AGE, GROWTH AND REPRODUCTIVE BIOLOGY OF CHISAWASAWA *Lethrinops. gossei* Burgess & Axelrod, 1973 –(Teleostei:Cichlidae) IN THE SOUTH EAST ARM OF LAKE MALAWI.

BY

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DECLARATION.

I hereby declare that the work presented in this thesis is an outcome of my own research effort and that it has not been previously submitted to the University of Malawi or any other institution for a degree or any other award. Where other sources of information have been used, acknowledgement has been made accordingly by means of references.

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CERTIFICATE OF APPROVAL

We hereby declare that this thesis is from the student's own effort and that it has been submitted with our approval.

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DEDICATION.

To my mum and dad, brothers Happy and Lottie, Sisters Lucy, Rhoda and Edna.

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ABSTRACT

Life history traits, including age, growth, reproduction, recruitment pattern and mortality rates of *L. gossei* (Burgess & Axelrod, 1973) locally known as Chisawasawa from the south east arm of Lake Malawi were studied between March 2005 and February 2006. A total of 1208 male and female fish ranging from 58 – 146mm SL and 73 – 200mm TL were sampled on monthly basis during the ongoing fishing trials carried out by the Department of Fisheries using a research vessel *R.V. Ndunduma*. The vessel pulls a gulloppur bottom trawl net with a 23m head rope and a 38mm cod end mesh. A total of 659 sagitta otoliths were used to age fish. Mean monthly gonadosomatic index was computed to determine the peak breeding period. Size at maturity was estimated by fitting a logistic ogive. A recruitment pattern of the fish was constructed using length frequency data. Mortality rates were estimated using the catch curve analysis. Validation of age was done by using a combination of analysis of marginal increment and length frequency distribution.

The results of age validation assumed that a single opaque ring was laid down annually in the otoliths. The maximum age for *L. gossei* was estimated at 6+ years (175 ± 1.14mm mean TL). Growth was best described by the 3-parameter von Bertalanffy growth model as $L_t = 150.06(1 – e^{-0.27(t + 1.94)})$ $r^2 = 0.95$ SL or $L_t = 204.59(1 – e^{-0.24(t + 2.28)})$ $r^2 = 0.96$ TL. Growth was fastest in the first and second year and decreased progressively thereafter.

Fish bred between November and August with a peak breeding activity from February to March/April and a trough between September and October. The mean size at maturity for females was estimated at 135.95mm TL or 104.05mm SL. Using length-at-age data from this study, age-at-50% maturity was estimated at 2.14 years. The condition factors increased with spawning activities and were significantly different among months ($p < 0.05$). The recruitment pattern of *L. gossei* appeared to be continuous throughout the year, but showed increased recruitments during the period of May to June with a peak of 22.46% in May. The mean value for total mortality (*Z)* from the catch curve analysis was estimated at 0.63 year^{-1}, natural mortality (*M*) was 0.38 year^{-1}, fishing mortality (*F*) calculated ($F = Z – M$) was 0.25 year^{-1} and the exploitation rate was 0.40.

The age and growth information showed that this species is relatively long lived and, slow-growing, reaching sexual maturity after two years. The slow growth rate and precocial breeding habits imply that *L. gossei* populations are relatively stable and could remain the same in the future if effort is kept constant. However, once the fishery is over fished, it would require a long period for the stock to rebuild to levels that could support sustainable catches. A management strategy for the south east arm of Lake Malawi, therefore, has to place emphasis on the maintenance of the spawning stock of the species.

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ACRONYMS

GOM	Government of Malawi.
GNP	Gross National Product.
FISAT	FAO-ICLARM Stock Assessment Tools.
SEA	South East Arm.
SWA	South West Arm.
FAO	Food and Agricultural Organization.
VPA	Virtual Population Analysis
YPR	Yield per Recruit.
MSY	Maximum Sustainable Yield.
Fmsy	Optimal level of fishing effort
VBGF	Von Bertalanffy growth function
LFDA	Length Frequency Distribution Analysis.
L_m	Length at maturity
L_{max}	Maximum length
IAPE	Index of Average Percent Error
GSI	Gonad somatic index.
NORMSEP	Normal separation procedure
DMRT	Duncan’s multiple range test.
ELEFAN	Electronic Length Frequency Analysis.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1. Physical characteristics of Lake Malawi.

Lake Malawi is a vast lake with a surface area of 30,800 km^2, length of 603 km, maximum width and depth of 87 km and 785 m, respectively (Ribbink, 1994). The lake lies between 9°30'S and 14°30'S, 33°50'E and 35°20'E at an altitude of about 500m in a tropical climate (Figure 1.1). However it lies far enough south of the equator to experience marked seasonal variations in wind, temperature, and precipitation (Eccles 1974). The deepest is located between Nkhata Bay and Chilumba, but there is a second smaller basin over 500m deep off the eastern shore (Patterson & Kachinjika, 1995). Several publications explicitly state that the lake has only a single basin (Eccles, 1974; Ribbink, 1994), while others state that there are two (Meyer *et al.*, 1994).

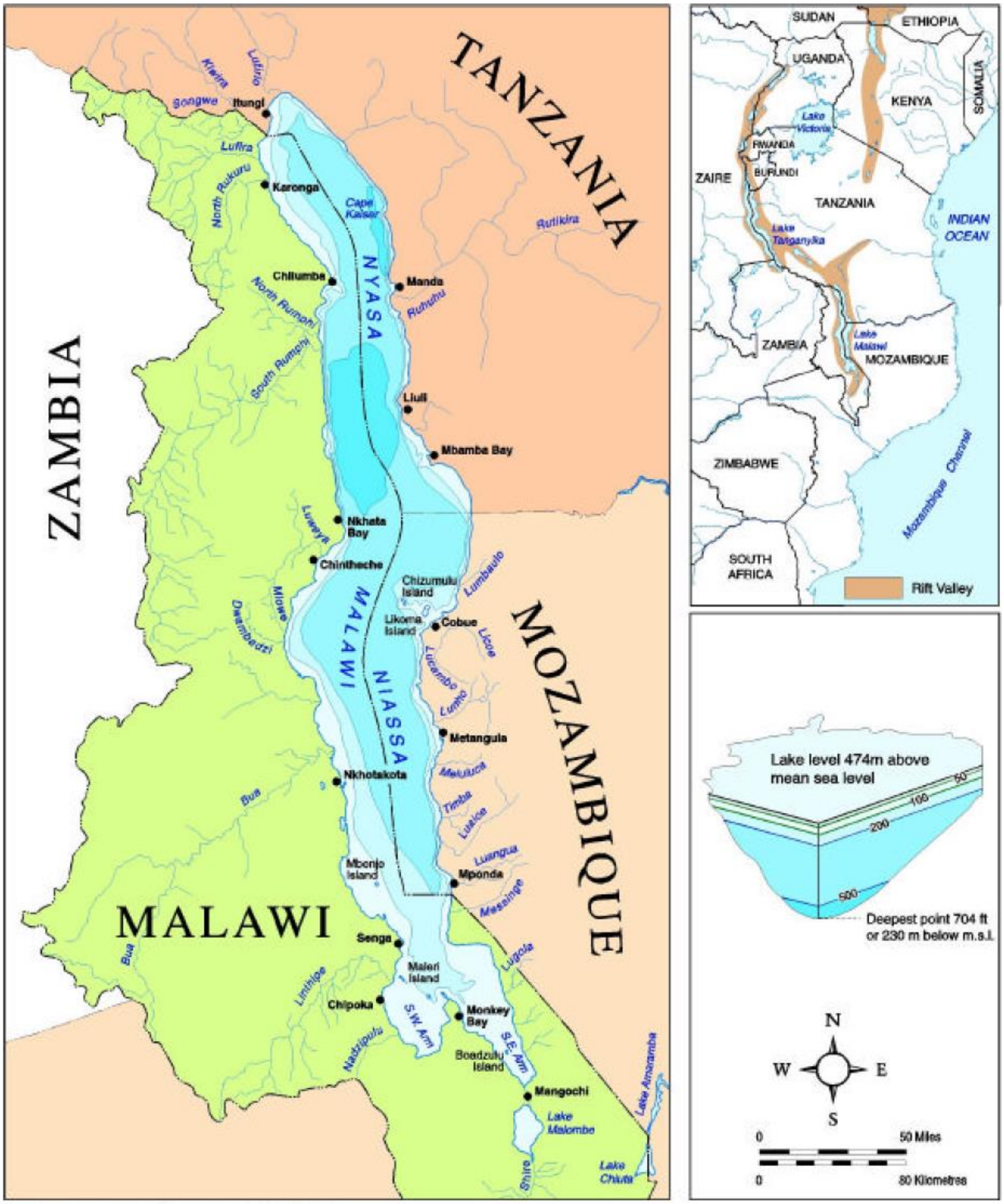

Figure 1.1. Lake Malawi, its catchment and the Rift valleys.

The lake has an estimated total catchment area of 125,000 square km with numerous inflowing rivers, such as the North Rukuru in the north east, the Songwe from the north and the South Rukuru, Dwangwa, Bua and Linthipe in the west being the main ones (Patterson & Kachinjika, 1995).

1.2. Species diversity

Lake Malawi is the world's most diverse lake in terms of fish species and harbors fish species in two major communities of shallow water and deep water zones. It is estimated that as many as 1000 species exist, most of which have not yet been described (National Environment Action Plan, 1994). The diversity of fish fauna in the lake is influenced by its unique biophysical characteristics: Deep and shallow basin with clear water, plankton distribution at different levels and anoxic water below 250 meters, which are largely devoid of fish life. The main types of fish from Lake Malawi are *Oreochromis* spp (Chambo) in the pelagic zone, *Bagrus* spp (Kampango), *Lethrinops* spp (Chisawasawa), *Clarias* spp (Mlamba), *Bathyclarias* spp (Bombe) *Lebeo mesops* (Ntchila), *Opsaridium microlepis* (Guther) (Mpasa) and *Opsaridium microcephalus* (Sanjika) in the demersal zone. *L gossei* is a deep water species occurring at a depth of 46 to at least 128m and forms one of the major species of commercial importance in the deep water zone.

1.3. Fisheries of Malawi.

The fish industry in Malawi comprises capture fisheries and aquaculture. Fishes of Malawi provide up to 75% of the annual protein consumed (Turner, 1994) while aquaculture contributes less than 1% (Kaunda, 1994). Between 1979 and 1996 fish from Lake Malawi accounted for 53% of the country's total annual fisheries production (Bulirani *et al.*, 1999); the remainder originated from lake Malombe (14%), Lake Chirwa

(20%), Shire River (10%) and Lake Chiuta (3%). Fish yields from Lake Malawi are fluctuating and yields from other lakes and rivers have declined (Bulirani, Banda, Pálsson, Weyl, Kanyerere, Manase, & Sipawe, 1999). Fluctuations in landings are attributed to great variation in the production of some lakes, which are believed to be fully exploited (Bulirani *et al.*, 1999). Drought has also contributed to decline in fish yield in Lake Chirwa, due to lowering of water levels.

Total annual yield from all species Lake Malawi varies widely between 30 000 and 80 000 mt, with landings in most years ranging between 50 000 and 60 000 mt. Between 2000 and 2003, catches have fluctuated between 32 600 mt in 2002 and 63 500 mt in 2000. In 2003, the estimated total catch was 48 200 mt. Table 1.1 below shows the total production between 2000 and 2003 (Department of Fisheries Frame Survey 2003).

Table 1.1. Total production of fish in Malawi during the past four years.

Year	*Total catch (mt)*
2000	43,000
2001	40,620
2002	41,330
2003	53,540

Source: Department of Fisheries Frame Survey 2003

Total catch in 2003 was relatively high because of advanced fishing technologies among certain groups of fishers that are exploring deep water species where there is a relatively high concentration of fish than the shallow and mid waters.

Lake Malawi supports a highly diverse fishery that can be categorized as large scale mechanized commercial, small scale commercial and subsistence (artisanal or traditional) (Banda, Jambo, Kachinjika, & Weyl, 2001). The large-scale commercial fishery is a mechanized fishery that operates trawls with 38mm mesh size cod end. The fishery consists of vessels *M.V Kandwindwi* (380hp), *M.V. Kampango* (190hp), *M.V. Chenga* (190hp) and R.V. *Ndunduma* (380hp) trawling in the mid and deep water in the southern part of Lake Malawi. The small-scale commercial fisheries are capital intensive and use mainly trawling and purse seining (ring net) and are confined in the southern part of Lake Malawi. The fishery consists of pair trawlers units (wooden boats about 8 m long with a 20-40 hp inboard engine) (Banda *et al*, 2001). The artisanal fisheries comprises of a wide range of fishing units, ranging from traditional fishing gears, such as fish traps and hand lines operated from dugout canoes to relatively modern gears. The main fishing gears for artisanal fishery are gillnets *chambo* seine nets, *kambuzi* seine nets, *nkacha* seine nets, *chilimira* seine nets, longlines, handlines and fish traps.

1.4. Importance of fisheries resources in Malawi**.**

The fish stocks of Malawian waters are undoubtedly among the important natural resources of the country. There is therefore little doubt that a large proportion of Malawian population depends directly on the fishery as a source of food security, livelihood and income. In 1999, the artisanal fisheries of Lake Malawi and Malombe employed 40,000 fishermen of whom 20% were gear owners and the remainder crew (Weyl, Banda, Sodzapanja, Mwenebombwe, Mponda, & Namoto, 2000). The fishery employs 48,000 fishermen and also contributes about 4% to the Gross national Product (GNP) of the country (Weyl *et al.*, 2000). The small-scale commercial fishery accounts for about 80% of the catch, and provides employment to nearly 30,000 people (Banda & Tomasson, 1997). The large scale commercial fishery confined to the southern part of the lake accounts for about 20% of the annual catch and provides jobs to nearly 1000 people (Banda & Tomasson, 1997) while the contribution from subsistence employs proportionally fewer people.

1.5. Requirement for management plan of *Lethrinops* species.

Recent assessment indicates that additional fish will have to be drawn from the deep water community (Duponchelle, Ribbink, Msukwa, Mafuka, & Mandere, 2000a) where *L. gossei* is one of the most principal targets because of its economic importance. Due to the nature of fishing gears used in Lake Malawi, most of the fishing in the lake is concentrated in the inshore zone as they can not go into deeper water because most gears do not have the capacity to trawl in deeper water. The deep water community fishery resource which can only be accessed by motorized gears remains under-utilized because there are fewer fishers exploring in these depths. In order to expand the range of operation and thus avoiding over exploitation of the inshore fishery, there is need to increase the number of motorized fishing crafts in the lake. The Malawi government is currently collaborating with the African Development Bank (ADB) to develop the deepwater fishery (Banda M.C. National Fisheries Research Coordinator – personal communication).The rationale behind is to increase deep water fish yield thereby reducing fishing pressure on the inshore stocks, which has reached unsustainable levels because most fishers will concentrate in deep water. The deep water fishery is currently under full operation comprising of vessels *M.V Kandwindwi*, *M.V. Kampango*, *M.V. Chenga*, and R.V. *Ndunduma* and yet very little is known about the biology of fish in this community for its sustainability. *L. gossei* being one of the principal targets in this community has to be studied in order to understand its biology that is important for its sustainability.

It is evident that efficient management of Lake Malawi fisheries requires stringent control of effort and an improvement in the enforcement of regulations. Following the decline of the inshore stocks (<30m depth), fishing pressure is now being directed towards the relatively unexploited offshore water (>30m depth) that comprises about 80% of the lake's area (Menz, 1995).

1.6. Age and growth in fish.

Knowledge of age profile of fish population is of primary importance for the stock assessment and thus for fish management. The significance of determining age is that it allows fish scientists in stock assessment and fisheries management to relate their observation to a time frame and estimate various biological rates for various species. Age information is used to estimate growth rate, age at recruitment, maturity schedules, and age specific fecundity for a specific species. Since age and growth parameters of *L. gossei* from hard parts have not yet been developed, this seems to be a good opportunity to study the age and growth of the fish in the southern part of Lake Malawi in order to gather information, which can be used to formulate strategies for the rational exploitation of the resource.

There are several approaches or methods for ageing fish, each with its particular advantages and disadvantages:

• Direct observations of individual fish, either held in confinement or from marking/recapture experiments.

• Ageing of individual fish based on annual patterns in hard structures e.g. otoliths, scales, bones etc.

