning or recruitment failure is draught. The weak year classes for age 6 and 7 are a result of 1991/92 spawn. Figure 1.1 shows that 1991/92 season had the lowest rainfall.

Compensatory mortality operates when the population compensates for fishing mortality by reducing rates of natural mortality (Allen *et al.* 1998). This suggests that total

mortality remains constant at low to intermediate level of harvest, but increases as fishing mortality surpasses a compensation point. Assuming that mortality is partly compensatory and taking a compensation point as the point where fishing and natural mortality are the same, it is clear that all the three species can sustain a substantial increase of fishing effort without the danger of stock collapse.

Gill net Selectivity:

Gill net selectivity is affected by many factors including mesh size, twine thickness and method of fishing (Hamley 1975). There are three ways in which a fish can be caught in a gill net (Baranov 1914):

1. Wedged- Held tightly by a mesh around the body;
2. Gilled- Prevented from backing out of the net by a mesh caught behind the gill cover;
3. Tangled- Held in the net by teeth, maxillaries, or other projections, without necessarily penetrating the mesh.

The length frequency distribution for *B. aeneus* and *L. capensis* from the gillnets were normally distributed for mesh sizes showing that tangling percentage in these species is negligible. In *O. mykiss* tangling percentage increased with mesh size and the catch length frequency distributions for the species were only normally distributed in meshes 50 and 70. The selection curves for meshes 90 and 110 were very narrow and were almost identical in range (Fig 6.2). From these results it is clear that tangling is a factor in rainbow trout and should not be ignored as suggested by Baranov (1914).

The factors other than mesh size mainly affect the efficiency of the net although they may also affect selectivity (Hamley 1975). For instance visibility and stretchability of meshes may affect the avoidance behaviour of fish that swim into the net. The experimental gill nets used in this study were all white in colour and their visibility must have changed during the course of the sampling programme as they got older and darker. However, the most important factor thought to have affected the visibility of the nets is the seasonal changes in turbidity. This might have partly contributed to low catches in winter when turbidity was at its lowest level. Visibility of nets can affect their selectivity, because the reaction of fish to a net can change with growth. After finding that more visible nets caught a small proportion of large perch, Steinberg (1964) postulated that the larger, older fish approach nets more cautiously. This might also explain the reason behind the observed small proportion of large fish in stations closer to the dam wall where turbidity is consistently lower than in stations further away from the dam wall. This can be investigated by using gill nets with different colours and assessing variation in length frequency distribution between different colours.

Another important factor influencing selectivity of gill nets is the method of fishing. As different sizes of fish may occupy different habitats, the size caught may depend on the location and depth of fishing (Hamley 1975). When the experimental gillnetting was initiated in May 1998 only surface set nets were used. From July till September the *L. capensis* catches were negligible. This was thought to be a result of two factors. Firstly the species were not caught because they were less active due to cold water temperature. Secondly the species moved into deeper water below the thermocline in response to low

water temperature and therefore were inaccessible to surface set gill nets. *L. capensis* is also better adapted to benthic habitats than the other two species. The bottom set gill net was only introduced in November and the catches in both surface and bottom set gill net were virtually the same until June. However reports from Lesotho Fisheries Project staff indicate that in July and August (1999) *L. capensis* were caught in bottom set gill net (P. 'Matli, organisation pers. comm.). This is an indication that the species is not available for surface set gill nets in winter. It should be interesting to see how introduction of different colours will influence the selectivity pattern of the nets.

