THE POTENTIAL ROLE OF LAKE MALAWI NATIONAL PARK SANCTUARY AREAS FOR BIOLOGICAL CONTROL OF SCHISTOSOMIASIS AND DEVELOPMENT OF A SUSTAINABLE FISHERY

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Abstract

The potential role of sanctuary areas for biological control of Schistosomiasis and development of sustainable fisheries was investigated at Cape Maclear, Lake Malawi National Park (LMNP). There has been a recent increase in the incidence of schistosomiasis infection which is a threat to the local community as well as the tourism industry which is the major source of income to LMNP as well as Chembe Village. At the same place there is increasing fishing pressure due to growing human population and declining fish resource.

The increase in the incidence of schistosomiasis transmission was attributed in part to over-fishing of the molluscivorous fish which are believed to control the vector snails for schistosomiasis. Four molluscivorous fish species, *Trematocranus placodon*; *Trematocranus microstoma*; *Mylochromis sphaerodon* and *Mylochromis anaphyrmus* were reported to account for more than 90% of the fishes (by numerical abundance) which feed on the gastropods above 15 metre depth. The gastropod numbers was reported to be highest at 1.5 to 4.5 metre depth. Of the four molluscivores, *T. placodon* was proposed as a biological control agent for schistosomiasis based upon the previous observations of its feeding habits in artificial conditions. Captive propagation of *T. placodon* for reintroduction at Cape Maclear in Lake Malawi has been proposed. The present study aimed at providing baseline data required to test the hypotheses that: 1) Over-fishing of the molluscivorous fish has resulted to the increased incidence of schistosomiasis at Cape Maclear. A sub hypothesis to this was that an extension of the LMNP can act as a sanctuary area for the biological control of schistosomiasis by protecting molluscivorous fish which could control schistosomiasis vector snails. 2) A park initially designed to protect the colourful rock dwelling fish and for promotion of tourism may not effectively protect the food fish.

To test the first hypothesis, the biology and ecology of *T. placodon* were investigated with a view to evaluating the effect this species could have on the schistosomiasis vector snail population and hence the control of bilharzia in the lake. The proportions of various gastropod species at Cape Maclear was compared with those found in *T. placodon* guts. Comparisons of *T. placodon* abundance and demographic structure

inside and outside LMNP were made. To test the second hypothesis, this study investigated the food fish species that use LMNP 100 m protected zone and some basic ecological factors to appreciate the extent to which the adjacent fishery might benefit from their use of the park waters.

T. placodon numerical abundance (number of individuals per unit area) ranged from 5.7 to 40.5 / 200 m^2 and it significantly ($P < 0.05$) varied between sampling sites. Otter Point and Mitande which are inside the park had the lowest abundance as compared to the other three sites; Nguli inside the park; Fisheries and Nchenga outside the park. Two sites in the park, Otter Point and Mitande, had a greater proportion of mature *T. placodon* individuals than all other sites. The abundance of *T. placodon* fluctuated significantly from month to month at Nchenga, Nguli and Fisheries (X^2 test, $P<0.0001$ for all the three sites) and insignificantly ($P>0.05$) at Otter Point and Mitande (X^2 test). *T. placodon* densities found in the present study corresponded to the peak density of 30 individuals / 200 m^2 reported in 1986 but did not correspond to that of 1.0 / 200 m^2 for 1994. There was no evidence to support the previous reports that *T. placodon* abundance had decreased tremendously from 1986. The reason suggested to account for the discrepancies of *T. placodon* abundance reported in the present study and other studies was inadequate sampling in the previous studies which did not take into account spatial and temporal variability in *T. placodon* abundance. The findings reported in this thesis show that there is no need for captive propagation of *T. placodon* to be reintroduced into the lake at Cape Maclear and that it may prove to be unsuccessful. However, since juvenile *T. placodon* dominated in abundance at the three sites along the major beach which is outside the park boundaries, it is suggested that the park boundaries be extended to this area so that *T. placodon* should be protected to allow individuals to grow to bigger size which would be more effective for gastropod control.

T. placodon between 60 mm and 80 mm TL fed on benthic insects, phytoplankton and from detritus material. Individuals between 80 mm and 100 mm fed on a mixture of benthic insects, fish scales and small gastropods and at sizes greater than 100 mm individuals specialized feeding on gastropods. Gastropods of five genera were taken and they were: *Melanoides*, *Bulinus*, *Gabiella*, *Lanistes* and *Bellamya*. Of these genera

Melanoides formed the greatest part of *T. placodon* diet. *Bulinus* was the second most abundant genus but compared to *Melanoides* its proportion was very small. Of the three *Bulinus* species taken by *T. placodon*, *B. globosus*, is a confirmed vector for *Schistosoma haematobium* which is prevalent at Cape Maclear. This species was eaten in the least quantities. A comparison of the five gastropod proportions in *T. placodon* diet and in the habitats they occupy showed that *Melanoides* were taken in proportionately more quantities than *Bulinus* at most sites. These findings contrasted the previous reports that *T. placodon* preferred *Bulinus* to *Melanoides*. By applying the optimal foraging theory which predicts that an animal species searching for food will go for the type of prey with the highest profitability, it is concluded that the *Bulinus* cannot be eliminated completely by molluscivores because if their population size falls below a certain level, the fish will switch to other gastropod types. It is concluded that the increase in schistosomiasis may not be necessarily due to overfishing the molluscivorous fish but could be due to the fact that there has been an increase in the proportion of the *B. globosus* albeit in small numbers which are infected with schistosomiasis parasites. An integrated approach to schistosomiasis control at Cape Maclear comprising vector control, improved water supply, sanitation and health education is suggested since no method can be effective in isolation.

Few food fish species were observed to use the park at various times, varying from one species to another with regards to duration, life history stages and abundance. Only a few fish species taken by the adjacent artisanal and commercial fisheries were represented among those observed in the park. This was attributed to the limited diversity of habitat types covered. Only small population size of some species visited the protected area and only part of the life cycle of some species were observed in the park. The use of the park area was seasonal for some species and the protected zone boundaries can be crossed more than once within a day because 100 m distance is just a few minutes swim by fish. Under such circumstances the park cannot function as an effective sanctuary for food fish. An increase of the park size may be a better option to effectively protect the food fish.

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CHAPTER 1

Introduction

Background information

Lake Malawi is the southernmost of the great Rift Valley Lakes of Africa. It is the third largest lake in Africa and the 9^{th} largest lake in the world. The Lake stretches from the northern to the southern region of Malawi and it lies between 9°30'S and 14°30'S and 33°50'E and 35°20'E. (Figure 1.1). It is about 600 km long, up to 75 km wide with a maximum depth of 785 metres (Owen, Crossley, Johnson, Tweddle, Kornfield, Davison, Eccles, & Engstrom, 1990). Its surface area is 28,800 km^2 and its volume is 8400 km^3 giving an average depth of 292 metres (Patterson & Kachinjika, 1995).

Lake Malawi is so important because its fisheries contribute a major proportion of the fish supplied to the nation which provides 75% of animal protein in Malawi (Mkoko, 1992 cited by Turner, 1994; Bland, 1992 and Bland & Donda 1994 cited by Munthali, 1995); the lake has world wide scientific recognition as a living laboratory for the study of evolution (Fryer, 1972b; Barel, Dorit, Greenwood, Fryer, Hughes, Jackson, Kawanabe, Lowe-McConnell, Nagoshi, Ribbink, Trewavas, Witte, & Yamaoka, 1985); it is the major source of potable water for domestic uses for lake shore dwellers; it is a major tourist area in Malawi (Anonymous, 1989) because of which many vacation cottages and hotels have been constructed along its shores, the lake is also used for portable water, for agriculture and for transport by boat or ship.

The lake is deeper in the north than the south where the depth is reported to be generally less than 100 metres (Owen *et al.* 1990). It was earlier reported that only upper layers, above 250 metres depth, have enough oxygen to sustain life (Eccles, 1974; Twombly, in Lewis, unpublished report, Fryer, 1972b; FAO, 1993) but current research shows that this layer varies between 200 and 230 metres (Dr Harvey Bootsma, SADC/GEF Lake Malawi

Biodiversity Conservation Project, Pers. Comm.). From the fisheries perspective the lake is more productive in the southern part than in the northern part because of the seasonal upwelling of deep water resulting in increased algal productivity (FAO, 1976; Haberyan & Mhone, 1991) and hence major fisheries of the country are supported by this part in the South East Arm of Lake Malawi.

Lake Malawi has more fish species than any other lake in the world with an estimate of about 500 to 1000 species almost all of which are endemic to it (Ribbink, Marsh, Marsh, Ribbink, & Sharp 1983). The most fascinating are the diverse colourful rock dwelling cichlids locally known as "mbuna" which are popular fish in the aquarium fish trade. In 1980 the Government of Malawi established Lake Malawi National Park (LMNP), the first fresh water park in a deep lake in the world specifically to protect fish. The park is located in the Nankumba Peninsula, the promontory separating the south east and south west arms of Lake Malawi. It covers 87 square kilometres of land and 7 square kilometres of water. The terrestrial area includes the islands and hills in the Nankumba Peninsula and the aquatic area covers the 100 metre distance from the shore line surrounding all islands covered by the park and the main shoreline except the beaches in front of the park enclave villages (Figure 1.2). The primary objective of the park was to protect a representative sample of Lake Malawi fish fauna, the endemic rock dwelling cichlids, and secondary to this was to serve as a breeding and feeding area for important food fish species (Clarke, 1983; Lewis, Reinthal, & Trendall, 1986). The park has a high diversity of fish species particularly the rock dwelling species and about 40% of Lake Malawi fish species are found in it (Munthali, 1995; Ribbink *et al.* 1983). Other objectives of the park included protection of woodlands and their fauna, and the preservation of sites of historical importance. In 1984 the park was awarded the status of world heritage site by the UNESCO because of its uniqueness.

Threats to Lake Malawi resources and / or its inhabitants

Threats of Lake Malawi include: high fishing technology and oxygen demanding pollution (Fryer, 1972a & b; Coulter, Allanson, Bruton, Greenwood, Hart, Jackson, &

Ribbink 1986; Ribbink, 1987; Tweddle, 1992); introduction of alien species (Barel *et al.* 1985, Ribbink, 1987), lake level changes, deforestation of Lake Malawi Catchment Area that may lead to siltation of various aquatic habitat types, water abstraction and hydroelectricity generation, (Tweddle, 1992, Munthali, 1995) and the threat to the inhabitants of or visitors to the lakeshore areas is the current rise in schistosomiasis infection along its shores (Cetron, Chitsulo, Addis, Sullivan, Tsang & Pitcher, 1993; Cetron, 1994; Malawi Government, undated; Stauffer, Arnegard, Cetron, Sullivan, Chitsulo, Turner, Chiotha & McKaye, 1997).

Overfishing in Lake Malawi:

Over fishing is evident from the fact that fish catches have been declining since the major trawling industries started in 1968 (Turner, 1977) and it applies for the whole lake starting from the north to the south (Munthali, 1995; in press). Exploitation of fish stocks is by both the commercial fishery and artisanal fisheries which mainly operate in the shallows (0 to 50 metres).

In LMNP conflicts have sometimes arisen between the park management and the enclave fishermen. These conflicts arise because fishermen think the 100 metre park zone is not important to them (Msukwa, 1995). Most of the local people argue that the park favours tourists who are allowed to camp in the park while the local people would not do so when fishing. Despite some education the fishermen have had about the importance of the park through meetings between the park management and local leaders, and also through the environmental education unit at Cape Maclear, most fishermen think the park does not benefit them and they should therefore fish in certain areas of the park such as Mumbo Island, Chinyankwazi and Chinyamwezi provided that they do not target at the rock dwelling cichlids (Msukwa, 1995). Illegal fishing often takes place in the park and this practice is worsened by the fact that LMNP Law Enforcement Team does not have sufficient resources to make enough effort to curtail fishing in the park.

One of the arguments put forward to educate the fishermen about the park's 100 m zone importance has been that it is used for breeding and as nursery area for food fish which after growing migrate to the areas where fishing is allowed thus benefiting the fishermen besides protection of the colourful rock dwelling fish. No data are, however, available to substantiate this claim. It was not known as to what extent food fish use the park, when, for what purpose, for how long, how they migrate to and from the park and to what extent this could contribute to the sustainability of the fishery. Such information is required to validate the claim that the 100 m zone is indeed of benefit to the fishermen.

Schistosomiasis in Malawi

Schistosomiasis has been known to occur in Malawi as early as 1920s (CHSU, 1996). Two main types of Schistosomiasis are found including *Schistosoma haematobium* that primarily affects the urinary bladder and the genitourinary tract and *S. mansoni* which mainly affects the intestine and gastrointestinal tract (Cetron, Chitsulo, Sullivan, Pitcher, Wilson, Noh, Tsang, Hightower & Addis,1996; CHSU, 1996). *S. haematobium* is the predominant infection affecting about 80% of the human population and is usually found in low lying areas as opposed to *S. mansoni* which tends to predominate in upland areas (CHSU, 1996).

Schistosomiasis transmission has recently been found to be increasing among lake shore dwellers and foreign tourists visiting Lake Malawi (Cetron *et al.* 1993). Epidemiological surveys have implicated Cape Maclear in Lake Malawi National Park as the site accounting for the most frequent transmission of schistosomiasis (Cetron *et al.* 1993, 1996). School children at Cape Maclear Primary School were found to be the most seriously affected age group (Cetron, 1994; Cetron *et al.* 1993, 1996).

Lake Malawi had for a long time been considered to be schistosomiasis free because it was thought that transmission could not occur along the wave washed beaches of Lake Malawi. This was supported by the fact for many years searches for schistosomiasis transmitting snails did not show their presence in the open shores of Lake Malawi and it had therefore been concluded that these snails could not survive in unprotected areas

(Cetron *et al.*, 1996). Most of the schistosomiasis snails were usually found in marginal swamps e.g. Lake Chilwa (Cantrell, 1981) and ponds (Chiotha & Jenya, 1991). Foreign scientists who dived at Cape Maclear between 1978 and 1987 never contracted schistosomiasis (Malawi Government, undated; Stauffer *et al.* 1997) but nowadays it is contracted almost every time people dive at certain sites in Cape Maclear (Dr A.J. Ribbink SADC/GEF Lake Malawi Biodiversity Conservation Project, Pers. Comm.). The epidemiological survey by the Ministry of Health in conjunction with the Centres for Disease Control and Prevention, Atlanta, USA in 1993 revealed that people were getting infected with schistosomiasis parasites in Lake Malawi (Cetron, *et al.* 1993; Cetron, 1994; Cetron *et al.* 1996). *Bulinus globosus* and *Biomphalaria* spp, the intermediate host and vector snails for *S. haematobium* and *S. mansoni* respectively were reported to be found for the first time along the south-western shores of Lake Malawi (Cetron, 1994; Cetron *et al.* 1996). The percentage of schistosomiasis infected school children at Cape Maclear Primary School has increased dramatically over the last 13 years from 46 % in 1981, to 67 % in 1991 (Cetron *et al.* 1993) and 83 % in 1994 (Stauffer *et al.* 1997). In 1992 two U.S. Peace Corp Volunteers contracted central nervous system schistosomiasis due to *S. haematobium* and this was attributed to their contact with water at Cape Maclear (Cetron *et al* 1993; Cetron, 1994).

The suggested reasons to account for the sudden change in schistosomiasis transmission in Lake Malawi include: 1) Ecological changes such as heavy rainfall might have caused a) fluctuations in the lake levels and washing of vegetation into the open lake area resulting in the occurrence of schistosomiasis snails in the open shores of Lake Malawi (Cetron *et al.* 1993, 1996) and b) creation of ponds and swamps where vector snails multiplied and increased schistosomiasis transmission (Malawi Government, undated). 2) Vector snails may have always been present in the lake but their population might have been limited by snail eating fish and a decline in the numbers of these fish may have resulted in an increase in vector snail population (Stauffer *et al.* 1997; Cetron *et al.* 1996). Stauffer *et al.* (1997) and Cetron *et al.* (1996) reported a sharp decline in the population of molluscivorous fish in Cape Maclear and Lake Malawi as a whole over the past 10 years to support the suggestion that their decrease may have resulted in an increase in gastropod population. Stauffer *et al.* (1997) have proposed that a programme to breed *Trematocranus placodon* Regan, a molluscivore, be initiated for reintroduction into the lake at Cape Maclear.

Schistosomiasis cycle:

The parasite cycle involves man, water and snails. Adult schistosomiasis fluke in human beings lays eggs which are passed together with human excreta. The eggs hatch into miracidia within 24 hours in the presence of water. The miracidia infect host snails in which they undergo asexual multiplication which results in one miracidium producing thousands of cercaria. The cercaria leave the host snail and freely swim in water where they infect man in contact with water. One infected snail can release millions of cercaria (Barbour, 1982; Frandsen, 1979) over a period of up to one year (Barbour, 1982). In man the cercaria develop to adult flukes within three weeks (Barbour, 1982).

The scope of the present study:

The increase in schistosomiasis contraction and the declining food fish resources which has created pressure from fishermen to fish in LMNP prompted the present study to take place at Cape Maclear in LMNP where these problems jointly manifest themselves.

LMNP has the highest ranking park in Malawi with regards to visitation and revenue collection from visitors, (Jalale, 1993: Munthali, 1990, 1995). Most of the foreign tourists who visit Cape Maclear especially the backpackers stay in Chembe Village. The local community benefits from these tourists by selling them accommodation, food, curios, boat rides etc. The increase in schistosomiasis contraction poses a threat to tourist industry as foreign tourists who bring money may stop coming to the lake for fear of contracting schistosomiasis.

Since LMNP was established no studies have looked into the extent to which LMNP is used by the popular food fish species in the surrounding fisheries. Most studies have instead focused on the rock dwelling cichlids locally known as "mbuna", the distribution of which can be mostly restricted within the park 100 m protected zone alone (Ribbink *et al.* 1983). Considering that the rock dwelling fish were the focus of tourist attraction, the park was set with the objective of promoting tourism in the area and its design seems not to have taken into account the protection of other species which are non-rock dwellers. Fishermen surrounding LMNP argue that they should be allowed to catch other fish species in the park provided that they do not catch mbuna (Msukwa, 1995). To stop fishermen from fishing within the park, the fishermen are told that the park protects food fish besides mbuna for the fishermen's own benefit though no scientific data exist to substantiate the claim. Fishermen have a general feeling that the park is meant to be used by foreign visitors at their expense (Msukwa, 1995). LMNP 100 m zone can only be seen to serve the fishermen if its presence results to an improvement in the fishermen's catch. Reserve areas are designed for specific purposes (Robert & Polunin, 1991) and as such a reserve designed to protect the colourful rock dwelling fish and for promotion of tourism may not effectively protect the food fish species because the fish may be different in terms of movement patterns and use of the reserve itself.

Guiding hypotheses

This study was primarily based on two main hypotheses as outlined below: The first was the null hypothesis is that over-fishing of snail eating fish has resulted in an increase in schistosomiasis contraction in Cape Maclear against the alternative that it may be due to other factors other than overfishing alone. The underlying assumptions about the biological control of schistosomiasis were that: Any control of schistosomiasis involves breaking its life cycle (Thomson, 1995; Slootweg, 1989). Control of schistosomiasis by fish involves the fish feeding on schistosomiasis intermediate host snails to an extent that the snail population is significantly reduced to minimize the chances that any incoming miracidia be able to find a suitable host snail. To achieve this: 1) the population of snail eating fish should always be high in an area infected with schistosomiasis because in a predator prey relationship a decline in the predator population results in an increase in prey population; 2) the schistosomiasis intermediate host snails should form a major part of the fish diet. Failure to achieve one of these conditions may mean insufficient control of schistosomiasis intermediate host snails and hence ineffective biological control of schistosomiasis. To test the above hypothesis in relation to the reason for the increase in schistosomiasis infection in Chembe Village, the feeding biology, distribution and abundance of one of the major snail eating fish were studied in relation to the above raised assumptions. Other aspects of the snail eating fish such as breeding biology, movement and migration behaviour which can also affect their population were also partly looked into. The sub hypothesis to the above was that a sanctuary area may be of value to schistosomiasis control by protecting snail eating fish consequently increasing their effectiveness in controlling schistosomiasis.

The second hypothesis was that LMNP 100 m zone is of very limited value to the food fishery as it covers very limited area and habitat types (only rocky areas). To be effective as a sanctuary area for food fish, the fish must significantly use the park especially during important life history stages such as juvenile stage when the fish are too small to be caught and during the breeding season. To significantly contribute to the fishery there should be sufficient fish migrations from the park to fished areas.

Aims of the study

Concerning schistosomiasis problem the study aimed at providing basic data required to find out whether schistosomiasis infection has recently increased in Cape Maclear because of reduction in the number of the snail eating fish or due to other factors, and also to look into the potential value of a sanctuary area for schistosomiasis control. The aim pertaining to food fish study was to provide preliminary information about how many food fish species and to what extent they use the park 100 metre zone and whether this could benefit the surrounding fishery.

Species studied

Snail eating fish

McKaye, Stauffer Jr, & Louda, (1986) have reported that within Cape Maclear there are more than a dozen species of fish (the species names were not listed) which feed on gastropods. Only a total of thirteen fish species reported to take gastropods in their diet were compiled in the present study from Eccles & Trewavas (1989), Lewis (1982) and Ribbink *et al* (1983) (Appendix 4). Four fish species comprising *T. placodon, Trematocranus microstoma* Trewavas, *Mylochromis sphaerodon* Regan and *Mylochromis anaphyrmus* Burgess & Axelrod were reported by McKaye *et al* (1986) to account for more than 90 % of the fishes which feed on snails at less than 15 metre depth. Of these four species, *T. placodon* has been suggested as a biological control agent for schistosomiasis (Jackson *et al.* 1963 cited by Chiotha, McKaye, & Stauffer, 1991; McKaye *et al.*, 1986). *T. placodon* is thought to have a high potential as a biological control agent for schistosomiasis because it is reported as a voracious snail eater (Chiotha *et al.* 1991; Pruginin, 1976) and it has also been reported to prefer snails of the genus *Bulinus* in natural conditions (McKaye *et al.* 1986) and ponds (Chiotha *et al.* in Slootweg, Malek & McCullough, 1993). One of these *Bulinus* species, *B. globosus* is a confirmed vector for *S. haematobium* (Brown, 1994; Gray, 1981; Cetron *et al.* 1993, 1996; Stauffer *et al.* 1997). *T. placodon* was therefore studied to test the above hypothesis with regards to schistosomiasis transmission and control at Cape Maclear. However, it was recognized that the data obtained from the study of one snail eating fish species alone may not be representative of all the snail eating fish species. Considering that *T. placodon* is among the four fish species accounting for more than 90 % of the fish species which feed on gastropods within the peak snail distribution depth and also that preliminary observations of the present study indicated that its abundance (probably a small proportion was *T. microstoma*) was more than half of the four above fish species (Appendix 5), the data of the present study may represent at least 45% of the fish abundance that feed on gastropods at less than 15 metre depth at Cape Maclear.

Food fish:

Lewis *et al.* (1986) have produced an inventory of fish species in LMNP which includes cichlids and non cichlids. However it is not reported what method of sampling was used to produce this inventory. Smith (1993) has listed the commonly caught fish species in the artisanal fishery of LMNP (Appendix 1) all of which are reported by Lewis *et al* (1986) to form part of the park's fish community. Of the commonly caught fish species in the artisanal fishery of LMNP, pelagic fishes such as *Engraulicypris sardella* and *Ramphochromis* species were reported by Lewis *et al.* (1986) to be transient and not to form a permanent part of the park's fish community. Such species probably derive little protection from the park boundaries. *Copadichromis* spp. have been reported to be associated with rocky shores and to have limited distribution ranges (FAO, 1993; Turner, 1994) and thus though it can be hypothesized that some of their populations could be protected by LMNP which covers mostly rocky shores, their protection by the park area may not be of importance for the fishery.

In terms of breeding and feeding habits and also migration behaviour, previous studies of *Oreochromis* species "Chambo", (Lowe, 1952; McKaye & Stauffer, 1988; Turner, Witman, Robinson, Grim, & Pitcher, 1991; Turner, Grimm, Mhone, Robinson, & Pitcher, 1991) and *Bagrus meridionalis* Gunther "Kampango" (McKaye, 1983; 1986; McKaye, Mughogho, & Stauffer, 1994) have shown that these two species use the shallow sandy and rocky areas for breeding and feeding and that they probably migrate from shallow to deep waters. In this study it was further hypothesized that the objective of the park to serve as a breeding area for some food fish species (Clarke, 1983) could be met with regards to chambo and kampango since LMNP is characterized by a mixture of sandy and rock habitat.

Objectives:

The specific objectives of the present study, which have been split into two for convenience, are outlined below.

Objectives pertaining to the schistosomiasis problem

1) To investigate the feeding biology, distribution and abundance of *T. placodon* with a

view to understanding this species' role in controlling schistosomiasis vector snails at Cape Maclear in LMNP.

2) To compare *T. placodon* status inside and outside the LMNP 100 metre zone with a view to evaluating the extent to which the present LMNP boundaries protect the species.

3) To investigate the distribution and abundance of various gastropod species and relate them to the diet of *T. placodon* so as to evaluate *T. placodon* feeding preferences with respect to the available gastropods.

Objectives pertaining to the food fish

1) To investigate the number of the commonly caught fish species in the artisanal fishery of LMNP that use the park waters

2) To evaluate the extent to which the food fish use of the park 100 metre zone can benefit the surrounding fishery.

3) To examine how food fish in the artisanal fishery of LMNP can be protected to benefit the artisanal fishery.

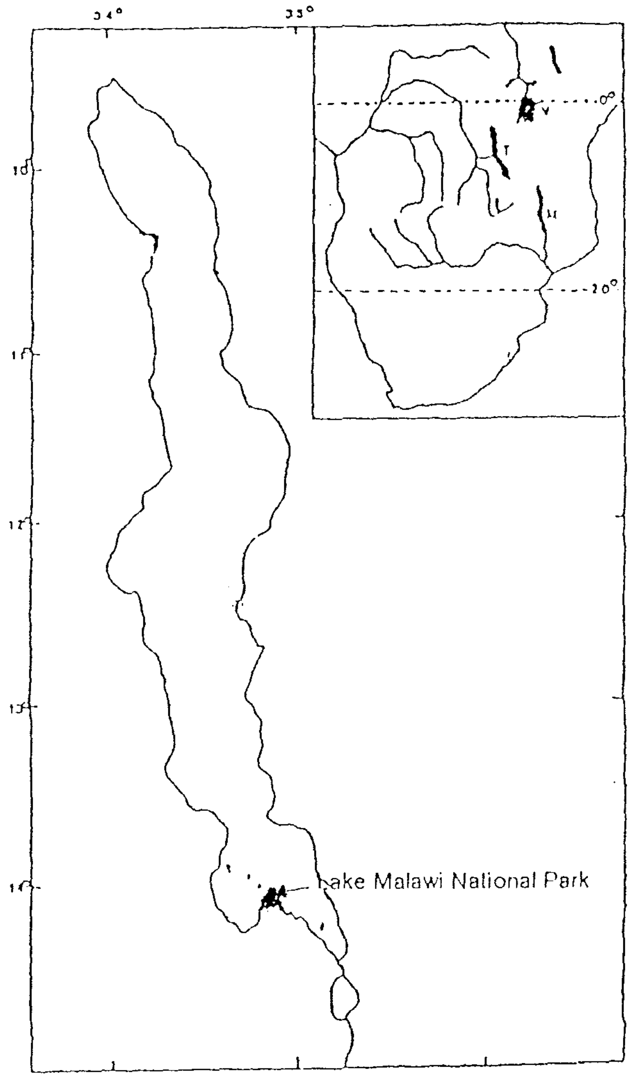


Figure 1.1: Map Showing a) the location of Lake Malawi with respect to the other African Great Rift Lakes and b) the location of the centre of the Lake Malawi National Park in Lake Malawi.

