THE CULTURE AND FOOD OF OREOCHROMIS NILOTICUS (LINNAEUS) (PISCES : CICHLIDAE) IN WASTEWATER LAGOONS

BY

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DECLARATION:

"THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED FOR ANY OTHER DEGREE IN ANY OTHER UNIVERSITY".

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THIS THESIS HAS BEEN SUBMITTED FOR EXAMINATION WITH OUR APPROVAL AS UNIVERSITY SUPERVISORS.

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ABSTRACT

The rate of wastewater flow was found to be the major factor controlling the variability of physico-chemical and biological parameters in the wastewater lagoons. Low and irregular wastewater flow particularly during the dry season resulted in reductions in water depth, light penetration, dissolved oxygen concentration, primary production and pH, and increases in conductivity, water temperature, nitrates and phosphates. This situation reversed during periods of regular wastewater flow. A large biomass of algae (as judged from chlorophyll *a* concentration and photosynthetic rate determinations) dominated by the blue-green algae, *Microcystis* sp., *Spirulina* sp. and *Synechocystis* sp. was encountered at the lagoons. The mean chlorophll *a* concentration obtained was 926.8 ± 65.996 mgl^{-1} while the mean gross photosynthesis was 1393.778 ± 114.61 mg O_2 m^{-3} h^{-1}. The average conversion efficiency of radiant energy into gross photosynthetic production was 3.772%. The presence of the large algal biomass was attributed to high ambient temperature, nutrient rich organic wastes brought in by sewage, high pH and alkalinity. The mean level attained by these parameters in the lagoons were: temperature - 28.7 ± 1.20°C, nitrates (NO_3 - N) - 4.306 ± 0.58 mgl^{-1}, phosphates - (PO_4 - P) - 3.349 ± 0.41 mgl^{-1}, pH - 8.7 ± 0.66 and alkalinity - 299.7 ± 22.61 (mg $CaCO_3$ l^{-1}). Self-

shading by dense algal blooms and the presence of particulate organic matter were the major factors limiting primary productivity. This was deduced from the low Secchi disc depth of 10.7 ± 0.31cm and a shallow euphotic zone of only 36.0 cm as determined by light intensity measurements.

Food selection studies in *Orechromis niloticus* revealed that the abundant blue-green algae constituted the bulk of the material eaten by the fish, contributing 73.05%, followed by the green algae - 13.68%, then diatoms - 7.28%, then the invertebrates - 4.16%, and lastly, other forms of algae - 1.83%. Among the common algal species, *Microcystis* sp. *Spirulina* sp. and *Merismopedia* sp. had positive selection as judged from the three measurements of selection namely, the forage ratio (FR), Ivlev's index of electivity (E) and the linear food index (L), while the algae *Synechocystis* sp. and *Scenedesmus quadricauda* had negative selection. The fish substantially fed on bottom deposits which contained large numbers of Chironomidae and Oligochaeta.

Caged *Oreochromis niloticus* in replicate densities of 50,70,90 and 110 fish m^{-3} exhibited better growth rates during periods of suitable environmental factors, that is, periods of regular wastewater flow; hence water renewal and high natural productivity. Depressed growth rates were observed during the dry season when the physico-chemical conditions were unsuitable. The mean overall

growth rates ranged from 28.398 g(2.497cm) month^{-1} fish^{-1} at an initial stocking density of 110 fish m^{-3} to 36.256 g (2.821 cm). month^{-1} fish^{-1} at an initial stocking density of 50 fish m^{-3}. The mean overall condition factor improved as the stocking density dropped. It ranged from 2.041 ± 0.100 at an intial stocking density of 50 fish m^{-3} to 2.124 ± 0.100 at an initial stocking density of 110 fish m^{-3}. The major factor contributing to the drop in the stocking densities of fish in the cages was low dissolved oxygen concentration. Diel dissolved oxygen concentration ranged from 0.5 mg l^{-1} at the bottom to 7.6 mg l^{-1} at subsurface. Seasonal dissolved oxygen concentration ranged from 3.6 -9.5 mgl^{-1}. The overall mean sizes attained by *O. niloticus* after a culture period of five months ranged from 19.435 ± 0.247cm (156.527 ±12.687g) to 20.982 ± 0.767 cm (188.25 ± 19.6366g). The overall gross yields attained without supplemental feeding ranged from 2.380 ±0.310 kgm^{-3} at an initial stocking density of 90 fish m^{-3} to 2.644± 0.457 kgm^{-3} at an initial stocking density of 50 fish m^{-3}. Single factor analysis of variance showed that there were no significant differences between the growth rates and gross yields attained at different stocking densities. Estimates of fish production using two independent methods by Huet (1975) and Sreenivansan (1972) gave 1.9398 and 10.176 kg of fish per m^{-2} yr^{-1} respectively.

CHAPTER 1

GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

As the human population keeps increasing, the demand for animal protein also increases. This has resulted in increased pressure on many world fisheries, most of which have shown signs of decline. In Kenya, the fisheries of the Nyanza Gulf of Lake Victoria and Lake Naivasha have already shown signs of decline (FAO, 1982; 1984). The decline in the catches notably in the Nyanza Gulf has been attributed to overfishing and predation by *Lates niloticus* (Garrod, 1961 a and b; Cadwalladr, 1965 and FAO, 1982 ; 1984). Due to the decline of the tilapia catches from the traditional sources and the increased demand for fish protein in Kenya, there is a need for alternative methods of fish production.

Pond culture and to some extent culture in raceways are the systems currently in practice in Kenya. Other systems such as integrated farming are at the experimental stage. Fish culture in wastewater lagoons has had little attention. Preliminary studies at the Thika wastewater lagoons however indicate that it is possible to culture *Oreochromis niloticus* in wastewater lagoons and that this practice improves the water quality (Nyaga, 1981). Unfortunately, no further studies have been carried out in

Kenya. Wastewater lagoons have been recommended as a means of wastewater treatment in the tropics (Edwards, 1980a and Olah *et al.*, 1986). Kenya needs low cost fish culture systems to augment the protein needs of its population. In this respect, the culture of fish in wastewater lagoons is an opportunity worth exploring.

Oreochromis niloticus is one of the fishes commonly used in wastewater aquaculture (Edwards *et al.*, 1981). This is due to its better culture qualities such as rapid growth, resistance to disease and tolerance to low dissolved oxygen concentrations and wide temperature fluctuations. In general, it is a hardy fish (Coche, 1976).