• Identification of cohorts based on length frequency distributions from one or several samples representing a wide range of the population.

The first method is by far the oldest, initially described by fish culturists more than 250 years ago (Bagenal, 1978). The inherent problem of this approach is the problematic extrapolation from observed values to the true population values. Cultivated or tagged fish seldom have the same growth rate as their wild or untagged relatives. The second approach is now the preferred and most widely used method. It is based on the observation that temporal variations in the growth rate of the fish are reflected in the deposition of material in the hard parts. This leads to alternating bands or growth zones of varying transparency (Campana, 2001).

A wide variety of age determination techniques of individual fish based on annual patterns in hard structures have been developed, which depend on the detection of contrasting bands in body parts such as scales, otoliths, fin rays, spines, and vertebrae of fish, as well as external and internal structures. These parts are used to age fish, with varying degrees of success. (Weatherly & Gill, 1987). For example, scales have been found to underestimate longevity and therefore overestimate growth rate (Farade, 1974, Pannella, 1974; Hecht, 1980; Booth *et al.*, 1995). Spines, in particular have been used to age catfish of *C. gariepinus*, but reabsorption and the resultant increase in lumen diameter renders them useless to age older fishes (Pannella, 1974). Sectioned otoliths are currently considered the most suitable hard tissues for determining age of fish in tropical and subtropical areas (Hecht 1980a, Beamish & McFarlane 1987, Hammers & Miranda 1991, Booth *et al.* 1995, Campana 2001).). In Lake Malawi successful studies on age and growth have been done using hard parts on few deep water species and results have shown that fish in the tropics can be aged using these parts (Banda, 1992; Kaunda & Hecht, 2003; Kanyerere *et al.*, 2004). In the tropics formation of marks might be influenced by a variety of factors often varying in timing and intensity from year to year. Those factors amongst other, include temperature, light, salinity, turbidity, food supply or a myriad of other environmental factors such as, oxygen, pH etc could be involved and cause a reduction or cessation in growth of calcified tissue and affect formation of a zone.

The third approach is based on an analysis of modes (peaks) in a length frequency distribution. Most species seem to be spawning regularly and during a relatively short period of time. If the progeny exhibit a roughly uniform growth rate, it is assumed that each mode in a length distribution represents a separate cohort. The method requires lengths of a large number and size range of fish from the population and little overlap in the sizes of fish from adjacent age groups. This last requirement is usually only met in the younger part of the population because the growth rates decrease with age, so the modes (cohorts) tend to merge. This method has been given increasing attention, partly because it is often the only alternative for tropical stocks, but also because the necessary data are easily obtained and the handling of big samples has become easy with the introduction of computerized techniques. However, length frequency distribution has some limitations. It is sometimes difficult to separate the components of a composite frequency distribution. This limitation applies especially to the older parts where the overlaps become increasingly bigger. Intuitively, one would expect that proper identification and resolving would become troublesome when either the mean values are lying relatively close or when increasing variance will extend the overlapping areas or a combination of both. To assess the reliability of resolving the components, a separation index has been introduced and is an automatic feature in the Bhattacharya method implemented in FISAT.

Other technique that has been used in age determination include age-length key that uses a series of rather narrow length intervals for which the age composition is computed as a fraction or percentage of all the fish of that length and then applied to the length frequency distributions to estimate age composition. This technique has usually been considered less useful for many tropical fishes because their spawning periods are often protracted and moderate or large variation in year class can introduce significant bias and decrease the accuracy of a distribution computed from an age length key (Ricker, 1979).

However, these methods were considered under utilized for tropical species and that the problems had generally been over emphasized (Pauly, 1983).

1.7. Growth and reproduction in fish.

Studies on life history-traits such as growth and reproduction are indispensable for successful management of a natural fishery or an aquaculture facility (Wootton, 1990; Mathews, 1998). The catch that can be taken from a fishery depends largely on the growth of fish in the exploited population (Pitcher & Hart, 1982) and fish are recruited into a fishery through reproduction (Pitcher & Hart, 1982). Calculation of age structure and growth rate in a population can be made if the age of fish sampled is accurately determined (Beamish & McFarlane 198; Wootton, 1990).

Growth and reproduction are complementary processes (Wootton, 1990). The process of natural selection leads to selection for growth that tends to maximize the infective production of offspring (Mathews, 1998). Further within the framework of growth and reproduction, the onset of maturity represents a critical transition in life history of an individual. At this stage, resources are partitioned between reproduction, survival and growth. From a fisheries perspective particular elements of the reproductive strategy are of interest since they coupled with mortality rates, determine how many fish survive to recruit to the fishery. These recruits ultimately reproduce to form further cohorts and therefore have a direct bearing on the sustainability of production.

1.8. Main objective.

The development of deep water fishery, which targets *L. gossei* coupled with lack of management guidelines for sustainable exploitation of this resource imply an urgent need for a management plan. The goal of this study is therefore to estimate age, growth, reproduction and the exploitation rates of *L. gossei* from Southern part of Lake Malawi in order to contribute towards knowledge on the management plans for Chisawasawa. The study is expected to provide scientific information required to undertake a per-recruit analysis, which will promote the development and rational management of this deep-water resource in Lake Malawi.

1.8.1. Specific Objectives.

- To estimate growth parameters; length at infinity (L_∞,), growth constant (*K*) and age of the fish at zero length(t_o) and growth performance phi-prime index (*ø*') of *L. gossei* from the south east arm of Lake Malawi.
- To determine breeding seasonality and reproductive strategies such as size or age at maturity of *L. gossei* from the south east arm of Lake Malawi.
- To determine recruitment pattern of *L. gossei* from the south east arm of Lake Malawi.
- To estimate total, natural and fishing mortality of *L. gossei* from the south east arm of Lake Malawi.

1.8.2. Hypothesis

- *L. gossei* deposits growth rings twice a year in the otolith

- Growth rate of *L. gossei* is constant throughout the life span
- *L. gossei* breeds through out the year.
- Recruitment of *L. gossei* into fishery is throughout the year

1.9. Justification of the study

The southern part of Lake Malawi is the southern most of the African rift valley lakes and harbors one of the most diverse fish faunas in the world (Fryer & Iles, 1972; Turner, 1996).). This region is generally shallow and exposed to strong southeasterly winds, which result in the up welling of nutrient-rich waters from the intermediate layers (Eccles, 1974). For this reason the SEA and SWA are the most productive parts of the lake (Turner, 1994; Banda, 2000). The southern part of the lake is an area of intensive fishing activity and accounts for 60% of total landings from Lake Malawi (Banda, 2000). *L. gossei* forms one of the most important species in deep water of the south east arm of Lake Malawi. It dominated the benthic community at depth of 92 to 130m (Eccles & Trewavas, 1989).

L. gossei is one of the principal targets of the multispecies artisanal fishery in Malawi; but until recently, there have been no scientific studies on the age, growth and population dynamics of this species in Lake Malawi. *L. gossei* has a very high commercial importance. In 1992 trawl survey, it occurred at depth of 46 to at least 128m. It was generally one of the dominant species at the depth of 90m or more. *L. gossei* dominated in proportion in weight of the main demersal species trawled at 75m, 100m and 125m depth in the southwest arm of Lake Malawi (Duponchelle *et al.*, 2000a). Hence there is need to study its age growth and reproductive biology for better conservation and utilization. This information would allow for more advanced age structured population dynamics models such as multi species (YPR) and multi species virtual population analysis (VPA) to be used in obtaining management for the lake. To date, population dynamics of *Diplotaxodon limnothrissa* in the deep water community has been described (Kanyerere *et al.*, 2004). It is therefore important that population dynamics of other commercially important fish species like *L. gossei* in Lake Malawi be investigated.

In modern fisheries research, ageing of fishes is considered very important because it has been realized that knowledge of age and growth rate of fishes is of great importance for many practical and scientific questions. Through age determinations, we have the means to identify the age composition of a fish population, and it can be determined to which degree the various age classes are utilized by the fishery. Only an exact knowledge of the age of the fish allows inferences on the appropriateness of or need for management measures such as closed seasons or minimum mesh size. Only by comparing the annual growth of fish from different water bodies will the environmental (biotic and trophic) conditions be identified which are optional for given species.

Otoliths are considered one of the best structures for age determination. Otoliths contain the best permanent pattern of fish growth, since they are internalized and are not exposed to the harsh outer elements. Also, they are not known to undergo bone resorption. Otoliths are unique in the fact that they can be put to use in several different fashions.

Use of otolith to age fish produces fewer interpretational problems and generally improves the accuracy of age determinations. For a sustainable fisheries management, the demography of the considered stock is of major importance. The reliability of demography data is largely dependent on the validation of traditional age determination, which is derived from annual growth zones on otoliths (Ricker, 1979; Beamish & McFarlane, 1987).

There is little doubt that current interest in otoliths studies is driven by the chronological capabilities of these structures than any unique properties. Nonetheless, otoliths have several properties that set them apart from all other skeletal structures and without which many of the current applications would be impossible. Otoliths are a focus of attention by fisheries scientist because of the precision of age estimates based on annuli and annuli enumeration. The clarity of annual increment in otoliths of fish from both marine and freshwater can be remarkable (Campana & Jones, 1998). To be useful for aging, otoliths must grow throughout the life of fish and display an internal structure of increments.

Investigating the reproductive biology of a fish species is an essential component in understanding its ecology, life history and population dynamics. Such studies also provide an understanding of the extent to which species reproductive strategies are controlled by abiotic, food availability, the presence of predators and the habitat of the parental fish (Lagler *et al.*,1977; Mathews, 1998). Reproductive strategies such as size or age at maturity and spawning seasonality are of particular interest to fisheries as they provide some of the information required for developing fisheries management regulations (Welcomme, 2001).

CHAPTER TWO

2.0. DESCRIPTION OF THE STUDY AREA AND SPECIES UNDER STUDY

2.1. Study area

2.1.1. Physical characteristics of south east arm

The southern end of the Lake Malawi divides into two segments, namely the south east arm (SEA) and the south west arm (SWA). The south east arm has a surface area of 1742 square km (Figure 2.1), approximately 80km long and 30km wide with a maximum depth of 130m (Banda, 2000). The fisheries of the SEA are exploited by both a large scale commercial fishery using stern and pair trawls as well as purse seines (Bulirani *et al.,* 1999) as well as by a multi gear small scale fishery which includes gill nets, open water seines, beach seines, hand lines and long lines (Banda *et al.*, 1996; Weyl *et al*., 2000).

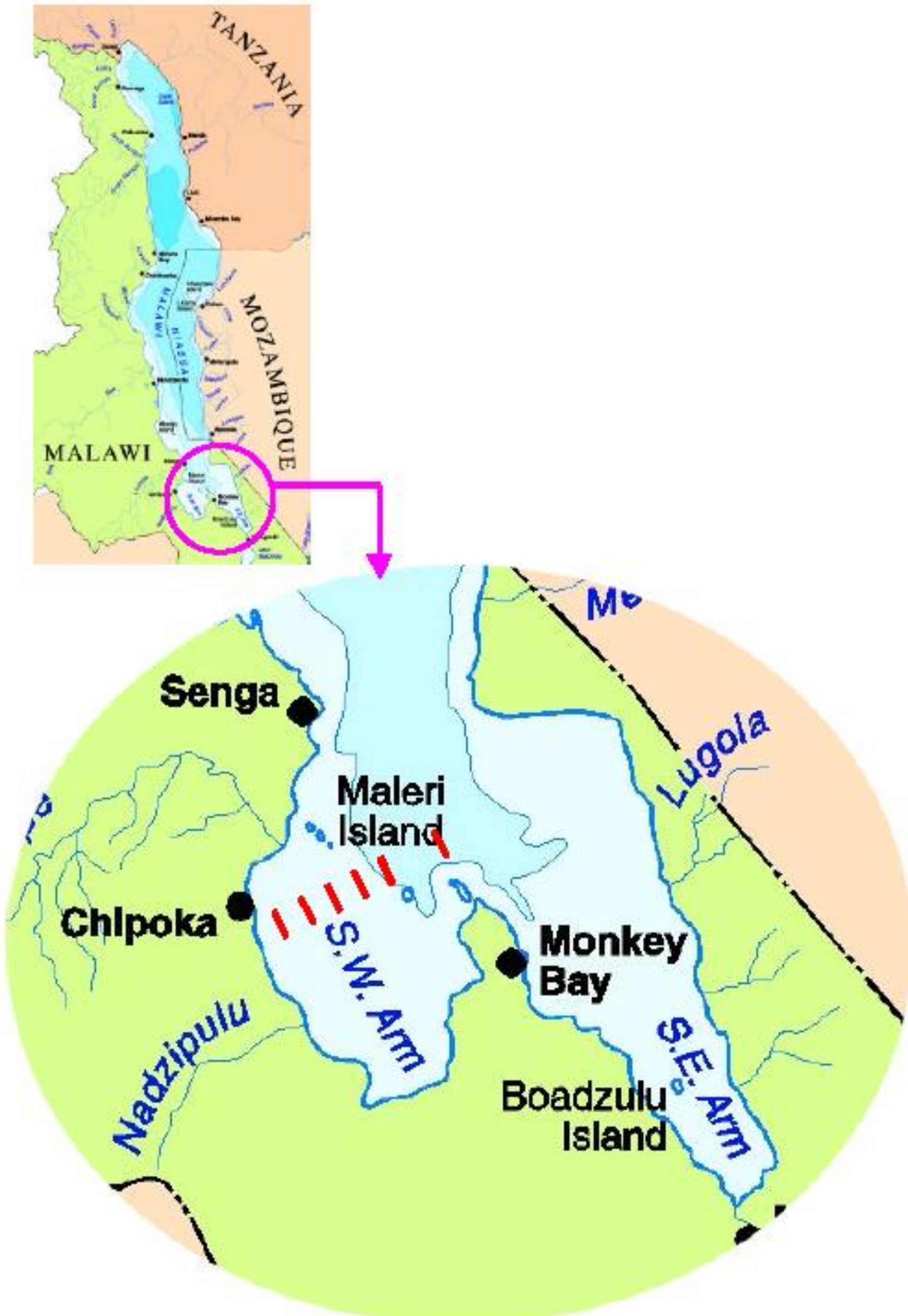

Figure 2.1. The southern part of the Lake Malawi showing the south east arm (SEA).

2.1.2. Climate and limnology of the south east arm of Lake Malawi.

The region around the lake has three seasons. The cold season runs around May to August/September and is dry, cool and windy. The hot season runs from September through to the first real rains and is hot, dry and the water in the lake is at its clearest. The rainy season is variable in its onset. It can rain in November or December, but the normal rainy season usually gets going from January to March/April and the temperature cools down when it rains (Turner, 2004). Surface temperature vary from 23-29^{o}C (Ribbink, 1994). During cold season, the main axis of wind is from the south east to the North West. The south easterly winds locally known as mwera blow strongly during the cool season of May to August and causes an upwelling of nutrient-rich water. This leads to a peak in primary productivity around July to August (Patterson & Kachinjika, 1995).

2.2. Biology of species under study.

L. gossei belongs to a big genus containing at least more than 38 species and belongs to a family of cichlidae, sub family Pseudocrenilabrinae, order Perciforms and class Actinopterygii (ray finned fishes). *L. gossei* are haplochromine cichlids, endemic to the Lake Malawi basin and characterised mainly by the shape of the lower jaw and by the dentition. They are demersal fresh water species favoring tropical climate between 12^{0}S-15^{0}S and are locally known as Chisawasawa (Marechal, 1991).

L. gossei are micro predators, which sift sand to extract small edible organisms and feed on benthic arthropods, lake fly (Duponchelle *et al.*, 2000a). They have weak jaws and teeth, which are used for sifting sand. They are polygamous mouth brooders. Ripe males are strongly barred with dark purplish or greenish iridescence on their heads. They can reach a maximum size of 20 cm TL (Figure 2.2).

L. gossei are precocial (k-selected) fish producing very few young at a time and consequently unlikely to recover quickly from heavy fishing pressure (Ribbink, 1994). The advantage of parental care is lost as young are spewed out when brooding females are caught. Nets dragged across the bottom also destroy spawning platforms. These fish (sandy inshore) deserve every effort to preserve them and their habitats must be protected because of the vulnerability of these unique and irreplaceable endemic cichlid fauna and in order to safeguard their sustainable utilization.