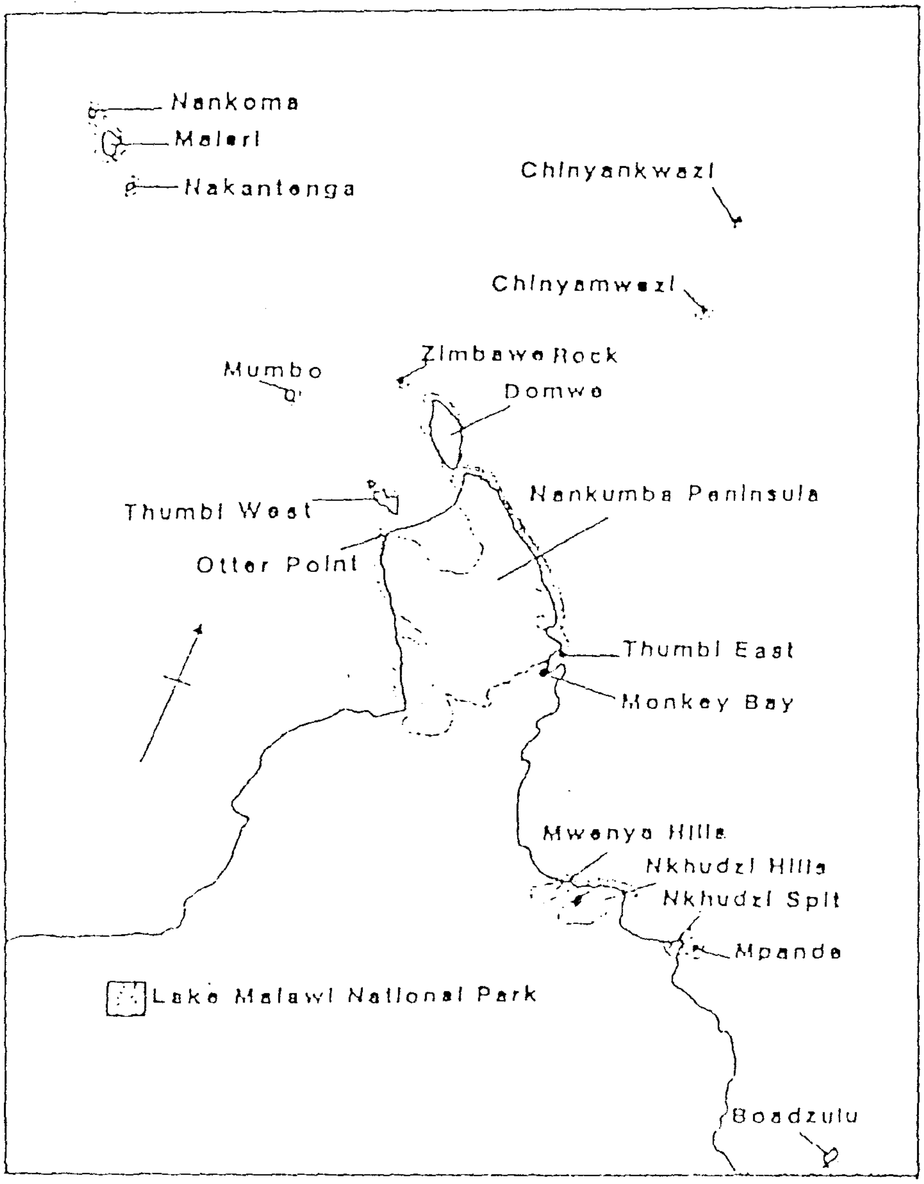


Figure 1.2: Map of Lake Malawi National Park showing the islands it includes: Nankoma, Maleri, Nakantenga, Mumbo, Thumbi West, Thumbi East, Otter Point, Chinyankhwazi, Chinyamwezi, Domwe, Zimbawe, and Boadzulu.

CHAPTER 2

The biological control of schistosomiasis through molluscivorous fish at Cape Maclear, Lake Malawi National Park.

Introduction

The illness caused by human schistosomiasis is recognised world wide. Though effective medicines for treatment of schistosomiasis exist, the rapid reinfection that occurs after treatment and the high cost of repeated medication necessitates the need for control of snail hosts to reduce the risk of schistosomiasis transmission (Slootweg, *et al.* 1993; Slootweg, 1995). In artificial conditions gastropods can be controlled by: application of molluscicides; biological control through molluscivorous fish; and habitat modification such as vegetation removal and concrete lining of ponds and canals (Slootweg 1989; Slootweg, Vroeg & Wiersma, 1993; Thomson 1995). In Malawi most people infected with schistosome parasites get treated but there have been few control attempts and those which have been attempted were restricted to aquaculture ponds. Chiotha, Seyani & Fabiano, (1991); and Msonthi, (1991a & b) investigating the use of chemical compounds of plant origin to control the gastropods in aquaculture ponds found that these compounds may not be very useful because they were found to be toxic against both fish and gastropods. Although fish have been widely used world-wide for gastropod control in man made environments such as aquaculture ponds and irrigation canals with varying success (Slootweg, *et al.* 1993), no reports have been published about the use of fish to control gastropods in their natural environment. The use of fish as a biological control agent for gastropods requires knowledge of their feeding biology besides their population dynamics. The present study sought to investigate the feeding biology and some ecological aspects of *T. placodon* which was necessary to test the hypothesis that the increase in schistosomiasis at Cape Maclear may be related to the reduction of the molluscivorous fish.

Methods

Underwater assessment of *T. placodon*

Underwater observations of *T. placodon*, were undertaken by means of SCUBA diving from October 1994 to April 1996 except for January 1995 and February, 1995 due to logistical problems. This sampling method was suitable in the park because it is not destructive (Keast & Harker, 1977; Buxton & Smale 1984; Francour, 1991). There were five fixed sites three in the LMNP 100 metre zone: Otter Point, Mitande and Nguli and two were outside the 100 metre zone: Fisheries and Nchenga (Figure 2.1). All the five sites are sandy and weedy. Their differences are proximity to rocky areas, depth gradient and sand / mud depth (sand mud depth was measured by the length of a ruler that could be perpendicularly pushed by hand into the lake bottom substratum) (Table 2.1). Otter Point, Mitande and Nguli which are inside the park 100 m zone, are closer to the rocky habitats than other sites except that at Nguli the rocks are isolated in the sandy area. The site at Otter Point is on a sandy area breaking from the rocky shore at 4 to 4.5 metre depth. Mitande site has steeper depth gradient than the other four. Sediment load measured for a period of five months, November 1994 to December 1994 and March 1995 to May 1995 varied among sampling sites (Table 2.1).

Two fixed transects were established per site one at 4 to 4.5 metre depth and the other at 6 to 7 metre depth at Fisheries, Nchenga and Nguli. This depth covers the reported peak distribution depth of 6 metres for *T. placodon* (McKaye *et al.* 1986) and it was within 50 to 100 m distance from the shoreline. For Otter Point and Mitande one fixed transect was established at each site between 6 and 8 metres depth. Transect bands were 50 metres long and 4 metres wide along a depth contour.

The fish were given five minutes to recover from the disturbance caused by divers, then two divers swam parallel along the transect for three times, at the same speed and in the same direction, about 1 to 1.5 metres above the substrate. Every time the transect was swam, each of the two divers counted the *T. placodon* within the 2 metre width. The average of the three counts was expressed as number of individuals per 200 m^2. Total length of the observed *T. placodon* was estimated to the nearest cm by comparing with a ruler. The behaviour of *T. placodon* fish i.e. whether feeding, courting, mouth brooding was noted. All the observations were recorded on an underwater slate and transcribed after each dive. Once a month there was morning reading and then an afternoon reading at each site to reduce the bias due to sampling time of the day.

Non parametric statistics selected from UNISTAT (1993) Statistical Package were employed to compare *T. placodon* abundance among sites, to examine the temporal trends and differences in demographic structure among sites by grouping all the sizes into three categories: <10 cm, 10-15 cm and 15^{+} cm.

It has been pointed out that fixed sampling sites may not represent the average situation of the population that would be revealed with random sampling (Johnson & Nielsen, 1983). Cape Maclear which was selected as the location of the present study (Chapter 1) has very limited sandy areas which are suitable habitat types for *T. placodon* (most of the shores are rocky). The fixed transect sites were spread in such a way as to represent patches of most of these sandy areas and also all the habitat characteristics within these areas (Table 2.1) were taken into account. The transect observations in the present study may therefore give a good estimate of the average situation of *T. placodon* population parameters at Cape Maclear (i.e Chembe Village which is infected by schistosomiasis). Thus, pseudoreplication which in sampling (mensurative experiments) is often a consequence of having inadequate samples with regards to the inference space implicit in the hypothesis being tested (Hurlbert, 1984), was avoided. The fixed sampling sites made it possible to replicate samples in time (monthly) and the data collected from these sites may be comparable with future studies at the same sites.

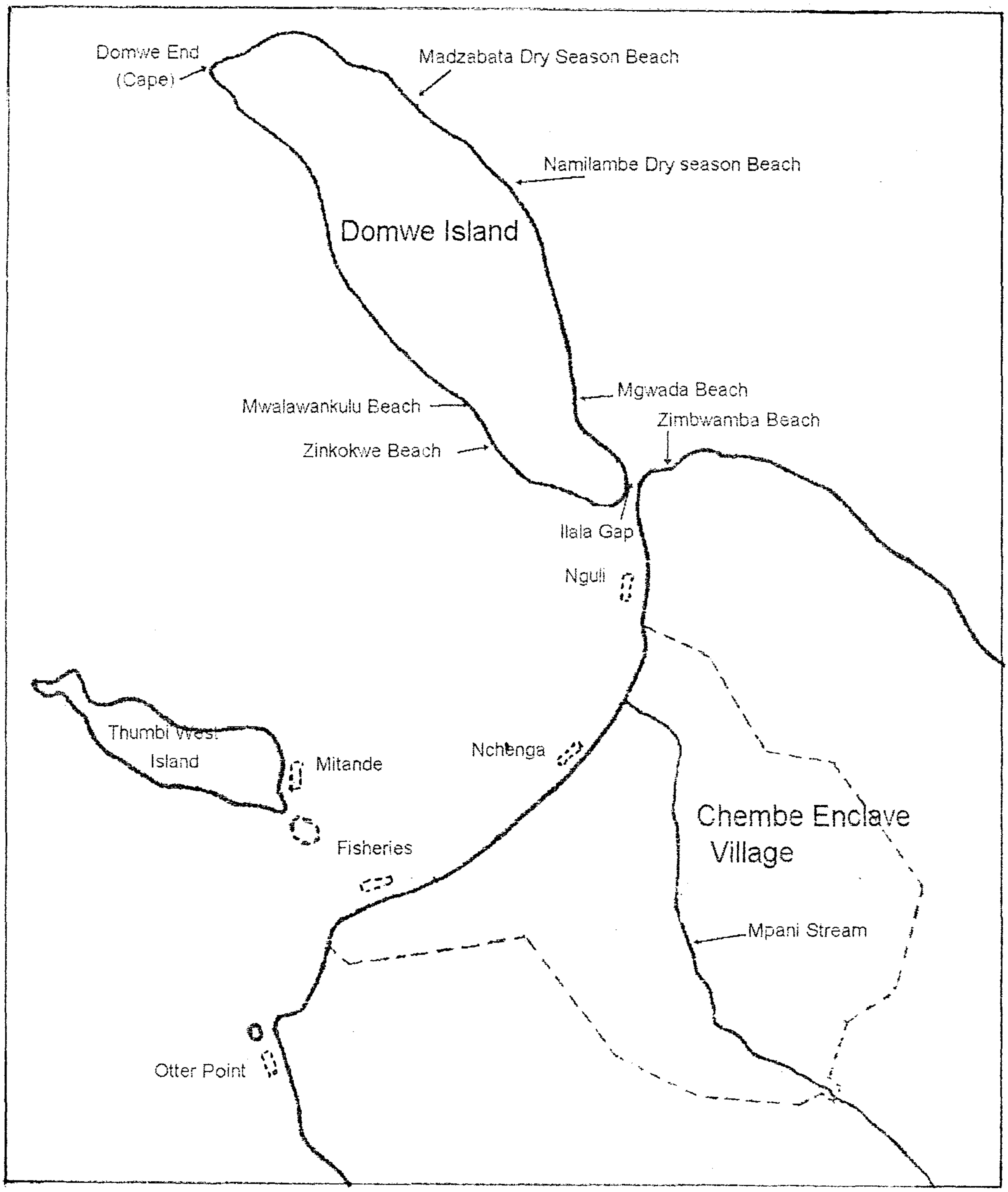


Figure 2.1: Map of Lake Malawi showing the sites (Fisheries, Otter Point, Mchenga, Nguli and Mitande) where *T. placodon* was studied. Represents transect points and positions.

Table:2.1 Characteristics of the sites where underwater studies of *T. placodon* were made from November 1994 to February 1996 at Cape Maclear. Ott. Pt = Otter Point, Mit. = Mitande, Fis. = Fisheries Station, Nch. = Nchenga

Habitat characteristics	**Ott. Pt.**	**Mit.**	**Fis.**	**Mch.**	**Nguli**
Sand/mud depth (Mean ± sd from November, 1994 to May, 1995)	8.63 ± 2.05 cm	7.79 ± 1.03 cm	9.93 ± 2.55 cm	12.55 ±3.99 cm	11.95 ± 4.95 cm
Proximity to rocky areas	Rocky shore breaking into sandy habitat from 4 to 4.5 metre depth	Small beach (about 60 m long) close to rocky areas	far from rocky areas on a 4 km beach	far from rocky areas on a 4 km beach	sandy with a few isolated rocks
Depth (metres)	6 to 8	6 to 8	4 to 7	4 to 7	4 to 7

Search for and collection of gastropods

Gastropod numerical abundance (expressed as the number per unit area) was investigated by means of transects at Fisheries, Nchenga, Nguli, and Otter Point. The number of transects and their depth for each site were as follows: 3 transects for Fisheries Station at 1.5 metres, 3.0 metres and 6 metres depth; 2 transects for Nchenga at 2.5 metres and 4.5 metres; 2 transects for Nguli at 1.5 metres and 4.0 metres and 2 transects for Otter Point at 6 metres and 7.5 metres. Depth and the number of transects could not be standardised for all the sites because of variation in the sites' physical characteristics.

A 50 metre transect line was laid on the lake bottom substratum. About 1 litre sand or sediment was scooped by using a spade from the substratum within a band 1 metre in total width at approximately two metre intervals along the transect to search for gastropods which sometimes bury themselves in the mud or sand (Louda & McKaye, 1982). Besides quantitative evaluation of gastropod numerical abundance by means of transect methods, random (qualitative) searches were also made with regards to gastropod habitat types and depth ranges during other dives. After transect counting samples of gastropods of every type encountered were collected and fixed in 10% formalin solution for identification.

The gastropods were identified either to species where possible or to genus. The proportion of every species or genus by numerical abundance was calculated for every sampling site.

The breeding biology of *T. placodon.*

During SCUBA diving any spawning or mouth brooding fish, preferred breeding sites, breeding season and other related aspects were noted. A total of 904 *T. placodon* specimens were collected between May 1995 and February 1996 from the following sources: fishermen; captured monthly during diving by chasing fish into a net; and Malawi Fisheries Department Research Unit Demersal Trawling Surveys at Namiasi and

Malembo in the South East Arm (SEA) and South West Arm (SWA) of Lake Malawi respectively (Figure 2.2) by the "RV Ndunduma", 380 hp. The dates and number of the Fisheries Trawling surveys are shown in Appendix 2. 69 *T. placodon* were captured during SCUBA diving at Cape Maclear between January 1995 and April 1995. In total 973 specimens were examined between January 1995 and February 1996.

The *T. placodon* specimens collected from Fisheries Department Demersal Trawling Surveys were injected with formalin and deep frozen before they were examined. Those obtained from fishermen and during diving were examined immediately after collection while they were still fresh. Aspects of breeding biology investigated include: absolute fecundity (total number of eggs per ripe female) and its relationship with fish length; female maturity size and breeding seasonality. The peak breeding season was inferred from the period of the highest proportion of ripe and mouth brooding females among the specimens examined.

All three lengths (TL, FL, and SL) of *T. placodon* specimens were measured using a measuring board. Each fish was weighed to the nearest gram by using a spring balance, dissected, sexed and the gonad state was macroscopically examined. Eggs from the preserved ovaries were examined through the microscope and their sizes (diameter) were measured in mm.

Assessment of fish gonad maturity was based on 5 stages namely: Immature Stage I (undeveloped juveniles), Developing virgin (Stage II), Developing or spent/recovering (Stage III), Ripening (Stage IV), Ripe (Stage V). This was similar to cichlid maturity stage codes described by Mous, Goudswaard, Katunzi, Budeba, Witte & Ligtvoet, (1995) except that the latter recognised six stages while in the present study only five stages were discerned. The Stage VI described by Mous *et al.* (1995) could not be differentiated from stage III for *T. placodon*.

Male gonad classification proved difficult as no proper criterion could be used, for instance, size of testes could not be used because testes of different sizes had milt inside them. It was also difficult to use male breeding colour because it tends to be lost upon capture. It was therefore thought that female gonads alone would shed reasonable light on the breeding of *T. placodon* since males can mate with females any time the females are ready to spawn.

Due to difficulties in classifying stage III gonads as mature or immature, only the gonads of *T. placodon* sampled between January and March 1995 and November to February, 1996 (apparent peak breeding season) were used for determination of maturity size. While all the gonads in stages 4 and 5 were classified as mature only those of Stage III in which there was evidence that the females were mouth brooding (with distended buccal cavities, and / or eggs or fry remains in their buccal cavities) or recovering (large ovary with a large empty space and an assortment of egg sizes) were considered to be mature. The rest of stage III individuals were considered to be immature which might not have been necessarily the case and this may result in underestimation of percentage maturity at size with the effect of overestimating size at 50% maturity. However, since only specimens of *T. placodon* collected during the apparent peak breeding season were included in the analysis of maturity size the extent to which this size might have been overestimated was probably minimised.

Ripe female gonads were weighed and fixed in 4% formalin solution. After about 1 week in formalin the ovaries were rinsed in water and total egg count was done macroscopically as the eggs were big enough to be counted with the naked eye. The peak breeding season was determined as the period with the highest percentage of ripe females. Maturity size was determined as size at which 50% individuals were mature from a logistic curve constructed by plotting percentage maturity at size against length (Lockwood & Shepherd, 1984; Mous, *et al.*, 1995).

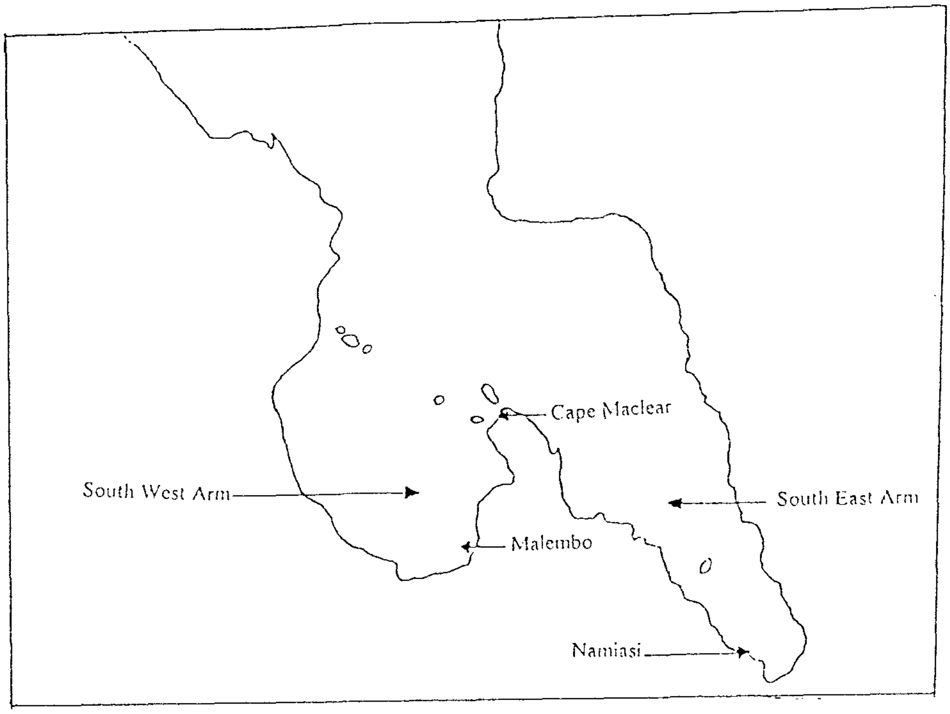


Figure 2.2: Map of Southern Lake Malawi showing Namiasi in the South East Arm (SEA) and Malembo in the South West Arm (SWA) of Lake Malawi where *T. placodon* specimens were collected from the Fisheries Demersal Trawling Surveys.

T. placodon feeding biology

T. placodon do not have a defined stomach hence the whole gut including intestines was inspected for diet studies. *T. placodon* have a strong pharyngeal jaw apparatus which enables them to crush gastropod shells. Although most pharyngeal crushers separate and eject shell fragments after crushing (Hoogerhoud, 1986; Meyer, 1989; Slootweg, 1987), *T. placodon* seemed not to separate them but swallowed most of them. This was evident from the observation that all guts were filled with partly crushed shell fragments some of which had gastropod flesh attached to them. All the parts of gastropods taken by the fish were assumed to have been swallowed. Characteristic parts of a prey item can be used in estimating the number of prey items in the stomach (Bowen, 1983) and in the present study spire tips remained among partly crushed shells in the *T. placodon* gut. These plus some complete shells found were assumed to be equal to the number of gastropods taken. From whole gastropod shells collected at Cape Maclear, relationships were drawn between complete or part of spire length (e.g. first three whorls from the tip) and the complete shell dimensions. These relationships were used for estimating the sizes of gastropods taken by fish. Identification of gastropod species in the gut was done either to species or genus depending upon the ease of identification, by using keys provided by Gray, (1981) and Brown, (1994).

Prior to sampling of fish for diet studies, the daily feeding peak which tends to have effects on the observed stomach contents of some fish species (Windell & Bowen, 1968; Hyslop, 1980; Bowen, 1983) was investigated from 60 *T. placodon*, 30 collected on the 28th of March and 30 on the 29th of March 1995. On each of these days, 10 *T. placodon* were collected in the morning between 07 hours and 10.00 hours; another 10 between 11.00 hours and 13.00 hours and the last 10 between 13.30 and 16.00 hours. All of the guts had similar fullness ranging from 70% to 100% without any apparent variation due to the sampling time of the day. Hoogerhoud (1986) reported that the shell fragments which were ingested by fish appeared to be unaffected in the faeces. It is also unlikely that once ingested the shell fragments would be released in the faeces within a day. Due to these reasons *T. placodon* specimens collected at different times of the day and also from different sources were used for diet studies with the assumption that the shell fragments in the gut could not be affected by sampling time of the day and digestion which takes place after fish capture for some prey items (Windell & Bowen, 1968; Bowen, 1983).

Each gut was measured (length) and its fullness (expressed as the fraction of the gut length with prey items inside it) was determined. The gut contents were sorted into separate identical gastropod shells or parts. The number of individuals of each gastropod species taken was estimated from the number of complete shells and spires. However, the proportion of spires in the shell fragments reported to be ejected by pharyngeal crushers (Hoogerhood, 1986; Meyer, 1989; Slootweg, 1987) was not known and hence the number of gastropods counted in *T. placodon* guts might have been less than what was eaten.

Numerical methods (Windell & Bowen, 1968; Hyslop, 1980) were employed for the analysis of the diet data. Frequency of occurrence and percentage composition by numerical abundance of various gastropods were computed. Non parametric statistics selected from UNISTAT, (1993) Statistical Package were employed on numerical data to examine the effects of sampling site and season on fish diet. The proportions of various gastropod species in *T. placodon* guts were compared with the proportions of the same gastropods in the transect count data by sampling site using two Sample X^2 test (Unistat, 1993) to test the null hypothesis that the proportions of various gastropods in *T. placodon* gut were equal to those from transect counts i.e. *T. placodon* did not selectively feed on any gastropod species against the alternative hypothesis that the proportions in the gut contents were different from those of transects i.e. *T placodon* was selectively feeding on some gastropods.

Movement and migration behaviour of *T. placodon*

Tagging was initiated during the early stages of the study to look into the movement and migration behaviour of *T. placodon*. Prior to tagging, tag retention was determined by tagging 16 *T. placodon* fish in the aquarium at the Environmental Education Centre (Cape

Maclear). A total of 395 *T. placodon* were tagged at Otter Point and 37 at Mitande in May 1995 (Table 2.2). T- tags made of plastic filaments, manufactured by Hallprint, Australia; Ref. No. T1347 were used for tagging *T. placodon* in both aquarium and the lake. The tags were 27 mm long and each tag had its own number marked on its orange coloured end. *T. placodon* were captured by a diver chasing them into or encircling them within a net. They were measured (TL) and tagged in the occipital region with T tags made of plastic filaments, Hallprint, Australia, Ref. No. T1347, 27 mm long with orange coloured ends by using a Monarch Model Sure Fire Tag Attacher. Fish size, tag number, date and place of tagging were recorded. Any sightings of tagged fish during subsequent dives were to be noted. Tagging more fish proved difficult as the fish became more difficult to capture.

Table 2.2: Number of *T. placodon* tagged and the dates tagging was done at Otter Point and Mitande in May 1995.

Date	No. of *T placodon* tagged at Otter Point	No. of *T placodon* tagged at Mitande
8th May 1995	-	18
9th May 1995	-	13
10th May 1995	80	-
11th May 1995	53	-
17th May 1995	65	-
22nd May 1995	49	-
23rd May 1995	21	-
26th May 1995	11	6
28th May 1995	7	-
Total number tagged	395	37

RESULTS

T. placodon relative abundance:

T. placodon was observed at all the five transect sites (Fig. 2.2) especially in the sandy areas off the beaches. The species was also occasionally observed in rocky areas close to sandy areas between Golden Sands and Otter Point, at some areas of Thumbi Island West and Domwe Island. There were significant differences in mean abundance between sampling sites (Fig. 2.2; Appendix 6; Kruskal Wallis Test, $P < 0.0001$). Pairwise comparisons of *T. placodon* density between sampling sites (Figure 2.2, and Appendix 6) by the Mann Whitney U test showed no significant ($P > 0.05$) differences in density among the three pair combinations between Fisheries, Nchenga, and Nguli, and also between Otter Point and Mitande but significant ($P < 0.05$) differences between any pair across the two groups i.e. the group of Otter Point and Mitande and that of Nchenga, Fisheries and Nguli. The mean relative abundance for each site is given presented Table 2.3. Ranks of the sites according to the descending order of abundance were as follows: Nchenga, Nguli, Fisheries Station, Otter Point, and Mitande. At Nchenga, Nguli and Fisheries Station most of the *T. placodon* were concentrated between 3 and 6 metres depth and exploratory dives up to 20 metre depth indicated that densities declined with depth.