1.2 LITERATURE REVIEW

Recent attempts have been made at recycling organic wastes into fish (Schroeder, 1977 ; Edwards, 1980a and Edwards *et al.*,1981). The major wastes used to culture fish in ponds were sewage and agricultural and food canning industry wastes.

The use of wastewater lagoons in recycling wastes has a promising potential. They have already been used to obtain fish yields many times higher than those obtained from ponds fertilized with artificial fertilizers (Allen and Hepher, 1976; Hepher, 1985 and Olah *et al.*, 1986). Fish grown on wastes have also been observed to have fast growth rates (FAO, 1971 ; Burns and Stickney, 1980) and in some cases high survival rates (FAO, 1974 and Burns and Stickney, 1980). This is because the wastes provide abundant nutrients and particulate organic matter which stimulate the proliferation of natural fish foods. Allen and Hepher (1976) observed a 70% greater yield with a 40% reduction in the feed given to fish in organically manured ponds. They further obtained a yield of 4,900kg ha^{-1} of fish (based on extrapolated data) in fish ponds fertilized with cowshed manure in Israel. The Chinese produce about two thirds of the world's aquaculture harvest from fish ponds fertilized with sewage and other organic wastes (Wohlfarth, 1978). In the Netherlands, fish yields of over 1,000 kg ha^{-1} were obtained in domestic wastewater without artificial feeding (Thorslund, 1971). Edwards (1980a) has reviewed in detail the recycling of organic wastes into fish.

Current research is aimed at the utilization of domestic waste as a basis of producing a large biomass of primary producers on which complex food webs are built (Kerzan *et al.*, 1974; Stirn *et al.*, 1974 and Anon, 1975). This requires that fish with phytophagous or planktivorous habits be used to harvest the algae and produce a large fish biomass at a lower trophic level. Examples of such fish are *Oreochromis niloticus*, *Cyprinus carpio*, *Ctenopharyngodon idella* and *Hypophthalmichthys molitrix*. The fish feed on the phytoplankton and keep its population (and biomass) at an exponential phase of growth (multiplication into new cells), thus also causing an exponential rate of nutrient removal from the water. The removal of some of the nutrients such as phosphates is further enhanced by the high alkalinity and pH conditions which prevail in the oxidation ponds. These parameters are also responsible for the high natural productivity in the form of fish foods and fish yields. The fish in wastewater lagoons feed on organic particles on which are encrusted microfauna and flora (Schroeder, 1978). For example, observations by Wolhfarth and Schroeder (1979); Hepher and Pruginin (1981); Edwards *et al.* (1985) and Polprasert *et al.* (1986) indicate that fish feed directly on both human and animal wastes and derive nutriment from the associated bacteria and other micro-organisms. Further observations by Polprasert, *et al.*(1986), working in Thai fish ponds show that fish directly consume nightsoil (human excreta) composted with water hyacinth and straw, when it is applied the ponds as a fertilizer. McGarry (1976;1977) notes that night soil is regarded as market commodity in Taiwan and that it is used both as a fertilizer and a dierct fish food. During the time when it is added to the ponds, fish gather expectantly at the input point and feed on it voraciously. The wastes serve as a source of energy (Edwards, 1982) and also enhance the growth of the fish (Pillay, 1966 and McGarry, op, cit.).

Studies conducted in Israeli fish ponds have shown that, fish convert wastes directly into fish flesh

(Wohlfarth and Schroeder, op cit. and Wohlfarth, 1978). Shan et al. (1984) using stable isotopes of carbon, observed that there was a strong contribution of fresh pig manure to the growth of two filter feeding species, the silver carp, *Hypophthalmichthys molitrix* and the big head carp, *Cyprinus carpio*. Observations by Zhang *et al.* (1987) indicate that waste-fed fish in Chinese ponds loaded with pig manure converted the wastes and aquatic grass into fish biomass. Schroeder (1983a and b) notes that one of the pathways contributing to the growth of fish in ponds concerns the food chain beginning with manure as input. Examples of other fish which feed directly on wastes in ponds are *Tilapia zillii*, *Oreochromis niloticus*, *Oreochromis mosambicus* and *Chanos chanos* (Edwards, 1980a and b). Further information on the direct feeding by fish on wastes is provided by Avnimelech *et al.* (1986) and Edwards, et al. (1986). The feeding on wastes by fish provides for nutrition deficiencies which occur in artificially manufactured feeds.

Techniques have been developed to harvest the primary producers (algae) and seaweeds (for coastal sewage works) produced as a result of the fertilization effect of the wastes and convert them into valuable commercial products such as fish feeds, agar-agar and fertilizers. In the same system, finfish and shellfish are cultured and harvested for food (MIT, 1977 ; 1978). Studies by Thorslund (1971), Seow and Tay (1973), Chan (1974), Carpenter (1978) and Oswald *et al.* (1978) have indicated that fish can improve the waste-treatment capacity of wastewater lagoons. They therefore improve the sanitation of the environment, provide a financial return on the system and protein for the public (Edwards *et al.*, 1986). The high pH and dissolved oxygen concentration resulting from intense algal photosynthesis provide the wastewater lagoons with a high capacity of disinfection against pathogens, a fact supported by the high fish yields obtained suggesting a healthy environment (Oswald,1973).

The production of fish by recycling organic wastes has been found to be cheaper than through other methods such as traditional pond culture and capture fisheries. The latter methods are expensive in that the cost of fuel for trawlers and their maintenance, fishing gear, fish pond fertilizers and feeds continue to rise (Kildow and Huguenin, 1974 ; Anon, 1975 and Wohlfarth, 1978). In the tropics, pond culture is more advantageous because fish production can be undertaken on a year round basis (Thorslund, 1971; Schurr, 1976 and Schroeder, 1977). The capital investment and maintenance costs are low and the ponds are fuelled by sunlight (Edwards, 1980a).