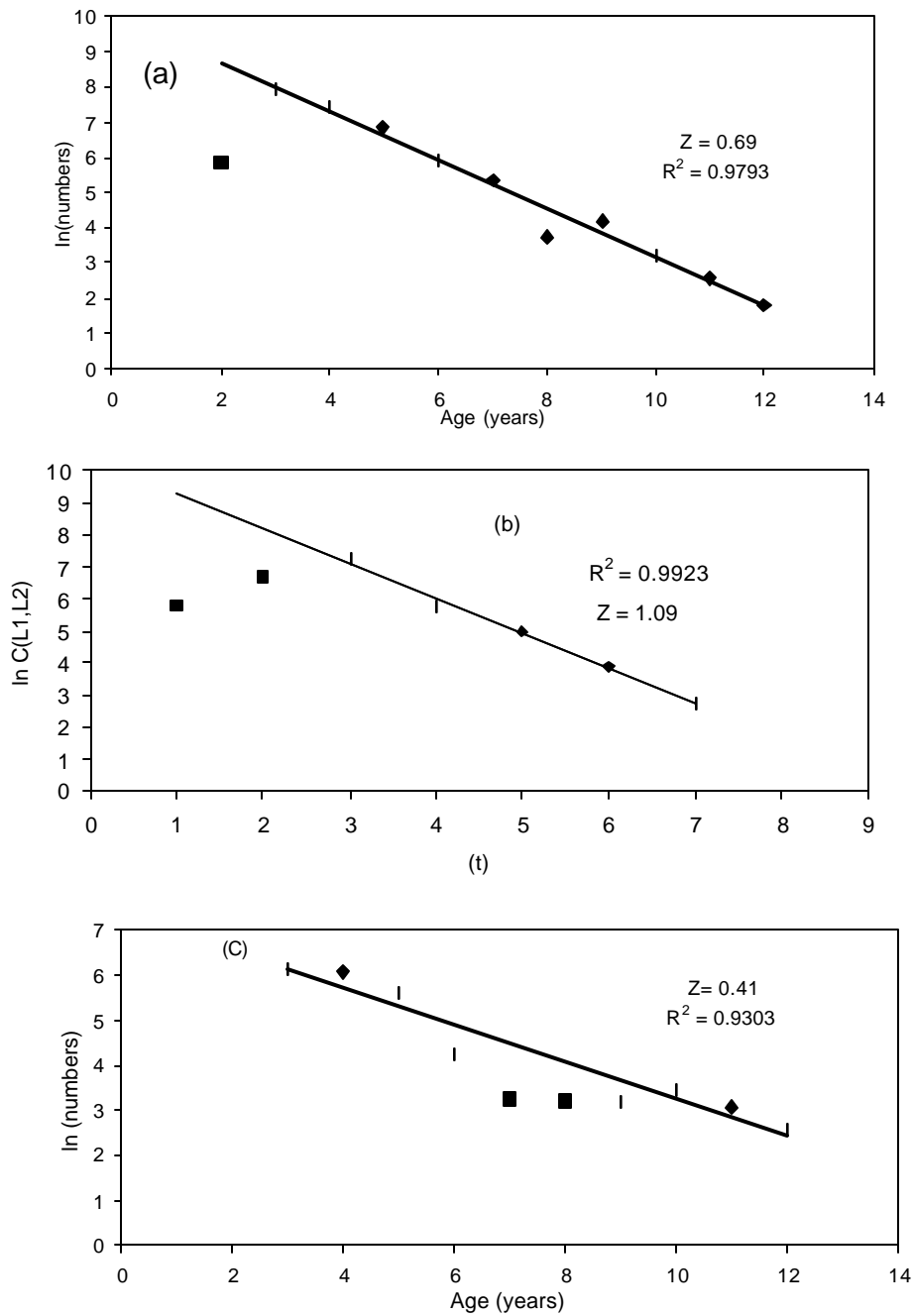


Figure 6.1: Estimates of total mortality rate (Z) (a) *B. aeneus*, (b) *O. mykiss*, (C) *L. capensis* in Katse dam. Fitting linearised catch curve to age-frequency distribution obtained from experimental gill net fleets approximated the Z values. For *O. mykiss* length converted catch curve was used to estimated Z .