A test of *T. placodon* monthly abundance fluctuations (Appendix 6 and Figures 2.2 a to e) against the mean monthly value for each sampling site (Table 2.3) using one sample X^2 test for uniformity indicated significant fluctuations at: Nchenga ($X^2 = 299.54$, $P < 0.0001$), Fisheries ($X^2 = 145.36$, $P < 0.0001$) and Nguli ($X^2 = 76.70$, $P < 0.0001$) and insignificant fluctuations at Otter Point ($X^2 = 9.82$, $P > 0.9$) and Mitande ($X^2 = 9.82$, $P > 0.70$). The patterns of fluctuation were similar for Fisheries, Nchenga and Nguli showing a general increase in abundance from November 1994 to June 1995. After June 1995, the patterns started to differ. At Nguli the peak was in July 1995 after which there are fluctuations in a decreasing trend of abundance. At Fisheries there was a sharp decline in December 1995 after which the abundance started increasing again. At Nchenga the abundance continued to increase up to February 1996 (Figure 2.2 a to e). A composite graph (Figure 2.3) of the average density of *T. placodon* at the five studied sites (Appendix 6) shows lowest *T. placodon* abundance of 5.8 to 7.6 individuals per 200 m^2 between November 1994 and March 1995 after which there was an increase up to 24 individuals per 200 m^2 in June 1995. The average density between June 1995 and January 1996 fluctuated between 19.4 and 30.4 individuals per 200 m^2. The highest average abundance value was reached in February 1996. The general increase in the average *T. placodon* abundance from 1994 to 1995 (Figure 2.3) was due to an increase in the juvenile *T. placodon* at Mchenga, Fisheries and Nguli.

Demographic structure

The sizes (Total length) of *T. placodon* were estimated to the nearest cm but analysis of their demographic structure involved sorting them into three size categories (<10 cm, 10-15 and greater than 15). The proportions of three *T. placodon* size categories (<10 cm, 10-15 cm and 15^+ cm TL) varied between sampling sites and month (Table 2.4). There were significant differences of *T. placodon* numerical abundance between sites for each of the three *T. placodon* size categories (Appendix 7, Kruskal Wallis, $P< 0.0001$ for < 10 cm size, $P<0.05$ for 10-15 cm size and $P < 0.003$ for 15^+ cm size).

At Fisheries, Nchenga and Nguli *T. placodon* below 10 mm TL dominated in numerical abundance; a few fish were in the 10-15 cm size range and very few in the 15^+ cm range (Table 2.4). At Otter Point there was almost an equal proportion of the fish in the 10-15 and 15^+ cm range few were less than 10 cm. At Mitande fish in the 10-15 cm category were most abundant followed by those 15^+ cm few were <10 cm (Table 2.4). *T placodon* less than 5.5 cm TL were never observed at any of the sites.

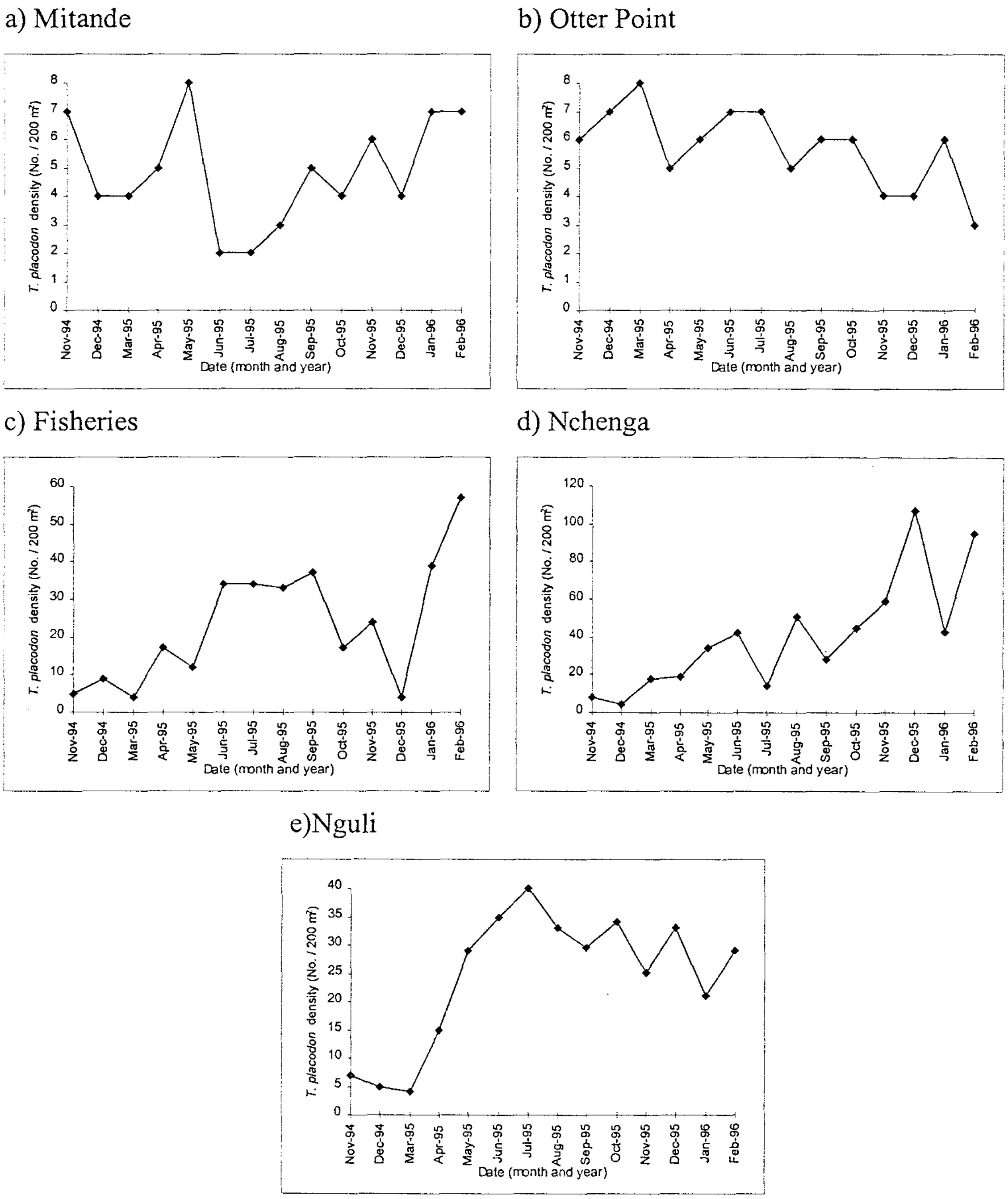


Figure 2.3: Density of *T. placodon* (expressed as number of individuals per 200 m^2) at various study sites a) to e) at Cape Maclear between November 1994 and February 1996. Each graph has its own Y Axis scale owing to the variation of *T. placodon* density between sites.

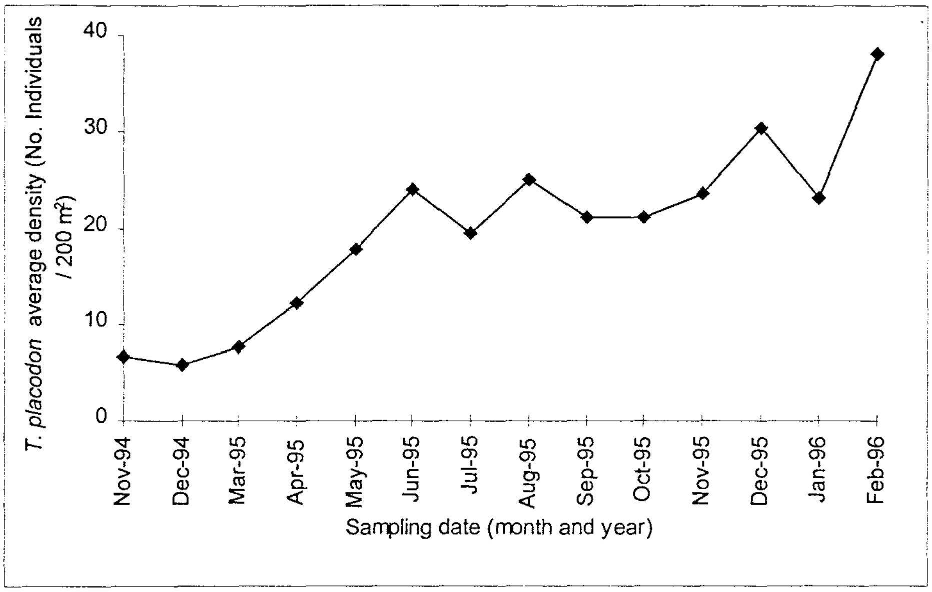


Figure 2.4: Mean *T. placodon* density for the five study sites: Mitande, Otter Point, Fisheries Station, Nchenga and Nguli between November 1994 and February 1996 showing an increase in density from 1994 to 1996.

Table 2.3: Mean *T. placodon* abundance by site (November 1994 to February 1996).

Site	Mean ±SD *T. placodon* abundance (No. individuals per /200 m^2).
Otter Point	5.7±1.4
Mitande	4.9±1.9
Fisheries	23.3±16.1
Nchenga	40.5±30.6
Nguli	24.3±12.0

Table 2.4: Demographic structure of *T. placodon* by month and site expressed as a percentage by numerical abundance. SC1 = Size category 1 (<10 cm, TL); SC2 = Size category 2 (10-15 cm, TL); SC3 = Size category 3 (15^+ cm).

	Mitande			Fisheries			Otter Point			Nchenga			Nguli		
	%SC1	%SC2	%SC3	%SC1	%SC2	%SC3	%SC1	%SC2	%SC3	%SC1	%SC2	%SC3	%SC1	%SC2	%SC3
Nov-94	30.2	43.0	26.7	100	0	0	0	50	50	100	0	0	71.4	28.6	0
Dec-94	0	75	25	100	0	0	0	57.1	42.9	100	0	0	62.3	37.7	0
Mar-95	75	25	0	100	0	0	0	37.5	62.5	66.7	33.3	0	60	20	20
Apr-95	0	80	20	94.1	5.9	0	0	80	20	74.5	25.5	0	60	40	0
May-95	0	70	30	83.3	16.7	0	0	61.7	38.3	90.9	9.1	0	83.2	16.8	0
Jun-95	0	100	0	94.1	5.8	0	0	42.9	57.14	85.8	14.2	0	85.7	14.3	0
Jul-95	0	100	0	91.2	8.8	0	42.9	57.1	0	78.7	21.4	0	74.4	25.6	0
Aug-95	0	100	0	81.8	18.3	0	0	60	40	94.2	5.8	0	87.9	12.1	0
Sep-95	0	60	40	81.9	18.1	0	0	55.9	44.1	83.5	16.5	0	74.3	17.9	7.8
Oct-95	0	80	20	94.5	5.5	0	0	58.3	41.7	73.0	22.5	4.5	70.7	14.7	14.7
Nov-95	0	66.7	33.3	82.4	17.7	0	0	50	50	79.7	20.3	0	66.2	26.1	7.8
Dec-95	0	75	25	50	50	0	0	25	75	75.7	19.6	4.7	87.1	9.0	3.9
Jan-96	0	28.6	71.4	15.4	76.9	7.7	0	27.1	72.9	70.6	22.4	7.0	56.3	24.9	18.8
Feb-96	0	42.9	57.1	36.4	52.0	11.7	0	25	75	64.2	32.6	3.2	24.1	27.6	48.3

Searches and collection of gastropods:

Most gastropods were found buried in weed beds and underneath the litter accumulated on the bottom of the lake from 1 to 6 metres. Only *Lanistes nyassanus* of 20 to 60 mm length were commonly observed in the open sandy areas at all sites visited including Domwe and Thumbi West islands and the beach from Otter Point to Ilala Gap and also in deeper water (up to 26 metres). The relative abundance of different gastropods (No. per 50 m^2) at different sites are given in Tables 2.5, 2.6, 2.7 and 2.8. These values are likely to have underestimated the actual relative abundance of gastropods because to account for every gastropod one may have to scrutinise every part and also scoop mud from every patch within the 50 m^2 transects which may not be practical. However, these values could still give a representative picture of the proportions of various gastropods by site. The gastropods were not evenly distributed within the 50 m^2 transects but they tended to congregate together within specific patches especially weed beds, litter material or underneath any big object lying on the substratum such as dead wood.

Table 2.5: Relative abundance of gastropods (number per 50 m^2) at three depths (1.5 m, 3.0 m and 6.0 m) at Fisheries Station, Cape Maclear in January, 1996.

Transect depth (metres)	Transect substratum type	Time of the day	*Lanistes nyassanus*	*Melanoides* spp.	*Gabiella stanleyi*	*Bulinus* species	Bivalves
1.5	sandy and litter patches at two points	900-10.00 hrs	14	61	2	0	2
3.0	sandy and one weedy portion of about 3 m^2	10.12 - 11.00 hrs	17	28	0	0	8
6	sediment deposited area	13.00 - 13:48 hrs	6	1	0	0	0

Table 2.6: Relative abundance of gastropods (number per 50 m^2) at two depths (6.0 m and 7.5 m) at Otter Point, Cape Maclear in January, 1996.

Transect depth (metres)	Transect substratum type	Time of the day	*Lanistes nyassanus*	*Melanoides* spp.	*Bulinus succinoides*	*Bulinus globosus*	*Bulinus nyassanus*	Bivalves
6	sandy near rocks	8.07 - 8.41 hrs	4	8	0	0	0	0
7.5	sandy with some sediment	8.57 - 9.24 hrs	2	3	0	0	0	0

Table 2.7: Relative abundance of gastropods (number per 50 m^2) at two depths (1.5 m and 4.5 m) at Ilala Gap, Cape Maclear in January 1996.

Transect depth (metres)	Transect substratum type	Time of the day	*Lanistes nyassanus*	*Melanoides* spp.	*Bulinus succinoides*	*Bulinus globosus*	*Bulinus nyassanus*	Bivalves
1.5	sandy, weed patches near rocks	9.07 - 9.39 hrs	0	33	3	2	0	6
4.0	sediment deposited, litter, and dead wood	9.52 - 10.27 hrs	5	18	2	0	0	4

Table 2.8: Relative abundance of gastropods (number per 50 m^2) at two depths (2.5 m and 4.5 m) at Nchenga, Cape Maclear in January,1996.

Transect depth (metres)	Transect substratum type	Time of the day	*Lanistes nyassanus.*	*Melanoides* spp.	*Bulinus succinoides*	*Bulinus globosus*	*Bulinus nyassanus*	Bivalves
2.5	sand and litter (dirty water)	9.08-9.43 hrs	9	47	4	2	7	9
4.5	sand with sediments, three weed patches (all about 7 m^2)	10.03 - 10.32 hrs	12	19	0	0	0	2

***T. placodon* breeding biology**

Underwater observations at various sampling sites sometimes revealed mouth brooding *T. placodon* females but courting, spawning and males defending nests were not observed. Males in breeding colour were occasionally seen being followed by mouth brooding females and usually one to three females followed one male. Thus the breeding area of *T. placodon* was not revealed in the present study.

Of the 973 *T. placodon* examined between January 1995 and February 1996, 524 were females at different stages of gonad development. The rest was composed of males and undeveloped juveniles which could not be sexed. Female gonad developmental stages discerned in the present study are described below.

In Stage I (Immature or undeveloped juveniles) tiny thin and transparent gonads which could not be sexed were noted in *T. placodon* fish mostly less than 80 mm, TL. In Stage II (Developing juveniles) the ovary was thin as in the first stage but a few tiny ova (<0.5 mm) were observed on a small section in the caudal part of the ovary. In Stage III (developing, spent or recovering), the ovary started enlarging with eggs of different sizes ranging from 0.4 to 1.5 mm diameter. All mouth-brooding females (identified by distended buccal cavities and/or the presence of eggs or fry in their buccal cavities) had ovaries in Stage III. Some ovaries presumably of recovering fish individuals had a large empty space with an assortment of egg sizes like the rest of stage III individuals and so were also classified as Stage III. In Stage IV (Ripening) the ovary had substantially increased in size and had more bigger (up to 2.6 mm) and uniform eggs than smaller (less than 1.4 mm) ones. Stage V (Ripe) ovaries were pink in colour with large (3 to 4.3 mm in diameter depending upon individual *T. placodon* fish) and uniform sized eggs. Since VI described by Mous *et al.* (1995) could not be discerned in any of the 524 females examined from January 1995 to April 1996 it was concluded that after spawning female *T. placodon* returned to stage 3.

The size at which 50% females were found to be mature was 142 mm TL (112 mm SL).

Minimum maturity size was 109 mm TL (94 mm, SL) and all *T. placodon* female individuals were mature at 165 mm TL (Figure 2.4).

The appearance of females of all gonad developmental stages throughout the year suggests that *T. placodon* breeds throughout the year. However, from the proportion of ripe females in the specimens examined every month, it was noted that there were variations from month to month with the major peak occurring between November and January (Figure 2.6). During the same period most of females observed at Otter Point, Golden Sands and a few at Mitande were mouth-brooding.

Fecundity (total number of eggs per ripe female) ranged from 72 to 217 with a mean ± SD of 146.0 ± 38.0 eggs. Both Least Squares and Stepwise Regression of fecundity on standard length yielded a significant ($P < 0.0001$) positive linear relationship between fecundity and standard length (Fecundity = 2.1053 (SL)-136.7846, $R^2 = 0.647$) (Figure 2.5).

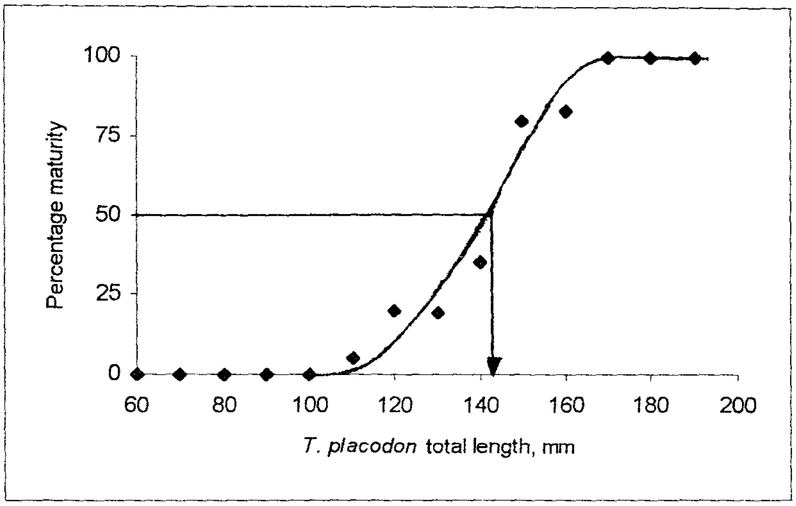


Figure 2.5: Percentage of female *T. placodon* mature at size (TL mm) (Curve and line at 50 % maturity fitted by hand). An arrow points to a total length of 142 mm, the female maturity size.

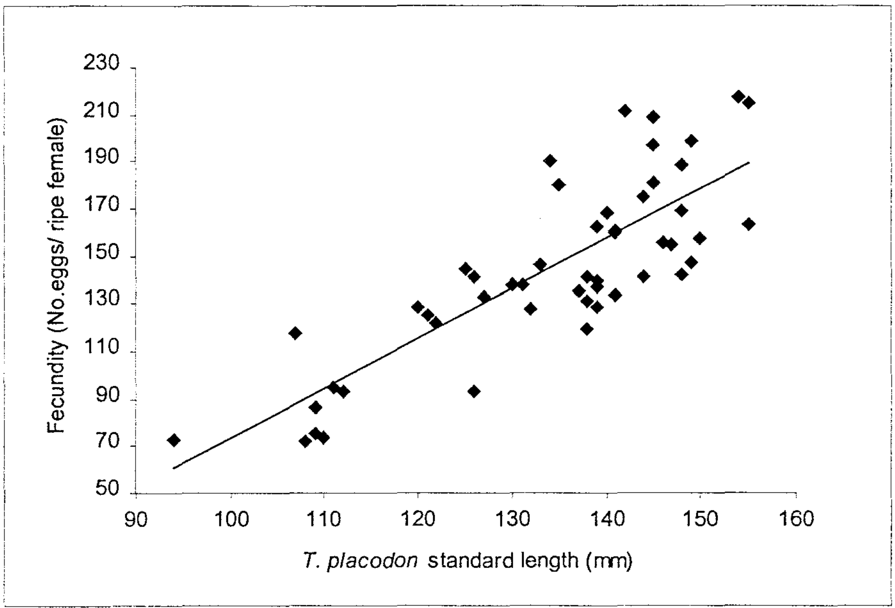


Figure 2.6: Linear regression of fecundity on standard length of female *T. placodon*. Fecundity = 136.78 + 2.105 (SL); $r^2 = 0.647$, N = 51, P<0.0001). Total egg counts of only ripe ovaries (Stage V) were included in this regression.

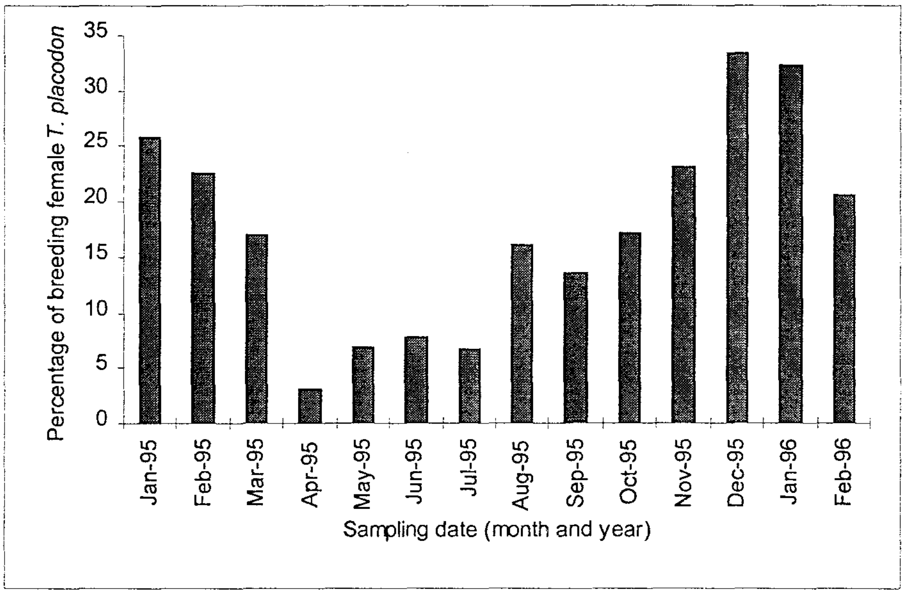


Figure 2.7: The proportion of *T. placodon* females greater than 100 mm TL sampled at Cape Maclear that were breeding. Breeding females were defined as those which had ripe ovaries (Stage V) or were mouth brooding.

General ecological and biological observations of *T. placodon*.

Distribution and abundance:

Tweddle & Willoughby, in Eccles & Trewavas, (1989) reported that *T. placodon* is widespread in Lake Malawi. Fisheries demersal trawling surveys between June 1994 and December, 1995 showed that besides being widespread it is also abundant in some areas. It was more abundant in the South West arm than in the South East arm. In the seven Quarterly surveys undertaken by the Fisheries Research Unit between June 1994 and December 1995 in the South East Arm of Lake Malawi, estimated *T placodon* catch per quarterly survey varied from 112 kg to 440 kg (Figure 2.7a) and its proportion of the total catch varied from 1.46% to 5.95% (Figure 2.7b). The proportion shown in Figure 2.7b do not directly reflect *T. placodon* relative abundance because weight of big fish species such as *Bathyclarias*, and *Bagrus meridionalis* which was included in the total catch weight masked the proportion of smaller fish species such as *T. placodon*. Mass units other than fish numerical abundance values were used in Figures 2.7 a & b because the Fisheries Department Catch records from which these data were extracted are in mass units. A total of 204 *T. placodon* specimens were sampled from three quarterly survey catches from South East Arm of Lake Malawi and their total mass was 17.424 kg. From this weight and number of specimens, the estimated catches of 112 kg to 440 kg per survey translate to 1,300 to 5,152 *T. placodon* fish per survey assuming that the same *T. placodon* size structure and condition factor were maintained for all the seven surveys. Unfortunately, in the Fisheries Survey Records from which these data were, the area covered in the pulls were not recorded so the number of fish per unit area cannot be computed.

During the trawling surveys at the South East Arm of Lake Malawi most *T. placodon* were caught between 6.5 and 25 metres depth; a few from 25 to 30 metres and rarely at 30 to 40 metres (Figure 2.8). There was no correlation between Catch Per Unit of Effort (CPUE) and trawl depth (average of lowest and highest cruise depth) within *T. placodon* occurrence depth range [CPUE= -0.1831(Depth) + 27.469, R^2 = 0.0007, P = 0.8278) (Figure 2.8). Since CPUE may also reflect numerical abundance, the lack of correlation between CPUE and depth may also imply there was no correlation between *T. placodon* numerical abundance and depth within its depth range of occurrence at the stations surveyed.

The size of the *T. placodon* caught tended to increase with depth. Below 30 metres depth the catch composed of mostly bigger *T. placodon* individuals the majority of which were males. In two trawls at South West Arm of Lake Malawi in June 1995 at 35 and 31 metre average depth, all the individuals caught were males.

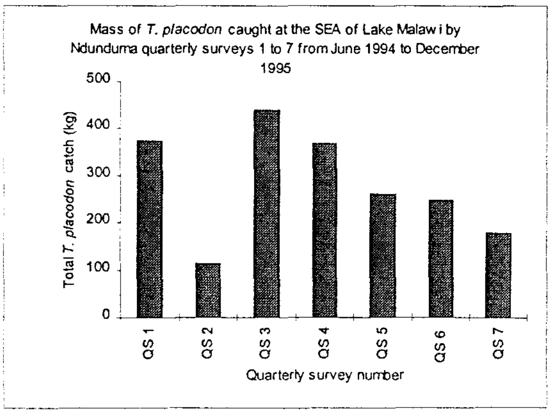
Size reached:

The maximum observed *T. placodon* size was slightly bigger than the previously reported size of 165 mm SL (Eccles & Trewavas,1989: Konings,1990; 1995). Males reach a bigger size than females; males attaining 240 mm TL (191 mm SL) were sampled from Cape Maclear: Golden Sands and Otter Point; South West Arm of Lake Malawi at Malembo and South East Arm of Lake Malawi at Namiasi with the largest encountered male from Namiasi measuring 244 mm TL (192 mm, SL). The biggest females were 191mm TL (154 mm SL) and 192 mm TL (155 mm SL) from Otter Point and Golden sands respectively. Most specimens from Malembo were generally bigger than those from other sites.