Despite the high fish yields obtained from wastewater lagoons, there are socio-economic problems associated with this method of raising fish. The reasons are that the fish may be contaminated with toxic pesticides and heavy metals (Kerfoot and Jacobs, 1976 and Wong *et al.*, 1982), pathogens and parasites which pose a potential threat to human health (Allen and Hepher, 1976). Therefore, fish culture using wastewater contaminated with toxic chemicals such as heavy metals (industrial waste-water) should be avoided. For example, Wong *et al* (op cit.) observed that fish reared in ponds fertilized with animal manures had accumulated high heavy metal concentrations in their flesh. A study by FAO (1977b) in a municipal waste treatment system, revealed an accumulation of the heavy metals chromium, nickel, manganese, copper, cadmium, lead and zinc in the cells of algae present in the treatment system and that were passed along the food chain to cladocerans and eventually to fish. Wong and Kwan (1981) working in fish ponds receiving 70-85% sludge, found that fish accumulated manganese, zinc and copper by factors ranging from 1.4-2.5 in their visceral organs. Hepher *et al.* (1986) working in Israeli fish ponds, found that fish raised on sewage had residues of several organochloride insecticides and polychlorinated biphenyls (PCBs) in their flesh, and that when the concentrations of these were high, the fish did not feed nor gain in weight. PCBs are stable compounds which cause poisoning in humans. They are also known to be carcinogenic (Hicks, 1982).

On the other hand, uncontaminated human and animal wastes (not contaminated with industrial wastes) could be used for fish culture, particularly after some form of primary treatment, for example using wastewater lagoons. Further, industrial wastewater can be used if the levels of harmful chemicals in them can be kept at low and acceptable concentrations. Thus it is possible for fish raised on wastes to be consumed by humans, as has been practiced for many years in China and many parts of South East Asia.

Recent research on the parasites and pathogens of waste-water cultured fish, have been undertaken to a considerable extent in south East Asia and Israel. Gerba *et al.* (1986), observed that viral contamination of fish grown in treated domestic wastes was not any greater than that in commercial fish farms in Thailand. Edwards *et al.* (1987) found that both the fish raised on excreta-fed ponds and the final products made from them such as fish silage, based feeds and dry feeds were safe for human consumption. Thorslund (1971) notes that there were no differences in the occurrence of parasites and diseases in sewage raised fish as compared to those reared in normal ponds. Allen and Hepher (1976) observed that fish cultured in well treated domestic wastes are equal to or even superior in taste and odour to non-waste cultured fish. Buras *et al.* (1986) working in waste-fed fish ponds in Israel, found that fish produced using wastewater were safe for human consumption provided that attention is paid to the critical concentration of bacteria (not coliform) in the pond water and in the fish. In general, a great majority of reports on wastewater aquaculture suggest that the fish thus reared are safe for human consumption.

Contrary to the observations above, few papers report some negative aspects of wastewater raised fish. Edwards *et al.* (1981) Edwards et al. (1986) ; Buras *et al.* (*op cit.*) and Polprasert *et al.* (1986) have observed in Thai and Israeli fish ponds, that faecal coliform counts in both the raw sewage and stabilization ponds exceed the World Health Organization (WHO) standard of 10^2 organisms per 100 ml of wastewater for growing crops and culturing fish for human consumption. In China prior to 1949, people who used fish cultured in wastewater lagoons receiving raw sewage (night soil) were faced with a wide occurrence of diseases of insanitation (McGarry, 1976; 1977 and FAO, 1977a; 1978). This is now declining since the nightsoil is treated before culturing fish in it.

Some common human parasites have been found in fish raised in wastewaters. It is worthwhile to enumerate the common ones. These are the bacteria *Vibrio* sp. and *Salmonella* sp. The protozoans *Entamoeba histolytica*, *Endolimax nana* and the helminths, *Ascaris*, *Ancylostoma*, *Enterobius* and *Diphyllobothrium* (Polprasert, *et al. op cit.*, McGarry, 1977; Shephard, 1977 and Yanez et al. 1986). The infective dose of the human pathogens of 10^2 organisms per 100 ml of wastewater is low, and the mere presence of the parasites in water is a potential public health problem (Buras *et al., op cit.*). Gerba *et al. (op cit.)* observed in fish ponds in Thailand that, large numbers of human enteric bacteria occur freely in the intestines and skin of fish raised in wastewater. These can be removed by keeping the fish in clean flowing water (depuration) at least for several weeks.

It has therefore been recommended that for the wastewater to be used for fish culture it has to be treated and irradiated to kill the pathogens and parasites which can infect man (MIT, 1977 and Edwards, 1980a) such as those indicated above. Oduors and off-flavours can be removed by depuration (Shuval, 1977, Edwards, 1980a and McGarry, *op cit.*). Then the fish should be properly cleaned and cooked before eating. Despite this, Buras *et al., (op cit.)* have observed that depuration is not effective when the bacteria are present in the fish flesh. Thus when eating fish raised in waste waters, strict hygienic conditions have to be adhered to.

As Edwards *et al.* (1987) have pointed out, food produced by human excreta re-use has long fed many mouths in China. Despite this fact and also the fact that night soil is used extensively to culture fish in South East Asia, its application in some parts of the world is limited by religious, cultural, social customs , beliefs and aesthetic reasons. For example in Bangladesh, direct application of human excreta to fish ponds is not practiced. In Malaysia, the Indians and the Malay neither use sewage nor piggery wastes as fish pond fertilizers (McGarry and Wing, 1986). A thorough understanding of the knowledge on the role of nightsoil and other wastes in enhancing the production of high fish yields is required. This can be achieved by enlightening the public on the usefulness of waste recycling using cheap means which have returns on the system, and on how they enhance the natural productivity on which fish yields depend.

Wastewater cultured fish can be used in many other ways if they cannot be used for human consumption in some places. The wastewaters can be used to produce (a) fingerlings for commercial growers. (b) baitfish for sport fishing (c) juvenile stages in anadromous species and (d) fish to be used in the manufacture of fresh and dry fish and animal feeds. The fish can also be used as research specimens and teaching aids in educational institutions.

1.3 OBJECTIVES OF THE STUDY.

The proposed project was carried out to study:

(i) The effects of stocking density on growth rate, condition factor and net yield of *Oreochromis niloticus* cultured in cages in wastewater lagoons.

(ii) The food composition and selection of *O. niloticus* in wastewater lagoons.

(iii) The physico-chemical and biological parameters which principally affect fish growth and natural productivity in waste water lagoons.

CHAPTER 2

2.1 THE STUDY SITE: THE LOCATION AND DESIGN OF NYALENDA WASTEWATER LAGOONS, KISUMU

The Kisumu wastewater lagoons are situated on the eastern side of Kisumu town on the eastern end of the Nyanza Gulf of Lake Victoria. They were constructed in 1976/77 to treat sewage from the south-eastern sector of the town. Fig.1 shows the drainage system and the areas of the town served by the lagoons.