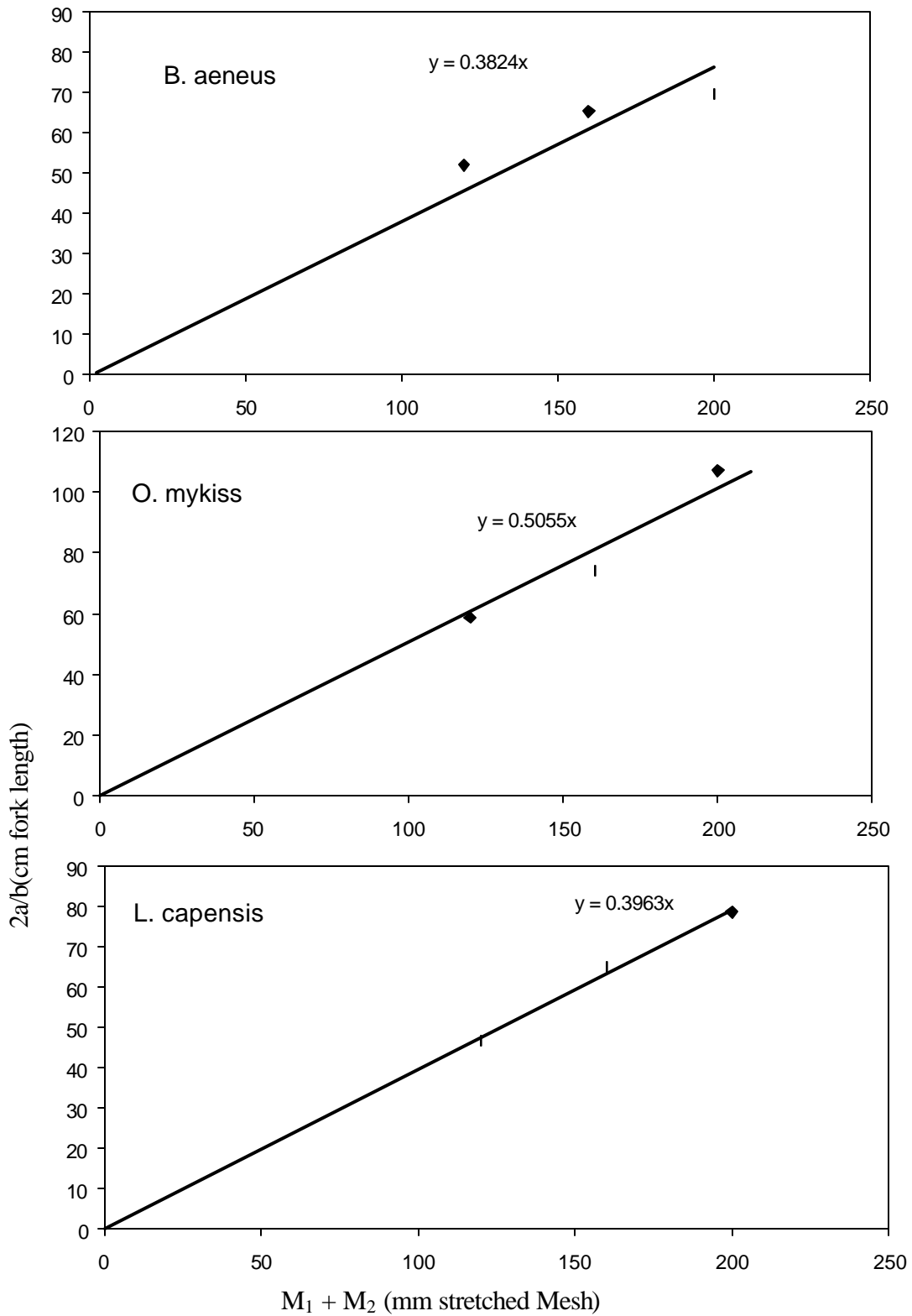


Figure 6.2: Plots of $-2a/b$ on $(M_1 + M_2)$ per species, for the estimation of selection factors