Movement and migration behaviour:

Of the 395 and 37 *T. placodon* tagged at Otter Point and Mitande respectively, not much direct information pertaining to the movement behaviour of the species was yielded. After tagging a few tagged fish were sighted within the first three days and were never seen afterwards. The only exception was one fish probably tagged at Otter Point between 10th May and 28th May 1995 (Table 2.2) but sighted at Golden sands about 400 metres away on 10th June 1995 two to four and a half weeks after tagging. Poor sighting rate of tagged fish where they were tagged was not due to tag shedding because in an aquarium tags were retained on tagged *T. placodon* for more than two months. At the same time mortality due to tagging could not be directly invoked because in an aquarium only 2 of the 16 tagged *T. placodon* died after a period of two months. The only plausible explanation for poor sighting rate of tagged *T. placodon* fish after a period of three days was that tagged fish probably moved farther away than the areas dived. The number of tagged *T. placodon* may also have been too small to yield tag returns. The fact that abundance of *T. placodon* fish fluctuated from month to month may also suggest that these fish wander over a wide area probably in search of food.

a)



b)

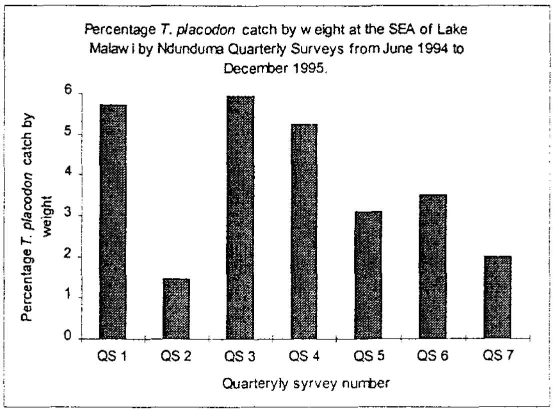


Figure 2.8: a) Mass of *T. placodon* and b) its proportion caught in the South East Arm of Lake Malawi during the Quartely Demersal Trawling Surveys by the Fisheries Research Unit from June 1994 to December 1995. The percentage in b) was computed based upon total catches of fish from survey stations where *T. placodon* was caught. QS = Quarterly survey. The dates each of the seven Quaterly survey were carried out are shown in Appendix 2.

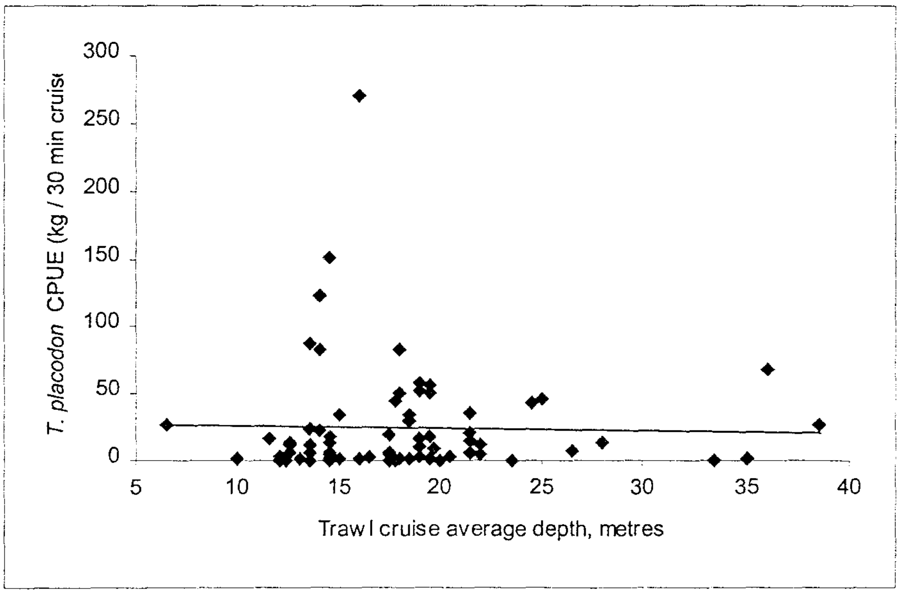


Figure 2.9 *T. placodon* Catch Per Unit Effort (kg / 30 min trawling cruise) versus average trawlling depth. There was no correlation between *T. placodon* CPUE and depth within the species occurrence depth range of 6.5 to 40 metres, $r^2 = 0.0007$. $P = 0.8278$, $N = 75$). The data were extracted from South East Arm Fisheries quarterly demersal trawling surveys between June 1994 and December 1995.

Feeding biology of *T. placodon*

T. placodon is reported to feed in the weedy areas (Eccles & Trewavas, 1989) but in the present study the species was seen to feed mainly on open sandy substratum perhaps because there were fewer weedy areas compared to open sandy areas in the sampling sites of the present study. Sometimes the species frequented the sandy/rocky interface or intermediate habitats of sand and rocks.

Small (less than 8.0 mm TL) *T. placodon* fed on benthic insects (larvae, pupae and adults) and from detritus material. Those slightly bigger (between 8.0 cm and 10 cm TL) fed on a mixture of benthic insects, fish scales, and small gastropods (1 to 2 mm long). Fish greater than 10 cm mostly fed on gastropods and to a small extent on bivalves and fish scales. All advanced mouth brooders had empty guts and those which had just started mouth brooding (eggs not hatched) had a few gastropod shells in their guts (less than a quarter full) implying that mouth brooding *T. placodon* fish did not eat.

Gastropods of five genera including: *Melanoides*, *Bulinus*, *Gabiella*, *Lanistes*, and *Bellamya* and bivalves were eaten. Some gastropods could not be identified so they are referred to as unidentified species. Of the five genera, *Melanoides* dominated the gut contents in both abundance and frequency of occurrence and *Bulinus* came second (Figures 2.9 and 2.10). All the gastropods taken were relatively small in size as compared to the ones observed during underwater dives signifying that *T. placodon* selectively fed on juvenile gastropods. The *Melanoides* eaten by *T. placodon* ranged from 1 to 17 mm length while the *Bulinus* ranged from 1 to 14 mm. The corresponding gastropod widths for these lengths varied with gastropod species depending upon its shell dimensions. All the *Gabiella stanleyi* shells found in the gut were uncrushed.

Bulinus globosus, *B. nyassanus*, and *B. succinoides* were taken by *Tplacodon*. Of these only *B. globosus* is a confirmed vector for *S. haematobium* (Brown, 1994; Cetron *et al.* 1993; 1996: Stauffer et al. 1997). *B. globosus* were noted in the gut contents of *T. placodon* collected from Golden Sands, Otter Point, Ilala Gap, Mitande and Nchenga, but its frequency of occurrence in the guts was generally low as compared to other gastropod species and no *B. globosus* was seen in the gut contents of *T. placodon* collected from Fisheries (Figure 2.10).

A test for the difference in the percentage composition in *T. placodon* guts of different gastropod species by sampling site (Figure 2.9) using Chi Square Test indicated significant differences between sites for *B. globosus* ($P < 0.03$), *B. succinoides* ($P< 0.01$), and *G. stanleyi* ($P<0.01$) and insignificant differences between sites for *B. nyassanus* ($P = 0.5465$), Bivalves ($P=0.3546$), *Lanistes* ($P>0.1$), *Melanoides* ($P>0.1$) and *B. capillata* ($P>0.1$).

There was a significant positive but weak relationship between the number of gastropods eaten and *T. placodon* size (only *T. placodon* whose guts were more than 75% full were included in the analysis). [No. gastropods = 0.4637 (TL) - 23.485], $R^2=0.1957$, $P < 0.0001$) (Figure 2.11). Figure 2.11 shows that there was no relationship between *T. placodon* size within the 75mm to 180 mm TL, and the number of gastropods eaten. *T. placodon* in this size range mostly ate 100 or less gastropods. However, above 180 mm TL there was an increase in gastropods taken with *T. placodon* size which contributed to the overall relationship depicted in Figure 2.11. It was commonly observed that small gastropods alone in the gut were taken in greater numbers than bigger ones alone and also that small *T. placodon* ate small gastropods while bigger *T. placodon* ate bigger gastropods. This partly accounts for the weak relationship between the number of gastropods taken and *T. placodon* size in Figure 2.11 especially within the 75 mm to 180 mm *T. placodon* size range.

The *Bulinus* eaten were of a wide size range and there was a weak but significant ($P< 0.0001$) positive relationship between maximum *Bulinus* size eaten and *T. placodon* size (Figure 2.12). This relationship between gastropod size and *T. placodon* size not only applied to *Bulinus* species but also to *Melanoides*. Only *Bulinus* were included in this analysis owing to their role in *Schistosomiasis* transmission.

Comparison of gastropods in the guts and transect counts:

The proportions of various gastropods in the transect counts (Tables 2.5 to 2.8) were significantly ($P<0.00005$) different from that of the *T. placodon* gut contents (Figure 2.9) for all sites (X^2 =199; 270; 812 and 347 for Fisheries, Ilala Gap, Otter Point and Nchenga respectively) implying that *T. placodon* were at least selectively feeding on some gastropod species.

Table 2.9 summarises the comparisons of the gastropod proportions between *T. placodon* guts and transect counts by Two Sample X^2 test. The table shows that *T. placodon* were selecting for *Melanoides* and *G. stanleyi* at all sites. *Bulinus* and Bivalves were selected for only at Otter Point and not at other sites. No *Bulinus* were observed at Otter Point (Table 2.6) yet *T. placodon* collected from Otter Point had the greatest proportion of *Bulinus* snails in their guts when compared to Fisheries, Nchenga, and Ilala Gap (Figure 2.9 a, c, d, and e). *L. nyassanus* were not selected for at all sites.

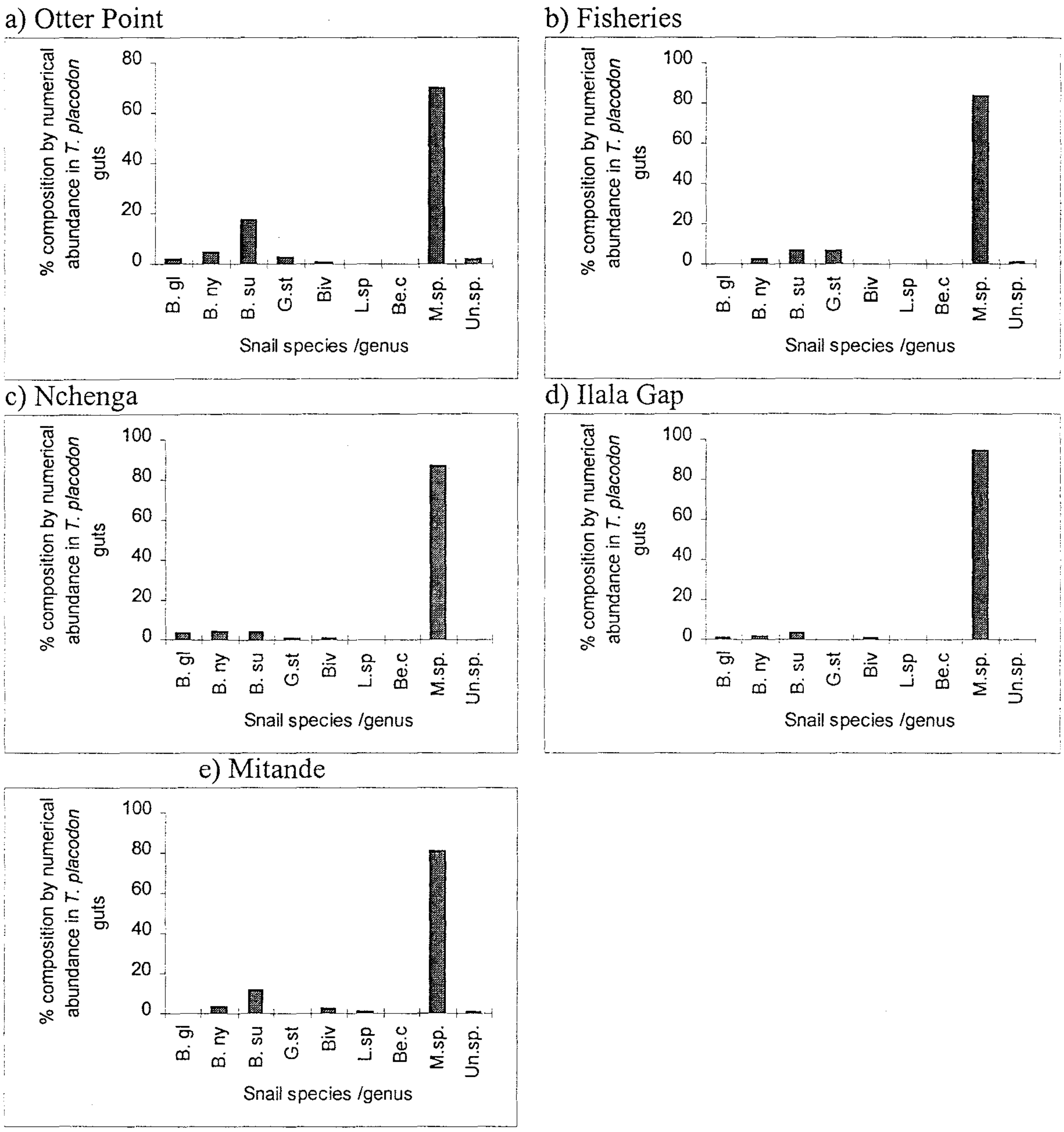


Figure 2.10: Proportions of various gastropod species in the diet of *T. placodon* at each sampling site between May 1995 and April 1996. B. gl. = *Bulinus globosus*, B. ny = *Bulinus nyassanus*, B. su. = *Bulinus succinoides*, G. st. = *Gabbiella stanleyi*, Biv. = bivalves, L. spp. =*Lanistes* spp., Be. c. = *Bellamya capillata*, M. spp. = *Melanoides* spp, Un. Spp. = Unidentified spp.

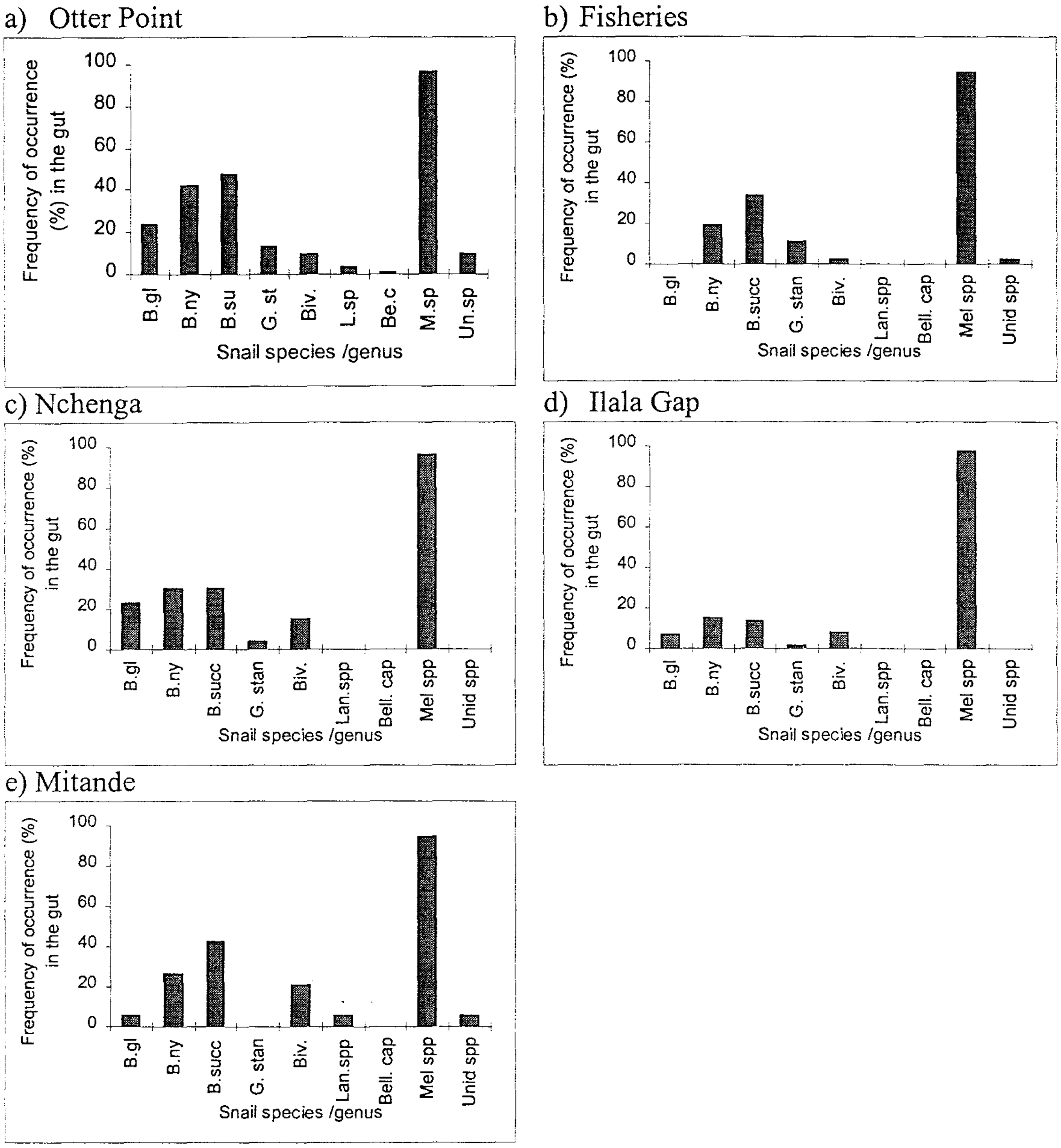


Figure 2.11: Frequency of Occurrence of various gastropod species in *T. placodon* stomachs sampled from different sites. B. gl. = *Bulinus globosus*, B. ny. = *Bulinus nyassanus*, B, su. =*Bulinus succinoides*, G. st = *Gabiella stanleyi*, Biv = Bivalves, L spp. =*Lanistes species*, Be. C. =*Bellamya capillata*, M. sp = *Melanoides spp*, Un. sp = unidentified species.

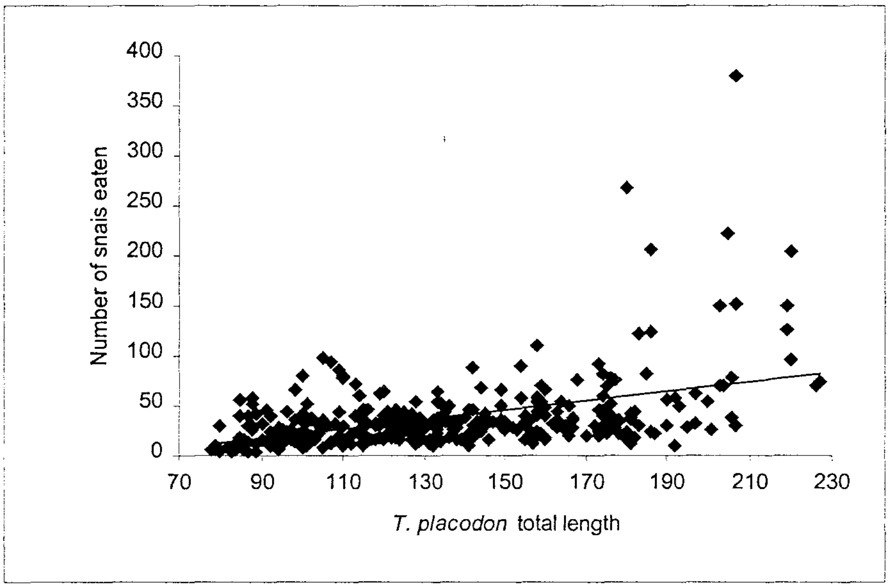


Figure 2.12: The relationship between the number of gastropods counted in the gut and the size of *T. placodon* (TL) based upon guts which were equal to or greater than 75% full (N=327). There was a significant but weak positive correlation between number of gastropods taken and *T. placodon* size, [No. gastropods = 0.4637(TL) -23.485; R^2 = 0.1957; P< 0.0001).

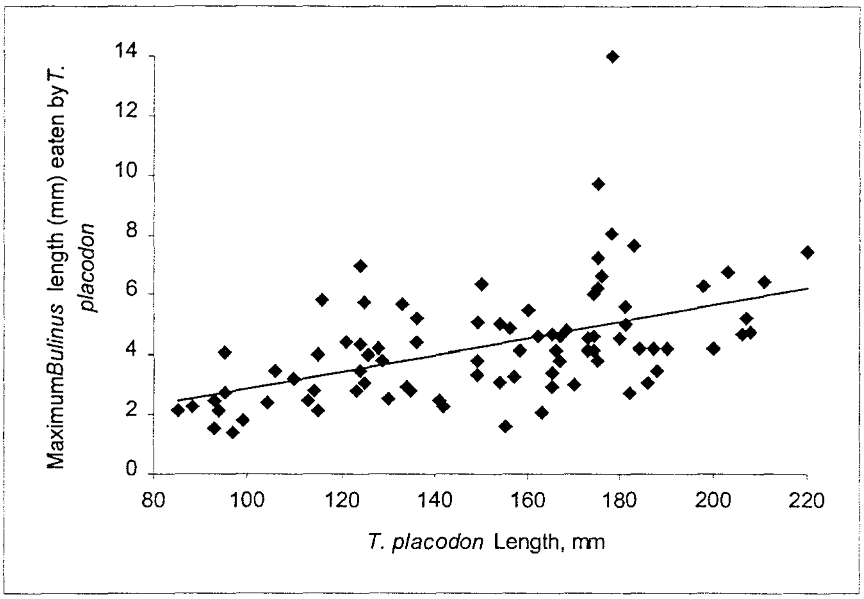


Figure 2.13: Graph showing the relationship between the maximum size of *Bulinus* species eaten and *T. placodon* size (TL, mm). There was a significant positive but weak relationship between *Bulinus* size eaten and *T placodon* size Y = 0.028X-0.08; $R^2 = 0.25$; $P < 0.0001$; where Y = maximum *Bulinus* species size eaten by *T. placodon* of a particular size, X = *T. placodon* total length, mm.

Table 2.9: Proportion of gastropods in the diet of *T. placodon* compared with that of the transect sampling sites, using two sample X^2 test.+ sign shows lower proportion of the gastropods in the diet than transect counts i.e. not selected for. 0 means equal proportions in the diet and transect counts. - sign shows higher proportion in the diet than transect i.e. the gastropod was selected for. The differences between the proportions of the five gastropod types in the diets and transects were significant (P<0.00005) for all four sampling sites. Degrees of Freedom (DF) differ between sites because of zero values of some gastropods proportions which meant omission of pairs in the comparisons and hence adjusting for the corresponding DF.

Sampling site	*Melanoides* spp.	*Bulinus* spp	Bivalves	*Lanistes nyassanus*	*Gabiella stanleyi*	X^2 Value	D.F.	P. value
Otter Point	-	-	-	+	-	812	1	<0.00005
Ilala Gap	-	+	+	+	-	270	2	<0.00005
Nchenga	-	+	+	+	-	347	3	<0.00005
Fisheries station	-	0	+	+	-	199	2	<0.00005

DISCUSSION

T. placodon abundance

McKaye *et .al* (1986) reported on the abundance and distribution of four major molluscivorous fish in Cape Maclear (in front of Fisheries station); *T. placodon*, *T. microstoma*, *M. spharaedon*, *M. anaphyrmus* in which they classified the former two as "spotted" and the latter two as "oblique striped" species. They reported a peak distribution of the "spotted species" of 1.5 individuals / 10 m^2 (30.0 / 200 m^2) to be at 6 metre depth (Table 2.10). Below 10 metre the reported density was 1/3 that of the peak while above 10 metres the density was 1 individual / 20 m^2 (10 / 200 m^2). A similar survey of the same fish species was repeated in 1994 by the same workers and they found that the number of the spotted molluscivores (*T. placodon* and *T microstoma*) had declined at all depths (Stauffer et al. 1997). The peak distribution at 6 metre depth is reported to have declined to 5/1000 m^2 (1.0/200m^2) (Table 2.10). A drastic reduction was also reported of *M. anaphyrmus* and *M. sphaerodon* and also that no molluscivores had been observed at the shallowest depth (Stauffer *et al.* 1997).

The density range of the "spotted fish" of 4.9 ±1.9 individuals / 200 m^2 to 40.5±30.6 individuals / 200 m^2, at the depth of 4 to 7 metres found in the present study (Table 2.3) covers the peak of 30 / 200 m^2 reported by McKaye *et al.* (1986). The mean monthly density of 40.5 / 200 m^2 found at Mchenga is higher than the reported peak for 1986. The densities of 23.3±16.1 / 200 m^2 and 24.3±12.0 /200 m^2 at Fisheries and Nguli respectively are slightly lower than the 30 / 200 m^2 but by considering the high standard deviation values due to temporal fluctuations in abundance in the former two, the densities may be considered to be within the same range. By comparing the present study's density Mchenga, Nguli and Fisheries to the density reported by McKaye *et al.* (1986) which was based upon Fisheries Site, no evidence exists to support the fact that the density of the spotted molluscivores has drastically declined. The density at Otter Point and Mitande may not be comparable to that of Fisheries, Mchenga and Nguli along the Golden Sands Ilala Gap Beach and also to the findings by McKaye *et al.* (1986) because of the differences in the site characteristics such as depth, and proximity to rocks (Table 2.1). 53 (93%) of 57 "spotted fish" collected at Cape Maclear between September 1994 and November 1994 were identified using the identification key outlined by Eccles & Trewavas, (1989), as *T. placodon* and only 4 (7%) were identified as *T. microstoma*. All the "spotted fish" subsequently observed in the same area were assumed to be *T. placodon*. *T. microstoma* catches in the Fisheries Department Demersal Trawling surveys between June 1994 and December, 1995 were occasional and low compared to *T. placodon* (personal observation) indicating that *T. microstoma* is probably a rare species.

The densities found in the present study show a wide discrepancy with the 1994 peak of 1.0 individual / 200m^2 reported by Stauffer *et al* (1997) yet the present study started towards the end of the year of 1994. Such an anomaly of the reported fish abundance may be a reflection of the following factors:

1) Distribution seasonality: The present study showed that abundance of *T. placodon* fluctuated from month to month. For instance *T. placodon* abundance was low at all sites from November, 1994 to March 1995 (Figures 2.2 a to e) and if the survey was restricted to this period only, lower average abundance values could have been depicted especially for Fisheries Station, Nchenga, and Nguli which indicated the highest fluctuations. Even after taking into account the seasonal fluctuations of *T. placodon / T. microstoma* abundance, the value of 1 / 200 m^2 (Stauffer, 1997) may be still questionable when compared to the minimum of 5 / 200 m^2 and 9 / 200 m^2 observed in the present study at Fisheries between November and December 1994 respectively considering that the two independent surveys are based on one site at similar depths.

2) Sampling method differences: *T. placodon / T. microstoma* abundance reported in the present study were based upon five fixed sampling stations for a period of 14 months while the reported *T. placodon / T. microstoma* abundance by McKaye *et al.* (1986) and Stauffer *et al* (1997) are based upon Fisheries Station alone and the period over which the data were collected is not specified. One sampling site may not truly represent *T. placodon* abundance for the whole Cape Maclear especially since there is spatial variability in *T. placodon* distribution as was shown in the present study by sampling at 5 sites.

Table 2.10: Summary of reported *T. placodon* / *T microstoma* density at Cape Maclear between 1986 and 1996. * Assumed to be the peak density because transects covered the depth at which the "spotted molluscivores" were reported by McKaye *et al.* (1986) to be most abundant.