There are a total of nine lagoons arranged in three rows (Fig.2). One of the lagoons in each row is the facultative (lagoons with an aerobic layer at the top and an anaerobic one below) and the rest are maturation lagoons (those which are shallow and aerated throughout the water column). The facultative lagoons F1-F3 have a mid depth area of 34,476 m^2, a liquid depth of 1.75 m and a volume of 60,334m^3. The first three maturation lagoons M1-M3 have each a mid-depth area of 12,290m^2, a liquid depth of 1.25m and a volume of 15,360 m^3 (Fig.2). The last three maturation lagoons M4-M6 have each a mid-deepth area of 12,290m^2, a liquid depth of 1.20m and a volume of 14,748m^3, (Fig.2)

The design of the lagoons constituted of a works inlet with two screens which remove all solids from the incoming wastewater. Following the screens are two constant velocity channels in which heavy grit is settled.

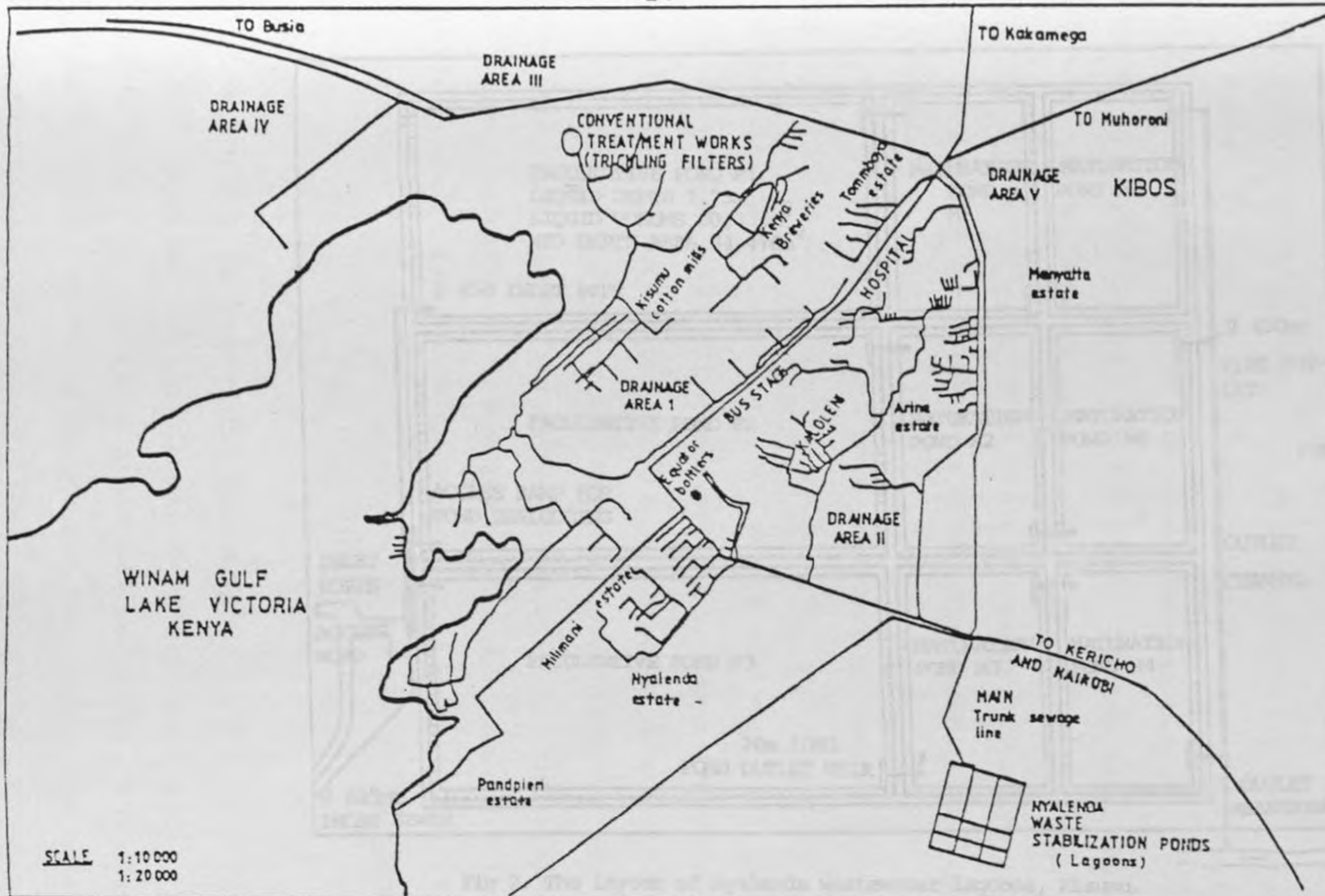

Fig 1. Map of Kisumu municipality showing the sewage drainage system into Nyalenda wastewater lagoons (modified from a report by H-P Gauff K-G · Consulting engineers, Kisumu municipality, Kenya, 1980).