Figure 2.2. Photograph of male (a) and female (b) *Lethrinops gossei* caught using demersal trawl gear at a depth of > 75m from the south east arm of Lake Malawi.

The length at maturity may be defined as the length at which 50% of the individuals within a population are sexually mature (*Lm* 50), where mature individuals are characterized by the presence of spermatophores or ova in the gonads. Studies done by Lewis & Tweddle, 1990, Kanyerere, 1999 and Duponchelle *et al.*, 2000a show that female *L. gossei* matures at 147mm TL, 159mmTL and 92mmTL respectively. Because maturation is age or size dependent it is strongly linked to growth. Fish that grow fast and big have the potential to reach the size at maturity quickly and produce more eggs. This in turn is regulated by the temperature regime of the water in which the fish live (Wootton, 1990).

Major objective of the Malawi fisheries policy is regulating production within safe sustainable limits for each fishery (Government of Malawi, 2001), safe harvest levels for *L. gossei* must be determined if the resource is to be utilized sustainably. This requires an understanding of its biology and life history, as well as the application of quantitative methods which require age-based estimates of growth, maturity and population structure.

Early studies have reported the growth rate of *L. gossei*, but were based on length-frequency methods (Duponchelle *et al.*, 2000b). The study described growth using the von Bertalanffy growth function (VBGF). The accurate determination of age in fishes is a fundamental requirement for determining the population age structure and growth rate (Beamish & McFarlane, 1987), both of which are needed for reliable stock assessments.

CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1 Field techniques

3.1.1. Sampling of Lethrinops gossei

The samples of *L. gossei* were collected onboard the research vessel *R.V. Ndunduma* using demersal trawl gear on monthly basis from March 2005 to February 2006 in the south east arm of Lake Malawi. The vessel is a 17m long, which pulls a gulloppur bottom trawl net with a 23m head rope and a 38mm cod end mesh. The multispecies fish were caught at random at a depth of more than 75m and *L. gossei* was selected from each trawl. A total of 1208 male and female *L. gossei* (58 – 146mm SL and 73 – 200mm TL) were collected during the ongoing fishing trials carried out by the Fisheries Department. A total of 659 otoliths were collected for age and growth analysis. Efficient sampling was carried out to include the widest possible range of lengths. There was variation in fish sizes and fish population ranged from immature specimens to fully mature ones.

Reproductive activity was investigated by removing the gonads of female fish by dissecting using a pair of scissors. The gonads were removed, weighed to the nearest 0.1g using an HF – 3000 electronic weighing balance and categorized according to six developmental stages according to (Munro & Thompson, 1983) (Table 3.1). The total length (TL) and standard length (SL) were measured to the nearest millimeter using a measuring board and weighed to the nearest 0.1g using an HF – 3000 electronic weighing balance while fish were still fresh onboard *R.V.Ndunduma*. Total length was measured from snout to the tip of the tail fin while Standard length was measured from snout to the base of the caudal fin.

Table 3. 1. General definition of maturation stages of *Lethrinops gossei* from the south east arm of Lake Malawi adopted from Munro & Thompson (1983).

Stage	Development	Gonad appearance (Ovary)
I	Immature	Ovary thread like, transparent and close to abdominal wall
II	Inactive	Ovary cream colored, translucent, elongates wider than testis. No oocytes visible
III	Active	Ovary not yet swollen, oocytes visible and yellowish
IV	Ripe	Yellow, green, orange eggs, large uniform size. Ovary occupies all visceral cavity space
V	Ripe running	Ovary extremely swollen and eggs run under hand pressure or separate if ovary is opened
VI	Spent	Flaccid, shrunken ovary, reddish with blood capillaries and small eggs discernible

3.1.2 Otolith extraction.

To remove the sagitta otolith bones, fish were held upside down and cut through the gill arches and isthmus to expose the roof of the mouth. The fish were cut three quarters through the roof of the mouth (parashenoid bone) where the first gill arches join the roof of the mouth. While holding the head of the fish, the backbone was broken downwards where the cut was made in the roof of the mouth. This exposed the otolith bones within membranous sacs on either side of the mid-line at the posterior ventral portion of the brain cavity. Otoliths were extracted unbroken and as clean as possible, using small forceps. Both the right and left sagitta otoliths were removed at the Fisheries Research Unit Laboratory. Otoliths were stored in small, manila envelopes labeled with the following information: Date of collection, species name, standard length, total length, weight and an individual identification number which acted as a link between the age sample and other detailed biological information collected from the specimen. Otoliths were taken to Bunda College for further processing.

3.2. Laboratory technique

3.2.1 Otolith preparation and examination

Both sagitta otoliths were weighed to the nearest 0.01mg using an HF – 3000 electronic weighing balance. Otolith length and width were measured to the nearest 0.01mm using digitated caliper. Otolith length was the distance from the anterior tip to the posterior tip, and the otolith width was the distance from the dorsal edge to the ventral edge across the nucleus perpendicular to the otolith length. Measurements were made as close as possible to the nucleus as described by (Lou, 1992).

Left or right sagitta otolith from each fish was selected for ageing. To enhance otolith growth zones visibility, a burning technique was employed (Kanyerere, 2003). Each otolith was lightly burned to a light brown color using a double coil electric hot plate with adjustable heat settings at Bunda College of Agriculture, Aquaculture and Fisheries Science Department laboratory. To avoid charring, as this tends to obscure the internal structure and margin of the otolith (Booth & Merron, 1996), a specially designed tray was used to hold the otoliths about 5cm above the heating element. Each otolith was embedded in a block of clear fibre glass resin by placing medial side down. Otoliths were sectioned along the dorsoventral plane through the nucleus at 0.05mm using a dual blade high-speed diamond saw.

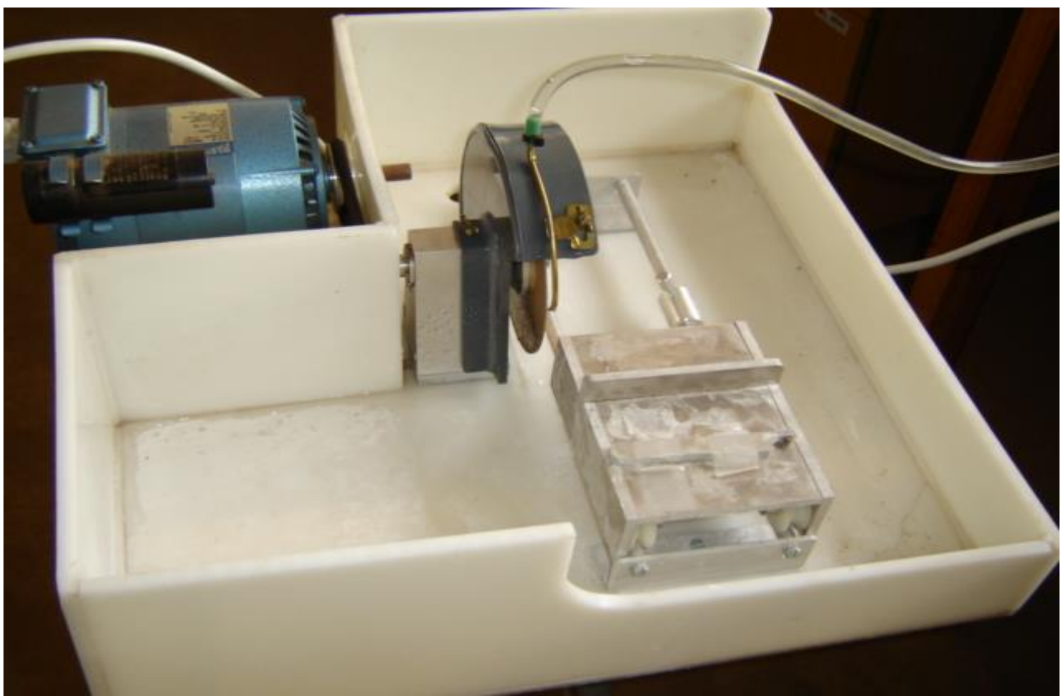

Figure 3.1. An otolith cutter with a dual blade high-speed diamond saw used for cutting thin transverse sections of *Lethrinops gossei* sagitta otoliths.

The sectioned otoliths were mounted on glass slides with DPX mountant and were viewed with a compound microscope connected to a video display system transmitting white light (Figure 3.2).

Figure 3.2. A compound microscope connected to a video display system used for viewing the *Lethrinops gossei* transverse sectioned sagitta otoliths.

Age assessment from calcified structures is subjective (Weatherley & Gill, 1987). Therefore, to minimize subjectivity in age determination, a reader had to make three independent observations, without reference to the date of capture or length of the fish. The first two readings were done at Bunda College, while the third reading was done at Rhodes University in South Africa. The reading was only accepted if at least two or three readings were identical. If the three readings differed by one year, the mean of the three estimates was taken. If the readings differed by more than two years the otolith was rejected.

3.3. Estimation of growth parameters.

The selected model for estimation of growth parameters was the Von Bertalanffy growth model (VBGF) for individual growth, which has shown to conform to the observed growth of most fish species. This model was chosen since its parameters are commonly used in empirical estimates of natural mortality (Pauly 1980), in per-recruit modeling (Ricker 1975) and for ease of comparison with growth studies conducted in other localities and on other species.

The Von Bertalanffy growth model was fitted to the observed length-at-age data for *L. gossei* using an iterative least squares procedure (Microsoft EXCEL) SOLVER routine with Newton algorithm option. Recommendations by (Punt & Hughes,1992) for determining and fitting appropriate growth models were followed. The non-parametric one-sample runs test for randomness and the Bartlett's test for homoscedascity (Hughes, 1986) were applied. PC-YIELD 2.2 was used to execute the above procedure.

The Von Bertalanffy growth model was of the form:

$$L_t = L_\infty\left(1 - e^{-K(t-to)}\right) \qquad \text{Equation 1}$$

where L_∞ is asymptotic length. It is the mean length of the fish of a given stock that would be reached if they were to grow indefinitely. This is also known as length at infinity. K is a curvature parameter or growth constant. It determines how fast the fish obtains its maximum size. The value t_0 is the age of the fish at zero length or is the initial condition parameter if they had grown in the manner described by the equation. Thus t_o is a parameter, which determines where the growth curve starts.

Age-length table for the percent or fractional age-frequency distribution was described. Age-length keys were constructed following the determination of the age of each individual fish from the otolith and the frequency distributions were obtained.

3.4 Validation of otoliths rings

3.4.1 Otolith marginal increment analysis

The time of opaque band formation was determined by marginal increment analysis. In this method, the transverse section on the dorsal side of the otolith was examined to determine whether it was opaque or translucent. The percentage of opaque otolith margin was calculated for samples of different months. Growth ring deposition periodicity was identified by plotting monthly percentage of otoliths with opaque zones as a function of time. Following this, age of an individual fish was reflected by alternating opaque and translucent rings.

3.5 Length frequency distribution analysis.

The length frequency distribution analysis is an alternative method of ageing fish (Pitcher & Hart, 1982). It was also used to compare the observed results from the otolith (Banda, 1992). Analysis and processing of length data was done using the Length Frequency Distribution Analysis (LFDA Version 5.0) by Kirkwood *et al.* (2001) and FAO-ICLARM Stock Assessment Tools (FISAT II) (FAO 2002) packages. Estimation of growth parameters ($L\infty$, K, t_o) of the Von Bertalanffy growth curve was done by defining grid boundaries using ELEFAN (Electronic Length Frequency Analysis). When several pairs of $L\infty$ and K parameter estimates were identified by the LFDA programme, the pair with the value of $L\infty$ and K that were giving maximum score per chosen defined grid after several trials and iterations was chosen. These values were taken to be near the maximum observed length of the particular species (LFDA user manual by Kirkwood *et al.*, 2001). Growth parameters $L\infty$ and K were used in fitting the von Bertalanffy growth curves.

The overall growth performance index phi-prime (ø') is used for comparing the growth rate of a species in a particular fishery to the standard growth rate of the species. Populations with different growth parameters may have a similar growth performance (Pauly & Munro, 1984). Growth performance index was computed using the $L\infty$ and K values derived in EXCEL and FISAT, respectively, using the equation shown below (Pauly & Munro, 1984):

$$\phi = \ln \mathrm{K} + 2 \ln L_{\infty} \qquad \text{Equation 2}$$

The asymptotic length (L_{∞}) estimated by the Von Bertalanffy growth model and Length-at-50% maturity based on mature stages (3, 4, 5) were compared with L_{∞} and length-at-50% from an excel spreadsheet (Froese & Binohlan, 2000). The equations were used to estimate life history parameters in fishes. The asymptotic length and 95% confidence interval were estimated from the maximum length (L_{max}) observed using the following empirical equations (Froese & Binohlan, 2000):

$$L_{\infty} = 10(0.044 + 0.9841 * Log10(L_{\max})) \text{ .... Equation 3}$$

$$Lm = 10^\wedge(0.898 * Log10(L\infty)) - 0.0781 \text{ .... Equation 4}$$

3.6 Estimation of ageing precision.

Precision was estimated age using the average percent error method. The Index of Average Percent Error (IAPE) was suggested to be the better method for assessing the precision of age determinations compared to the percent agreement method, since the latter does not evaluate the degree of precision equally for all species (Beamish & Fournier, 1981).

If N fish are aged and R is the number of times each fish is aged then X_{ij} is the ith age determination of the jth fish and X_j is the average age calculated for the jth fish.

$$Xj = \frac{1}{R}\sum_{i=1}^{R} Xij \text{ .... Equation 5}$$

The Average Percent Error (APE) in ageing the jth fish, as a fraction of the average of the age estimates was calculated as:

$$APE = \frac{1}{R}\sum_{i=1}^{R}\left[\frac{|Xij - Xj|}{Xj}\right]*100 \text{..............................Equation 6}$$

The Index of Average Percent Error for all fish in this sample was calculated as:

$$\text{IAPE} = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij} - X_j|}{X_j}\right]\times 100 \text{..............................Equation 7}$$

The Coefficient of variation (CV) was obtained by replacing the average absolute deviation from the arithmetic mean in equation of IAPE with the standard deviation (Chang, 1982) as follows:

$$CV = 100\% * \frac{\sqrt{\sum_{i=1}^{R}\frac{(Xij - Xj)^2}{R-1}}}{Xj} \text{..............................Equation 8}$$

The percent error contributed by each observation to the average age-class was estimated by an index of precision:

$$D = \frac{CVj}{\sqrt{R}} \text{..............................Equation 9}$$

and the percent error in each age determination made for each observation was obtained by multiplying the index of precision (D) by the average age for the jth fish.

3.7. Relationships between fish length and otoliths length.

The relationships of otolith length, width and weight to total length of *L. gossei* were estimated using the following formulas (Griffiths & Hecht, 1995):

$OL = aTL + b$ ……………………………………………………………Equation 10

where OL = Otolith length (mm)

L = Total length (mm)

a and b are constants.

$OW = aTL + b$ …………………………………………………………...Equation 11

where OW = otolith width

$Owt = ae^{bTL}$ ……………………………………………………………Equation 12

where Owt = otolith weight

The relationships between weight to total length of male and female *L. gossei* were determined using the following formulas (Lagler *et al*., 1977):

$W = aTL^{b}$ ……………………………………………………………...Equation 13

where W = weight of fish (g); TL = Total length (TL, mm); a and b are constants

3.8 Reproductive biology.

The mean length-at-50% sexual maturity (the size at which 50% of the fish are sexually mature) was determined from 246 female *L. gossei* by fitting a logistic ogive to the proportion of reproductive active fish (stages 3, 4, 5) during the spawning season in mm size (TL, SL) classes (King, 1995).

$$\psi = \frac{1}{\left[1+e^{-(L-Lm_{50})/\delta}\right]} \text{...Equation 14}$$

where ψ is the proportion of sexually mature fish by length.

Lm_{50} is the mean length at 50% sexual maturity

L is individual total length

δ is the width of the logistic curve

The age-at-50% maturity was determined by fitting the same logistic ogive to the proportion of reproductive active fish during the spawning season arranged in year classes.

Temporal patterns in reproductive activity were assessed on a monthly basis using a Gonadosomatic index (GSI) and development stages of the gonads. A total of 262 female *L. gossei* were sampled. To eliminate distortion of the breeding seasonality pattern caused by influxes of large numbers of young fish with low incidence of breeding individuals, all specimens below average length at first maturity were excluded from the computations of breeding pattern.