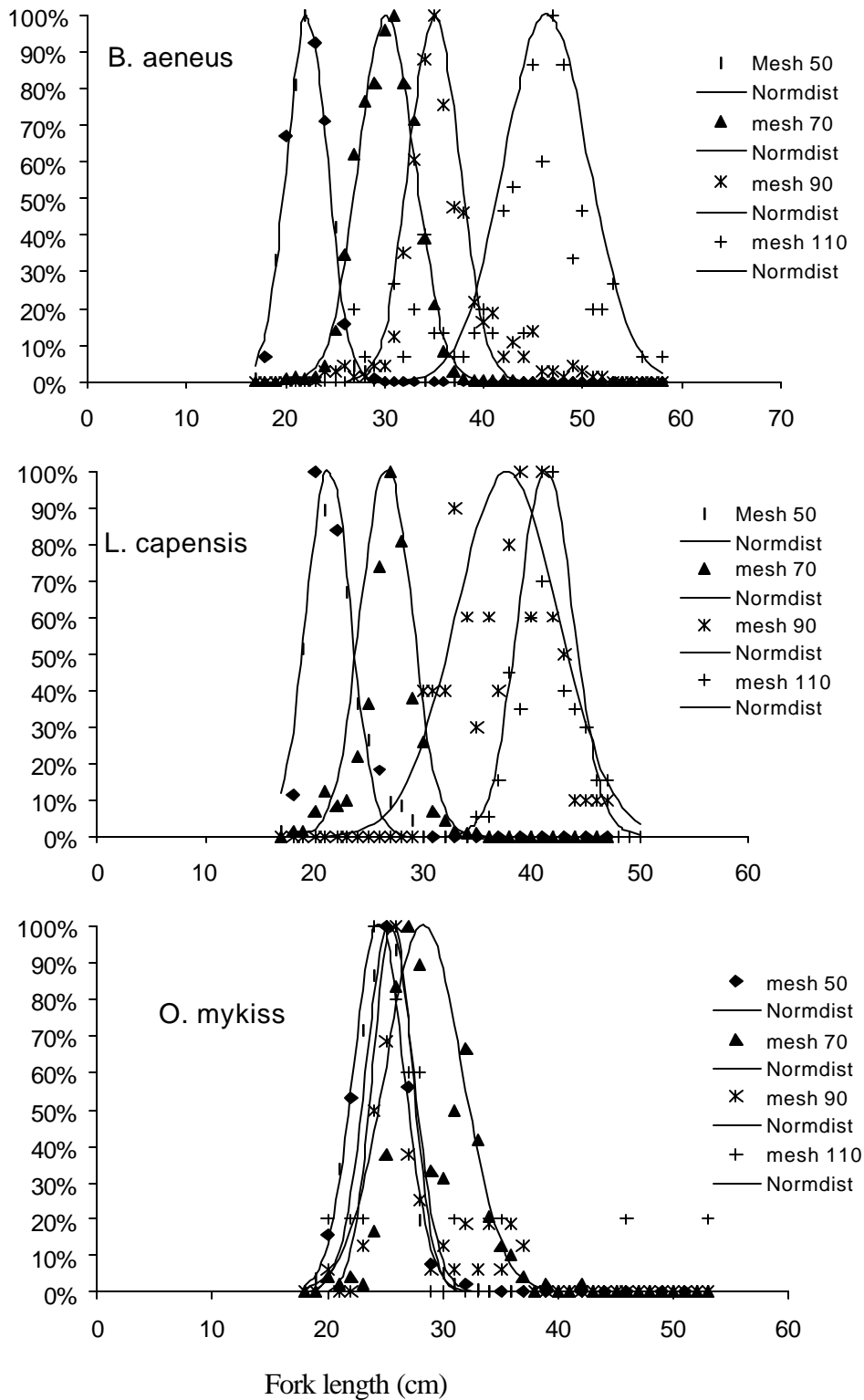


Figure 6.3: Relative selectivity of gillnets of different mesh sizes estimated by Holt's method.