Reference	Reported "spotted molluscivores" (*T. microstoma* / *T. placodon*) peak densities (converted to number of. Individuals / 200 m^2).
McKaye *et al.* (1986)	30.0 / 200 m^2
McKaye *et al.* (1994, cited by Stauffer *et al.* 1997)	1.0 / 200 m^2
Msukwa 1994 to 1996	5.714 to 40.5 / 200 m^2 * (varied between sampling sites within this range)

Distribution of T. placodon

Konings (1990) reports an average depth of *T. placodon* occurrence of 5 metres which is similar to McKaye *et al.* (1986). My diving data support these observations but the catches from Fisheries' surveys showed that *T. placodon* occurs commonly at greater depths in the South East Arm of Lake Malawi. This raises questions as to whether or not there are variations in the depth limit of *T. placodon* with its populations or if two different species were being looked at. The former is possible especially that during my diving at Cape Maclear *T. placodon* were observed up to 20 metres depth. More intensive sampling of *T. placodon* at various localities and depths is required to gain a greater insight into how *T. placodon* distribution and abundance are related with depth.

The difference in *T. placodon* size structure between sites may be attributed to the difference in the habitat types and partly by the difference in protection from the park 100 metre zone. Two of the three sites inside LMNP 100 metre zone, Otter Point and Mitande both of which are deeper and close to rocky areas have similar densities and size structure of fish. Nguli is inside the park 100 metre zone but it showed similar size structure to Fisheries and Nchenga and all the three sites are relatively shallow with a very mild depth gradient. However, since Nchenga and Fisheries are outside the park waters fishing may have contributed to reduction in the proportion of individuals greater than 15 cm TL and if this is the case Nguli which is very close to Nchenga might also have been affected by the same problem because it is also near Chembe Village thus making it easier for fishermen to poach. Areas far from Golden Sands where Lake Malawi National Park Law Enforcement team operates from are generally more poached than those closer.

Where *T. placodon* fry are deposited after mouth brooding stage and where the juveniles less than 55 mm TL lived are aspects never observed in this study. *T. placodon* juveniles were never observed among juveniles of a few sand dwelling fish like *C. eucinostomus*, and *Nimbochromis spp* observed in schools in water column and weedy areas respectively. Kocher & McKaye

(1983) noted the same thing about most sand dwelling fish.

Breeding biology:

The data presented in this study with regards to *T placodon* breeding biology are too limited to throw enough light pertaining to the reproductive biology of the species. Nonetheless a few comments can be made. *T. placodon* appeared to breed throughout the year with a peak breeding season between December and February. Breeding throughout the year is a common characteristic of many cichlid fishes of Lake Malawi (Lewis, 1981; Thompson, Allison, Ngatunga, & Bulirani, 1995; Tweddle & Turner, 1977). Based upon snorkelling observations, Konings (1990; 1995) reports a peak breeding season of *T. placodon* between July and September which differs from the one noted in the present study. Such an anomaly is perhaps due to inadequate sampling by the former. If specimens for study were sampled only from a breeding arena for instance, the sample could reflect that most fish were in breeding season giving a superficial peak breeding period.

Breeding period is usually correlated with factors such as photoperiod and temperature (Buxton, 1990; Hyder, 1970). Lake Malawi surface temperature is lowest in June (23°C) and rises from August until a maximum of 28°C is reached between December and January (Eccles in Ribbink *et al.* 1983). In the present study the period of high water temperature and rainfall coincided with the period when the greatest proportion of female specimens were in breeding condition suggesting that at least one of these factors may play a role in *T. placodon* breeding. Detailed studies of the reproductive biology are required to shed more light in this regard.

Spawning or nest defending fish were never observed thus it is difficult to comment on courtship and breeding location. Konings (1995), however, reports that males construct large sand castle nests, with a diameter of about 70 cm where they mate with females. In the present study several mouth brooding females were encountered, juveniles between 60 and 90 mm, TL were constantly recruited to three study sites; Fisheries, Nchenga and Nguli, throughout the study period, indicating that breeding took place elsewhere throughout the year. This coupled with the fact that distribution of the species may extend to 40 metre depth and also that the proportion of males increases with depth (extreme cases were two trawl pulls at Malembo at 35 and 31 metre depth in which only male *T. placodon* were caught) suggests the possibility of a *T. placodon* lek at these depths (see McKaye (1983) for lek characteristics) which are perhaps periodically visited by females.

Although in many fish fecundity is believed to vary with the power (2nd to 3rd) of length (Bagenal & Braum, 1978), *T. placodon* fecundity length relationship was linear and such a linear relationship has also been demonstrated in the Lake Malawi rock dwelling cichlids: *Cynotilapia afra* Gunther 1893; *Pseudotropheus tropheops* "red cheek"; *P. tropheops* "orange chest" (chironyms used by Ribbink *et al.*, 1983); and *P. zebra* Boulenger, 1899 (Munthali, 1995) and the sand dwelling species, *Copadichromis eucinostomus* (McKaye, 1983). The fact that mouth brooding female *T. placodon* had developing eggs in their gonads suggests that the species may spawn more than once a year.

Feeding biology:

Based upon previous studies which looked into aspects of the feeding biology of *T. placodon* under artificial conditions (Chiotha, *et al* in Slootweg *et al.* 1993; Chiotha, *et al* 1991) and natural conditions (McKaye, *et al.* 1986; Louda, Gray, McKaye & Mhone, 1985), the species was suggested biological agent for schistosomiasis control. Chiotha *et al.* in (Slootweg *et al.* 1993) experimenting with cement ponds demonstrated that *T. placodon* as opposed to *M. anaphyrmus* significantly reduced the population of *Bulinus* and *Lymnae* species. McKaye *et al.* (1986) experimenting with fish in the open sandy area using cages, demonstrated that the densities of gastropods increased significantly after one week in cages without *T. placodon* but after *T. placodon* was introduced in the cages there was no significant difference in gastropod density with the control outside the cage. They also reported that *T. placodon* fed more on *Bulinus* spp. than *Melanoides* spp. Due to these findings they concluded that open shore areas of Lake Malawi might have been relatively free of schistosomiasis because molluscivorous cichlids prevented schistosomiasis vectors from colonising the areas. Chiotha *et al.* (1991) in their laboratory studies to observe the feeding behaviour of *T. placodon* on *Bulinus tropicus* noted that

T. placodon had some problems to capture prey gastropods which were attached to objects. Fish less than 13.8 cm, SL were unable to consume gastropods greater than 10 mm.

The present study has indicated that *T. placodon* under natural conditions start feeding on various gastropod species, *Bulinus* inclusive, at a size as small as 8 cm TL and also that the gastropod size taken increases with *T. placodon* size. Observations of gastropods by transects and also during the exploratory dives conform to the previous reports (Louda, & McKaye, 1982; Louda *et al.* 1985; McKaye *et al.* 1986) that there are fewer gastropods in the open sandy area than in weed beds. The suggestion that fish predation may affect burying behaviour of snails (Louda & McKaye, 1982; McKaye *et al.* 1986) may also be supported by the present study. Concentration of gastropods in weed beds may support the observation by Chiotha *et al.* (1991) that gastropods attached to objects tended to be captured with difficulty as opposed to those on open sandy area.

Melanoides form the major diet of *T. placodon* and they were preferred at all sites. Though the *Bulinus* was the second most abundant genus of gastropods in *T. placodon* guts, it was taken in very low numbers as compared to *Melanoides* (Figure 2.9) and it was also not preferred except for Otter Point *T. placodon* specimens. This is in contrast to the results of McKaye *et al* (1986) where *Bulinus* were preferred to *Melanoides*. This can be partly explained by the limited *Bulinus* distribution and abundance compared to *Melanoides* as confirmed by the present study's gastropod searches and previous surveys of schistosomiasis snails by Cetron *et al.* (1993) and Cetron, (1994). *L. nyassanus* were taken in the lowest proportion and were also negatively selected for because of their larger size compared to other gastropods.

Of the three *Bulinus* species, *B. globosus*, the confirmed vector for *S. haematobium*, was the least abundant in *T. placodon* guts. The optimal foraging theory predicts that an animal species searching for food will go for the type of prey with the highest profitability measured as energetic yield per unit of handling time (Hoogerhood, 1986; Meyer, 1989; Slootweg, 1987 & Slootweg *et al.* 1993). According to this theory a lower ranking prey type will be accepted if the density of the higher ranking prey declines. Applying this theory to the results of the present study may reflect that though *Bulinus* species are higher ranking (because they are thin walled therefore less handling time required), their density is low; they are apparently restricted to specific habitats such as weeds and litter deposited in the lake and they usually burrow in the sand or mud, consequently the searching time for fish to get them could increase. In this case it would be more profitable to go for *Melanoides* which might seem lower ranking but are more abundant. Thus the *Bulinus* cannot be eliminated completely by *T. placodon* because below a certain population of the *Bulinus*, *T. placodon* may switch to other gastropods such as the *Melanoides*. The fact that the *Melanoides* found in *T. placodon* guts were smaller than those observed underwater may also mean that their shells were softer than those of bigger ones thus increasing their ranking value and hence their apparent preference by fish.

One may therefore wonder as to why, very few confirmed schistosomiasis transmitting snails are present and yet schistosomiasis continues to increase in Cape Maclear. One explanation could be that the few *B. globosus* gastropods which cannot be easily located by fish because they are covered by litter or weed beds may be responsible for schistosomiasis transmission. Secondly other *Bulinus* gastropods apart from *B. globosus* may be possible vectors for schistosomiasis transmission (Gray, 1981; Stauffer *et. al.* 1997). While the latter explanation needs verification, the former definitely accounts for much of the above paradox. Although the models (e.g. Barbour, 1982) may predict that reduction of gastropod population to a particular level might reduce schistosomiasis incidence, it is difficult to point out what the minimum level is due to lack of relevant data. Few highly infected gastropods can release millions of cercaria (Barbour, 1982, Frandsen 1979) and increasing schistosomiasis contraction may mean that there has been an increase in the proportion of the seemingly few schistosomiasis vector snails that are infected other than the increase in vector population. Schistosomiasis incidence might have increased due in part to the increase in human population along the lakeshore whose dependency upon the lake for domestic chores, fun, recreation and fishing, has increased correspondingly to promote schistosomiasis incidence by re-infecting the water and getting infected by the parasite. In Cape Maclear, the re-infection of water with schistosome eggs from human host may be particularly high because most households do not have toilets.

Although the present study focused on one molluscivorous species, the findings of this study could equally apply to other molluscivores especially with regards to the influence of various gastropod abundance on the molluscivorous fish feeding preferences.

Two speculations have arisen from the question of how the schistosomiasis vector snails came to be found in the lake where they were previously not found. The first one is that the snails have appeared recently along the open lake shore as a result of ecological changes (Cetron *et al.* 1993; 1996). Secondly it is suggested that vector snails may have always been present in the lake but their population limited by natural predators (Cetron *et al* 1996; Stauffer *et. al.* 1997). The present work was not directly related to the above question but some inferences can still be made for instance, the fact that *Bulinus globosus* were found in the guts of *T. placodon* sampled from Cape Maclear, South East (Namiasi) and South West Arm (Malembo) (Figure 2.9) of Lake Malawi albeit in small quantities questions the first speculation. At all the three areas it is very unlikely that *B. globosus* snails have recently appeared due to ecological changes such as heavy rainfall causing washing of vegetation into the open lake area, after all rains have always been there. Besides vegetation, birds are also reported as gastropod dispersal agents (Michel, 1994) but it is unlikely that the birds could disperse the snails concurrently to different parts of the lake. Thus the second speculation that vector snails may have always been present in the lake is a more plausible explanation. Their population has been and still appears to be limited by natural predators.

Recommendations

In light of the findings of the work reported in this chapter some suggestions previously raised with regards to schistosomiasis problem at Cape Maclear can be modified. For instance captive propagation which was a subject of a project proposal and also a suggestion by Stauffer *et al.* (1997) may not be necessary at least with regards to *T. placodon*. High abundance of *T. placodon* irrespective of size meant that *T. placodon* population is not declining. However it is important to let the fish grow big to increase their effectiveness in snail control. Captive propagation is recommended if the fishes cannot recover in their own environment (Ribbink, 1986; 1987). Other factors which may disqualify the use of captive propagation as a measure to restore molluscivorous fish population include phenotypic plasticity of the pharyngeal jaw apparatus, changes in feeding behaviour and the cost of initiating the captive propagation program.

Phenotypic plasticity of the pharyngeal jaw for crushing gastropod shells has been demonstrated in the molluscivorous cichlids *Astatoreochromis alluaudi* from Lake Victoria (Hoogerhoud, 1986; Smits, in press; Smits & Witte, 1996; Smits, Witte, & Povel, in press; Smits, Witte, & van Veen, in press) and *Cichlasoma citrinellum* (Meyer, 1987; 1989;1990a &b). In general all these studies indicated that fish fed on soft food had reduced pharyngeal jaw apparatus which included reduction in horn width, keel depth, and associated muscles compared to the ones caught in the wild with the consequence of reducing their ability to crush snails. Smits & Witte (1996) also noted that it was almost impossible in experiments or artificial conditions to grow *A. alluaudi* with an anatomy approaching that of the wild caught individuals, experimental fish indicated less developed pharyngeal jaws. Slootweg (1995) and Slootweg *et al.* (1993) have ascribed phenotypic plasticity as one of the major reasons for the failure of fish to control snails in artificial condition. Before *T. placodon* or any Lake Malawi molluscivore can be used for captive propagation it may be necessary to first determine the phenotypic plasticity of their pharyngeal jaws otherwise it could be a waste of effort and other resources to undertake the captive propagation program. Secondly, the migratory patterns of *T. placodon* needs to be established before it can be bred and released otherwise released individuals may end up swimming away from the areas they are intended to be to control schistosomiasis vector snails.

Habitat modification which has been used in artificial ponds for controlling gastropods (Slootweg, 1995; Slootweg *et al.* 1993) is worthy of consideration in Cape Maclear area. Nothing can be done to weedy areas where some gastropods were concentrated because besides the gastropods, they are also suitable habitats for some fish species such as *Hemitilapia oxyrhynchus*. However, it is important to educate residents of Chembe Village not to deposit litter such as plastic bags, bottles and the like in the lake as the litter tends to accumulate together on the lake bottom and act as good habitat types for gastropods. Periodic campaigns to clean up the litter accumulating on the lake bottom in Cape Maclear can help to minimise the suitable habitats for gastropods and hence improve the control of schistosomiasis.

Other recommendations made for schistosomiasis control (Cetron, *et al.* 1993; 1996; CHSU, 1996; Stauffer *et al.* 1997) advocate the development of an integrated community based control program combining vector surveillance and control, treatment of infected people, improved water supply and sanitation, implementation of regulations to prevent over-fishing of molluscivorous fish, health education and epidemiological surveys to aid in choice of control strategies. Indeed this may be the only reasonable approach as each one of these can have a contribution albeit small to the interruption of the life cycle of schistosomiasis parasites in one way or another (Slootweg, 1987, Thomson, 1995) and also since none of the control methods can be effective in isolation (Slootweg, 1995; Slootweg *et al.* 1993). All these measures can be more effective in schistosomiasis control if they are simultaneously effected.

The following recommendations are made for future studies of the use of molluscivorous fish as biological control agents for schistosomiasis in Lake Malawi.

1. Further investigations should be made on *T. placodon* ecology especially on movement and migration behaviour by undertaking a more intensive tagging programme; and also its distribution with depth by using appropriate sampling strategies.
2. An investigation of other possible schistosomiasis vector snails should be undertaken in the lake.
3. Characterisation and mapping of the habitat types preferred by the schistosomiasis host snails should be done with a view to determining how the snails can best be controlled.
4. Determination of the proportion of snails from various places infected with schistosomiasis parasites to identify specific places where schistosomiasis transmission occurs.
5. The biology and ecology of other molluscivorous fish at Cape Maclear should be studied with a view to understanding their role in the control of gastropods.

CHAPTER 3

Lake Malawi National Park as a sanctuary area for food fish

Introduction:

The need to properly manage Lake Malawi fish to sustain the catches and to satisfy the protein requirements of the increasing human population has been recognised for a long time (Jackson, 1973; Turner, 1977; Ribbink, 1987 and Anonymous, 1988). Given the declining catches over the last decades it is clear that the fisheries in the lake are poorly managed and that the stocks are being overfished. Decline of CPUE has been documented for fish such as *Oreochromis* spp., *Copadichromis* spp., and *Engraulicypris sardella*, (Turner, 1977; FAO, 1993 & Turner, 1994). Such fluctuations are attributed mainly to fishing, although Tweddle & Magasa, (1989) argue that catch fluctuations may also be due to an influence of factors other than fishing such as recruitment variation following changes in lake levels. Changes in fish size structure and species composition due to trawling have also been reported (FAO, 1976; Turner, 1977; & FAO, 1993). Although no studies have specifically looked into the effects of artisanal fisheries on fish species composition and size structure, the artisanal fisheries are likely to have had great effects on fisheries through gill-netting and seine netting in shallow areas where some fish species breed and nurture their young.

Due to problems associated with conventional forms of fishery management, underwater sanctuary areas are gaining popularity world-wide as viable alternatives for managing fisheries for various reasons (Buxton, 1987; Penny, Buxton, Garratt & Smale, 1989; Bennett & Attwood, 1991, 1993; Robert & Polunin, 1991; 1993). These reasons include, maintenance of population size structure, protection of spawner stock, maintenance of genetic variability, supply of recruits to surrounding areas, insurance against failure of other management techniques, enhancement of catches in adjacent fisheries through adult fish migration, conservation of biodiversity, undisturbed habitat and natural life support processes. Most of these benefits are desirable from both conservation and fisheries perspectives. A few of these benefits have been demonstrated in marine reserves but not in freshwater reserves.

This chapter aimed at providing basic information required for the understanding of the extent to which the LMNP 100 m zone which was initially designed to protect rock dwelling cichlids may serve as a sanctuary area for food fish. The specific objectives are outlined in Chapter 1. Key questions raised included:

i) Which food fish species use the LMNP 100 m protected zone (0.1 km from the shoreline)?

ii) what is the area used for?

iii) for how long?

iv) do the fish remain in the 100 m protected zone and can this have significant effects on the fishery adjacent to it?

Methods

Food fish species that use the protected area:

Underwater observations of food fish species that use the LMNP 100 metre protected zone were undertaken by means of SCUBA diving at Otter Point, Fisheries, Nguli, Nchenga and Mitande (Figure 3.1), from October 1994 to April 1996 on a biweekly basis. These sites have also been referred to in Chapter Two of this thesis. Four of these sites: Otter Point, Fisheries, Nchenga and Nguli are spaced at almost equal distance along a 4 km beach between Otter Point and Ilala Gap while Mitande is at Thumbi west Island (Figure 2.1). The habitat characteristics of each site are described in Table 2.1 in Chapter two. Two transects were established per site. At all the sites the first transect was established at 4 to 4.5 metre depth but the second transect was established at 6 to 7 metres depth at Fisheries, Nchenga and Nguli and at 6 to 8 metres depth at Otter Point and Mitande. Mitande has the steepest depth profile so that the first transect was located at 10 to 15 metres from the shore line and the second transect at 20 metres from the shoreline. The corresponding distances of the two transects at Otter Point, with the second steepest depth profile, were 25 metres and 40 metres respectively. Fisheries, Nchenga and Nguli have a gentle depth profile and the first transect was 60 metres from the shoreline while the second transect was 80 to 100 metres away from the shoreline. Each transect was 50 metres long and 4 metres wide (covering an area of 200 m^2) and was laid along a depth contour. After the fish had recovered from the disturbance caused by diving, two divers swam parallel along the transect in the same direction, at the same speed at 1 to 1.5 metres above the substrate, three times. Every time the transect was completed, each diver observed the fish within the 2 metres width of the transect (a line was laid in the middle of the transect).

Besides the five fixed transect sites described above several exploratory dives were also undertaken in the 100 metre protected zone surrounding Thumbi West and Domwe islands and from Mfuli Beach to Zimbwamba Beach (Figure 3.1). Exploratory dives were done in the areas not covered by fixed transects. During these dives, fish species composition, habitat types and fish behavioural observations were made. All food fish species which could not be identified to species level by their external characteristics during underwater observations e.g. *Oreochromis* spp., *Copadichromis* spp., *Lethrinops* spp., *Rhamphochromis* spp. and others were identified to genus level.

Behavioural characteristics such as feeding, courting, mouth-brooding within the 100 metre protected zone of the park were noted. The number of individuals of each species of fish observed in the transect was counted to obtain an estimate of their relative abundance (number of fish per 200 m^2). For shoaling species it was not possible to estimate their abundance because they were too many to count and they were also sporadically encountered for very brief periods. Every time SCUBA diving was done a ruler was carried by divers to compare with length of individuals of each species of fish to the nearest centimetre. The fixed transects facilitated the observation of the temporal trends of the behaviour of fish in the 100 metre park protected zone. Exploratory dives supplemented observations from the fixed transects. For instance habitats which could not be covered by fixed transects could be easily covered by exploratory dives. All the underwater observations were recorded on plastic slates and transcribed after diving.

Food fish outside the protected zone

Catches of fish by fishermen outside the 100 m protected park zone, in offshore areas beyond diving depth were sampled. During the day fishermen were approached by using a boat and their catch was sampled and the fishing gear noted. Fishermen landing early in the morning with their night catch were asked about the fishing locations, fishing gear used and their mesh sizes. Total length of the fish in the catches was measured to the nearest centimetre for comparisons with

SCUBA survey observations of similar fish species in the protected zone. This was done to find out if the protection of the fish by the park had any effect on the fish size structure.

Ecological aspects of the food fish species

The following ecological aspects of the food fish species were investigated:

General distribution within the study sites:

The sighting of any commonly caught food fish species and their habitat types in the 100 m protected zone was noted during both routine transect and exploratory dives. Several exploratory dives were undertaken at Cape Maclear from July 1995 to April 1996 at different areas including inshore areas of Thumbi West and Domwe islands, Golden Sands to Mfuli Beach and from Fisheries Research Station to Zimbwamba Beach (Figure 3.1). The depth ranges explored in these areas are 0 to 36 metres for Thumbi West Island, 0 to 33 metres for Domwe Island and 0 to 19 metres for the area from Fisheries Research Station to Mfuli Beach.

Nesting site distribution and abundance:

Identification of nests of different fish species was made by identifying species of males which defended the nests and by referring to shape and size characteristics of various fish species' nests from literature. Only nests which were characterized by regular shape maintenance, lack of litter accumulation on their centre, or defended by a male or both male and female, were taken into account. The habitat types in which these nests were found were noted. Nests were counted along a 50 m by 4 m transect line as the number of nests per 200 m^2. The fixed transect sites used for counting the fish were also used for counting nests.

Breeding season:

The breeding season for each species was inferred from the period when the highest number of males in breeding colour was observed defending nests and mating with females. This could be achieved because the study covered all months of the year.

Fry development:

Fish species such as *B. meridionalis* establish a nest in which they lay their eggs. After hatching, both parents defend the fry on the same nest until the fry learn to fend for themselves (Lovullo, Stauffer, & McKaye, 1992; McKaye, Mughogho & Stauffer, 1994). For such fish species the total period the brood uses the nest and the growth rate of the fry could be monitored. Growth of the fry of 5 *B. meridionalis* broods, one at Mitande and four at Otter Point was monitored between October 1994 and December 1995 , on a biweekly basis from the time they were about 2 weeks old until they vacated their sites after the parents had stopped guarding them. A 30 cm ruler was used to estimate sizes (TL in mm) of 10 individual fry per brood to the nearest 5 mm from a distance of 30 to 45 cm by comparing the length of the fry with the ruler. This was done carefully so that the guarding parent(s) were not scared away. Average size of the 10 fry was considered as the mean for the whole brood. After the parents stopped guarding the fry, five fry per brood were captured by using a small nylon net, measured (for TL) and released. The number of surviving fry per brood was investigated from the *B. meridionalis* broods encountered during exploratory dives. The first time the brood was encountered the fry were counted. Other dives were done at the same spots to count the remaining fry until the broods disappeared. During the early stages of the fry, estimates of the brood size (number of fry per brood) were made as the fry tended to congregate together on a small area, underneath their guarding parent's head or belly with very restricted movements. As they grew bigger they became less in number but more widely spread and total counts of the number of fry were made.

Movement and migratory behaviour of food fish species:

T- tags (Hallprint, Australia; Ref. No. T1347) which were 27 mm long with orange coloured ends, were used for tagging fish. The fish were captured by encircling them within a net and catching them from the net while SCUBA diving. The fish were measured (TL, SL and FL) and tagged in the caudal region by using a Monarch Models Sure-Fire Tag Attacher. The fish tagged between December 1994 and February 1995 are as follows: 133 *Oreochromis* spp. individuals ranging from 13 to 22 cm TL and 72 individuals of *Oreochromis* spp. 10 to 19 cm TL at Mitande and Otter Point respectively; 21 individuals of *B. meridionalis*, 7 *Serranochromis robustus* and 32 *Dimidiochromis kiwinge* individuals around Thumbi Island West

All three lengths of the fish (TL, SL and FL), tag number, place and date of tagging were recorded. Fishermen were notified prior to tagging that they should bring forward any tagged fish caught and to indicate where and when the fish was caught. The fishermen were also told that tagged fish would be bought at a higher than normal price. The time and place of the tagged fish sighted.