The Gonadosomatic index was expressed following the formula below; (Wootton, 1990).

$$GSI = 100\% * \frac{Weight\ of\ \ gonads}{Weight\ of\ \ fish}$$ …………………………………………..Equation 15

Fish condition factor was determined following the formula below

$$c.f. = (W / L^3) * 100$$ ……………………………………………………Equation 16

where W is the weight of fish in grams and L is the total length of fish in mm

3.9 Recruitment pattern.

ELEFAN in FiSAT II was used to obtain expressions of the seasonal changes in recruitment patterns displayed in a graphical form. The seasonal recruitment pattern of the fish was reconstructed using length−frequency data and subdivided into normally distributed recruitment pulses. This involved projecting backward, along a trajectory described by the computed von Bertalanffy growth formula restructured onto a 1-year time scale (Pauly, 1983). Then, employing the maximum likelihood method, the distribution was resolved into its gaussian components using the NORMSEP (normal separation) procedure of (Hasselblad & Tomlinson, 1971). The growth parameter estimates $L\infty$ and K were used as inputs. Recruitment pattern was presented in terms of the percentage of recruitment versus time (months). The numbers of recruitment peaks for this species were examined using recruitment patterns.

3.10. Mortality and exploitation rates

The total mortality coefficient, Z (year^{-1}), was estimated using catch curve analysis. An age length key, constructed from length-at-age data was used to transform length frequency distributions to age frequency distributions (Butterworth *et al*., 1989) from which instantaneous total mortality (Z) was estimated by catch curve analysis (Ricker, 1975). The length frequency data was obtained from the bio-annual monitoring survey of 2000.

In addition, further estimates of Z were obtained by using the Butterworth et al. (1989) equation:

$$Z = In\left[1 + \frac{1}{(a_r - a_f)}\right] \quad \text{..........Equation 17}$$

where a_f is the mean age at full recruitment and a_r is the age of fully recruited fish sampled. A first approximation of Z was obtained by averaging the slope estimates from catch-curves and from the estimates obtained using (Butterworth *et al*., 1989) equation on age-converted data collected from the subsistence catches.

The natural mortality, M (year^{-1}) was estimated using (Pauly's, 1980) empirical equation relating M, L_∞, K and mean environmental temperature obtained from the Fisheries Research Unit data (taken at 23.5 C in this study):

$$\ln M = -0.0066 - 0.279 \ln L_\infty + 0.6543 \ln K + 0.4634 \ln T \quad \text{..........Equation 18}$$

Where T is the average annual temperature at the surface in °C, M is the natural mortality, L_∞, is the asymptotic length and K is the curvature parameter Differences in temperature are likely to have a minimal effect on estimates of M for these species, given the narrow temperature ranges. Fishing mortality rate (F) was calculated as below:

$$F = Z - M \quad \text{.....Equation 19}$$

The exploitation rate, E, was computed by dividing F by Z (F/Z). The parameter E expresses the proportion of a given cohort/population that ultimately dies due to fishing given existing exploitation pressure (Beverton & Holt, 1966).

3.11. Statistical analysis.

The softwares Microsoft EXCEL, PC- YIELD 2.2 (Punt & Hughes, 1992), FISAT II, and LDFA version 5.0 were used for statistical computations. SOLVER routine with Newton algorithm option was used to fit the Von Bertalanffy growth model to the observed length-at-age data for *L. gossei* using an iterative least squares procedure. Recommendations by (Punt & Hughes, 1992) for determining and fitting appropriate growth models were followed. The non-parametric one-sample runs test for randomness and the Bartlett's test for homoscedascity (Hughes, 1986) were applied. Variance estimates were calculated using the conditioned parametric bootstrap resampling method (Efron, 1982), with 500 bootstrap iterations. Standard errors and 95% confidence intervals were constructed from the bootstrap data using the percentile method described by (Buckland, 1984). PC-YIELD 2.2 was used to execute the above procedure. This soft ware uses a non-linear minimization routine (simplex method) to obtain parameter estimates for the selected growth model. Analysis and processing of length data was done using the Length Frequency Distribution Analysis (LFDA Version 5.0) and FAO-ICLARM Stock Assessment Tools (FISAT II) packages. ELEFAN in FiSAT II was used to obtain expressions of the seasonal changes in recruitment patterns displayed in a graphical form. For the linear regression total length and standard length were used as independent variables, where as the regression of total length and standard length, total length was used as independent variable. All regressions were at $p < 0.05$. Power function was used to model the relationship between weight and total length (Pitcher & Hart, 1990). Growth parameters from the Von Bertalanffy growth model and an EXCEL spreadsheet were compared using t-test.

CHAPTER FOUR.

4.0. RESULTS.

4.1. Age estimation.

The transverse sections of the sagittal otoliths of *L. gossei* showed distinct opaque and translucent zones deposited in the otoliths each year (Figure 4.1). These were validated as annuli (Figure 4.2) and could be used to estimate the age of the species. Out of 659 otoliths that were collected for 12 months, 604 (91.6%) were sectioned and aged while 55 (8.4%) were discarded, as they were broken before preparation. Three hundred and seventy two (61.6%) yielded useful age estimates. Zones were relatively widely spaced for the first 2 or 3 rings, and then became more closely spaced. Thirteen (2.2%) were rejected due to disagreement between replicate counts. Two hundred and nineteen (36.3%) otoliths were discarded as rings were difficult to read. The readings were done on three occasions and the readings were only accepted if at least two readings were identical otherwise average of the three was used only if the difference was ±1. Age estimate ranged from 0+ to 6+ years.

Age estimate were considered to be reasonably precise with an average percent error (APE %) of 10.2, a coefficient of variation (CV %) of 7.6% and an index of precision (D) of 5.5.

Figure 4.1. Photomicrographs of sagitta otoliths from a 180mm TL, 6 Years old *Lethrinops gossei* from the south east arm of Lake Malawi. Note the opaque margin (om) on the otolith. The growth rings are marked by numbers 1-6.

The plot of marginal increment analysis indicates that most fish caught in August had a ring close to the edge (Figure 4.2). Otoliths had opaque margins in August that coincided with the end of-breeding season which, runs between November to August with peak of activity from February to May.

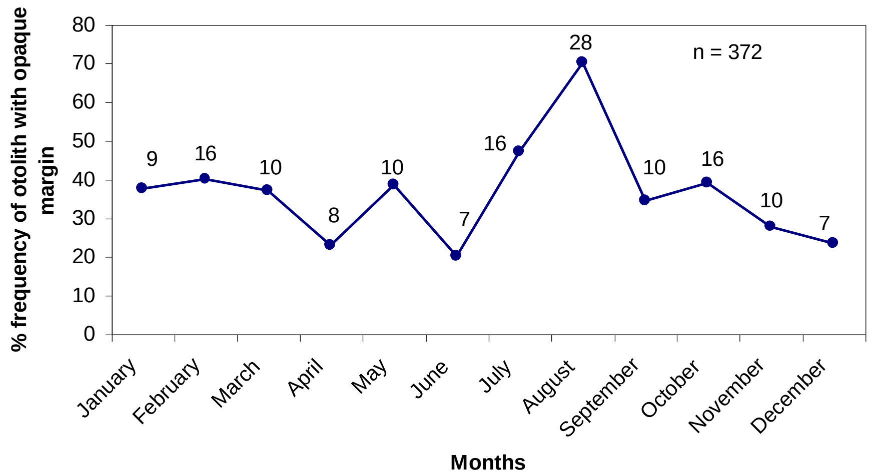

Figure 4.2. The monthly percent occurrence of an opaque margin in otoliths of *Lethrinops gossei*, sampled from the south east arm of Lake Malawi. The numbers of otoliths with opaque margins is shown in each case.

Seven age classes, ranging from 0 to 6 years old were defined by the transverse surface readings of the otoliths (Table 4.1). The resulting age-length-key presents a mixture of ages and lengths that suggested two main patterns. First, the number of ages within a 5cm length class increases as the fish grows larger. Second, with two exceptions (ages 1 and 2), each age contained only two to three length classes.

Table 4.1. Length-at-age (SL (a) and TL (b) key for *Lethrinops gossei* in the south east arm of Lake Malawi. Age was estimated from reading of sectioned sagittal otoliths.

(a)

Length	Age (years)						
(mm SL)	0	1	2	3	4	5	6
70-74	1	4					
75-79		1					
80-84		7	1				
85-89			13				
90-94			22				
95-99			34				
100-104			51	5			
105-109			27	16	1		
110-114			4	42	2		
115-119			2	21	23		
120-124				1	33	13	
125-129					1	17	
130-134						17	3
135-140						5	5
n	1	12	154	85	60	52	8

(b)

Length	Age (years)						
(mm TL)	0	1	2	3	4	5	6
90-94	1	1					
95-99		3					
100-104		2					
105-109		6					
110-114			15				
115-119			9				
120-124			22				
125-129			29				
130-134			54				
135-139			25	18			
140-144				32			
145-149				35			
150-154					33		
155-159					27		
160-164						21	
7165-169						17	
170-174						14	2
175-180							6
n	1	12	154	85	60	52	8

Table. 4.2. Observed mean length-at-age (± standard error) from combined sex of *Lethrinops gossei* determined using otoliths. Samples were collected from south east arm of Lake Malawi during the period March 2005 to February 2006.

Age	Observed mean length (± se)	n	Length range
0	90 ± 8.18E-15	1	0 – 90
1	101 ± 1.50	12	93 – 106
2	126 ± 0.59	153	110 – 135
3	141 ± 0.39	85	135 – 149
4	152 ± 0.34	60	150 – 158
5	164 ± 0.56	52	160 – 170
6	175 ± 1.14	8	171 - 180

Length -at- age for *L. gossei* was adequately described by the Von Bertalanffy growth model. The 3- parameter Von Bertalanffy model gave a realistic asymptotic length estimate that was close to the size of the largest fish sampled and was used for additional calculations (Figure 4.3).

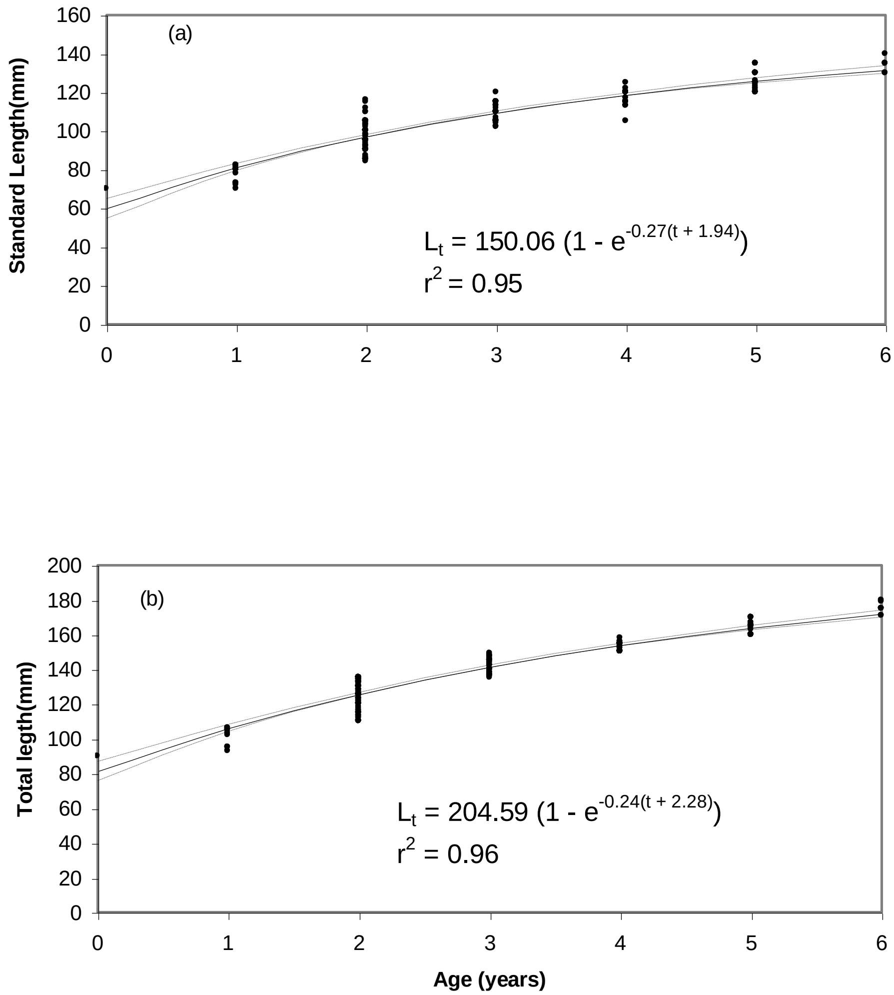

Figure 4.3. Observed individual length-at-age (a, SL and b, TL) of *Lethrinops gossei* determined using sagitta otoliths (n=372). Samples were collected between March 2005 and February 2006. The growth curves were fitted to combined sex data using the Von Bertalanffy growth model with an absolute error structure.

The Von Bertalanffy growth parameters, their associated estimates of mean, variation and confidence intervals for standard and total length are summarized in Table 4.3.

Table 4.3. Point estimates, mean, standard error (SE), coefficient of variation and 95% confidence intervals for combined sex length-at-age data fitted using the Von Bertalanffy model for *Lethrinops gossei* sampled from the south east arm of Lake Malawi during March 2005 to February 2006.

Parameter	Point estimate	Mean	SE	CV	95% confidence
TL					
L_∞	204.59	205.62	7.72	3.76%	[193.40, 223.03]
K	0.24	0.25	0.03	12.04%	[0.17, 0.28]
t_o	-2.28	-2.30	0.28	11.99%	[-2.89, -1.79]
SL					
L_∞	150.06	150.43	5.31	3.53%	[142.08, 163.18]
K	0.27	0.27	0.03	12.54%	[0.20, 0.34]
t_o	-1.93	-1.94	0.28	14.49%	[-2.54, -1.45]

The growth parameter estimates obtained using the best fits of PC-YIELD 2.2 were compared with growth estimates obtained by using the LFDA and FISAT (ELEFAN) and the empirical equations in EXCEL spreadsheet (Table 4.3). Comparisons of the growth parameters showed that parameter estimates from the LFDA and FISAT (ELEFAN) were slightly lower than parameter estimates from the PC-YIELD 2.2 although they were not significantly different ($P > 0.01$). The set values of parameters were plotted in VBGC to obtain the length frequency plots (Figure 4.4)

Table 4.4 Comparison of growth parameters (L_∞, *K* and t_o) of *Lethrinops gossei* from the south east arm of Lake Malawi) from PC-YIELD 2.2, FISAT II (ELEFAN) and EXCEL spreadsheet (nd = not done).

Source	Parameter	Estimate
PC YIELD 2.2	L_∞	204.59
	K	0.24
	t_o	-2.28
LFDA & FISAT	L_∞	204.00
	K	0.26
	t_o	-1.97
EXCEL spreadsheet	L_∞	203.96
	K	nd
	t_o	nd

Note: Parameters *K* and t_o were not analysed in excel as the spreadsheet by Froese & Binohlan, 2000 can not estimate the parameters.