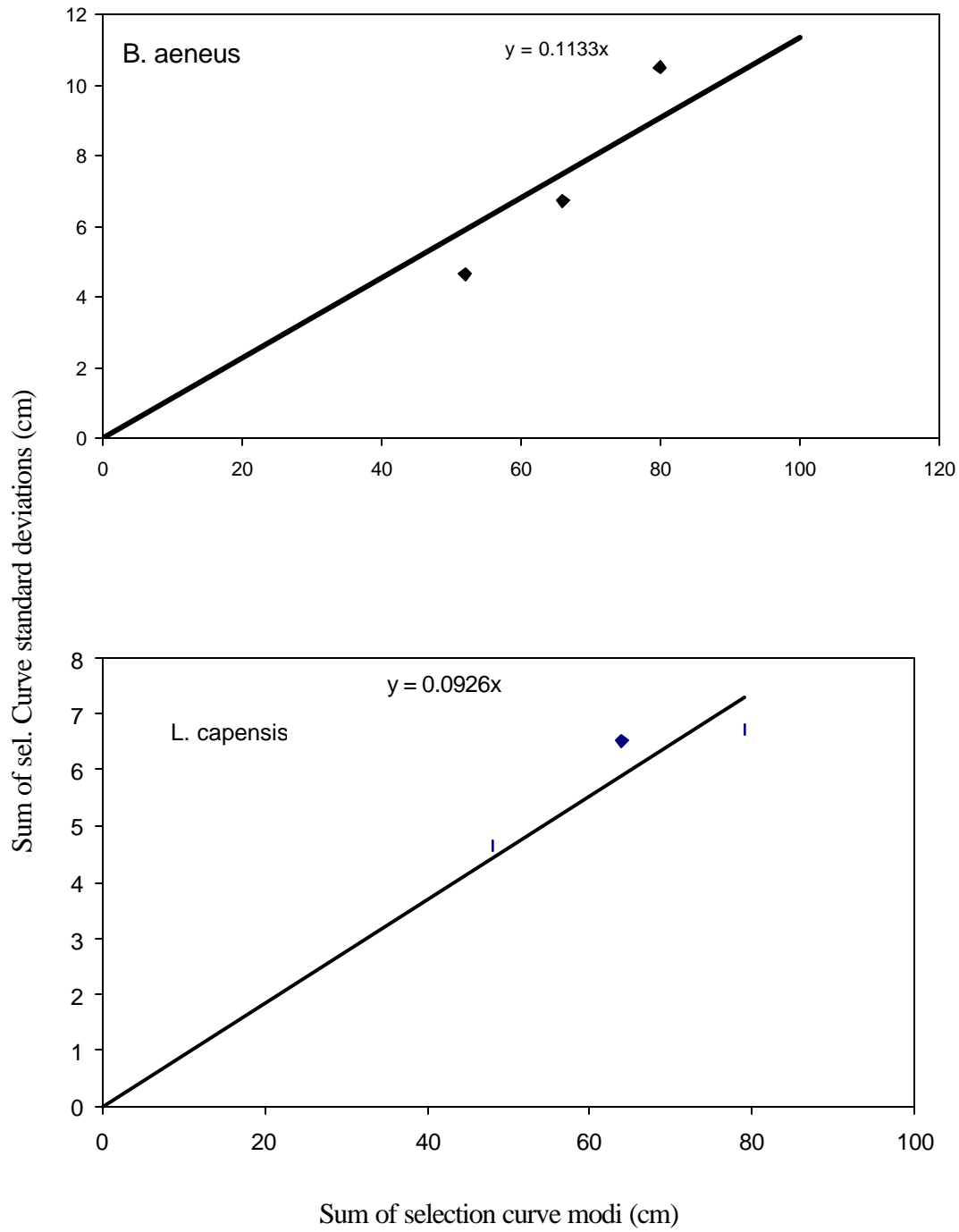


Figure 6.4: Plots of $(\sigma_1 + \sigma_2)$ on $(L_{opt1} + L_{opt2})$, showing a constant coefficient of variation in selectivity curves for *B. aeneus* and *L. capensis*.

CHAPTER 7

General discussion and management considerations

A number of interacting factors, including fish species present, temperature, altitude, and shape of the lake basin govern fish production in reservoirs (Eccles 1989). The conversion of primary production to fish yield is affected by the nature of the fish community. Herbivorous fish, such as *tilapia*, make more effective use of the resources than secondary consumers that feed on animal matter (Eccles 1989). In Katse dam there is only one species (*L. capensis*) which is primarily a herbivore. It is therefore unlikely that the fish in Katse dam will be able to fully utilise the primary production of the lake. Moreover, all the species present in the reservoir are primarily riverine and fish production in the lake might be restricted by the lacustrine conditions, which may not be ideal for the three largest and most important species.

Biological processes such as metabolism and growth increase with temperature (Eccles 1989, Wootton 1990). Temperatures in Katse dam are very low, ranging from 4°C to 22°C. These low temperatures and high altitude will result in reduced primary productivity in the lake, which would in turn limit fish production.

Shallow lakes and dams are more productive than those that are deep. The underlying reason for this is that nutrients remain locked in the depths of the basin and are not available for plant growth (Chutter *et al.* 1988, Eccles 1989). Katse dam is deep (average depth = 60m), a high volume (1950 hm³) and a relatively small surface area (37 km²).

The lake is stratified during the warmer summer months and nutrients released from decaying detritus will be locked up in the lower layers during summer stratification, when primary productivity would be at its highest.

In summary these factors suggest that Katse dam has limited fisheries potential and consequently cannot support a large-scale commercial fishery. There are however good prospects for a small-scale commercial fishery and a recreational fishery for rainbow trout.

The results of the study have shown that only three species occur in numbers large enough to support a small-scale commercial fishery and a recreational fishery. These species are *B. aeneus*, *O. mykiss* and *L. capensis*. In terms of relative abundance *B. aeneus* is by far the most important species in the reservoir (71%). It seems to have adapted very well into the new environment and has successfully colonised the entire reservoir. Although both subsistence and recreational fishers exploit the species, the former most commonly catch it. The mortality estimates of *B. aeneus* show that a greater proportion of total mortality is due to natural mortality than fishing mortality (Chapter 5). The compensatory mortality hypothesis postulates that a population's total mortality remains unchanged at low to intermediate exploitation rates because natural mortality decreases to compensate for reduced density (Allen *et al.* 1998). Assuming that a compensation point is reached when natural mortality is equal to fishing mortality, additional fishing effort in the form of a small-scale gillnet commercial fishery would not pose any threat to the fish stocks in the reservoir.