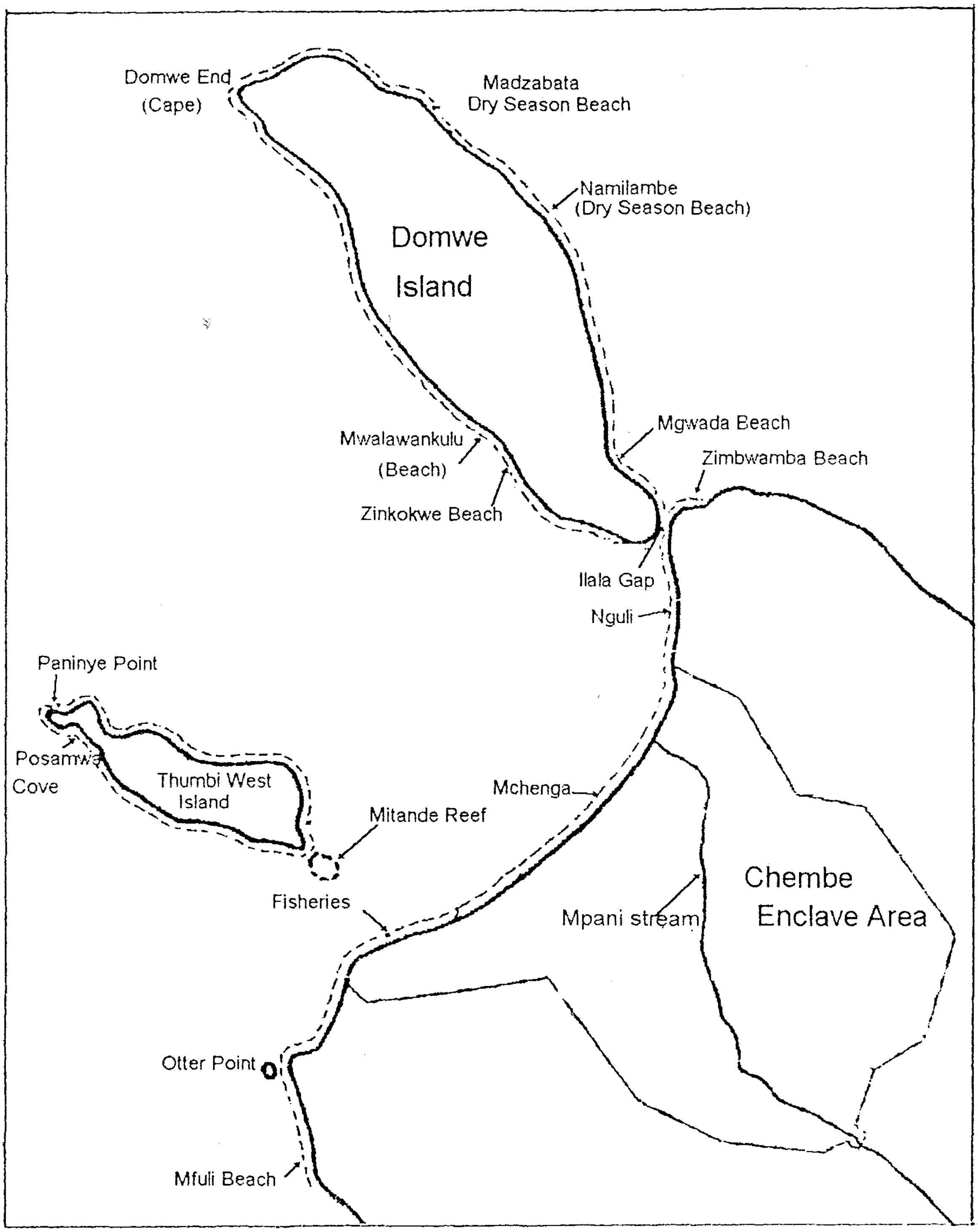


Figure 3.1: Map of Lake Malawi National Park showing transect sites (Otter Point, Fisheries, Nchenga, Nguli and Mitande) and areas explored by Scuba diving (From Mfuli Beach to Zimbwamba Beach and surrounding Domwe and Thumbi West Islands).

RESULTS

Food fish species observed in the Lake Malawi National Park Protected Area

It was difficult to identify most fish to species level during the underwater observations because of morphological overlap. Most of them were therefore only identified to genus level. Similar problems have been faced by McKaye & Stauffer, (1988) Turner, Pitcher & Grimm, (1989) Turner *et al.* (1991) in their study of *Oreochromis* spp. Table 3.1 provides a list of the most commonly caught food fish (identified to genus and or species level) which were observed in the 100 metre protected zone of the park between October, 1994 and April, 1996. Besides the fish taxa noted in the present study, Lewis *et al* (1986) reported other fish taxa to form part of the park's fish community. These included Mastacemblidae: *Mastacembelus shiranus;* Mochokidae: *Synodontis njassae*, Mormyridae: *Mormyrops* spp., *Petrocephalus catostoma*, Characidae: *Brycinus imberi*, Anguillidae: *Anguilla bengalensis* and *A. nebulosa*.

Table 3.1: Commonly caught food fish species observed in LMNP 100 metre protected zone at Cape Maclear between October 1994 and April 1996.

Family / Species of fish	Life history stage	Observed behavioural characteristics in the protected zone	Duration / period observed
Bagridae			
Bagrus meridionalis	nesting adults	breeding and guarding fry,	2 to 3 month
	early juvenile stage	shelter from predators	2 to 4 weeks
Cichlidae			
Oreochromis spp	All stages	feeding, breeding,	Year round
		nursery area	
Dimidiochromis kiwinge	Adults	breeding	Year round
	Juveniles	in water column	Year round
Copadichromis spp	All life history stages	feeding, breeding, nursery area	Year round
Rhamphochromis spp	Juveniles	hunting cichlid fry	Year round
Serranochromis robustus	Adults	in rocky areas	observed in October and December
Lethrinops spp	All life history stages	feeding, breeding, nursery area	Year round
Buccochromis spp	Adults	Sandy and rocky (feeding)	occasionally observed from August to December
Cyprinidae			
Labeo cylindricus	All life history stages	feed in rocky areas	All year round
Engraulicypris sardella	All life history stages	water column	Occasionally
Barbus johnstonii	All stages	feeding in rocky areas	All year round
Opsaridium microcephalus	Juveniles	In water column	February to May
Clariidae			
Clarias gariepinus	All stages	Seen in sandy and rocky areas	October, December and January

Relative abundance of the food fish species observed in the protected area

Not all the fish species could be quantified numerically in terms of abundance by means of underwater observations. For for example, it was impractical to count schooling fish. Also where some species were very abundant and swam quickly, they could not be accurately counted. As a result of these problems the fish have been classified into the following categories with respect to abundance: None (not observed at site); Rare (< 5 individuals / 200m^2); common (5 to 50 /200 m^2); abundant (> 50 / 200 m^2), e.g. for schooling species and females of *Copadichromis eucinostomus* which feed in groups of up to several hundreds. Besides this classification, they were also classified according to sighting frequency into the following categories: regular species (seen throughout the year); and occasional (seen periodically or seasonally) (Table 3.1). A qualitative description of food fish species abundance by sampling site is given in Table 3.2, which indicates that only two species *E. sardella* and *Copadichromis* species were seen in abundance at all sites (Table 3.1). The shoaling *Copadichromis* species, though seen in abundance year round, fluctuated in numbers from a few hundred to few thousand. The rest of the species were either common or rare. *E. sardella* was seen in large and extensive schools especially around Thumbi Island West and Domwe Islands. The relative abundance of two of the common species, *Oreochromis* spp., *Taeniolethrinops praeorbitalis*, and a few rare species, which were regularly encountered at almost all of the study sites are given in Table 3.3, Table 3.4 and Table 3.5 respectively. There were significant differences in abundance among sampling sites for both *Oreochromis* spp. (Two Way Anova, $P < 0.01$, $DF = 4$) and *T. praeorbitalis* (Two Way Anova, $P= 0.0000$, $DF =4$).

Mitande and Otter Point had the greatest abundance of *Oreochromis* compared to other sites. *Oreochromis* spp. abundance also varied with sampling season. For example, they appeared in high numbers between December and January 1995 at Nchenga, and from December to February at Nguli. At fisheries only one male *Oreochromis* sp. was observed defending a nest between October 1994 and November 1994. In June and July both Otter Point and Mitande had low numbers of *Oreochromis* spp. *T. praeorbitalis* on the other hand were most abundant at Nchenga but were regularly encountered at all sites.

Table 3.2: Qualitative descriptions of food fish species abundance by sampling site (October 1994 to April 1996).

	Sampling sites				
Species	**Mitande**	**Otter Point**	**Fisheries**	**Nchenga**	**Nguli**
Bagridae					
Bagrus meridionalis	Common	Common	None	None	Rare
Cichlidae					
Oreochromis spp.	Common	Common	Rare	abundant for two months only	Common
Dimidiochromis kiwinge	Common (breeding males)	Common (breeding males)	Common (juveniles and occasionally females)	Common (juveniles and occasionally females)	Common (juveniles and occasionally females)
Rhamphochromis spp.	Rare	Rare	Rare	Rare	Rare
Copadichromis spp.	Abundant	Abundant	only *C. eucinostomus* abundant	only *C. eucinostomus* abundant	only *C. eucinostomus* abundant
Lethrinops spp.	Rare	Rare	Rare	Common	Common
Serranochromis robustus	Rare	Rare	None	None	None
Buccochromis spp.	Common	Common	None	None	Rare
Taeniolethrinops praeorbitalis	Common	Rare	Common	Common	Common
Cyprinidae					
Labeo cylindricus	Common in rocky areas	Common in rocky areas	Common only from Dec to Jan	Abundant only from Dec to Jan	Common only from Dec to Jan
Engraulicypris sardella	Abundant but occasional	Abundant but occasional	Abundant but occasional	Abundant but occasional	Abundant but occasional
Barbus johnstonii	Rare	None	None	None	None
Opsaridium microcephalus	Rare	Rare	Rare	Rare	Rare
Clariidae					
Clarias gariepinus	Rare	Rare	None	None	Rare

Table 3.3: The relative abundance of *Oreochromis* species (all individuals including territorial males, juveniles and mature females expressed as number of fish per 200 m^2) by month and sampling site.

	Sampling sites				
Month	**Mitande**	**Fisheries**	**Otter Point**	**Nchenga**	**Nguli**
Oct-94	6	1	15	0	0
Nov-94	12	1	9	0	0
Dec-94	21	0	11	0	0
Mar-95	30	0	22	0	0
Apr-95	11	0	18	0	0
May-95	15	0	16	0	0
Jun-95	9	0	6	0	0
Jul-95	3	0	8	0	0
Aug-95	8	0	151	0	0
Sep-95	16	0	136	0	0
Oct-95	32	0	20	0	0
Nov-95	20	0	24	0	0
Dec-95	22	0	11	128	3
Jan-96	9	0	9	26	3
Feb-96	34	0	34	0	7
Mean relative abundance ± SD	16.5 ± 9.7	0.1 ± 0.35	32.7 ± 45.7	10.3 ±33.3	0.9 ± 2.0

Table 3.4: The mean (± Standard deviation) relative abundance (Number of individuals per 200 m^2) and total length (cm) range (in parentheses) of fish genera which were estimated as "not abundant" at the various sampling sites.

	Genera of fish and their relative abundance / total length range			
Sampling Sites	*Rhamphochromis* spp.	*Nimbochromis* spp.	*Protomelas* spp.	*Lethrinops* spp.
Mitande	1.0 ± 1.1 / 200 m^2 (13-17 cm)	4.3±2.5 / 200 m^2 (9-16.5 cm)	5.3±3.4 /200 m^2 (7-11 cm)	3.5±2.3 /200 m^2 (8-13 cm)
Otter Point	0.6 ± 0.8 /200 m^2 (9-16 cm)	1.5 ± 0.7 / 200 m^2 (12-17 cm)	5.0±2.6 /200 m^2 (10-14 cm)	4.8±2.1 /200 m^2 (10-14 cm)
Fisheries	1.5 ± 1.4 /200 m^2 (11-15 cm)	3.7 ± 0.7 / 200 m^2 (5-15 cm)	7.0±3.9 /200 m^2 (7-10 cm)	4.5 / 200 m^2 (8-13 cm)
Nchenga	1.8 ± 1.9 /200 m^2 (8-16 cm)	4.2 ± 1.4 / 200 m^2 (6-15 cm)	6.4±4.8 /200 m^2 (7-9 cm)	7.3±3.7 /200 m^2 (9-14 cm)
Nguli	1.2 ± 1.3 /200 m^2 (8-17.5 cm)	4.5 ±2.0 / 200 m^2 (7-14 cm)	9.0±5.1 /200 m^2 (7-10 cm)	6.6 ±2.4 / 200 m^2 (8-15 cm)

Table 3.5: The relative abundance of *Taeniolethrinops praeorbitalis* (number of fish per 200 square metres) by sampling site and month.

Month	**Mitande**	**Otter Point**	**Fisheries**	**Nchenga**	**Nguli**
Oct-94	5.5	3	6.5	13	6
Nov-94	4.5	2.5	5	11	8
Dec-94	4	2	6	8	4
Mar-95	3	3.5	7	9	3.5
Apr-95	7.5	4	4	11	9
May-95	5	5	3.5	8	7
Jun-95	5.5	4.5	4	12.5	7
Jul-95	6	4	6	10	6.5
Aug-95	6.5	4	5	10	8
Sep-95	8.5	2.5	4.5	9.5	8
Oct-95	8	3	2	13.5	5.5
Nov-95	6	5.5	5	8.5	7
Dec-95	4.5	3	4	9	6
Jan-96	6	5	6.5	11.5	6
Feb-96	5	4.5	5	12	10.5
Mar-96	7	4	5	7.5	7.5
Mean relative abundance ±SD	5.8 ± 1.5	3.8 ± 1.0	4.9 ±1.3	10.3 ± 1.9	6.8 ± 1.7

Length of the observed fish

Different sizes of the food fish species were observed at the sites studied. The size ranges of *Rhamphochromis* spp observed during SCUBA surveys were lower than those caught by fishermen (Figure 3.2). All the described *Rhamphochromis* spp according to Eccles & Trewavas (1989) attain a greater length than the length ranges of the observed fish (Table 3.4). This suggests that only juveniles were observed in the study sites. The observed upper values of length ranges of the other three "rare species" (*Lethrinops* spp, *Protomelas* spp., and *Nimbochromis* spp.) (Table 3.4) are similar to the sizes reported by Eccles & Trewavas (1989). This suggests that some adults of these species were observed in the protected zone of LMNP.

Typical lengths of the *Oreochromis* individuals that were observed in the protected zone at Otter Point (those tagged) were generally less than what the fishermen caught in the 2 inches and 3.5 inches mesh sized gillnets in March 1995 (Figure 3.3) (*Oreochromis* are seasonally caught with gillnets at Cape Maclear -mostly between February and March). Most of the *Oreochromis* spp. observed in the LMNP protected area were juveniles. Those of bigger sizes were mostly males in breeding colour defending nests and sometimes courting with females.

The *B. meridionalis* observed nesting in the protected zone around Thumbi West Island, Domwe Island and Otter Point were all 30 cm or larger (TL) and their sizes corresponded well with those that fishermen were catching with the handlines at night using light and *E. sardella* as bait in offshore areas outside the protected zone. *B. meridionalis* as small as 15-19 cm TL were caught in the 2 inch mesh sized gillnet (Figure 3.4). The length of *B. meridionalis* at 50% maturity is 37 cm for males and 33 cm for females (Tweddle, 1975; FAO, 1976). Most of the individuals in the gillnet catch were less than the sizes at maturity for both males and females (Figure 3.4).

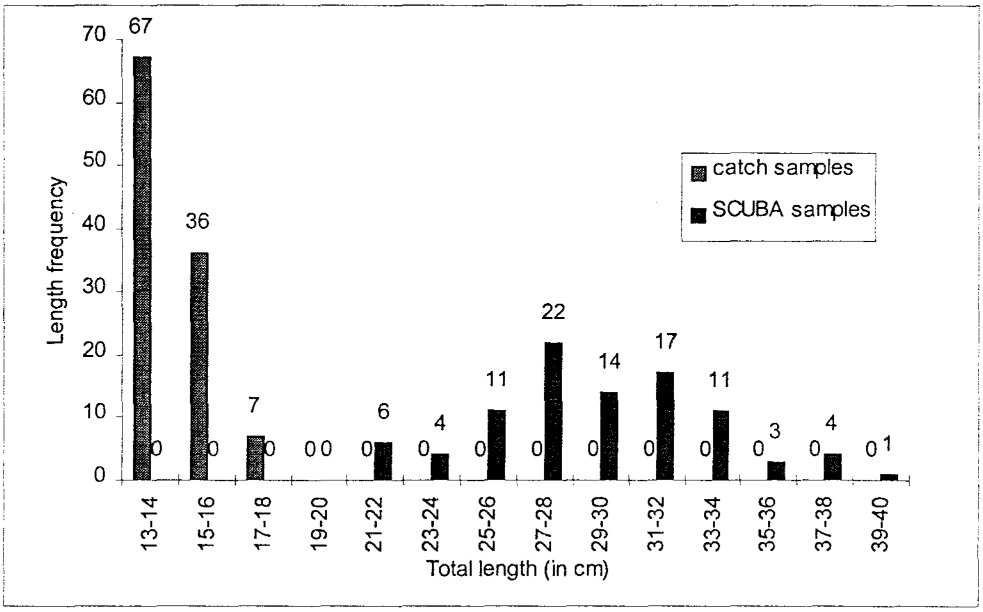


Figure 3.2: A comparison of the length frequency of *Rhamphochromis* species caught by fishermen with handlines (day time) using *E. sardella* as bait 1 km East of Otter Point between 4th August and 7th September 1995 with that of the *Rhamphochromis* spp. observed in the LMNP protected 100 metre zone during SCUBA surveys between October 1994 and April 1996 (all samples of catches from fishermen are lumped together and also all SCUBA samples are lumped together because individual samples were very small).

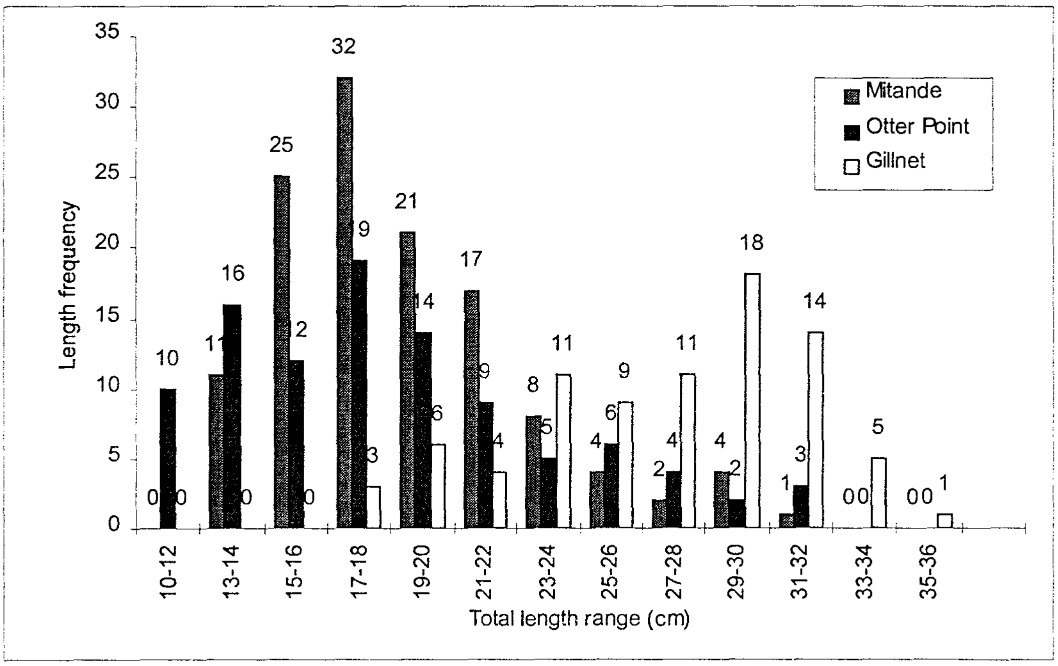


Figure 3.3: Length frequency of *Oreochromis* spp. sampled at Otter Point and Mitande between December, 1994 and March, 1995 and from fishermen's catch using 2" and 3.5" mesh sized gillnet West of Domwe Island between 20th and 27th of March 1995.

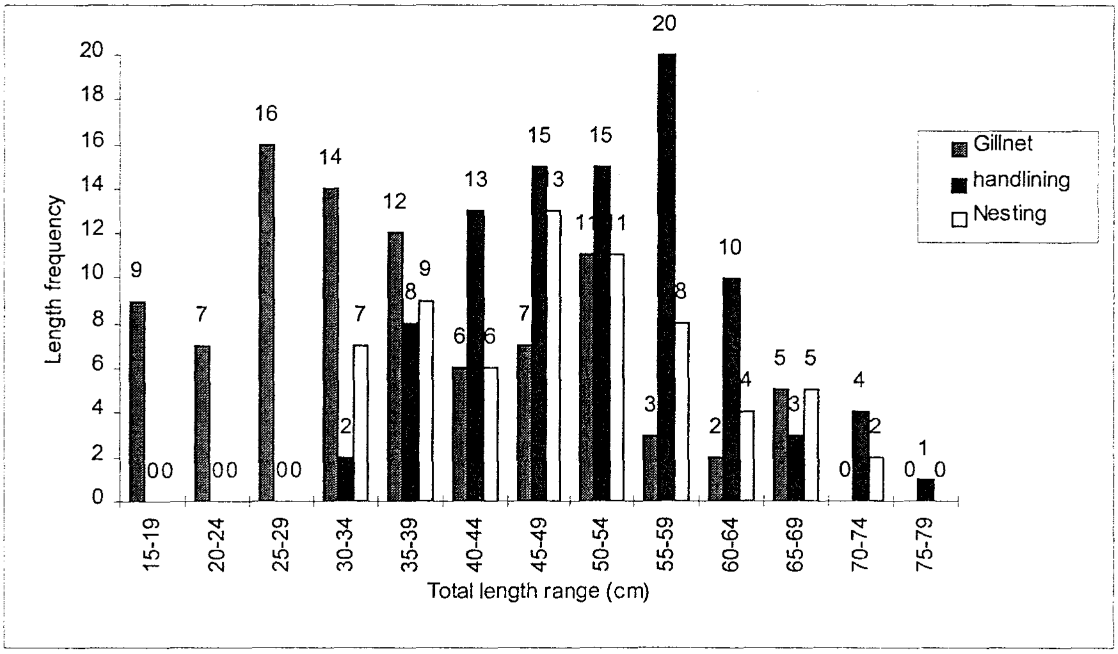


Figure 3.4: Length frequency of *B. meridionalis*: caught by hand lining fishermen using *E. sardella* bait and lamps at night North East of Thumbi Island West (12/2/95 and 30/5/95); caught by gillnets (2 inch and 4 inch) North Thumbi Island West (7/6/95 to 23/7/95); and those defending nests or the young (Thumbi Island West, Domwe Island and Otter Point).

Ecological aspects of the food fish species observed in the protected zone

In this section observations pertaining to the distribution, nesting habitats, nest site distribution and abundance, fish movement and migration behaviour, and other aspects necessary for the understanding of the behaviour of various species of fish in the park are presented. The findings for each species are presented separately.

Bagrus meridionalis **"kampango".**

B. meridionalis is an important species in the gillnet, long lining and hook and line fishery of the villagers. The fish are usually found in a mixture of sandy and rocky areas or sandy areas close to rocks where they guarded eggs or fry in their nests. Breeding pairs establish a nest in which the female lay eggs. The eggs are jointly defended by both parents. The fecundity (total number of eggs per ripe ovary) for *B. meridionalis* ranges from 16,000 to 50,000 eggs but only 2000 to 4000 eggs are laid at any one spawning (McKaye, 1986 and McKaye *et al.* 1994).

The nests were excavated in the open sandy area as well as underneath or adjacent to rocks. Nests in the open sandy area were conical in shape and had a top diameter of up to 120 cm, while those underneath or adjacent to rocks were smaller in size ranging from 43 cm to 95 cm diameter. Nests were only observed at two of the five fixed transect areas i.e. Otter Point and Mitande (Figure 3.5). However, exploratory dives revealed that *B. meridionalis* breeding areas were extensively spread (Table 3.6 and Figure 3.6) covering a wide depth range (3 to 33 metres) from the rocky. shore within the 100 metre park protected zone.

Initially, when the fry were small they congregated together underneath the guarding parent's head or belly. During the early stages of the brood, the number of fry was estimated by comparing the area occupied by a known number of fry on the peripheral of their congregation with that occupied by the whole brood at fry length of 5 mm to 20 mm. The estimated initial brood sizes varied between 400 and 650. After attaining 60 mm TL, total counts of the fry per brood were made. The mean number of fry per brood indicated a decline in number of fry as they grew indicating that fry mortality was high (Table 3.7).

The parents guarded the fry for a period of 8 to 10 weeks during which the fry reached a length of 105 mm to 130 mm TL (with an average of 124 ± 0.37 mm, N = 42). After this period, the juveniles sought refuge in rock crevices. Two to four weeks after being abandoned by the parents the juveniles leave their respective sites. At this stage the fish range from 140 to 181 mm TL (Appendix 3).

Breeding *B. meridionalis* were observed seasonally in the fixed transect sites at Otter Point and Mitande with some peak nesting season (Figure 3.5). However, exploratory dives in other areas indicated that the species breeds year round (Table 3.6).

It appeared that *B. meridionalis* tend to prefer specific sites for nesting. At Mitande, five rock sites were each used successively by three separate pairs between August 1995 and April 1996. One to two weeks after the juveniles of one brood vacated the sites, each of these sites was reoccupied by another pair of *B. meridionalis* (recognised as being different pairs as in each case the individuals differed in size from the previous pair). Two of the same sites were each used two times by different *B. meridionalis* broods between October 1994 and February 1995.

No results were obtained from tagged *B. meridionalis* to give an indication of their movement. This could be because of the small number of individuals that were tagged.

a)Otter Point b) Mitande

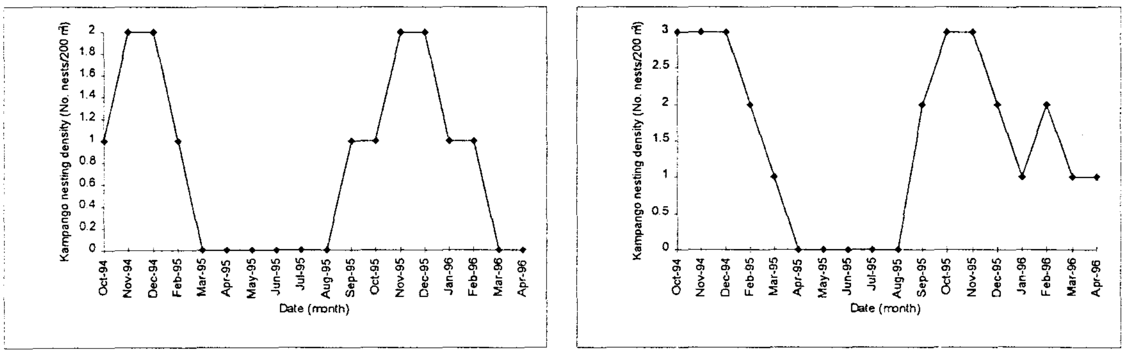


Figure 3.5: The relative abundance of *B. meridionalis* nesting sites at a) Otter Point and b) Mitande, in LMNP showing breeding seasonality.

Table 3.6: The number of *B. meridionalis* broods encountered at various sites at Cape Maclear in the LMNP, between August 1995 and April 1996. Note that different sites were explored at different time periods (month ranges) so that blank cells in this table mean that visual census did not take place at the site for those months.