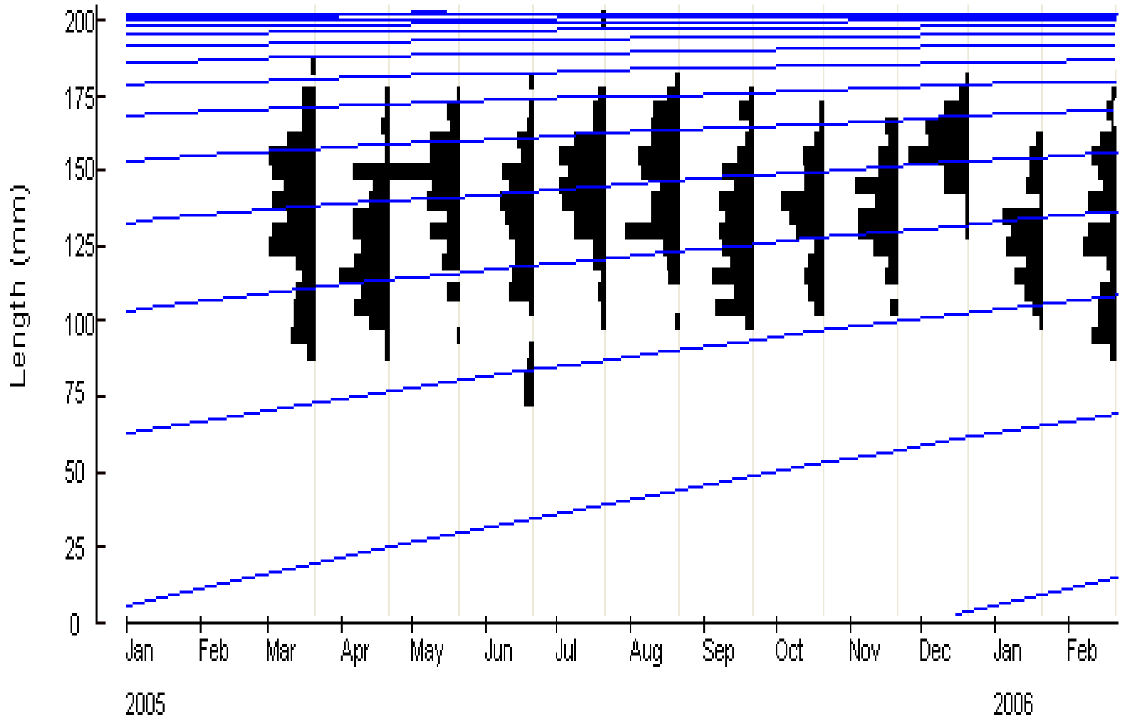

Figure 4.4. Length frequency plots for *Lethrinops gossei* fitted to Von Bertalanffy growth curves (L_∞= 204.59mm TL, K = 0.24 year $^{-1}$, t_0 = -2.28) n = 1208.

4.2. Otolith dimension and fish length relationships.

The relationship between otolith length, otolith width and fish total length was best described by a linear regression (Table 4.4) and (Figure 4.5 a, b, c), which fitted the data well. The linear relationship observed indicated that the otolith grew in length and width as the fish continued to grow. The weight of the sagitta otolith increased exponentially with the total length of the fish. This growth in thickness represented the deposition of new material over the proximal face of the otolith.

Table 4.5. Otolith dimension and fish length relationships of *Lethrinops gossei* from south east arm of Lake Malawi. Wt = weight, TL = total length, SL = standard length, Owt = otolith weight. Both sexes combined.

Relationship	Sex		r^2	P	N
OL (mm)	Combined	= 0.03898 +0.0384 * TL	0.88	<0.05	659
OW (mm)	Combined	= 0.7092 + 0.0205 * TL	0.62	<0.05	659
Owt (mg)	Combined	$= 0.1758 * e^{0.0183 * TL}$	0.72	<0.05	659

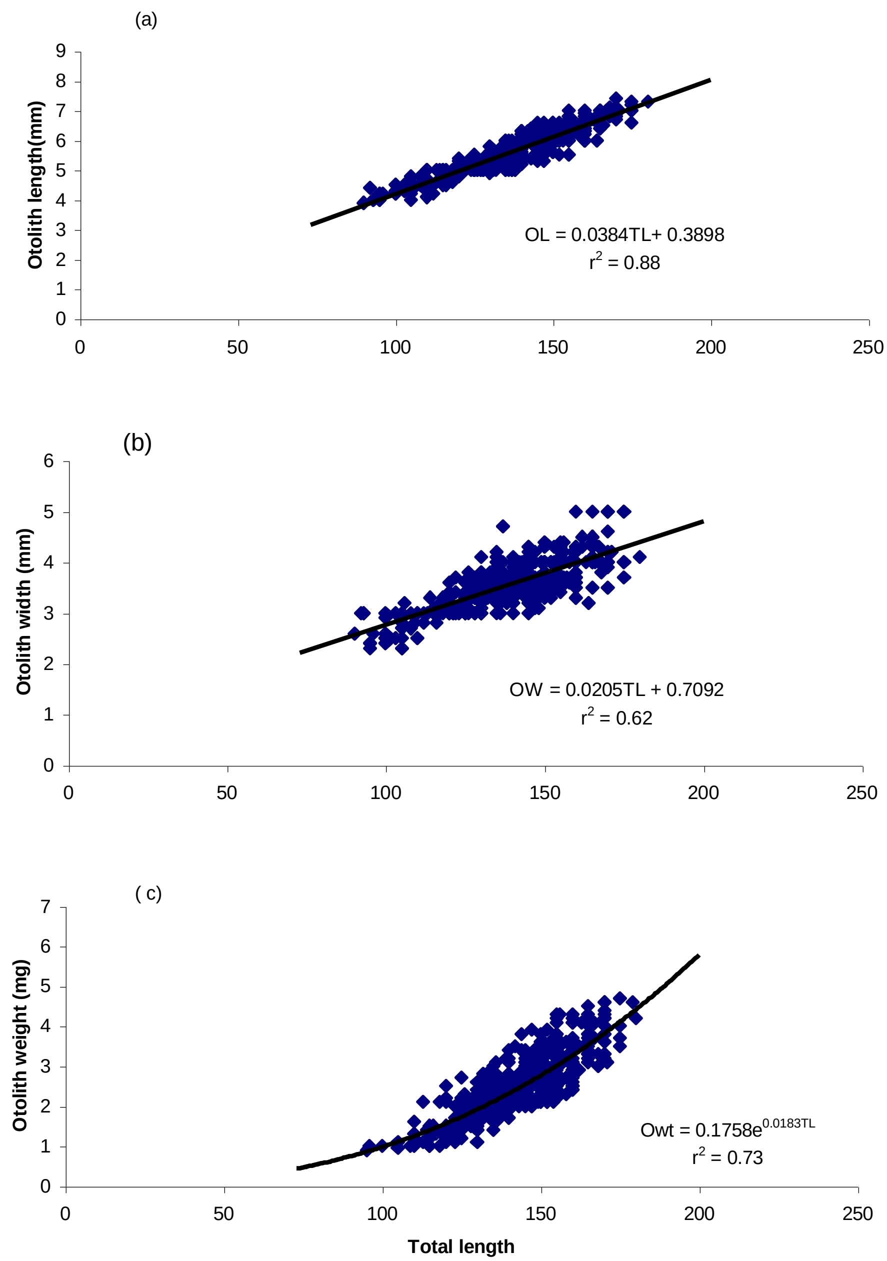

Figure 4.5. Scatter plots of the relationships between otolith (a) length, (b) width, (c) weight and fish total length (mm). Equations for lines of best fit have been determined by least squares regression.

4.3. Length – Weight relationship

The morphometric relationships between total length and weight, total length and standard length of *L. gossei* are summarized and shown in Table 4.6 and Figure 4.7 and 4.8 (n = 1208). The correlations of the relationships ($W = a\ TL^b$) (Table 3.2) were positive and significant ($p < 0.05$). Therefore the relationship between length (TL) and weight (Wt) for both male and female *L. gossei* was described by the following equations (Table 4.6):

Table 4.6. Morphometric relationships of *Lethrinops gossei* from south east arm of Lake Malawi. Wt = weight, TL = total length.

Relationship	Sex		r^2	P	N
Wt(g)	Combined	$=(7*10^{-6})*TL^{3.134}$	0.96	< 0.05	1208
Wt(g)	Male	$=(7*10^{-6})*TL^{3.1197}$	0.97	< 0.05	650
Wt(g)	Female	$=(7*10^{-6})*TL^{3.1328}$	0.95	< 0.05	558

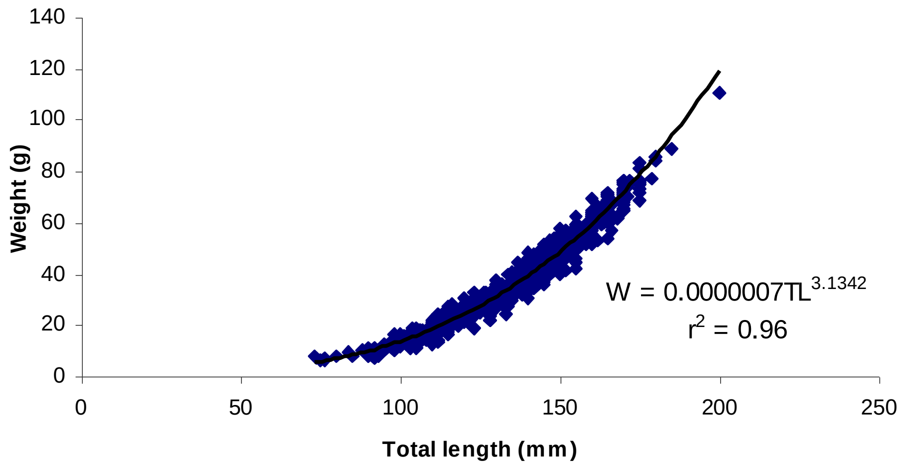

Figure 4.6. Morphometric relationship (TL and weight) of *Lethrinops gossei* from south east arm of Lake Malawi. Sexes have been combined.

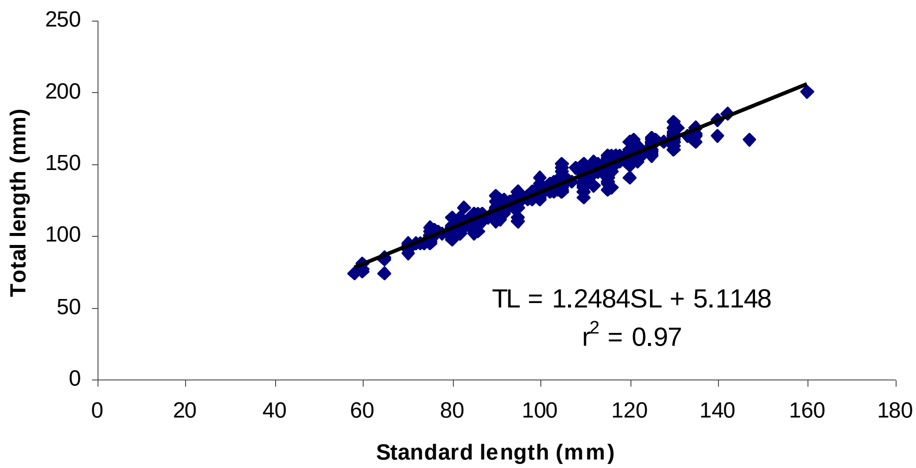

Figure 4.7. Morphometric relationship (TL and SL) of *Lethrinops gossei* from south east arm of Lake Malawi. Sexes have been combined.

4.4. Reproductive biology.

The Length and age-at-50% maturity were determined by fitting a logistic ogive to the proportion of reproductive active fish (stages 3, 4 and 5) during the spawning season (Figure 4.9 a, b, c). *L. gossei* females attained Lm_{50} at 135.95mm TL (a) or 104.05 mm SL(b). Mean age-at-50% maturity was calculated at 2.14 years (c).

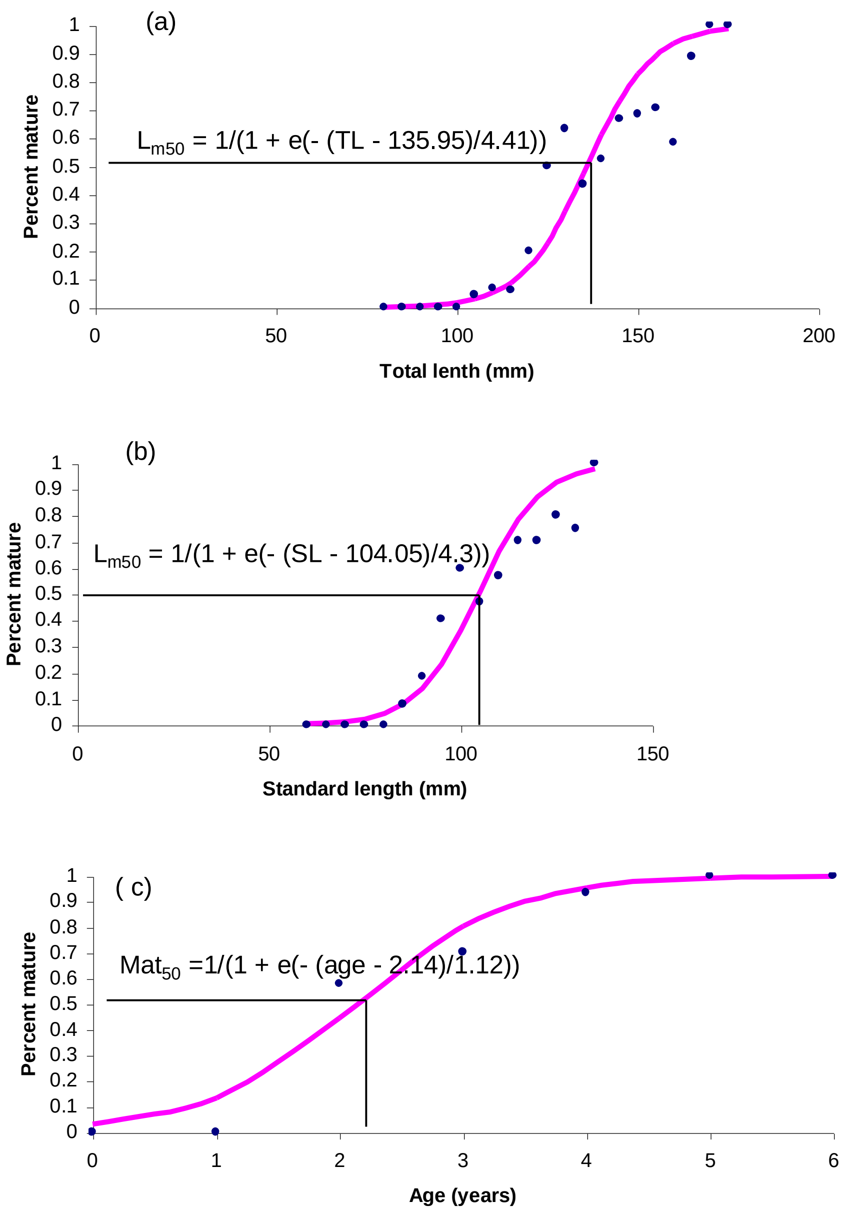

Figure 4.8. Sexual maturity in *Lethrinops gossei* females from south east arm of Lake Malawi, (a) total length (n = 245), (b) standard length (n = 245) and (c) age (n = 179). The length and age-at-50% maturity were calculated by fitting a logistic ogive to the data.

Comparisons of length at-50% maturity showed that estimates from the logistic ogive was slightly higher (135.95mm TL) than parameter estimates from the empirical relationship (133.74mm TL) for female fish although they were not significantly different ($P > 0.01$).

Breeding seasonality was studied by GSI (Figure 4.10). These studies permitted assessments made as to what time of the year and duration breeding fish may be protected. *L. gossei* displayed a marked periodicity in breeding. Breeding season occurred between November to August with peak of activity from February to May and a steady decline up to October. The mean GSI was higher in March than in all other months.

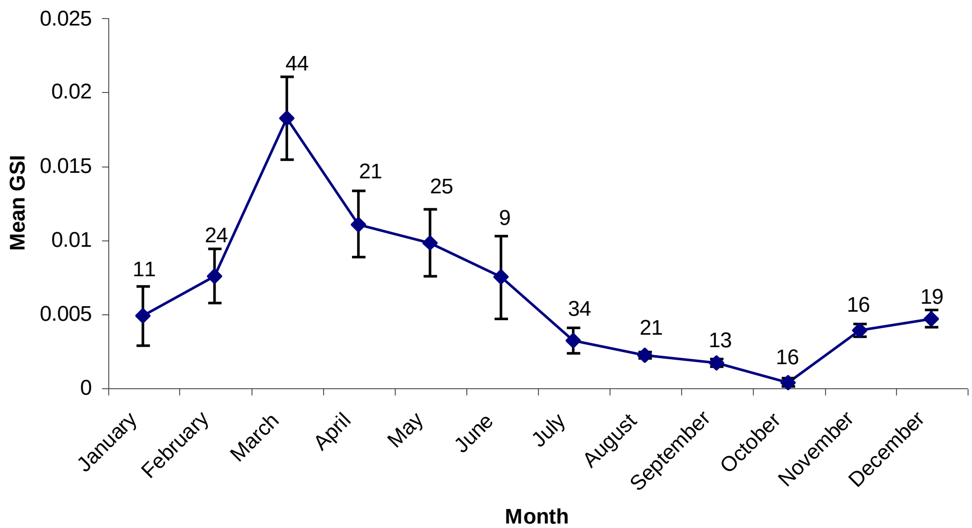

Figure 4.9. The monthly variation in mean Gonadosomatic index (GSI) ± standard error of female mature (above L_{m50}) *Lethrinops gossei* from the south east arm of Lake Malawi. The numbers on the specimen examined is shown in each case.