The data show that *L. capensis* is the second most abundant species in the reservoir. However, both local subsistence fishers and recreational fishers rarely catch this species on hook and line. This is also reflected by the low fishing mortality, which was much lower than that for *B. aeneus* and *O. mykiss*. Presently, the species is of little importance to local and recreational fishers. However, the planned introduction of a small-scale gillnet commercial fishery will change the situation. Analysis of spatial distribution showed that *L. capensis* are mainly concentrated in the river mouths. This means that the effective exploitation of the population can be achieved by setting gill nets in these areas. The major advantage of such an action would be in the form of increased catch rate with its correlate of improved profit margins. The reason for this is that the three most important species spawn in the river mouths. If caution is not exercised, this could easily result in recruitment failure as most of the spawning stock may be fished out in a very short space of time. Thus, long term implications of intense fishing in areas of high concentration could be unsustainable. As shown in this study and in a previous survey by Tweddle (1997), *L. capensis* are highly vulnerable to exploitation during the spawning season.

O. mykiss may also be severely affected by gillnetting in river mouths. Unlike *L. capensis* and *B. aeneus*, rainbow trout catch rates remain high in winter. If commercial and recreational fishing is continuous all year round, then the winter catches will consist mainly of trout. Since the highest proportion of the rainbow trout stock in the lake comprises juveniles, it might be advisable to target them. This will also help improve recreational fishing by reducing the numbers of small fish in the reservoir and hence

improving the growth rate of the fish, given that growth rate is controlled/restricted by density dependent factors such as the availability of space or food (King 1995). Trout undertake upstream migrations in winter and are highly vulnerable to exploitation during this time. This is true for both hook and line and gillnetting. If gillnetting is allowed in winter, care should be taken to avoid exploitation of the breeding stock. In the absence of proper monitoring, gillnets could have disastrous effects as fishers could deliberately block the migration routes of the species in search of large fish. This would not be beneficial to either small-scale commercial fishers or recreational fishers as it would result in recruitment overfishing and not reduce the number of small fish.

A fine balance must therefore be maintained between obtaining good catches in these areas and ensuring spawning success. There are four management options that can be explored to achieve this management objective. These are to:

1. Prohibit all fishing activities in these areas.
2. Allow controlled fishing throughout the year.
3. Implement a closed season during the spawning period of the three species.
4. Restrict the mesh size of gillnets..

The advantage of option 1 is that it would ensure sustained recruitment, as there would be less interference with the spawning stock. This would virtually eliminate the danger of recruitment overfishing. However, any conservation measure that offers insignificant benefits to the users of the resource are destined to fail. The total prohibition of fishing in these areas would concentrate fishing in less productive areas of the reservoir. This

would render small-scale commercial fishing unprofitable and would also mean that *L. capensis* populations would not be exploited to their full potential. The data showed that *L. capensis* catch rates are very low in the main dam compared to the river mouths. Therefore the prohibition of fishing in the river mouths would effectively exclude *Labeo* from the fishery. This would limit the growth of the small-scale commercial fishery sector. It would also be very difficult if not impossible to implement a strategy that prohibits access to abundant resources.

The main advantage of allowing fishing in river mouths throughout the year (option 2) is that fishers will obtain good catches of all three species in these areas. This will in turn improve their profit margins. *L. capensis*, which does not occur in large numbers elsewhere in the reservoir except in the river mouths, would contribute substantially in this regard. The only disadvantage of this option is that it cannot guard against recruitment overfishing. *Labeo* fisheries elsewhere have collapsed through overexploitation on breeding migrations, e.g. *Labeo victorianus* in Lake Victoria (Cadwalladr 1965), *Labeo mesops* in Lake Malawi (Anon. 1964, Skelton *et al.* 1991) and *Labeo altivelis* in Zambia (Jackson 1961).