	Sites explored by SCUBA diving and the number of *B. meridionalis* broods encountered by month			
Month	Golden Sands to Mfuli	Mitande area	Thumbi Island West excluding Mitande	Domwe Island
August 1995	2	3		
September 1995	6	7	16	
October 1995	8	6	23	
November 1995	5	7	20	22
December 1995	5	5	14	17
January 1996	2	3		13
February 1996		3		8
March 1996				4
April 1996				5
Total No. of broods encountered	28	34	73	69

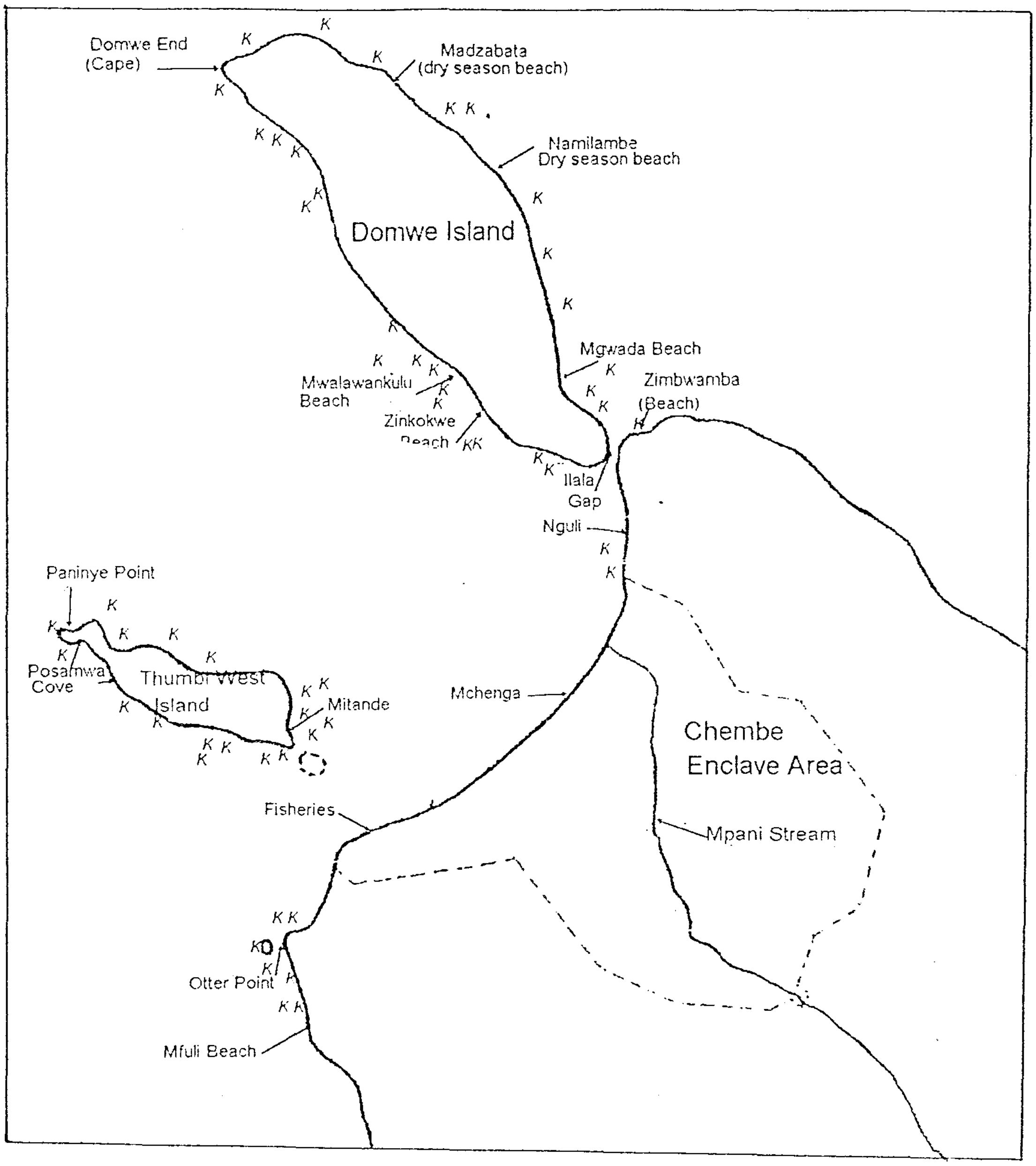


Figure 3.6: Map showing distribution of *B. meridionalis* nesting sites at Cape Maclear, Lake Malawi National Park, between October 1994 and April 1996. *K* indicates areas where *B. meridionalis* nests were found at Otter Point, around Domwe and Thumbi West Islands.

Table 3.7: A summary of the variation in number of fry of *B. meridionalis* per brood with fry/juvenile size (TL). The numbers marked with a star (*) are based upon estimates of the brood size as opposed to others which were based on total counts of the brood size.

	Fry size (total length) range			
	15-17 mm	60-80 mm	90-110 mm	120-150 mm
No. *B. meridionalis* broods studied (N)	5	12	16	9
Brood size range (No. fry/brood)	400-650*	61-126	22-97	23-59
Mean size of brood ± SD	564±103.1*	100.6±45.9	74.2±48.6	32±13.5

Oreochromis species "Chambo"

Distribution and abundance in the LMNP 100 metre zone

Oreochromis were observed in the LMNP 100 m protected zone during the entire study period. Juveniles and mature females congregated in groups of up to 300 individuals while mature males in breeding colour were mostly defending nests and occasionally courting with females in their nests. Juveniles dominated in numbers (Table 3.8) and they roamed over a wide area from sandy areas near rocks to rocky areas.

Distribution of nesting sites

Oreochromis spp. nests were characterised by a depression in the sand with a platform built in the centre similar to the description by McKaye & Stauffer (1988). Male *Oreochromis* mate with females on the platform in the centre of the nest. There were variations in nest diameter across the top depending upon the habitat in which they were excavated. The nests excavated adjacent to or under rocks varied between 40 cm and 144 cm, in top diameter while those in the open sandy area varied between 132 cm and 230 cm in top diameter.

Most nests were observed in mixed sandy and rocky areas at 1 to 8 metres depth. At Fisheries, Nchenga and Nguli (sandy areas), there were more nesting sites at 10 to 15 metres depth 400 to 500 metres offshore than at 4 to 7 metre depth (Figure 3.8) indicating that shallow sandy areas may not be as suitable as shallow areas in the mixed sandy and rocky habitats. The abundance of *Oreochromis* nests varied with time of the year. Most of them were observed between August and February and the least between April and July (Figure 3.8 and Figure 3.9).

Table 3.8: Percentage *Oreochromis* abundance by two size categories (< 20 cm TL and > 20 cm T) by sampling site and month.

	Mitande		**Fisheries**		**Otter Point**		**Nchenga**		**Nguli**	
Month	%<20cm	%>20cm	%<20cm	%>20cm	%<20cm	%>20cm	%<20cm	%>20cm	%<20cm	%>20cm
Oct-94	83.3	16.7	0	100	86.7	13.3	-	-	-	-
Nov-94	83.3	16.7	0	100	66.7	33.3	-	-	-	-
Dec-94	71.4	28.6	-	-	100	0.0	-	-	-	-
Mar-95	90.0	10.0	-	-	86.4	14.6	-	-	-	-
Apr-95	63.6	36.4	-	-	77.8	22.2	-	-	-	-
May-95	53.3	46.7	-	-	81.3	18.7	-	-	-	-
Jun-95	66.7	33.3	-	-	100	0.0	-	-	-	-
Jul-95	33.3	66.7	-	-	100	0.0	-	-	-	-
Aug-95	50.0	50.0	-	-	96.7	3.3	-	-	-	-
Sep-95	56.3	43.7	-	-	95.6	4.4	-	-	-	-
Oct-95	46.9	53.1	-	-	75.0	25.0	-	-	-	-
Nov-95	65.0	35.0	-	-	83.3	16.7	-	-	-	-
Dec-95	77.3	22.7	-	-	81.8	17.2	0.0	100	0	100
Jan-96	66.7	33.3	-	-	66.7	33.3	26.9	73.1	0	100
Feb-96	47.1	52.9	-	-	85.7	14.0	0	100	0	100

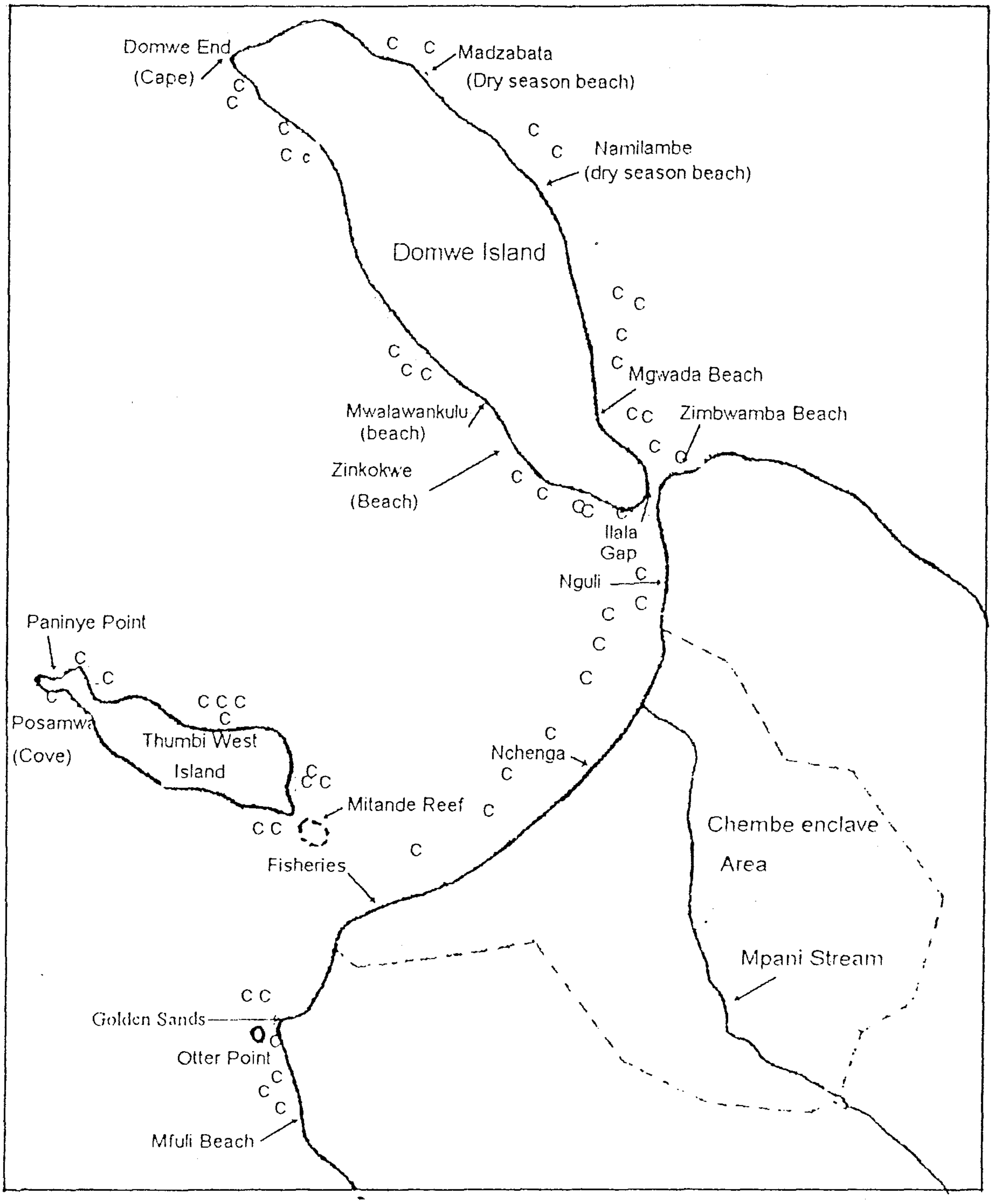


Figure 3.7: The distribution of *Oreochromis* nesting sites at Cape Maclear between October, 1994 and April, 1996 (areas explored inside and outside LMNP protected zone). C represents sites where the nests were observed.

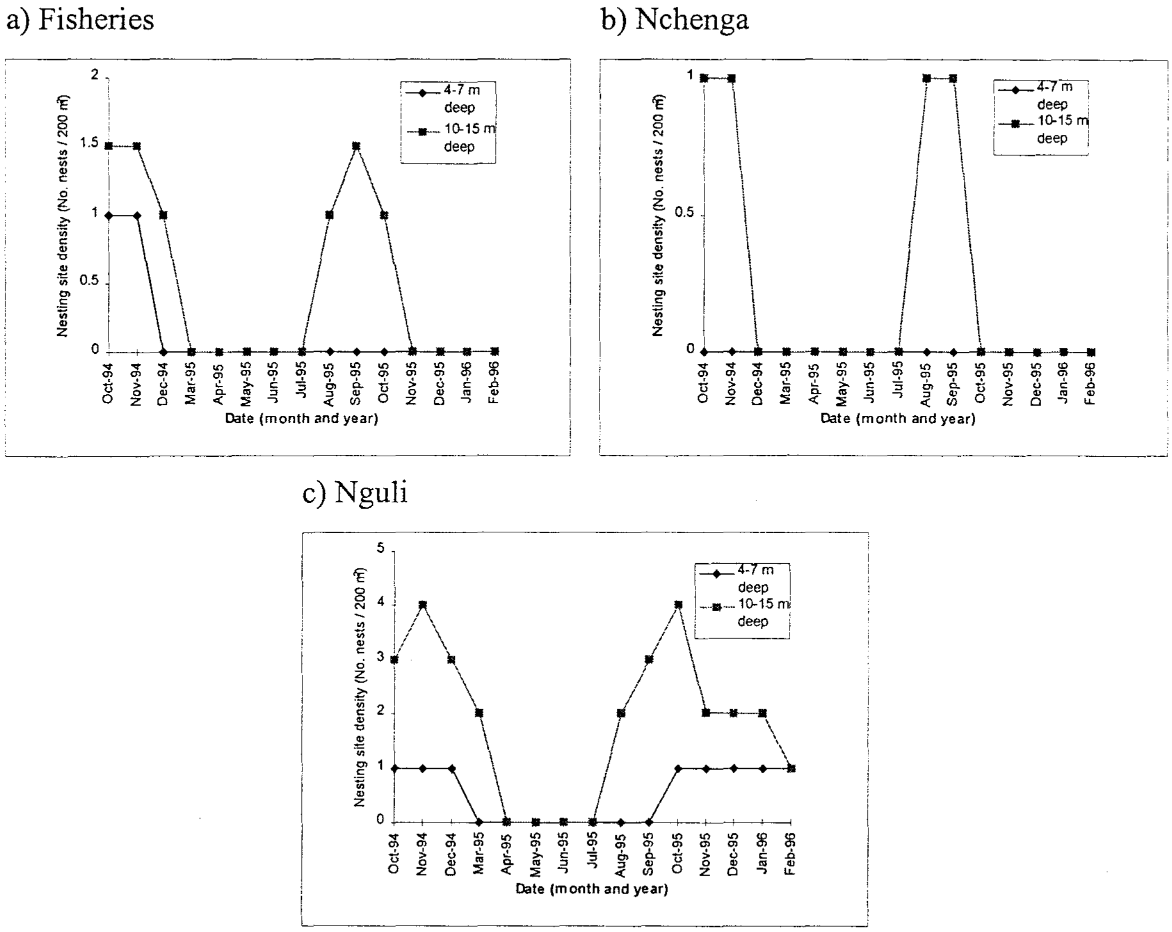


Figure 3.8: The relative abundance of *Oreochromis* spp. nesting sites at two depth ranges (4 to 7 metres and 10 -15 metres) at Nchenga, Fisheries and Nguli at Cape Maclear. Note that at all the three sites, the 10 - 15 metre depth range was more than 400 metres offshore and that at Nchenga no nest was observed at 4 to 7 metre depth (see Figure 3.7).

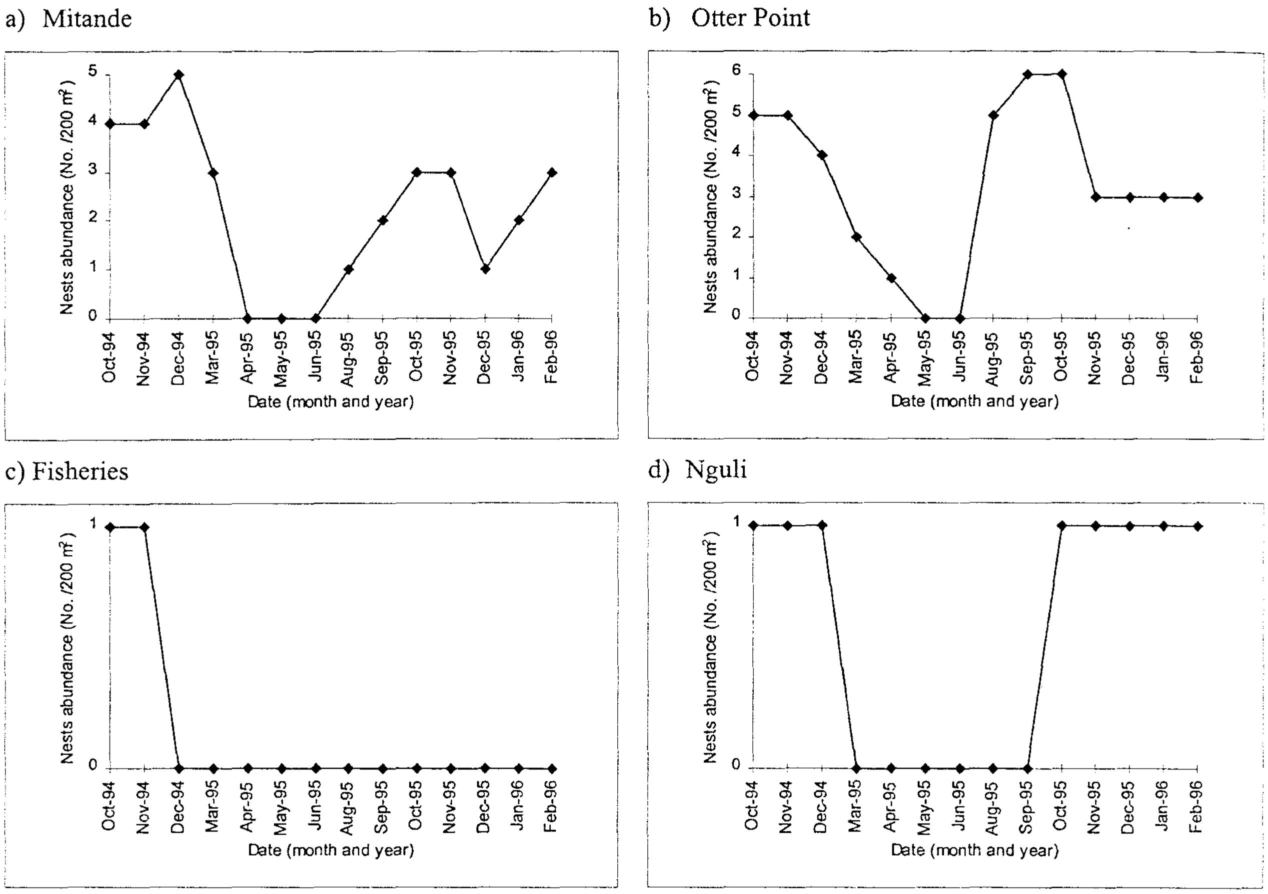


Figure 3.9: The relative abundance of *Oreochromis* spp. nesting sites at different sampling sites inside and outside LMNP 100 Metre Zone from 0 to 8 metre depth showing the breeding seasonality. Mitande, Otter Point and Nguli are inside the park 100 m protected zone while Fisheries is outside the 100 metre protected zone.

Migratory behaviour and fish movement

No tag returns were obtained from the 133 and 72 *Oreochromis* tagged at Mitande and Otter Point respectively. However, within the first five to seven days after tagging some tagged *Oreochromis* were sighted during follow up dives within the 0 to 200 metre distance from point of release especially at Mitande. After this period they were not seen again except one *Oreochromis* which was sighted about 500 metres from the Mitande tagging point six weeks after tagging. This suggests that fish moved farther away than the areas searched. Mortality due to tagging is unlikely to have been the cause of poor sighting rate because 6 out of 9 *Oreochromis* tagged during the same time survived over a period of two months in an aquarium at the Environmental Education Centre at Cape Maclear. Under the same aquarium conditions no tag was lost by any individual within the two months period. The temporal fluctuation in *Oreochromis* abundance may reflect a high mobility. A more intensive *Oreochromis* tagging by employing a better method of *Oreochromis* capturing e.g. beach seine netting, is required to understand more about *Oreochromis* movement and migration behaviour across LMNP boundaries.

Copadichromis eucinostomus **"Mdyamphipe"**

This is the only species within its genus that was widespread in all the shallow sandy areas between 2 and 20 metre depth. This species was observed to form the major catch in the small mesh sized (1 to 1.5 inches stretched) beach seine nets. Females and non-breeding males fed in shoals in the water column and sometimes from the substrate. Females were usually too abundant to accurately estimate their numbers by SCUBA surveys. Males construct their nests close together (in "leks") where they mate with ripe females after courtship. The nests were conical in shape ranging from 30 to 50 cm in diameter. Two Way Anova indicated that *C. eucinostomus* nesting site abundance (Table 3.9) varied significantly among sampling sites ($P = 0000$, $DF = 4$) and with sampling time ($P = 0.049$, $DF = 14$). However, the variation in abundance among Fisheries, Nchenga and Nguli, all of which have similar habitat types, was not significant (Two way Anova, $P>0.05$, $DF = 2$). Otter Point had the highest relative abundance of *C. eucinostomus* nesting sites and Mitande had the lowest. This suggests that the variation in abundance could be related to the variation in habitat parameters such as slope and proximity to rocks.

Table 3.9: The relative abundance of *C. eucinostomus* nesting sites (Number of nests per $200m^2$) by sampling site and month.

Month	Mitande	Otter Point	Fisheries	Nchenga	Nguli
Oct-94	6.5	30.5	8	18.5	14.5
Nov-94	5.5	27	7.5	18.5	13.5
Dec-94	4	18.5	5	8.5	12
Mar-95	2.5	23	5.5	10	8.5
Apr-95	7.5	33.5	9	15	7
May-95	5	18	10	10	6
Jun-95	4	17.5	4.5	7.5	4
Jul-95	7	17	13	10.5	7
Aug-95	9.5	33	8.5	9	13
Oct-95	16.5	13	10	15.5	15.5
Nov-95	5	9.5	7.5	17.5	17
Dec-95	7	29	7	17	10
Jan-96	7.5	26.5	15.5	12.5	12.5
Feb-96	11.5	32	21	11	11
Mean relative abundance ± SD	7.1 ± 3.6	23.4 ± 7.9	9.4 ± 4.5	12.9 ± 3.9	10.8 ±3.9

***D. kiwinge* "mayani"**

This species was observed at all the sites visited at Cape Maclear, surrounding Thumbi West and Domwe Islands, and from Mfuli Beach to Zimbwamba Beach from October 1994 to April 1996. Fishermen in Chembe Village stated that they caught most of the mayani with hooks and lines during the rainy season, between December and February. It was also reported by fishermen to be caught by gill nets and as a by-catch in the open water seine net, which mainly targets the *Copadichromis* species. Its nesting sites were cone shaped, ranging from 90 cm to 165 cm top diameter and were excavated in sandy areas close to rocky habitat at 1 to 6 metre depth. Males maintained their nests throughout the year. The nests were aggregated together into arenas and each nest was defended by a male within 1 to 1.5 metre above the substrate. Of the five transect sites, the nests were observed at Otter Point and Mitande only (Figure 3.10) and at these two sites there were significant differences in the nest sites abundance (T-test, $P = 0.0000$)

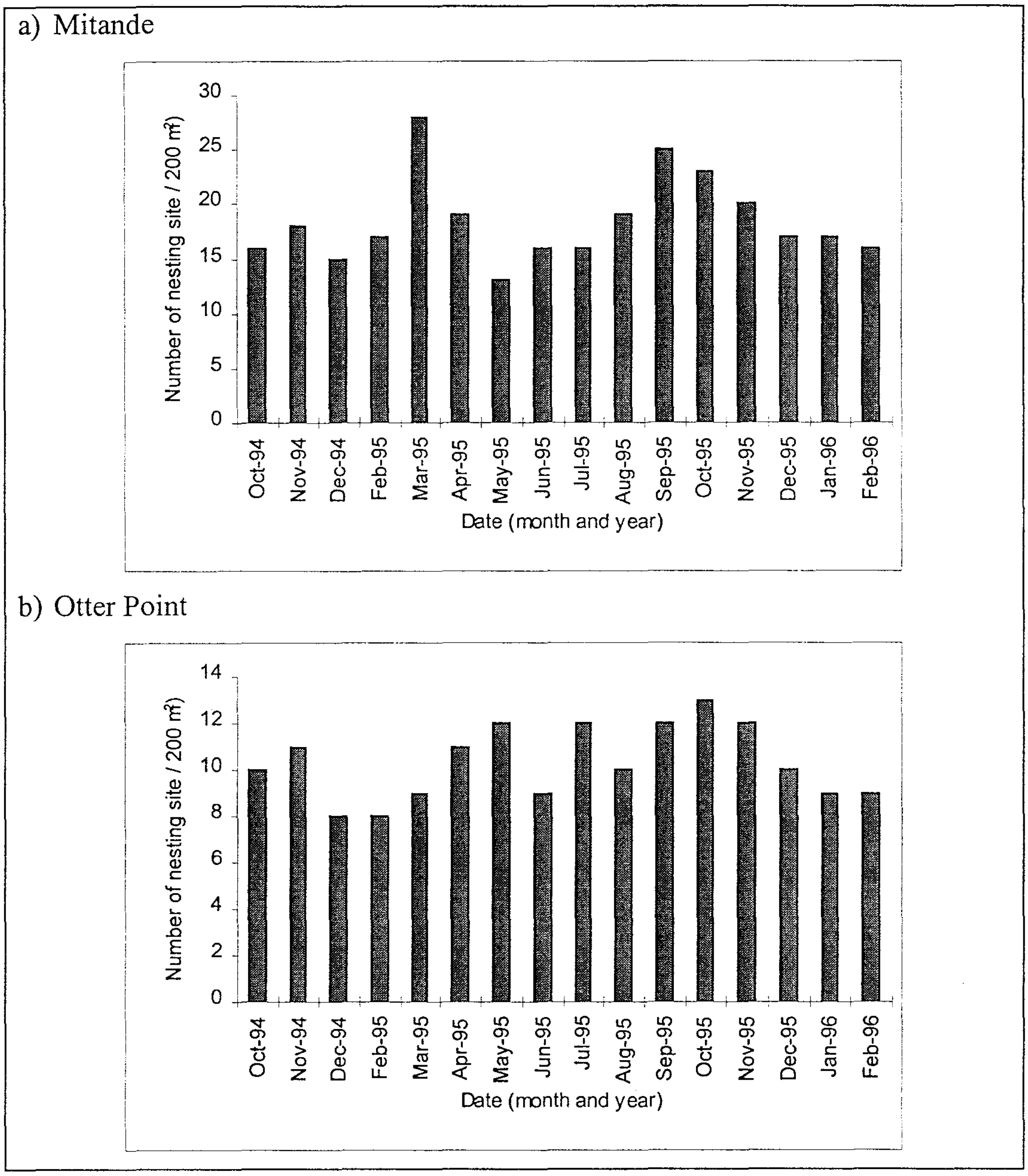


Figure 3.10: The relative abundance of *D. kiwinge* nesting sites (Number of nests per 200 m^2) at Mitande and Otter Point.

L. cylindricus

This species was observed during all exploratory dives in all rocky areas around Thumbi West and Domwe Islands and at Otter Point between October 1994 and April 1996. Fishermen of Chembe Village stated that they caught this species in greatest numbers near the river mouths or sandy areas far from rocky areas with gillnets after the onset of rains between December and January. Gonads of 16 *L. cylindricus* individuals sampled from gillnet catch set in a sandy area at Chembe Beach in January 1996 showed that all were ripe females.

***Rhamphochromis* species.**

During the exploratory dives, individuals ranging from 80 mm to 175 mm TL were commonly observed in the water column in all habitat types such as sandy, rocky, weedy and intermediate habitats between October, 1994 and April, 1996. They were common where *E. sardella* and the fry of other fish species were concentrated. Larger individuals such as the ones caught by fishermen using handlines (between 210 mm and 400 mm TL) (Figure 3.2) were never observed in the study sites.