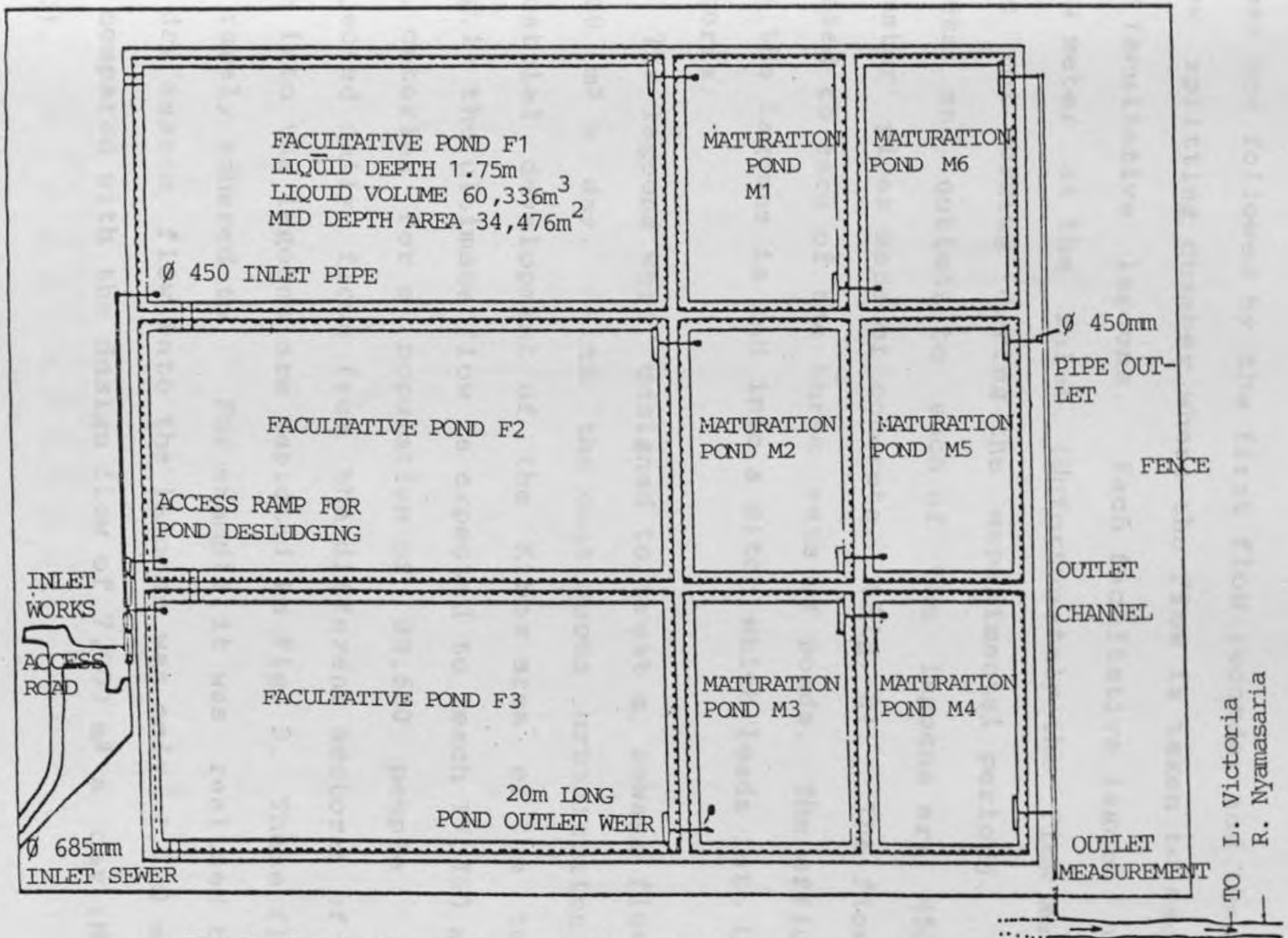

Fig 2. The layout of Nyalenda wastewater lagoons, Kisumu.
(Adapted from Ministry of Local Government, Kisumu)
Key: Ø = diameter (mm)

These are followed by the first flow recorder and then the flow splitting chamber where the flow is taken to each of the facultative lagoons. Each facultative lagoon has a flow meter at the inlet. (Unfortunately the flow meters were not working during the experimental period). The inlets and outlets to each of the lagoons are 450 mm diameter pipes made of concrete, (Fig. 2). The flow is rotated to each of the three sets of ponds. The effluent from the lagoons is led into a ditch which leads into Lake Victoria.

The lagoons were designed to treat a sewage flow of 7,000 m^3 a day. With the continuous urbanization and industrial development of the Kibos area of the town, (Fig.1) the ultimate flow is expected to reach 17,350 m^3 a day, catering for a population of 99,520 people. The projected daily flows from the different sectors of the town into the lagoons are depicted in Fig. 3. These flows are rarely adhered to. For example it was realized that the dry season flow into the lagoons was only 1,700 m^3 a day compared with the design flow of 7,000 m^3 a day (MOWD 1980).

2.2 THE METHOD OF WASTEWATER TREATMENT

The lagoons are designed to treat wastewater by natural processes involving algae and bacteria. The algae remove nutrients mainly nitrates and phosphates and others such as carbon, silicon, calcium and sulphur which can

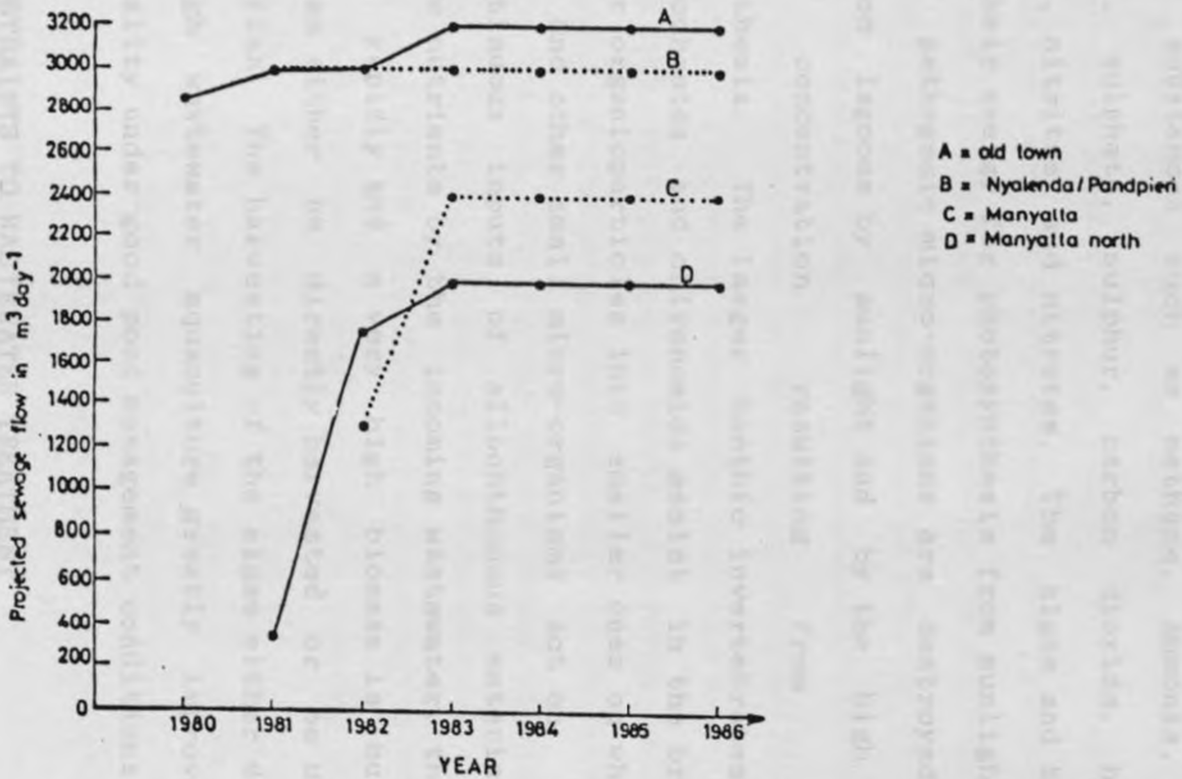

Fig 3. Projections of sewage inputs into Nyalenda waste water lagoons, Kisumu (Data source: Ministry of Local Goverment Kisumu municipality, Kenya 1980).