The monthly variation of gonad maturity in female *L. gossei* collected from southeast arm of Lake Malawi between March 2005 and February 2006 showed that there was correlation in the maturation of gonads and the Gonadosomatic index. Fish in ripe condition were high (56%) in the months of February, March and April and declined through to June (3.2%). Fish in spent condition were high (58%) in the months of July, August to September. Immature fish were high (16%) in the month of April.

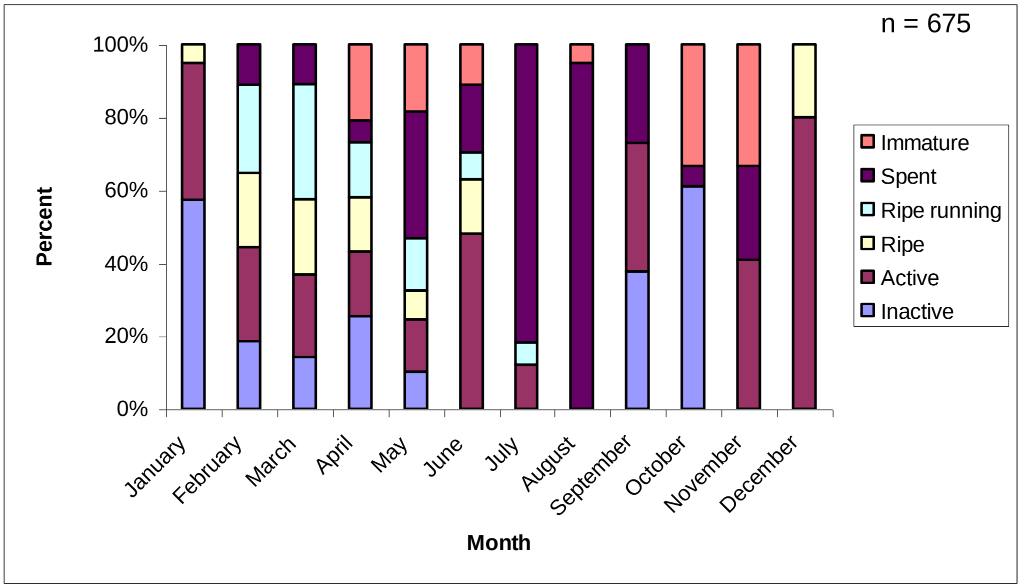

Figure 4.10. The monthly variation of gonad maturity in female *Lethrinops gossei* collected from south east arm of Lake Malawi between March 2005 and February 2006.

The calculated mean *C.F* value of *L. gossei* was 0.0014 ± 3.12E-05 with a minimum value of 0.0009 and maximum value of 0.0021.

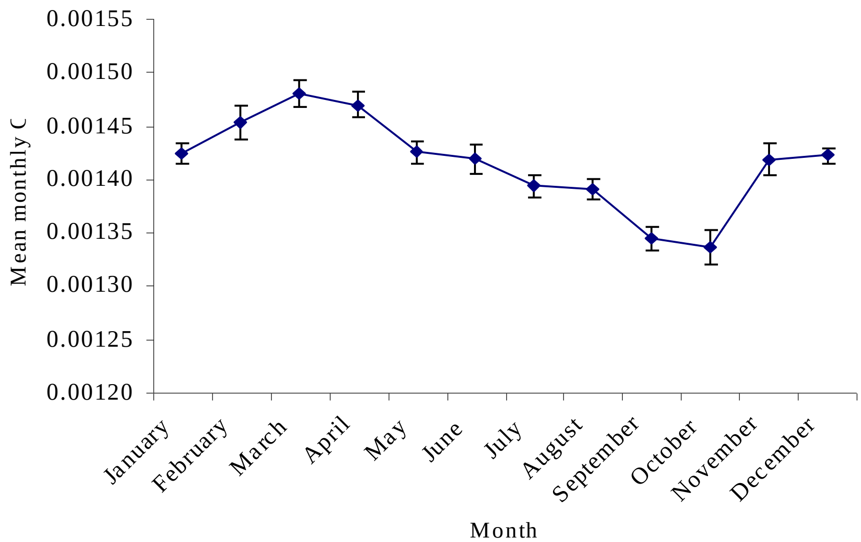

Figure 4.11. The monthly variation in condition factor (C.F) ± standard error of *Lethrinops gossei* from the south east arm of Lake Malawi (n = 1208).

4.5. Recruitment pattern.

The FISAT plot of the percentage recruitment of *L. gossei* into the fishery from south east arm showed a more or less continuous recruitment of young fish after spawning throughout the year with a peak of (≈ 22.46 %) in May to August (Figure 4.12).

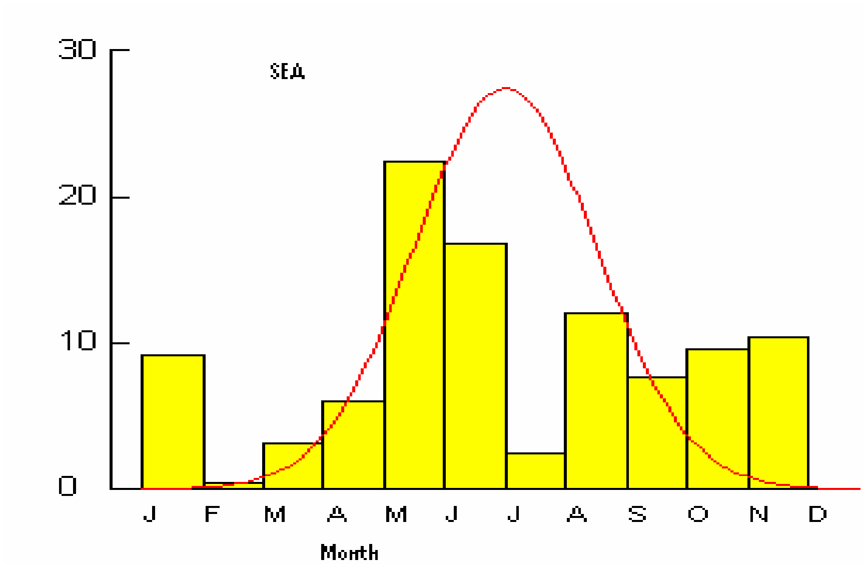

Figure 4.12. Percent Recruitment pattern for *Lethrinops gossei* from south east arm of Lake Malawi.

4.6. Mortality estimates**.**

Estimates of total annual mortality (*Z)* from catch curve analysis method and natural mortality from Pauly's empirical equation are shown in Figure 4.14. The mean value for total mortality (*Z)* from the estimate was 0.63 $year^{-1}$, natural mortality (M) was 0.38 $year^{1}$, fishing mortality (F) calculated ($F = Z - M$) was 0.25 $year^{-1}$ and the current exploitation rate ($E_{cuurent}$) was 0.40 $year^{-1}$.

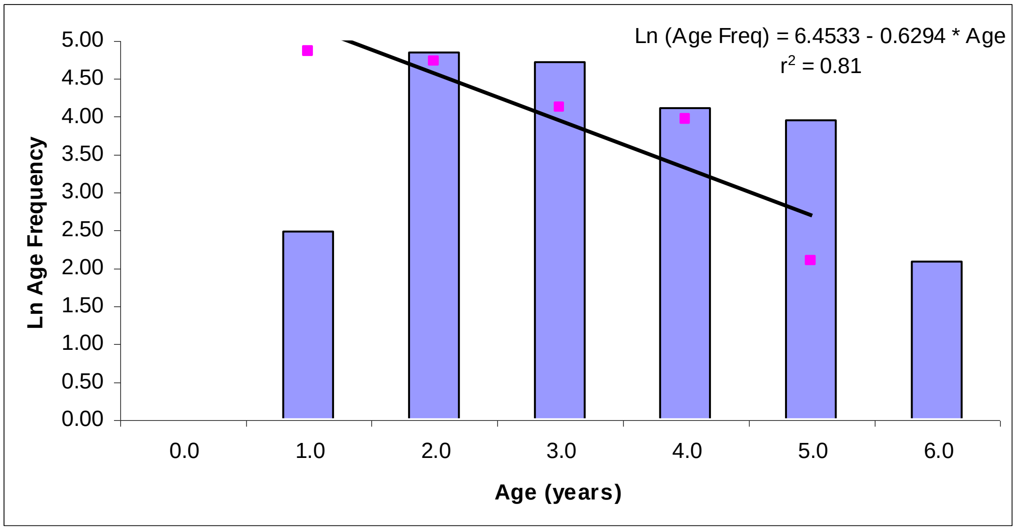

Figure 4.13 Age frequency distribution (bars) and catch curve (solid circles) for *Lethrinops gossei* caught in south east arm of Lake Malawi by using demersal trawl gear. The slope of the descending limb of the catch curve provides an estimate of total mortality (*Z*). Z= 0.63 year^{1}

CHAPTER FIVE.

5.0. GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS.

5.1. Discussion.

When viewed under the transmitted light, thin transverse sections of *L. gossei* sagitta showed opaque rings alternating with translucent rings similar to patterns described in other Lake Malawi fishes (Banda, 1992; Kaunda & Hecht, 2003, Kanyerere *et al.*, 2004). Most (61.6%) of the individual otoliths displayed a remarkable clarity of annual rings. For a few individuals (36.3%) the sectioned otoliths did not display remarkable clarity of annual rings showing that otolith can reliably be used to age *L. gossei*. This phenomenon has been observed commonly in many studies of age determination (Withel & Wankowski, 1998). This could be best explained by the calcium metabolism of fish in relation to ageing (Sinkiss, 1967). The suggestion that the calcium metabolism of fish may be interpreted as having some of the properties of open and closed system is a useful concept in this respect for it focuses attention upon several facts. First, an open system implies a fairly direct interaction between environmental variables and fish metabolism. Environmental variables such as temperature, salinity, food and light have the potential to influence otolith increment deposition (Campana, 2001). Opaque growth ring formation in otoliths has been attributed to one or more environmental variables which reduce metabolic rate, resulting in a slowing of the growth rate (Gauldie & Nelson, 1990). In cichlids from tropical and subtropical areas, growth zone formation has been linked to temporal variation in feeding intensity (Bruton & Allanson, 1974), reproductive periodicity (Bruton & Allanson, 1974; Hecht, 1980; Booth *et al.,* 1995; Booth & Merron, 1996) and temperature variation (Hecht, 1980; Weyl & Hecht, 1998). Second, a closed system implies some feedback control whereby there is some interrelationship between the relative rates of calcium deposition and resorption. Third, it would be apparent that in both the open and closed systems, the calcium metabolism of the fish is interrelated through a general calcium pool. Any organ making demands upon this pool is likely to influence the availability of calcium to other organs. This means that oscillating feedback systems could interact to produce longer periodicities. Opaque ring deposition is controlled by a combination of external environmental and endogenous factors such as age, sexual state and responses to stress (Beckman & Wilson, 1995).

The results of the age estimate for *L. gossei* from the south east arm of Lake Malawi indicate that the technique provides accurate age estimate. The periodicity of the rings was validated using the marginal increment analysis. The approach indicated that the rings were formed annually. The consistent appearance of annual rings on otoliths and the confirmation of their consistent formation in August for all age classes examined support the validity of the technique and accuracy of the age estimates. The time of ring formation coincided with the end of the breeding season of this species. This period of ring formation could have been a period of active feeding after termination of spawning activity and abundance of feed. The period coincides with the time when the south east winds blows strongly causing an upwelling of nutrient-rich water leading to a peak in primary productivity (Patterson & Kachinjika, 1995). *L. gossei* being polygamous mouth brooders it could be that during this time they release their off springs from the mouth to in order for the parents and off springs to feed.

For both sexes the growth rate was fastest in the first and second year and decreased progressively thereafter. This was evidenced by rings having relatively wide space for the first two to three rings, and then became more closely spaced. The widely spaced rings occurred before the age-at-50% maturity (2.14 years), showing that most fish had fast growth before sexual maturity and then growth reduced after sexual maturity showing that most of the energy during this time is utilized in somatic growth than reproduction. This is common in most cichlids and occurs after sexual maturation (Lowe, 1952; Fryer & Iles, 1972).

In this study the clarity and visibility of annual deposited growth rings in sectioned and burnt sagittal otoliths, leads to the first hard-part-based estimate of age and growth of *L. gossei*. The growth in length of *L. gossei* with age was well described by the Von Bertalanffy growth curve (Figure 4.3). The parameters of the Von Bertalanffy growth function for the combined data set were $L\infty$ = 204.59mm TL, K = 0.24 year^{-1} and t_0 = -2.28 (Table 4.3). This study's estimated growth rates from sectioned sagitta differed considerably from earlier estimates based on length-frequency analysis (Duponchelle *et al.,* 2000b), from the south west arm of Lake Malawi. If one assumes that otolith-based estimates of age are the most accurate, Duponchelle *et al.,* (2000b) appear to have overestimated the growth rate of the species. The findings of this study have shown that length-frequency analysis method (Duponchelle *et al.*, 2000b) greatly over estimated *K*.

Over estimation of K implies over estimation of growth rate and thus of productivity, potential yield per recruit and natural mortality (M). This may contribute to designing of in appropriate management strategies for *L. gossei* from the South East Arm of Malawi and may lead to significant over exploitation of the resource. Since several well known harvest rate strategies are dependent on the natural mortality values or the harvest rates are defined via the yield per recruit model, which is a function of both M and K, it is easy to see why over estimations of K may lead to over exploitation of the resource. The lack of reliable estimates of growth constrains the provision of management advice, especially in species-rich but poorly-known systems such as Lake Malawi. Length frequency methods used to age fish may be inaccurate if species have protracted spawning seasons and/or are long lived, which precludes accurate discrimination between older cohorts.

This study has also shown that *L. gossei* is a relatively slow-growing species, which matures in its second year of life. The species is relatively long-lived, with a maximum recorded age of 6+ years, and growth rate reducing significantly after the third year of life (Figure 4.1). This being the first study using sectioned otoliths to age *L. gossei* from Lake Malawi, direct comparisons with closely-related species was not possible. However, estimates for the VBGF parameters K and L_∞, determined using length-frequency analyses, are available for other Haplochromine species from the lake (Iles, 1971; Tweddle & Turner, 1977) (Table 5.1).

As there is interaction and dependence between the VBGF parameters K and $L\infty$, direct comparisons of parameter values between species are meaningless because species with different growth parameters may have similar growth performance. However, the parameter phi-prime (Pauly & Munro, 1984) takes the interaction and dependence between the VBGF parameters into consideration and provides a useful basis for comparison. Subsequent comparison between phi-prime values showed that the growth performance of *L. gossei* did not differ significantly from that of the other species (Students t-test; $P > 0.01$) (Table 5.1).This implies that haplochromine species respond almost in similar way to variations in environmental changes such as temperature, light, turbidity, food supply or a myriad of other environmental factors such as, oxygen, pH that may affect growth.

Table 5.1. Comparison of *Lethrinops gossei* von Bertalanffy growth function (VBGF) parameters (*to*, *K* and L_∞), estimated age-at-maturity (*amat*) and calculated phi-prime derived in this study, with length-frequency analysis-based estimates for other haplochromine cichlid species from Lake Malawi. (Na = not available)

Species	t_o	*K*	L_∞	*amat*	*phi-prime*
Copadichromis pleurostigmoides[1]	Na	0.764	144	3+	4.20
Copadichromis quadrimaculatus[1]	Na	0.650	190	2+	4.37
Copadichromis virginalis[1]	Na	0.775	121	2+	4.05
Diplotaxodon limnothrissa[2]	-1.36	0.240	211	3+	4.24
Ctenopharynx intermedius[3]	Na	0.571	229	2+	4.48
Lethrinops longipinnis[3]	Na	0.571	202	3+	4.37
Lethrinops parvidens[3]	Na	0.487	208	2+	4.32
Maravichromis anaphyrmis[3]	Na	0.671	196	2+	4.41
Lethrinops gossei[4]	-2.28	0.240	204	2+	4.02
Lethrinops gossei[5]	Na	0.780	185	Na	4.42

[1] Iles (1971), [2] Kanyerere 2003, [3] Tweddle & Turner (1977), [4] this study, [5] Duponchelle *et al.* (2000b)

Length-weight relationship of fish is of great importance in fishery assessments (Haimovici & Velasco, 2000). Length and weight measurements in conjunction with age data can give information on the stock composition, age at maturity, life span, mortality, growth and production (Beyer, 1987; Bolger & Connoly, 1989; King, 1996b, Diaz *et al.*, 2000). The relationship between total length and fish weight was isometric, meaning that the weight of fish proceeded in the same dimension as the cubed length (L^3) of fish (Figure 4.7).