***Opsaridium microcephalus* "Sanjika"**

Isolated juveniles of this species ranging from 12 cm to 17 cm TL were observed in the water column from February to May at all study sites. The juveniles were caught as a by-catch in the open water seine net "chirimira" fishery for *E. sardella*. Adults on the other hand were not seen but were occasionally caught in the 2" to 3.5" mesh gillnets by local fishers.

***S. robustus* "Tsungwa"**

This species was occasionally seen among rocks around Thumbi Island West, Domwe Island and once at Otter Point. The individuals were solitary, usually stationed at one position for a long time of the day (observed up to 32 minutes) unless disturbed at a very close distance. The observed individuals ranged from 35 to 42 cm in total length.

DISCUSSION

Inventory of food fish species in LMNP 100 meter zone:

The list of species observed in the LMNP 100 metre protected zone (Table 3.1) represent a small fraction of the species that form the catch of the artisanal fishery of LMNP (Smith, 1993) (Appendix 1). Some of the species that were not observed in the park protected zone such as *S. njassae*, *Bathyclarias* spp. and *Mormyrops anguilloides*, are offshore species preferring deeper areas, while others such as *Fossochromis rostratus* are restricted to the shallow sandy areas adjacent to the major beaches outside the protected zone (occupied by the enclave villages). From trawling catches, Turner (1996) recorded 47 species belonging to 19 genera in the northern Part of South East Arm of Lake Malawi (which covers part of the LMNP); 63 species belonging to 24 genera between Boadzulu and Monkey Bay (see Figure 2.2); and 70 species belonging to 35 genera in the Southern Part of South East Arm of Lake Malawi. In the present study most of these species were identified to genus level (not formally described). Eccles & Trewavas, (1989) have recorded about 116 species (including rare ones) belonging to 35 genera from trawling catches in the South East and South West Arm of Lake Malawi. Comparing the list of species observed in the protected zone with the species caught in the South East or South West arms of Lake Malawi it can be seen that only a small fraction of these species use the park waters. This indicates that the park is not of great value as a sanctuary for most food fish.

However, it is also possible that in the present study, fewer food fish species were observed than actually occur in the LMNP for the following reasons: 1) Sampling was carried out in a limited area of the LMNP. The protected area of the LMNP sampled in the present study included Thumbi West Island, Domwe Island and from Mfuli Beach to Ilala Gap, but excluding the beach adjacent to Chembe Village (Figure 3.1). The total area of this sampling area, calculated by measuring the total length of the shoreline from a scaled map of the LMNP and multiplying it by 0.1 km (width of the park boundary from the shoreline), was 1.318 km^2 which is 18.6% of the LMNP total aquatic area of 7 km^2. Also, not all of the 1.318 km^2 was intensively sampled because in most areas of Thumbi West and Domwe Islands the 100 metre zone extended to depths beyond diving limit. 2) The observations of fish in the present study were restricted to the day time which may not indicate the situation at night. Unfortunately, no information is available about the behaviour of these species at night except for *B. meridionalis* which is reported to come to shallow areas at night to catch small cichlids (McKaye, 1983). To get a clear picture of all the food fish species that are found in the park it is necessary to sample all the islands in the park (Figure 1.2) during both day and night. Sampling gears such as gillnets may be necessary at depths which cannot be reached by SCUBA diving and also for cryptic species.

Comparisons of the number of fish species among sampling sites cannot be made directly because of the differences in habitat types and the problem of the taxonomy of Lake Malawi fish. In Lake Malawi different fish species are found in different habitat types except for those which have a wider distribution range extending to different habitats (Ribbink *et al.* 1983, Konings, 1995). Most of the fish can be easily identified to genus but not to species level. Eccles & Trewavas (1989) provided a key for the identification of some of the Lake Malawi fish but it does not include all the sand dwelling or rock dwelling fish. Temporary names (cheironyms) are commonly used (Ribbink *et al.* 1983, Konings, 1990, 1995, Turner, 1996).

Distribution of food fish species in the protected park area

Restricted habitat types, e.g. mixture of sandy and rocky areas which are rather limited were preferred by species such as *Oreochromis* spp. *B. meridionalis, D. kiwinge* for breeding purpose. All *Copadichromis* spp. but *C. eucinostomus*, have very restricted distribution. Sand dwelling fish that require a wide sandy area were poorly represented in the protected area. Differences in the abundance of fish among the study sites were more related to habitat differences than to the protection offered by the park. For instance, *Oreochromis* were more abundant at Otter Point and Mitande, both of which have similar habitat characteristics such as being near rocks and having a mixture of sandy and rocky areas. *T. praeorbitalis* which is restricted to sandy areas (Eccles & Trewavas, 1989) was more abundant at Nchenga and Nguli (both of which are off Chembe Beach). The same also applies to *Protomelas* spp, *Lethrinops* spp and partly *Nimbochromis* spp. (Table 3.4). Such patchy distribution has also been previously noted for utaka which are reported to be associated with rocky shores (Bertram, Borleyi & Trewavas, 1942; FAO, 1993; Turner, 1994). Smith (1993) noted that most fishing trips for the *Copadichromis* spp., one of the two most important commercial fish species in the artisanal fishery of the LMNP, were located along rocky areas close to the shoreline.

Life cycles of food fish inside the park

This study has indicated that most food fish species use the park waters on a seasonal basis and only during a certain part of their life. For instance only juvenile *Rhamphochromis* were noted in low numbers. Similarly, only breeding and early juvenile stages of *B. meridionalis* were observed in the park area. *E. sardella* were transient and they could cross the park boundaries within a few minutes (usipa shoals could be easily seen as they were sometimes followed by birds which feed on them). *Copadichromis* and *Oreochromis* species were seen in varying abundance which suggests that they move from one point to the other in search of food. Iles (1971) reported that some *Copadichromis* spp. temporarily move away from their feeding habitat prior to their breeding which can also partly explain such fluctuation in abundance.

L. cylindricus spend all months in the rocky areas of the park where they feed but their potamodromous nature renders them susceptible to exploitation by gillnets during their spawning migrations (FAO, 1976; Tweddle, 1982; 1983; Smith, 1993 and Turner, 1994). Their exploitation at this critical life history stage can affect recruitment in the subsequent years.

Size of fish

Direct comparisons of fish size in the unprotected zone (Nchenga and Fisheries) cannot be made with that of sites inside the protected zone (Otter Point, Mitande and Nguli) for all species because of differences in species composition due to differences in habitat types. As noted above, variations of fish abundance, size structure and other aspects among sites appeared to have been mostly due to habitat differences. However, comparison of the fish size observed at all the five sites with the size of fish caught by fishermen further offshore and outside the protected area indicated that fishermen were catching bigger individuals in the offshore areas outside the protected area than those observed in the inshore areas including the protected area (for *Oreochromis* and *Rhamphochromis*). This shows that not all the size categories were adequately represented in the inshore areas including the park protected area. This also suggests that the park, which mainly covers the 0.1 km distance from the rocky shoreline, and other inshore areas are used mainly as nursery areas for these species.

Fish of a larger size are expected to be found in an underwater park (Robert & Polunin, 1991; Bennett & Attwood, 1991, 1993). *B. meridionalis* that were defending nests and young were large and of a similar size to those the fishermen were catching with handlines outside the park and further offshore. The small sized *B. meridionalis* individuals caught by fishermen using the 2 inch mesh sized gillnets (Figure 3.4) indicates that *B. meridionalis* is recruited to the fishery at a very early stage of their life. This has also been noted by Smith (1993). This stage is shortly after the parents have stopped guarding the juveniles (see Appendix 3). Considering that *B. meridionalis* females and males mature at 37 cm and 33 cm respectively (Tweddle, 1975; FAO, 1976), the individuals start being caught before they reach their maturity stage which could result in growth overfishing.

Nesting site distribution and abundance

This study showed that fish species such as *B. meridionalis*, *Oreochromis* spp. and *D. kiwinge* preferred a mixture of sandy and rocky areas for nesting. Most of such areas are inside the LMNP 100 m zone. Overall this area may however, not be big enough because most of the park shoreline is rocky and hence the benefit of protection of such nesting fish by the park may not be of much significance to the entire fishery. Nesting sites of fish species which prefer extensive sandy beaches such as *C. eucinostomus*, *Protomelas* spp. *Lethrinops* spp. (observed during the exploratory dives outside the fixed transect sites) and others are poorly represented inside the park. There is a limited number of beaches inside the park boundaries. These beaches are of small size since most of the major beaches are occupied by enclave villages of the park (outside the park).

Fish movement and migratory behaviour

Due to the low number of fish that were tagged this study was unable to gain useful information about movement and migratory behaviour of the food fish species. However, insights about the movements of some of these fish can be gained from the general observations made during the study and also from previous reports. For instance, the temporal fluctuation in the abundance of *Oreochromis* spp. noted at Cape Maclear (Figure 3.5) might reflect their movement from one place to another. Female *Oreochromis* spp. are believed to migrate from the northern part of the South East Arm of Lake Malawi to Lake Malombe a distance of over 50 km (Lowe, 1952; Iles, 1960; Chaika, 1981; & FAO, 1993). Juvenile *Oreochromis* are reported to migrate from the shallows to deeper waters as they grow and back to the shallows with onset of sexual maturity (Turner & Mwanyama 1992 cited by Smith, 1993). *Oreochromis* spp. are also reported to move to deeper waters during cold season (FAO, 1993). The former could also explain the low relative abundance of *Oreochromis* spp between the months of June and July (the coldest months in Malawi) at Otter Point and Mitande (Table 3.3). This suggests that as the fish move to deeper water (when the juveniles grow or during the cold season), the park does not protect these fish.

Disappearance of *B. meridionalis* fry from the nesting sites at a length of 140 to 181 mm, two to four weeks after the parents stopped guarding them, may reflect their movement to deeper waters where predation could be less due to protection from dim light (Coulter, 1991). Juveniles of *B. meridionalis* between 12 and 19 cm TL were common in the Fisheries Demersal Trawling Survey catches between June, 1994 and December, 1995 at 50 to 90 metres depth (Personal observation). However it is not clear whether they reached that depth through migration from the shallow areas or due to *B. meridionalis* breeding at that depth. That *B. meridionalis* migrate to shallow water to breed, is a commonly noted observation (Jackson, Iles, Harding, & Fryer, 1963; Lowe, 1952; Tweddle, 1982; Thompson *et al.* 1996), but the possibility of breeding in deep waters remains a hypothesis yet to be tested. The movement of *B. meridionalis* to shallow waters in sandy areas at night to feed on small cichlids (McKaye, 1983) shows a very temporary residence time in these areas.

Fishermen targeting *Copadichromis* spp. have their preferred fishing localities where they always fish (Smith, 1993; Msukwa, 1995) indicating that these fish do not migrate to other places. According to fishermen, *E sardella,* a pelagic shoaling zooplanktivorous species, moves from one point to another (pattern undefined) perhaps following the availability of the zooplankton on which they feed.

This study has shown that relatively few of the food fish species use the LMNP. The use of the park by these fish therefore appeared to be too limited to have any significant beneficial effect on the adjacent artisanal fishery. Some food fish species use the park for only part of their life cycle, e.g. for breeding and as a nursery area. This cannot offer sufficient protection for these species. The entire life cycle of a species need to be represented in a reserve if the park is to offer some measure of protection (Robert & Polunin, 1991). The 100 m park zone can be crossed within a few minutes by most fish species. Moreover, the abundance of most species in the park is so small that their protection by the park may not be of any significance to the fishery. Moreover the park does not appear to contain representative habitats used by food fish in Lake Malawi. For example, sand dwelling fish are the most exploited fish in Lake Malawi yet sandy habitats are the least represented in the park.

Conclusions and recommendations arising from this study are made in the final chapter.

CHAPTER 4

General discussion and conclusions

In this chapter a synthesis of the findings of the present study with particular reference to the underlying objectives is presented. The role Lake Malawi National Park may play as a sanctuary area for food fish and for bilharzia control is discussed and conclusions and recommendations pertaining to the objectives of the study are made.

The effectiveness of the park as a sanctuary area for food fish and biological control of bilharzia:

The park as a sanctuary area for schistosomiasis control

Underwater reserves or sanctuaries which started in marine ecosystems are relatively new with regards to the freshwater ecosystems. However the underlying principles of reserves are similar regardless of where the reserve is. Although aquatic reserves are advocated as good means of conserving biological diversity (Buxton & Smale, 1984; Hyslop, 1991; Francour; 1991; Reinthal; 1993; Robinson, 1989; Hockey & Branch, unpublished), few studies have linked this protection to the direct human use of protected species.

The present study has indicated that at Cape Maclear (both inside and outside the LMNP) there is a viable population of *T. placodon* which has been considered to be potentially the most active biological control agent for schistosomiasis (Jackson *et al.* 1963 cited by Chiotha *et al.* 1991; McKaye *et al.*, 1986) because it is a voracious snail eater (Pruginin, 1976; Chiotha *et al.* 1991) in natural conditions (McKaye *et al.* 1986) and in ponds (Chiotha *et al.* in Slootweg *et al.* 1993). There was no convincing evidence that its population has drastically gone down from 1986 to the present day. However, the fact that big individuals were not abundant at sites closest to Chembe Village could be ascribed to fishing or to the nature of the habitat. Fishing takes big fish first from their population but it is also possible that low population of big individuals is due to the fact that they prefer deeper water further offshore than the study sites.

To answer the question as to whether or not the park effectively protects this species for biological control of schistosomiasis depends upon many factors. Among many hypothesized factors about the protection of fish species by marine reserves (Chapter 3), increase in abundance and changes of size structure to natural state due to reserve establishment have been the most commonly reported factors (Buxton, 1993; Roberts & Polunin 1991). In LMNP fishing is not allowed anywhere within the 100 metre distance offshore but in front of beaches of the enclave villages (Carter, Tweddle & Sefu, 1984). Underwater observations of *T. placodon* indicated the presence of large but fewer individuals in the park and many but smaller individuals in front of the Village. Thus the park offers limited protection of the species. Though beach seine netting is discouraged by the Malawi Fisheries Department, it is difficult to control it (Lewis, 1985) and it may be attributed to *T. placodon* observed size structure in front of Chembe Village. *T. placodon* fish may therefore be less effective in controlling the bilharzia vector snail population because fewer large fish individuals in front of the village where most snails are distributed may mean failure to eat snails beyond a certain size (Chapter 2). For the park to effectively protect *T. placodon* population at Cape Maclear so as to increase its impact on gastropod population there is need to extend the park boundaries to the beach in front of Chembe Village and also to deeper water further offshore where big individuals of molluscivorous fish may also inhabit. It has been reported that Lake Malawi fish stocks can recover quickly from excessive fishing (Craig, 1992; Tweddle, 1992; Tweddle & Magasa, 1989) and it may be as short as two years (Tweddle, 1992). Thus banning fishing along the beach can allow *T. placodon* and other molluscivorous fish species to grow so that they can be more effective in controlling gastropod population. If this, in combination with all the recommendations made in Chapter 2 are put into practice, schistosomiasis contraction in Cape Maclear could be significantly reduced.

The park as a sanctuary area for food fish

This study was a preliminary survey based on underwater behavioural and ecological observations of the food fish in the park, restricted to depth within diving limit. Nonetheless a few things were noted when this information was combined with samples from or observations of fishermen's catches outside the protected area. Concerning food fish it was shown that relatively few species of fish use the LMNP as compared to those taken by fishermen. Although it has been reasoned that besides the rock dwelling cichlids other species widely distributed in the lake would derive some benefits from the park (Clarke, 1983; Coulter *et al.* 1986; Bootsma, 1990; 1992; Lewis *et al.* 1986), the use of the park by these fish is so limited to have any significant beneficial effect on the adjacent artisanal fishery. Some food fish species use the park seasonally for a short time. Some species do so for specific part of life histories. The 100 m distance is crossed within a few minutes by most fish species so that some fish come to the 100 metre protected zone for a specific time of the day for feeding purpose and then swim back further offshore. A much bigger, better designed park covering more habitat types to protect more food fish species and more life history stages is necessary as a food fish sanctuary. However, more comprehensive technically gained research programme should establish good baseline data on which to monitor changes and evaluate trends necessary for park design and fisheries management.

The need for conservation of resources in protected areas to benefit the surrounding community has been recognized in Malawi (Mkanda & Munthali, 1994; Munthali & Mughogho, 1992; Munthali & Banda, 1985; Munthali 1995; 1996; in press) though strategies to achieve this objective vary from one protected area to another. Similarly, the basis for advocating aquatic reserves as a form of fisheries management lies not only on conserving fish but also ensuring that they can be sustainably utilized for the present and future generations. However, several of the perceived benefits of aquatic reserves for fisheries management (Chapter 3) have not been demonstrated in a freshwater park. Key questions critical to the evaluation of the effectiveness of aquatic reserves in fishery management have been posed (Roberts & Polunin, 1991; Buxton, 1993; Bennett and Attwood, 1993; Hockey & Branch, unpublished); the questions mainly focus on the interaction between the reserves and adjacent fisheries based upon the reproductive biology and ecology of fish species concerned and they include: rates of emigration and migration of fish to and from reserves, enhancement of catches in areas surrounding a reserve, the supply of recruits to fished areas, relative rates of production inside and outside reserve and patterns of larvae transport and mortality, and the fate of eggs and larvae. Not all of these questions may be universally applicable to all aquatic reserves because there are variations in the reproductive biology and ecology of the fish concerned. For instance, almost all Lake Malawi fish take care of their young through mouth brooding or guarding (Ribbink, Marsh, Marsh & Sharp, 1980) and so the question of egg or larvae transport, which applies to marine fish which are pelagic spawners, is not applicable to Lake Malawi Fish. The interaction of LMNP and adjacent artisanal fisheries would thus depend on migration behaviour of juveniles and adult fish to and from the reserve. In this regard, there is an indication that very limited life history stages of species such as kampango, chambo, some utaka species, usipa, *D. kiwinge* and *Rhamphochromis* spp do emigrate and migrate to and from LMNP but in very limited numbers (Chapter 3) and within a short time. The fish could cross the 100 m zone border of the park more than once a day. The resident period in the park 100 metre protected zone may be for a few minutes or hours of feeding period after which the fish go back further offshore outside the protected zone and thus such movement cannot improve the catches in the adjacent fishery.

For the few species such as chambo and kampango which appeared to use the park zone to a greater extent than other species, there has been a decline of their Catch Per Unit of Effort (CPUE) from 1979 to 1993 in the artisanal fishery of LMNP (Smith, 1993) instead stable or increasing (CPUE) following the park establishment (Bennett & Attwood, 1993). This could be due in part to the following factors: 1) Fishing effort in the artisanal fisheries of LMNP may be higher than what the available stock of fish can sustain. For instance, fishing for utaka and usipa was observed to be almost on daily basis except when there was moonlight and Mwera Winds (South Easterly Winds) blow. 2) Most of the fish are caught before they reach maturity stage consequently total biomass production and recruitment could be affected. 3) Illegal gillnet fishing inside the park during the breeding period may have had some effects on recruitment because besides catching the potential parents there is a reduction in the number of potential young recruits which could be supplied by these parents. With the small park size plus the fact that illegal fishing commonly takes place in the 100 metre zone (Msukwa, 1995), there is very little or no protection of the food fish species by the park.

One of the basic tenets of reserves as a means of conserving biodiversity is that reserve sites should cater for many habitat types, high species composition and a diversity of ecosystems (Cohen, 1992; Coulter & Mubamba, 1993; Hockey & Branch, unpublished; Reinthal, 1993; Robinson, 1989). LMNP does not cover the sandy sites where majority of the food fish species are found.

The need for better protection of food fish is inevitable in the light of the increasing fishing pressure and this may be achieved by the following options:
1) There is need to increase the park size to have sufficient buffer zones from intensively fished areas (cf Cohen, 1992, Coulter & Mubamba, 1993). It has been suggested that fish species whose immature stages occur in the shallower depth but mature stages are benthic and found in the deeper waters, may need to be considered when setting reserve boundaries (Coulter & Mubamba, 1993). Information on movement and migration behaviour of the food fish of Lake Malawi is required to appropriately determine the park boundaries to serve as an effective sanctuary area for food fish. Before the park boundaries are changed anthropogenic factors should also be considered. Cohen, (1994) & Munthaili (in press) point out that regulations restricting the access of local communities (most of who are very poor) to resources cannot work if alternative income opportunities are not provided to them. Increasing the park boundary needs participation of the community so that the fishermen see that the change of the park boundaries is meant to benefit them. If the community are not involved in the decision making it may lead to the animosity between the fishermen and the park management. There is need to study the movement and migration behaviour of the food fish through intensive tagging

and also to survey the suitable habitats for these species. Such information can aid in determining where the park boundaries should be located to increase the protection of food fish species and at the same time ensuring that this protection is of benefit to the fishery.

2) Taking more serious measures to control fishing especially gill netting in the park and also ensuring that fishermen abide to the minimum gill net mesh size. This can ensure that fish are allowed to grow before being caught.

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Appendices

Appendix 1: List of the fishes commonly caught in the LMNP Artisanal Fishery [extracted from Smith, (1993)]. Fish names in parentheses are local names used in Chembe Village.

Most commonly caught fishes (which make 95% of the catch)

Engraulicypris sardella "Usipa"

Copadichromis species "Utaka"

Bagrus meridionalis "Kampango"

Oreochromis species "Chambo"

Bathyclarias species "Bombe"

Ramphochromis species "Ncheni"

Labeo cylindricus "Ningwe"

Species that make the other 5% of the catch

Cichlids

Dimidiochromis kiwinge "Mayani"

Buccochromis species "Saguga"

Lethrinops species "Tondo"

Fossochromis rostratus "Chimbenje"

Non - cichlids

Synodontis njassae "Nkholokolo"

Clarias gariepinus "Mlamba"

Mormyrops anguilloides "Samwamowa"

Opsaridium microcephalus "Sanjika"

Barbus johnstonii "Ngumbo"

Petrocephalus catostoma "Mputa"

Brycinus imberi "Nkalala"

Anguilla bengalensis "Mkhunga"

Appendix 2

Number and dates of Fisheries Demersal Trawling Quarterly Surveys in the South East Arm (SEA) and South West Arm (SWA) regions of Lake Malawi where some *T. placodon* ecological data and biological specimens were obtained.

Date	Quarterly Survey Number	
	SEA	SWA
June 1994	1	1
August / September 1994	2	-
September 1994	-	2
November 1994	3	3
March 1995	4	4
June 1995	5	5
September 1995	6	6
December 1995	7	-
January 1996	-	7

Appendix 3

Kampango fry growth rate based upon 4 broods at Mitande and one brood at Otter Point between October 1994 and December 1995. Numbers in bold for each brood indicate the time the fry were last seen defended

Average size of fry for the brood (TL in mm)							
Age (wks)	Br 1	Br 2	Br 3	Br 4	Br 5	Mean ±SD	Size gain/2wks
2	15	13	17	14	16	15±1.6	(mm)
4	45	43	55	50	50	48.6±4.7	33.6
6	76	64	70	75	67	70.4±5.1	21.8
8	105	90	**100**	**120**	95	102±11.5	31.6
10	**130**	**115**	135	140	**125**	129±9.6	27
12	165	155	150	vacated	155	157±7.6	28
14	181	179	vacated	vacated	179	180±1.4	23

Average size (TL in mm) gain per two weeks period 27.5± 4.6

Appendix 4: List of fish species reported to take gastropods in their diet [Source: Eccles & Trewavas (1989) Lewis (1982) and Ribbink *et al* (1983)].

Chilotilapia rhoadensii (Boulenger)

Mylochromis sphaerodon, (Regan, 1922)

Mylochromis anaphyrmus (Burgess and Axelrod, 1973)

Trematocranus microstoma Trewavas, 1935

Trematocranus placodon (Regan, 1922)

Lethrinops mylodon Eccles & Lewis 1979

Mylochromis ericotaenia (Regan 1922)

Mylochromis mola (Trewavas, 1935)

Platygnathochromis melanotus (Regan, 1922)

Labidochromis mylodon Lewis, 1982

Labidochromis caeruleus

Protomelas kirkii (Gunther, 1893)

Protomelas macrodon Eccles

Appendix 5: Density of the four reported major molluscivores at five sites at Cape Maclear, Lake Malawi (mean ± SD for six months period: November 1994 to April 1995 expressed as No. individuals per 200 m^2).

Sampling Site	Spotted molluscivores (*T. placodon* and *T. microstoma*) density (Mean No. / 200 m^2 ±S.D.)	Oblique striped molluscivores (*M. sphaerodon* and *M. anaphyrmus*) density (Mean No. / 200 m^2 ±S.D.)
Fisheries	8.8±5.9	4.8±3.0
Mitande	5.0±1.1	2.7±1.5
Otter Point	6.5±1.3	1.5±2.1
Mchenga	12.3±7.4	3.4±2.7
Nguli	7.8±5.0	8.0±5.3

Appendix 6: *T. placodon* relative abundance (Number of individuals per 200 m^2 to the nearest whole number) at the five sites studied at Cape Maclear between November 1994 and February 1996.

	Mitande	Otter Point	Fisheries	Mchenga	Nguli
Nov-94	7	6	5	8	7
Dec-94	4	7	9	4	5
Mar-95	4	8	4	18	4
Apr-95	5	5	17	19	15
May-95	8	6	12	34	29
Jun-95	2	7	34	42	35
Jul-95	2	7	34	14	40
Aug-95	3	5	33	51	33
Sep-95	5	6	37	28	30
Oct-95	4	6	17	45	34
Nov-95	6	4	24	59	25
Dec-95	4	4	4	107	33
Jan-96	7	6	39	43	21
Feb-96	7	3	57	95	29

Appendix 7: *T. placodon* relative abundance (No. individuals per 200 m^2) by size category and sampling site at Cape Maclear between November 1994 and February 1996. SC1 = Size category 1 (<10 cm, TL); SC2 = Size category 2 (10-15 cm, TL); SC3 = Size category 3 (15^+ cm).

	Mitande			Fisheries			Otter Point			Mchenga			Nguli		
	SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3
Nov-94	2.6	3.7	2.3	5.7	0	0	0	3	3	8.2	0	0	5	2	0
Dec-94	0	3	1	9	0	0	0	4	3	4	0	0	3.3	2	0
Mar-95	3	1	0	4	0	0	0	3	5	12	6	0	3	1	1
Apr-95	0	4	1	16	1	0	0	4	1	14.6	5	0	9	6	0
May-95	0	6.3	2.7	10	2	0	0	3.7	2.3	30	3	0	25	5	0
Jun-95	0	2	0	32.3	2	0	0	3	4	36.3	6	0	30	5	0
Jul-95	0	2	0	31	3	0	3	4	0	11	3	0	30	10	0
Aug-95	0	2	0	27	6	0	0	3	2	49	3	0	29	4	0
Sep-95	0	3	2	30.3	6.7	0	0	3.3	2.6	23.3	4.6	0	22	5.3	2.3
Oct-95	0	4	1	34.5	2	0	0	3.5	2.5	32.5	10	2	24	5	5
Nov-95	0	4	2	14	3	0	0	2	2	47	12	0	17	6.7	2
Dec-95	0	3	1	2	2	0	0	1	3	81	21	5	29	3	1.3
Jan-96	0	2	5	6	30	3	0	1.6	4.3	30.3	9.6	3	12	5.3	4
Feb-96	0	3	4	28	40	9	0	1	3	61	31	3	7	8	14