Option 3 is to implement a closed season during the spawning season of the three species. The main advantage of this option is that it would minimise the danger of recruitment overfishing, while maintaining high catch rates all year round except during the breeding season. This is in fact a compromise between the first and the second options. However, this is still not ideal for the Katse situation. In the first place catch

rates are very low in winter and as a result fishing is unlikely to be profitable during this time. If a closed season is imposed in these areas during the spawning period of *B. aeneus* and *L. capensis*, it would effectively mean that good catch rates would only be realised during six months of the year. Given that profit margins in any small-scale commercial fishery are not large, six months inactivity would render the whole operation unprofitable.

Option 4 is a restriction of mesh size. The management of gillnet based fisheries is effected by setting minimum length at first capture, which often takes into consideration the length at sexual maturity. The length at first capture is dependent on the type of fishing gear and the mesh size used (Thompson 1995). The choice of the length at first capture is dictated by a number of biological factors such as mortality rate and length at sexual maturity, and socio-economic factors including the need to catch sufficient fish to stay in business. For *L. capensis* and *B. aeneus* the total mortality rates are fairly low (0.61 & 0.72 respectively) (Chapter 5). This means that the population gain more total biomass through growth than they lose through mortality. Therefore, the spawning biomass can be maintained at reasonable levels when the length at first capture is near or greater than the length at sexual maturity. The reverse holds for *O. mykiss* as its high mortality rate (1.32) and slow growth rate result in the total biomass declining as the population ages. Though not modeled, rainbow trout could therefore be harvested at a size below the length at sexual maturity and produce high yields, without excessively reducing spawner stock biomass. The reduction in numbers of small trout could

theoretical also increase the growth rate and in turn produce trophy size fish for the sport fishery.

Deferring harvest to older ages to increase the average size of the catch can be offset by natural mortality (Johnson & Martinez 1995). Thus, an analysis of the competing effects of growth and mortality is central to selecting appropriate size regulations. If only *B. aeneus* and *L. capensis* were considered then the development of a management strategy would be relatively simple. The length at first capture would be set near or greater than the length at sexual maturity (Chapter 3). This would be achieved by choosing the gillnet mesh size that has the optimum selection length (Chapter 5). The presence of trout complicates the matter as most of the population consists of small fish. Because of its high mortality rate and slow growth rate, the length at first capture cannot be fixed at the length of sexual maturity.

It would be very difficult if not impossible to adopt a management strategy that will ensure that *L. capensis* and *B. aeneus* are only caught after reaching sexual maturity and conversely allowing trout to be caught before they reach sexual maturity. Targeting juvenile trout would allow the fishery to exploit the most abundant size classes of the stock and would produce good yields. Therefore a compromise has to be reached which will ensure that all the three species are exploited to their full potential without jeopardizing the fishing industry and the sustainability of the resource. Such a strategy can be implemented by choosing a mesh size that will exploit the size classes with the highest total biomass.

O. mykiss requires special attention as far as management is concerned. As mentioned this species is the best candidate for a sport fishery. However, any sport fishery requires a relatively high abundance of trophy fish (Hecht 1999). The present study has shown that rainbow trout in the lake are of a small size, which is not good for a sport fishery. It is not known whether the observed growth rate is a result of poor growth conditions or whether the strain of trout in the reservoir has limited growth capabilities. It might be advisable to introduce a new strain of trout (Hecht 1999) and monitor its growth performance or alternatively to fish out the juveniles to reduce intraspecific competition. It is recommended that the latter option be tested and if it fails, then to consider the former.

In this study catch per unit effort was used as an index of relative abundance. CPUE is related to absolute abundance by the catchability coefficient (q) (King 1995). The number of vulnerable individuals in an area may thus be estimated by multiplying the area by $CPUE/q$, where q is the value that is estimated from depletion experiments (King 1995). Since no depletion experiments were done in this study it was impossible to estimate absolute abundance from CPUE data. It was also not possible to estimate yield from surplus production models as there was no estimate of total biomass and the fishing effort was similar throughout the study period.

The number of fishing units that can be accommodated on the reservoir would be highly inaccurate in the absence of total biomass and absolute abundance estimates. The number of fishing units that can be initially accommodated was calculated on the basis of CPUE data and maximum yield (25 tonnes), estimated from the morpho-edaphic index (Chutter

et al. 1988). The CPUE data showed that 100m net catches approximately 1000kg of fish in 120 days, which equates to 8kg per day. It will therefore take 25 fishing units with similar fishing effort to realise the estimated 25 tonne annual yield. Though this is very simplistic it provides us with a number of units upon which to initiate the fishery. Depending on catch the number of units can be increased or decreased in future.

Regulation of the fishery.