In Lake Malawi wide investigation of the reproductive biology of *L. gossei* have been done (Lewis & Tweddle, 1990; Kanyerere, 1999; Turner, 2004, Duponchelle *et* a*l.*, 2000a). In this study breeding season of *L gossei* from the south east arm of Lake Malawi occurred between November and August with a peak of activity from February to March or April and a decline in September to October (Figure 4.10). The breeding season observed corresponded relatively well to that found by (Lewis & Tweddle, 1990), who reported a decline in October to November and a peak in March for the period 1983-85 and (Duponchelle *et al.*, 2000a), who reported a decline in September or October and a peak of activity from January to March or April. The peak breeding season coincided with the period of rain season. It can rain in November or December, but the proper rainy season usually starts from January to March or April and the temperature cools down when it rains (Turner, 2004). This could imply that *L. gossei* breed during rainy season when the surface water temperatures are low just before upwelling of nutrient water. Most of the reserved energy during this time is spent on reproduction than somatic growth.

The perpetuation and evolution of species is dependent upon the process of reproduction, the success of which depends upon resource allocation and location and the timing of reproduction defined by the reproductive strategy of the species (Welcomme, 2001). Surviving to sexual maturity and being able to contribute to the gene pool define fitness for an individual. Collectively, those surviving individuals determine the survival of the population. For a management regime to ensure, in the face of exploitation, that a sufficient number of juveniles reach maturity usually requires information on the size and age at first maturation.

The mean size at maturity for females was about 135.95mm TL or 104.05mm SL (Figure 4.9 a, b), which is less than the 147 mm and 159mm TL estimated by (Lewis & Tweddle, 1990) and (Kanyerere, 1999), respectively and higher than the 92mm estimated by (Duponchelle *et al.*, 2000a). Size at maturity may vary among successive years for a same population under environmental variation (Duponchelle & Panfili, 1998), or over longer time periods under fishing pressure (Lowe-McConnell, 1982; Trewavas, 1983; Stewart, 1988). The observed differences in size at maturity could thus lie in the distant time period and geographical area between the studies. Variations in size-at-50% sexual maturity may have management implications such that harvesting restrictions could be imposed on wrong mesh sizes and size of fish that could contribute to the next biomass. Using length-at-age data from this study, age-at-maturity was estimated at 2.14 years, which was similar to that estimated by (Iles, 1971) for *Copadichromis quadrimaculatus, Copadichromis virginalis* and by (Tweddle & Turner, 1977) for *Ctenopharynx intermedius, Lethrinops parvidens* and *Maravichromis anaphyrmis* (Table 5.1). Sexual maturation has been known to be associated with physiological and behavioral changes, the latter being sometimes manifested in the form of breeding aggregation, migration and territoriality. The relationship between these biological changes and growth, mortality and longevity has been studied by (Beverton & Holt, 1959) and (Pauly, 1984), among others. Using data in Fish Base, has likewise demonstrated that size and age at sexual maturity are strongly correlated with growth, maximum size and longevity (Froese & Binohlan, 2000).

The Condition Factor is a frequently used index for fish biology study, as it furnishes important information related to fish physiological state, based on the principle that individuals of a given length, exhibiting higher weight, are in a better condition. Based on this concept, this index of variation during the year has been used as an additional datum to study reproduction and seasonal cycles of feeding processes. Besides, the comparative study of distinct populations permits to evaluate the quality of the environments in which the fish live (Braga, 1986; Bolger & Connolly, 1989). The calculated mean *C.F* value of *L. gossei* was 0.0014 ± 3.12E-05 with a minimum value of 0.0009 and maximum value of 0.0021. The analysis of the expression used to calculate the Condition Factor indicates that the condition (*C.F*) and weight (*W*) should be directly proportional. Consequently, the higher the weight of individuals with the same length, the higher their Condition Factor (Bolger & Connoly, 1989). From such concept, it may conclude that, since individuals in a sample show no statistically distinct lengths, the Condition Factor variation should follow the weight variation of these individuals.

The condition factor increased with the increase in the spawning activities (Figure 4.12) The value of *C.F* may have been influenced by age of fish, sex, season, stage of maturation, full-ness of gut, type of food consumed, amount of fat reserve and degree of muscular development. In some fish species, the gonads may weigh up to 15% or more of total body weight. With females, the *C.F* value decreased rapidly when the eggs were shed.

The recruitment pattern of *L. gossei* appeared to be continuous throughout the year, but showed increased recruitments during the period of May to June with a peak of 22.46% in May. The continous recruitment agrees with the breeding season of *L. gossei*. The breeding season occurred between November and August with a peak of activity from February to March-April and a stop in September-October. This shows that new young fish are entering the fishery almost each month through reproduction. However, the results suggest that most fish are being recruited into fishery two months after the peak spawning months of March or April. This is again at a time when upwelling of the lake due to Mwera winds begins bringing abundant nutriate for the juveniles.

Mortality (fishing and natural mortality) rates are important for understanding the rate of population decay. Catch curve analysis was used to estimate the mortality rate of the species under study. The total mortality, *Z*, for *L. gossei* was estimated at 0.63 year^{1}. The value of total mortality has been greatly contributed by the natural mortality (0.38 year^{1}). The fishing mortality for *L. gossei* was 0.25 year^{1}. Assuming a mean environmental temperature of 23.5°C corresponding to the depth distribution of *L. gossei* (75 to 125 m) and considering all the distributions, the mortality estimated in this study are lower than those estimated by Duponchelle *et al.*, 2000b (Z=3.48, M=1.60 and F=1.88). Considering that the deep zone in this part of the lake is hardly exploited, it is very likely that mortality was overestimated by Duponchelle *et al.*, (2000b).

Carch curve analysis showed a typical form and justified the estimation of (*Z*) value for *L. gossei* and the exploitation rate of ($E_{current}$ = 0.40) is below $E_{0.5}$. (Gulland, 1971) suggested that as a rule of thumb a fish stock is optimally exploited at a level of fishing mortality that generates E = 0.5, and in the present study exploitation rate (*E)* is below optimal exploitation *(*E_{opt}*)*. This indicates that localised exploitation rates by bottom trawl net with a 23m head rope and a 38mm cod end mesh are below the range required to attain optimal exploitation levels of the stock. However, a preliminary selectivity study on the 38mm cod end mesh showed that the mesh is destructive to the demersal stocks since the rate of clogging in the 38mm cod end is very high as such it does not allow the juveniles to escape (Kanyerere, 1999). Since the deep water fishery is fast growing, concerns rise that in the long run the optimal exploitation rate would be reached and *L. gossei* being a K-selected species is unlikely to recover from overexploitation if management measures based on these findings are not put in place.

The life history of fishes in water bodies is highly variable with respect to growth rate, size at sexual maturity and reproductive periodicity (Garrod, 1959; Le Roux, 1961; Hecht, 1980; DeMerona *et al.,* 1988; Beamesderfer & North, 1995). It has been proposed that fishes may tend towards K-selection or precocial life history style, depending upon environmental conditions (Balon, 1979, 1981; Noakes & Balon, 1982). The precocial life- in large, deep, stable habitats such as reservoirs and lakes. Fish from unstable or harsh environments, which undergo unpredictable and near cataclysmic physio-chemical changes, on the other hand, tend towards the altricial life-history style of early maturation at a small body size (Noakes & Balon, 1982). Therefore, the proper assessment and management of a fishery requires an understanding of locality specific growth and reproductive life-history parameters of the species.

Several models and concepts have been developed to emphasize the need to control harvest levels of fisheries resources following the Hardin's (1968) theory of the 'tragedy of the commons', which provided a pivotal reference for resource managers in the western world. The Hardin model led to the conclusion that resources should be either privatized or controlled by a central government authority to ensure sustainable use (Hara 2001). Unregulated fisheries tend to be characterized by overexploitation of the stocks (van der Burg, 2000). The findings of this study show that *L. gossei* from the South East Arm of Lake Malawi may be heavily over exploited as the lake has open access nature to its fisheries resources. In relation to this, there has been an extensive search for management measures to reduce fishing effort. The basic objectives in managing a fishery are very general. Part of the general social and economic objectives includes more food, a better living for a fisher and more employment (Bagenal, 1978). Successful management of fisheries resources needs to be based on successful modeling. This requires the biological characteristics of the fish. While size and age structure can easily be computed from the available data in this study, information on stock abundance is also needed. The scientific information obtained in this study has prepared the foundation for more rigorous per-recruit analysis, which will promote the development and rational management of this deep-water resource in Lake Malawi.

5.2. Conclusion and recommendations.

This study has shown that burnt sagittal otolith can be reliably used to age *L. gossei* as they provided accurate age estimate for the species. The growth parameters (L_∞, K, t_o,), growth performance phi-prime index (ø') of *L. gossei* from the south east arm of Lake Malawi can be estimated using age determined from burnt sagittal otoliths. The commonly employed length based method greatly over estimated *K*. The age and growth information showed that this species is relatively long lived and, slow-growing, reaching sexual maturity after two years. Slow growth rate and precocial breeding habits imply that *L. gossei* populations are likely to have relatively stable population sizes and future catch levels if effort is kept constant. However, once the fishery is over fished, it would require a long period for the stock to rebuild to levels that could support future sustainable catches. The life history of *L. gossei*, therefore, makes it susceptible to overexploitation. The precocial reproductive behavior adopted by *L. gossei* implies that recruitment in this species may be highly dependent on spawner stock levels. A management strategy for the south east arm of Lake Malawi, therefore, has to place emphasis on the maintenance of the spawning stock of the species. It is therefore recommended that any expansion of the demersal trawl fishery needs to be carefully monitored and the management strategy based on the per recruit models for *L. gossei* has to be developed.

Although this study presents the work on some life history traits of *L. gossei*, it is based on a one year survey only. As inter annual variability of reproductive characteristics can be important in cichlids, the described breeding pattern might not represent a permanent situation but rather a situation representative of the prevalent environmental conditions. However, Lake Malawi is a stable environment where important environmental perturbations are unlikely.

The Department of fisheries has management strategies in place to ensure sustainable utilization of the resources. The management plans that are in place are mainly for inshore fishing in Lake Malawi. The following are some of the practical regulations that appear in the Fisheries Conservation and Management Regulations of 2000:

a) *Closed Fishing Season and Area*: This regulation was designed to protect certain species during their spawning period. Selected fishing gears (various beach seines) are prohibited to be used in the closed areas and during the closed season. The closed season runs from 1st November to 31st December of each year in Lake Malawi for all beach seines and from 1st January to 31st March of each year in Lake Malombe for all seine nets. To achieve the best management of *L. gossei* from the South East Arm of Lake Malawi this study recommends closed season in February to March or April in the deep water because fish are at peak of breeding. Study done by Kanyerere *et al.* (2004) on *D. limnothrissa* showed similar breeding seasonality trends with the findings of this study. The proportion of ripe females increased from 23% in January to *ca* 65% in April, and subsequently decreased to *ca* 19% between May and June when 47% of the female fish were in the ‘spent’ condition. Thereafter the proportion of ripe females continued to decline, with no ripe females being recorded in November. Subsequently, a gradual increase in the proportion of ripe females was noticed from December to April. The imposition of closed season in February to March or April in the deep water would greatly contribute to the management of other fish species like *D. limnothrissa.*

b) *Mesh size restrictions*: This regulation was formulated to supplement the one on closed season and areas, in order to protect young fish from being caught before they are mature to breed. Minimum mesh sizes for various types of fishing gears are set based on the size at maturity information for the target species. This study recommends restrictions on mesh size to not less than 3 inches should be enforced.

c) *Minimum takeable size of fish*: Based on size at maturity information, this regulation was designed to supplement the mesh size restriction regulation by protecting young fish. Different fish species have minimum allowed takeable sizes. This study recommends that fish size restriction should be imposed during the period of May to June when there is increased recruitments.

Deep water fishery being relatively new has very littler regulations that include; restriction of mesh size to not less than 3 inches and licensing of fishing gears to the vessels that trawl in the deep water. The regulations that are in place have not considered the age at maturity, growth rate, reproductive biology, recruitment and mortality rate of *L. gossei.* This therefore is putting the species at risk of being over exploited.

REFERENCES.

Bagenal, T. (ed.) 1978. Methods for assessment of fish production in fresh waters, IBP handbook No 3, 3d. edition. Blackwell Sci. Publ.,Oxford, London, Edinburgh, Melbourne.

Balon, E.K. 1979. The juvelinisation process in phylogeny and the altricial precocial forms in the ontogeny of fishes. Env. Biol. Fish. 4: 97 - 101.

Balon, E.K. 1981. Saltatory process and altricial to precocial forms in the ontogeny of fishes. Amer. Zoo. 21: 583 - 596.

Banda, M.C. 1992. Age and Growth parameters of the Chambo (Oreochromis species) in the Southern arm of Lake Malawi, as determined from opercular bones. GOM/UNDP/FAO Chambo Fisheries Research Project, Malawi. FI: DP/MLW/86/013; Field Document, 39pp.

Banda M., Tomasson T. & Tweddle D. 1996 Assessment of the deep water trawl fisheries of the southeast arm of Lake Malawi using exploratory surveys and commercial catch data. In: I.G. Cowx (ed.) Stock Assessment in Inland Fisheries. Oxford: Fishing News Books, Blackwell Science, pp. 53–75.

Banda, M.C. and Tomasson, T. 1997. Demersal fish stocks in the southern Lake Malawi: stock assessment and exploitation. *Fisheries Bulletin* 35:7-9 Malawi: Government of Malawi, Fisheries Department.

Banda, M.C. 2000. The biology and ecology of the cat fishes of the genera *Bathyclarias* and *Bagrus* in Lake Malawi. Ph.D Thesis. University of Zimbabwe.

Banda, M.C., Jambo, C.M., Kachinjika, O. and Weyl, O.L.F. 2001. Fisheries resources user groups in Malawi. Short communication 3. National Aquatic Resource Management Programme (NARMAP). Monkey Bay.

Beamesderfer, R.C. & North, J.A. 1995. Growth, natural mortality, and predicted response to fishing for largemouth bass and smallmouth bass populations in North America. N. Amer. J. Fish. Manag. 15: 688 - 704.

Beamish, R.J and Fournier, D.A. 1981 A method for comparing the precision of a set of age determinations. Canadian Journal of Fisheries and Aquatic Sciences **38**: 982–983.

Beamish, R.J. and Mc Farlane, G.A. 1987. Current trends in age determination methodology. In: Summerfelt RC and Hall GE (eds) The Age and Growth of Fish. Iowa 50010, Iowa State University Press, pp. 15–42.

Beckman, D.W., and Wilson, C.A. 1995. Seasonal timing of opaque zone formation in fish otoliths. In: Sector, D.H. Dean, J.M. Campana, S.E (Eds). Recent Developments in fish otolith Research. University of South Carolina press, Columbia, pp 27-43.

Beverton, R.J.H., S.J. Holt (1966). Manual of methods for fish stock assessment. Part 2. Tables of yield functions. FAO Fisheries Technical Paper, vol. 38, Rev. 1, 67 pp.

Beyer, J.E. 1987. On length-weight relationship. Part 1. Corresponding the mean weight of a given length class. Fishbytes 5(1): 11 – 13.

Bolger T., Connoly P.L 1989. The selection of suitable indices for the measurement and analysis of fish condition. J. Fish Biol. 34: 171 – 182.

Booth, A.J., Merron, G.S. and Buxton, C.D. 1995. The growth of *Oreochromis andersonii* (Pisces: Cichlidae) from the Okavango Delta, Botswana, and a comparison of the scale and otolith methods of ageing fish. Environment Biol. Fish. 43: 171-178.