cause eutrophication in the receiving waters, in this case, Nyanza Gulf, Lake Victoria. The bacteria oxidize various organic materials brought in by the flow into simpler substances such as methane, ammonia, water, nitrogen, sulphate, sulphur, carbon dioxide, hydrogen sulphide, nitrites and nitrates. The algae and bacteria derive their energy for photosynthesis from sunlight.

The pathogenic micro-organisms are destroyed in the maturation lagoons by sunlight and by the high pH and oxygen concentration resulting from intense photosynthesis. The larger benthic invertebrates namely the oligochaetes and chironomids assist in the breakdown of larger organicparticles into smaller ones on which the bacteria and other small micro-organisms act on. Due to the continuous inputs of allochthonous materials and therefore nutrients by the incoming wastewater, the algae multiply rapidly and a very high biomass is built up, which can either be directly harvested or be used to culture fish. The harvesting of the algae either directly or through wastewater aquaculture greatly improves the water quality under good pond management conditions.

2.3 CONSTRAINTS TO WASTEWATER TREATMENT

Adequate wastewater treatment is essential in order to meet water quality effluent standards and also carry out successful wastewater aquaculture. This requires constant capacity flow and flushing on schedule. Any factors which lead to a reduction of wastewater flow adversely affect the natural process of wastewater treatment.

The Kisumu wastewater lagoons were constructed in an extremely flat area with the result that there is very little difference in level between the inlets into the lagoons and the outlets. This makes the flushing of the lagoons difficult particularly during periods of low flow. This therefore requires that the wastewater is pumped into the facultative lagoons in order to ensure sufficient flow for adequate wastewater treatment and flushing. With the current little difference in level, flushing is irregular and for most of the year, the effluent is of poor quality. In the dry season, this leads to the decay of algal blooms resulting in fish kills and persistent odours.

The persistent low flow throughout most of the year results from several factors: (a) a common shortage of water in the town particularly during the dry season due to little supply from the works mains and (b) loss of wastewater due to burst pipes which supply the trunk sewage line to the lagoons, evaporation and underground seepage. The loss or reduction of water volume has been observed to be large. The shortage of the flow into the lagoons was observed to persist for as long as the system stayed unrectified. For example in March 1986, the trunk sewage line into the wastewater lagoons burst some 500 m from the works inlet and all the sewage was diverted away from the lagoons into a stormwater drainage leading into Lake Victoria and later onto land. For over three weeks, there was no flow into the lagoons. This resulted in the non-flushing (non-renewal of wastewater in the lagoons), reduced water depth and volume, and poor quality effluent.

The activity of various animals mainly the predatory fishes lead to the reduction of water depth and volume in the lagoons. During the heavy rains, crawling and burrowing predatory fish notably *Clarias mossambicus* and *Protopterus aethiopicus* migrate overland from the adjacent Nyamasaria River into the lagoons. Inside the lagoons, they burrow into the bottom and the banks. This introduces other channels of water loss, that is through vertical and lateral seepage through the already destroyed watertight polythene lining at the bottom. Holes dug by such fish have been located by fishermen fishing in the lagoons and are several feet deep.

Evaporation and soil water demand also resulted in reduced water depth and volume in the lagoons. Figures 4 and 5 show that evaporation exceeds rainfall (particularly in the dry season, around the month of October when rainfall is lowest) and at the same time; soil water demand is highest. This results in the reduction of water depth and volume, persistent non-flushing, decay of algal blooms, objectionable odours and fish kills as a consequence of deoxygenation.