The overall objective of fisheries management is to ensure that stocks are exploited on a sustainable basis, and the specific objectives depend on the type of fishery under consideration and the political agenda of the government (King 1995). In the case of Katse dam the political agenda of the government, through LHDA, is to provide alternative sources of income and employment for the displaced communities around Katse dam. Based on this agenda an appropriate objective is to ensure that as many people as possible have an opportunity to share in the resource.

Fisheries regulations are imposed on a fishery to support a strategy designed to achieve predefined objectives (King 1995). Normally a combination of regulations is needed to produce the desired results. Regulations are used either to reduce or contain effective fishing effort or to restrict the total catch to a certain limit. As two fisheries (sport fishery & small-scale commercial fishery) would be operating on Katse dam, the management regulations are different and are therefore discussed separately.

Small-scale commercial fishery.

This fishery would be best regulated by input controls such as limitation of number of nets used. The proposed measures for containing effective fishing effort include, limiting number of fishing units, types of fishing gear and minimum and maximum mesh size.

The fact that small-scale commercial fishers have to go through some basic training before they are allowed to operate on the reservoir makes it easier to restrict the number of entrants into the fishery. Training is conducted by the Lesotho Fisheries Project, which is responsible for managing the fishery. Only a limited number of fishers will be trained, which are unlikely to pose a serious threat on the resource. An adaptive management strategy can then be followed, whereby one or two fishing units can be allowed into the fishery each year during which the responses of the stock to increased fishing effort shall be monitored. Alternatively, depending on the response of the stocks to fishing effort, the number of units could be reduced by one or two per year. This approach may not be ideal for the Katse situation as many people in this area are unemployed and have lost their traditional way of living in the form of lost arable land and therefore would like to see less restrictions imposed on fishing. However, an adaptive management approach of this nature is much safer than an open access. An open access system would not be in line with the overall fisheries management objective of ensuring that fisheries are exploited on a sustainable basis. It should however, be clear that the entire enforcement, monitoring and management of the fishery should not cost more than the fishery is worth.

Although it is yet to be economically analysed, indications are that fishing in winter would not be profitable. It is therefore unwise to recommend such a regulation when fishers stand very little chance of catching enough fish to feed their families, let alone making any profit.

Sport fishery:

As mentioned, the major participants in the Katse dam sport fishery are tourists from South Africa and expatriates working for LHWP. The tourism industry is very important for the Lesotho highlands region and to the country as a whole, as it provides much needed cash and employment opportunities for the local people. Therefore, the management objective of the sport fishery should be to maximise the participation in this sector, while ensuring that anglers have access to large fish and that stocks are exploited on a sustainable basis. This objective can be achieved by placing limitations on catch (output control).

As the main objective of this fishery is to maximise participation from tourist fishers, no limit on the number of participants should be imposed. The most effective output control measure would be to set a conservative bag limit. The maximum permissible number of fish caught and removed per angler per day should be four. This is similar to many *salmonid* sport fisheries in the world (Schill & Kline 1995, Johnson & Martinez 1995). This will enable the sport fishery to expand without putting excessive pressure on the fish stocks. Unlike small-scale commercial fishers, the sport fishers mainly target large trout and yellowfish, which are very vulnerable during the spawning season (winter). The data

have shown that large trout constitute a very small percentage of the population. In order to avoid recruitment overfishing the spawner stock should be protected. It is therefore recommended that a two months (June to July) closed season be imposed to protect breeding trout. This action is unlikely to upset the angling fraternity as most anglers fish from September to April. Only a few anglers continue fishing in winter. This is mainly because the Katse dam area is very cold during this time and is therefore intolerable to most anglers. This will ensure sustainability by reducing the chances of recruitment overfishing.

Other fishing techniques besides hook and line should be prohibited, as they are likely to be detrimental to the resource. In winter when water levels are low in rivers, local fishermen hunt fish with spears. This is particularly prevalent on the Malibamatso River below the dam. Another unacceptable method of catching fish by locals when water levels are low in rivers is to foul hook them across the body using several hooks that have been tied together. Until such time as the impacts of these fishing practices are assessed it is recommended that these be prohibited.

The success of the small scale commercial and the sport fishery in Katse dam will largely depend on proper monitoring and close interaction between authorities and fishers. Many fisheries control measures do not normally work, unless the public understands what the rules are there for. Education and liaison between authorities, fishers and the general public is therefore crucial and this should form the next phase of fisheries development in Lesotho.

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