Booth, A.J. and Merron, G.S. 1996. The age and growth of the greenhead tilapia *Oreochromis macrochir* (Pisces: Cichlidae) from the Okavango Delta, Botswana. Hydrobiologia 321: 29–34.

Braga, F. M. S. 1986. Estudo entre fator de condição e relação peso / comprimento para alguns peixes marinhos. *Rev. Bras. Biol.,* Rio de Janeiro, v. 46, n. 2, p.339-346.

Bruton, M.N. and Allanson, B.R. 1974. The growth of *Tilapia mossambica* Peters (Pisces: Cichlidae) in Lake Sibaya, South Africa. Journal of Fish Biology **6**: 701–715.

Buckland, S.T. 1984. Monte Carlo confidence intervals. Biometrics 40: 811-817.

Bulirani, A.E., Banda, M.C., Pálsson, O.K., Weyl, O.L.F., Kanyerere, G.Z., Manase, M.M. and Sipawe, R.D. 1999. Fish Stocks and Fisheries of Malawian Waters: Resource Report. Government of Malawi, Fisheries Department, Fisheries Research Unit, 54pp.

Butterworth, D.S., Punt, A.E., Borchers, D.L., and Hughes, G.S. 1989. A manual of mathematical techniques for linefish assessment. S.Afr. Natl. Sci. Pro. Rep.

Campana, S.E., and Jones, C.M. 1998. Radiocarbon from nuclear testing applied to age validation of black drum, *Pogonius cromis.* Fish. Bull. U.S 96: 185-192.

Campana, S.E. 2001 Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. Journal of Fish Biology 59: 197–242.

Chang W.Y.B. 1982. A statistical method for evaluating the reproducibility of age determination. Can. J.. Aquat. Sci. 39:1208-1210.

De Merona, B., Hecht, T. & Moreau, J. 1988. Growth of African freshwater fishes. pp. 191 – 242. *In*: C. Leveque, M.N. Bruton & G. Ssentongo (eds.). Biology and Ecology of African Freshwater Fishes. Travaux et Documents 216. L'OSTROM, Paris.

Department of Fisheries Frame Survey 2003. Government of Malawi, Monkeybay

Diaz, L.S., Roa A,Garcia, C.B., Acero A, Navas, G. 2000. Length-weight relationships of demersal fishes from the upper continental slope off Colombia. The ICLARM Quarterly 23(3): 23-25.

Duponchelle, F. & Panfili J. 1998. Variations in age and size at maturity of female Nile tilapia, *Oreochromis niloticus*, populations from man-made lakes of Côte d'Ivoire. Envir. Biol. Fish. 52: 453-465.

Duponchelle, F., Ribbink, A.J., Msukwa, A., Mafuka, J., and Mandere, D. 2000a. Depth distribution and breeding patterns of the demersal species most commonly caught by trawling in the South West Arm of Lake Malawi. In: Duponchelle F and Ribbink AJ (eds) Fish Ecology Report. Senga Bay, Lake Malawi/Nyasa/Niassa Biodiversity Conservation Project, pp. 15–168.

Duponchelle, F., Ribbink, A.J., Msukwa, A., Mafuka, J. and Mandere, D. 2000b. Growth patterns of some of the most important fish species caught by demersal trawling in the South West Arm of Lake Malawi. In: Duponchelle F and Ribbink AJ (eds) Fish Ecology Report. Senga Bay, Lake Malawi/Nyasa/Niassa Biodiversity Conservation Project, pp. 169–188.

Eccles, D.H. 1974. An outline of the physical limnology of Lake Malawi (Lake Nyasa). Limnology and Oceanography 19: 730-742.

Eccles, D.H. and E. Trewavas, 1989 Malawian cichlid fishes: the classification of some haplochromine genera. Lake Fish Movies, West Germany.

Efron, B. 1982. The jackknife, the bootstrap and other resampling plans. Society for Industrial and Applied Mathematics, Philadelphia, 92 pp.

Farade, S.O. 1974. Age determination of *Tilapia melanotheron* (Ruppell) in the Lagos Lagoon, Nigeria with a discussion on the environmental and physiological basis of growth marking in the tropics. Pp114-123. In: T.E. Bagenal (ed). Ageing of fishes. Unwin Brothers. London.

Froese, R. and C. Binohlan, 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. J. Fish Biol. 56:758-773.

Fryer, G., and T.D. Iles. 1972. The cichlid fishes of the Great Lakes of Africa. Oliver & Boyd, Edinburgh; TFH Publications, Neptune City, New Jersey; 641 pp.

Garrod, D.J, 1959. The growth of Tilapia esculenta graham in Lake Victoria. Hydrobiologia, 12: 268-298.

Gauldie, R.W. and Nelson, D.G.A. 1990. Otolith growth in fishes. Comparative Biochemistry and Physiology **97A**: 119–135.

Gayanilo, F.C. Jr. & D. Pauly 1997. The FAO-ICLARM Stock Assessment Tool (FiSAT) Reference manual. FAO Comput. Info. Ser. (Fish.) 8, FAO, Rome. 262p.

Government of Malawi, 2001. National fisheries and aquaculture policy October 1999. Department of Fisheries, Lilongwe, 23pp.

Griffiths, M.H. & Hecht, T. 1995. Age and Growth of South African Dusky Kob *Argyrosomus japonicus* (Sciaemidae) Based on otolith. S. Afri. J. Mar. Sci.16: 119-128.

Gulland, J.A. (comp.), (1971). The fish resources of the ocean. West Byfleet, Surrey, Fishing News (Books), Ltd., for FAO, 255 p. Revised edition of FAO Fish.Tech.Pap., (97):425p. (1970)

Haimovici, M., & Velasco, G. 2000. Length-weight relationship of marine fishes from southern Brazil. The ICLARM Quarterly 23 (1): 14-16.

Hammers, B.E. and Miranda, L.E. 1991. Comparison of the methods for estimating age, growth and related population characteristics for White crappies. N. Amer.J.Fish. Manag. 11: 492-498.

Hara, M.M. 2001. Could co-management provide a solution to the problems of artisanal fisheries management on the south-east arm of Lake Malawi? Unpublished PhD thesis, University of the Western Cape, South Africa.

Hardin, G. 1968. The tragedy of the commons. *Science* 162:1243-8. Howard-Williams,

Hasselblad, V. & P.K. Tomlinson 1971. NORMSEP. Normal distribution separator. In: N.J. Abramson (Comp.), Computer programs for fish stock assessment. FAO Fish.Tech.Pap.

Hecht, T 1980. A comparison between otolith and scale methods of ageing, and the growth of *Sarotherodon mossambicus* (Pisces: Cichlidae) in a Venda impoundment (Southern Africa). South African Journal of Zoology 15: 222–228.

Hughes, G.S. 1986. Examining methods of fitting age/length data to the von Bertalanffy growth curve with a view to applying a simplified version of the Beverton and Holt Yield per Recruit model. Unpublished internal Report, University of Cape Town.

ILES, T.D. 1971 Ecological aspects of growth in African cichlid fishes. Journal du Conseil International pour l'Exploration de la Mer 33**:** 363–385.

Kanyerere, G.Z. 1999. Trawl selectivity and the effect of clogging on standard trawl surveys on Lake Malawi. Government of Malawi, Fisheries Department. Fisheries Bulletin No 39.

Kanyerere G.Z. 2003. Age, Growth and Yield per Recruit analysis of Ndunduma – *Diplataxodon limnathrissa* (Teleostei: Cichlidae) in the Southeast arm of Lake Malawi. MSc Thesis submitted to Rhodes University Grahamstown, South Africa.

Kanyerere, G.Z., Weyl, O.L., and Booth, A.J. 2004. Growth, reproduction and population structure of *Diplotaxodon limnothrissa* in the southeast arm of Lake Malawi. African Journal of Aquatic Science 2005, 30(1): 37–44

Kaunda, E. 1994. Aquaculture Development and Research in Malawi. In Coche A.G. (ed). Aquaculture development and research in sub-Saharan Africa. National Reviews. CIFA Technical Paper. No 23, Suppl. Rome, FAO. 1994. 397p.

Kaunda, E.K. & Hecht, T. 2003. Life history traits of *Bathyclarias nyasensis* (Siluroidei) in Lake Malawi. African Zoology 38 (1):45-55.

King, M. 1995. Fisheries Biology, assessment and management. Fishing News Books, Blackwell Science Ltd. Oxford.341pp.

King, R.P. 1996b. Length-weight relationship of Nigerian Coastal water fishes. Fishbyte, 19(4): 53 – 58.

Kirkwood, G.P., R. Auckland and S.J Zara 2001. LFDA. Length Frequency Distribution Analysis, Version 5.0, MRAG Ltd, London U.K

Lagler, K.F., Bardach, J.E, Miller, R.R. & May Passino, D.R. 1977. Ichthyology. John Wiley & Sons, New York. 506pp.

Le Roux, P.J. 1961. Growth of Tilapia mossambiccus peters in some transvaal impoundments. Hydrobiologia, 18:165-175pp.

Lewis, D.S.C. and D. Tweddle, 1990 Breeding seasonality in some commercially important trawl-caught species in southern Lake Malawi. Collected Reports on Fisheries Research in Malawi. Occas. Pap. 1:23-36. (Published by the Overseas Development Administration, London, U.K.).

Lou, D. C. 1992. Validation of annual growth bands in the otolith of tropical parrotfishes (Scarus schlegeli Bleeker). Department of Marine Biology, James Cook

University of North Queensland, Townsville, Qld 4811, Australia. The Fisheries Society of the British Isles.

Lowe, R.H. 1952. Report on the Tilapia and other fisheries of Lake Nyasa 1945-47. Fishery publications: Vol. 1 No 2.

Lowe-McConnell, R.H. 1982. Tilapias in fish communities. In The biology and culture of tilapias, Pullin R.S.V. and R.H. Lowe-McConnell (eds), pp 83-113. ICLARM Conference Proceedings 7, Manila, Philippines, 432 p.

Marechal, C., 1991. *Lethrinops*. PP 233-240. In J. Daget, J.P. gosse, G.G. Tengels and D.F.E Thys van den Audenaerde (eds). Checklist of the fresh water fishes of Africa (CLOFFA). ISNB, Brussels; MRAC Tervuren; and ORSTOM, Paris. Vol.4.

Mathews, W.J. 1998. Patterns in fresh water fish Ecology. Chapman and Hall. New York pp. 756.

Menz, A. (ed.) 1995. The fishery potential and productivity of the pelagic zone of Lake Malawi/ Niassa. Chatham, UK: Natural Resources Institute. 386pp.

Meyer, A., C. Montero, and A. Spreinat. 1994. Evolutionary history of the cichlid fish species flocks of the East African great lakes inferred from molecular phylogenetic data, Pp. 407-423 in Martens, K., B. Goddeeris, and and G. Coulter (eds.), Speciation in ancient lakes. Archiv für Hydrobiologie - Advances in Limnology, Volume 44: X + 508 pages.

Munro, J.L. and Thompson R., 1983. Areas investigated, objectives and methodology. ICLARM studies and reviews 7, 276pp. International Center for living Aquatic Resources Management, Manila, Philippines.

National Environment Action Plan Malawi, 1994. Environmental Affairs Department, 1994. Government of Malawi

Noakes, D.L.G. & Balon, E.K. 1982. Life histories of tilapias: an evolutionary perspective. pp. 61-82. *In*: (ed.) R.S.V. Pullin & R.H. Lowe-McConnell (eds.) The Biology and Culture of Tilapias. ICLARM Conf. Proc., 7. Manila, Philippines.

Pannella, G. 1974. Otolith growth patterns: an aid to age determination in temperate and tropical fishes. In: Bagenal (ed) Ageing of fishes. Unwin Brothers, London. 28-39pp.

Patterson, G. & Kachinjika, O. 1995. Limnology and phytoplankton ecology. pp. 1-67 in A. Menz (ed.). The Fishery Potential and Productivity of the Pelagic Zone of lake Malawi. Natural Resources Institute, Chatham, UK.

Pauly, D. 1980. On the interrelationship between natural mortality, growth parameters and mean environmental temperature in 175 stocks of fish. J. Cons. Int. Explor. Mer, 39: 175-192.

Pauly, D (1983). Some simple methods for the assessment of tropical fish stocks. FAO. Fisheries Techn. Pap. (234) FAO, Rome.

Pauly, D. (1984). Length converted curch curves: a powerfull toool for fisheries research in the tropics (part II) ICLARM fishbyte 2(1) pp 17-19.

Pitcher, T.J.and Hart, P.J.B. 1982. Fisheries Ecology. AVI publishing West port, CT, 77-108pp.

Punt, A.E. & Hughes, G.S. 1992. PC-YIELD II User's Guide. Benguela Ecology Programme Report No. 26, Foundation for Research and Development, South Africa. Quick, A.J.R. and Bruton, M.N. 1984. Age and growth of Clarias gariepinus in the P.K. le Roux Dam, South Africa. S. Afr. J. 2001. 19: 37-45.

Ribbink, A.J. 1994. Lake Malawi. Pp. 27-33 in Martens, K., B. Goddeeris, and G. Coulter (eds.), Speciation in ancient lakes. Archiv für Hydrobiologie - Advances in Limnology, Volume 44: X + 508 pages. ISBN 3-510-47045-1.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can., 191: 1-382.

Ricker, W.E. 1979. Growth rates and models. In fish physiology, Vol 8 (Hoar, W.S.; Randall, D.J. and Brett, J.R., eds), pp 677-724. New York: Academic press.

Sinkiss, K. 1967. Calcium in reproductive physiology. A comparative study of vertebrates. Chapman and Hall, London.

State of Environment Report for Malawi 1998. Environmental Affairs Department, 1998 Government of Malawi, Lilongwe.

Stewart, K.M. 1988. Change in condition and maturation of the *Oreochromis niloticus* population of Ferguson's Gulf, Lake Turkana, Kenya. J. Fish Biol. 33: 181-188.

Silvestre, G. T., R. Len and L. R. Garces (2004). Population parameters and exploitation rate of demersal fishes in Brunei Darussalam (1989–1990). In Fisheries Research 69 (2004) 73– 90.

Trewavas, E. 1983. Tilapiine fishes of the genus *Sarotherodon*, *Oreochromis* and *Danakilia* . British Museum (Natural History), London. 583 p.

Turner, G. 1994. Description of a commercially important pelagic species of the genus Diplotaxodon (Pisces: Cichlidae) from Lake Malawi, Africa. Journal of Fish Biology 44: 799-807.

Turner, G.F. 1996. Offshore Cichlids of Lake Malawi. Department of Biology, University of Southampton, England, UK.

Turner, G.F. 2004. Lake Malawi habitats. http://www.hull.ac.uk/cichlids/Malawi-habitats.htm, 2006.

Tweddle, D. and Turner, J.L. 1977. Age, growth and natural mortality rates of some cichlid fishes of Lake Malawi. J. Fish Biol. 10: 385-398.

Van der Burg, T. 2000. Neo-classical economics, institutional economics and improved fisheries management. *Marine Policy* 24:45-51. Pergamon, Elsevier Science Ltd. 20 November, 2001. http://www.elsevier.com/locate/marpol, 2006.

Weatherly, A.H and Gill, H.S. 1987. The Biology of fish growth. Academic Press. New York. 443pp.

Welcomme, 2001. Inland fisheries: Ecology and management. Renewable Resources Assessment group, Imperial College of Science, Technology and Medicine, London, UK.

Weyl, O.L. & Hecht, T. 1998. The Dynamics of a Subtropical Lake Fishery in central Mozambique, PP24-40. PhD thesis submitted to Rhodes University Grahamstown, South Africa.

mossambicus (Pisces: Cichlidae) in a subtropical lake in Mozambique. South African Journal of Zoology. **33**(3):178–188.

Weyl, O.L.F., Banda, M.C., Sodzapanja, G., Mwenebombwe, L.H., Mponda, O.C., and Namoto, W. 2000. Annual frame survey. Sep 1999 Fisheries Bulletin No. 42. Department of Fisheries Lilongwe.

Withel, A.F. and Wankowksi, J.W.J. 1998. Estimates of age and growth of Ocean perch, *Helicolenus percoids* Richardson in south eastern Australian waters. Australian journal of marine and freshwater research 39, 441-459.

Wootton, R.J. 1990. Ecology of Teleost fishes 1st edn. Chapman and Hall, London.