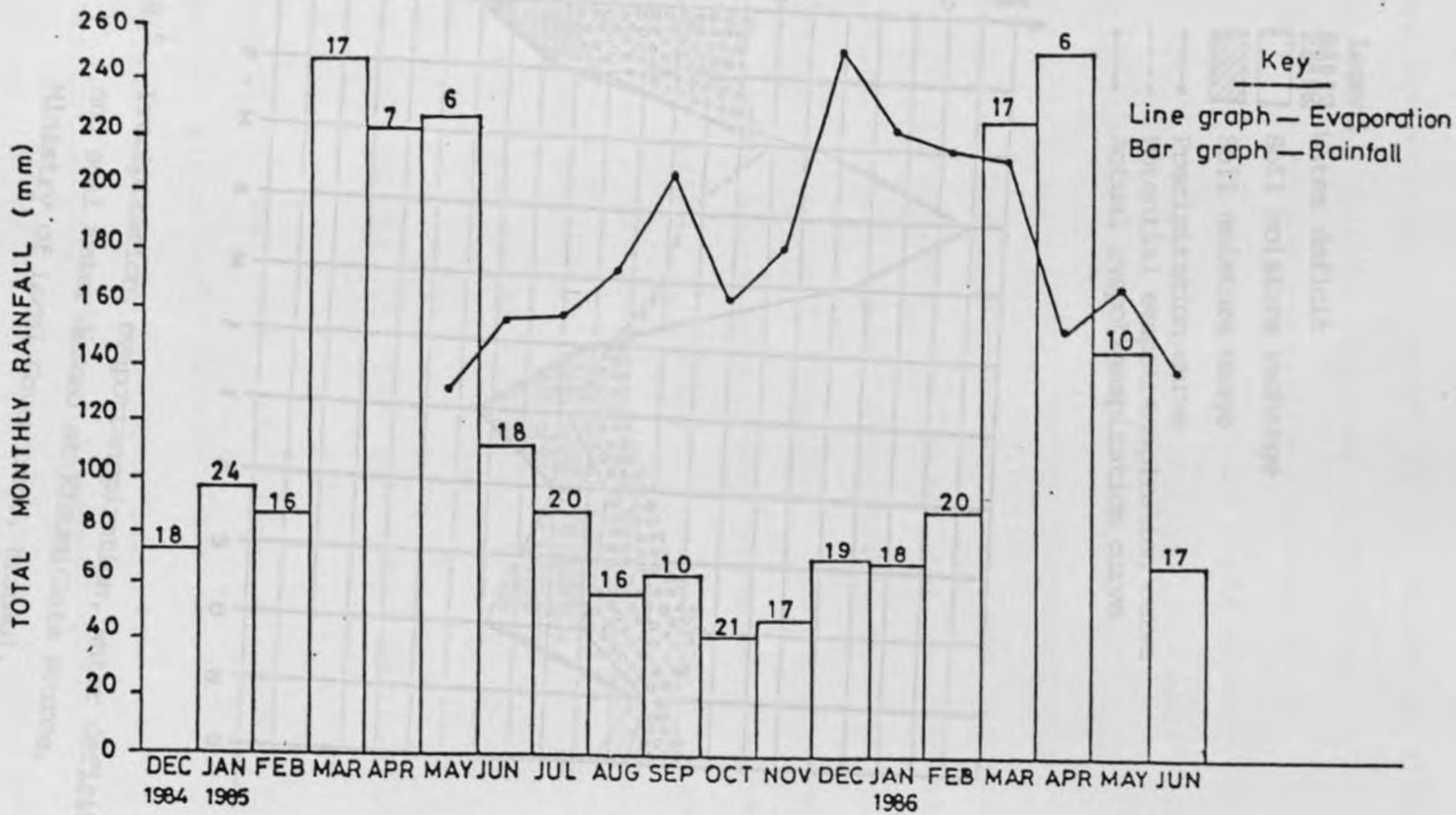

Fig 4. Total monthly rainfall and evaporation at Kisumu, Kenya (Data source: Kisumu hydrometerological station, Kenya) Numbers above the bar graphs indicate number of days without rainfall.

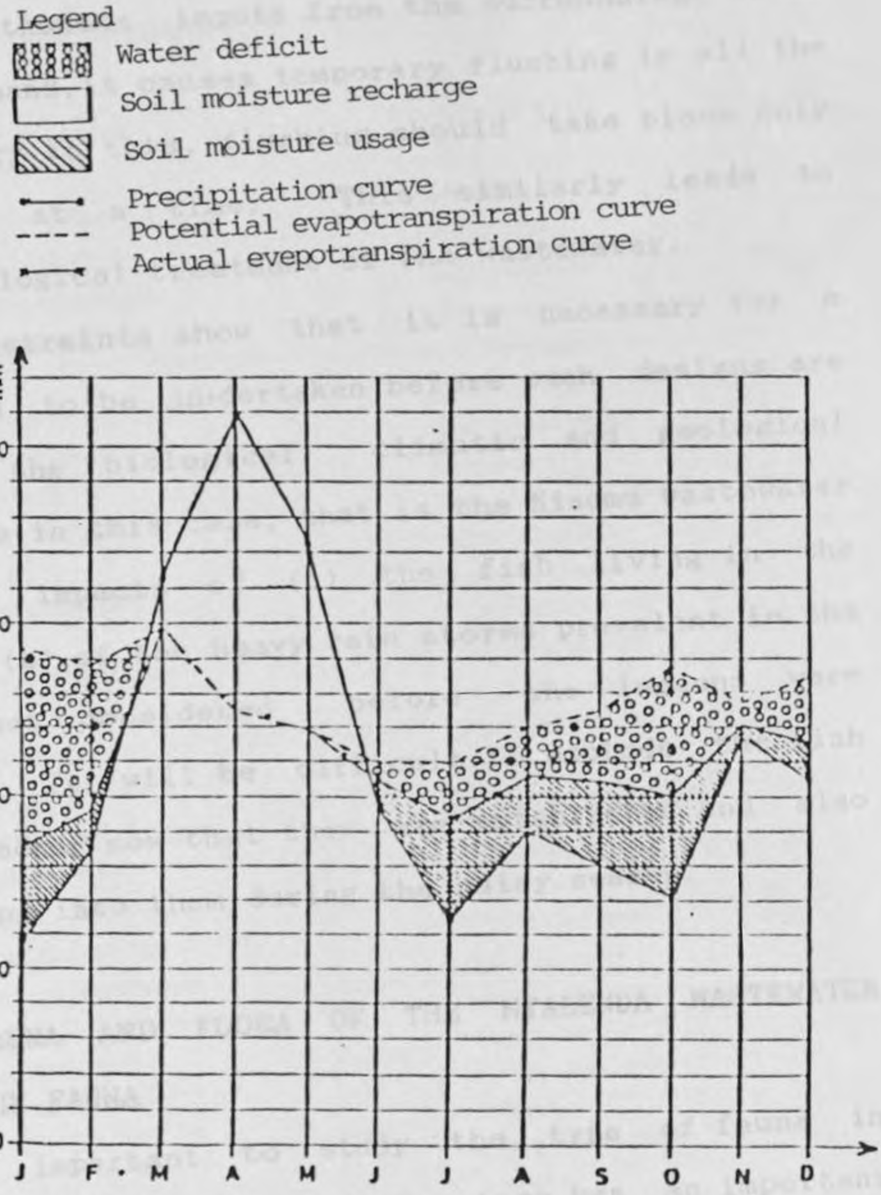

Fig.5. Precipitation, evapotranspiration, water deficit and soil water demand at Kisumu(Data source. Ministry of Local Government, Kisumu).

The flow of wastewater into the lagoons spontaneously increases during the period of heavy rains, bringing with it extra allochthonous inputs from the surrounding area. On the other hand, it causes temporary flushing in all the ponds. Contrary to this, flushing should take place only in one series at a time. This similarly leads to incomplete biological treatment of the wastewater.

Such constraints show that it is necessary for a sound research to be undertaken before such designs are put up; on the biological, climatic and geological factors, since in this case, that is the Kisumu wastewater lagoons, the impacts of (a) the fish living in the vicinity and (b) of the heavy rain storms prevalent in the area were not considered before the lagoons were constructed. It will be difficult to exclude the fish from the lagoons now that they are established and also keep migrating into them during the rainy season.

2.4 THE FAUNA AND FLORA OF THE NYALENDA WASTEWATER LAGOONS: THE FAUNA

It is important to study the type of fauna in wastewater lagoons since their presence has an important bearing on both the wastewater treatment and fish culture. The animals assist in the water treatment process by removing materials from the water, such as algae and invertebrates; they fertilize the water with their nutrient rich faeces; some of them act as intermediate and

TABLE 1 : BIRD SPECIES FOUND AT THE KISUMU WASTEWATER LAGOONS

	SCIENTIFIC NAME	COMMON NAME	RELATIVE ABUNDANCE
1.	Threskiornis aethiopicus	Sacred ibis	*
2.	Hagedashia hagedash	Hadada ibis	*
3.	Himantopus himantopus	Black winged stilt	**
4.	Gallinago nigripenis	African snipe	**
5.	Ceryle rudis	Pied Kingfisher	*
6.	Actinophilornis africanus	African jacana	**
7.	Vanellus spinosus	Spur winged plover	*
8.	Ardea cinerea	Grey heron	+
9.	Dendrocygna viduata	White faced tree duck	***
10.	Ispidina picta	Pygmy Kingfisher	*
11.	Balearica regulorum	Crowned Crane	+
12.	Ibis ibis	Yellow billed stock	+
13.	Lophaetus Occipitalis	Long crested eagle	*
14.	Haliaeetus Vocifer	African fish eagle	*
15.	Egretta alba	Great white eggrett	*
16.	Ardeola valloides	Squaco heron	*
17.	Halicycon leucocephala	Grey headed kingfisher	*
18.	Egretta garzetta	Little egrett	**
19.	Charadrius venustus	Kittlitz's plover	***
20.	Anas erythrorynchos	Red peaked duck	***
21.	Anastomus lamelligerus	Open bill stock	*
22.	Pelecanus onocrotalus	White pelican	+
23.	Plegadis falcinellus	Glossy ibis	*
24.	Aythya erythrophthalmia	African porchard	**
25.	Recurvirostra avosetta	Avocet	+
26.	Thalasiornis leuconotus	White backed duck	*
27.	Scopus umbreta	Hamekop	*

Key

+	<10 Birds	+	10 - 100
**	100 - 300	+++	> 300

definitive hosts of important fish parasites; they compete with the fish for important resources such as food, space and dissolved oxygen, while some act as fish predators. The Kisumu wastewater lagoons depict a good example of the above interractions.

Amongst the larger fauna at the lagoons are the birds and fish. Data from casual observations on the birds found at the lagoons on the course of the execution of the project are presented in Table 1. Of the birds, the most abundant are wild ducks *Dendrocygna viduata* and *Anas erythrorynchos* which for most of the year number over 600. They swim and defaecate in the water; their nutrient-rich faeces acting as a fertilizer. At the same time, they feed on the abundant algae and in this way assist in the reduction of the algal biomass at the lagoons and thus assist in the water treatment process. The presence of large numbers of wild ducks (*Dendrocygna viduata* and *Anas erythrorynchos*) in the lagoons supports the idea of integrating the three aspects, that is, wastewater treatment, fish culture and duck farming. Other bird species which are abundant for most of the year are the plovers (*Charadrius venustus*). The latter are less frequent and occur in large numbers during the July-August rains. Of significance to fish culture is the occurrence of some fish eating birds namely the white pelican, *Pelecanus onocrotalus*, the grey headed kingfisher, *Halicycon leucocephala*, the African fish eagle, *Haliaeetus* *vocifer*, the pygmy kingfisher, *Ispidina picta* the pied kingfisher Ceryle rudis and the grey heron, *Ardea cinerea*. Their occurrence at the lagoons however is low and seasonal. Table 1 shows the different bird species found in the lagoons and their relative abundance.

The other fauna in the wastewater lagoons include various fish species which invade the lagoons from the lake and adjacent rivers and swamps during the rainy season. They do this by crawling overland and through the weirs from the effluent channel. The fishes include *Protopterus aethiopicus*, *Clarias mossamibucus*, *Oreochromis niloticus*, *Ctenopoma muriei*, *Labeo victorianus*, small *Barbus sp.*, *Haplochromis* sp. and one species of the small Mormyridae. The first three occur in all the lagoons including the facultative ones. The others are restricted to the maturation lagoons only for a short period during the wet season after which they disappear completely from the lagoons. This may be due to predation by *Clarias mossambicus* and *Protopterus aethiopicus* and predatory birds or due to lack of ability to adapt to the lagoon environment as the water quality deteriorates towards the dry season.

The fact that the three species namely *P. aethiopicus*, *C. mossambicus* and *O. niloticus* inhabit such adverse habitats as the facultative lagoons suggests that they are suitable candidates for wastewater aquaculture on a polyculture basis.

The other fauna which occur in the wastewater lagoons include the tortoises (Testudinidae) which also occur in all the ponds, but are more abundant in the facultative ones, monitor lizards (*Varanus* sp) and some larger aquatic hemiptera such as the Notonectidae and Belostomatidae.

Apart from the biological interractions mentioned, the animals also serve to disperse the algae and zooplankton and probably other micro-organisms into and out of the lagoons. It is therefore not surprising to find that the plankton in the lagoons bears a striking similarity with that of the adjacent waters and the lake. For example the algal assemblages constituting of *Microcystis* sp., *Anabaena* sp., *Scenedesmus* sp., *Merismopedia* sp. and the diatoms *Nitzschia* sp., *Diatoma* sp., *Cymatopleura* sp., *Melosira* sp., and *Navicula* sp., both occur in Lake Victoria, the lagoons and the adjacent waters (pers. obs.).

2.5 THE FLORA

Apart from the phytoplankton which are discussed in detail in Chapter 3 and presented in appendix 1, the other flora include *Carex* sp. and *Ipomea aquatica var reptans* both found along the edges of the lagoons. The rapid proliferation of these plants attests to the presence of high nutrient concentrations in the water.

CHAPTER 3

PHYSICO-CHEMICAL AND BIOLOGICAL PARAMETERS

3.1 INTRODUCTION

The physico-chemical and biological parameters of a water body determine its fertility. For example, turbidity due to suspended colloidal materials reduces light penetration into the water column and adversely affects primary productivity. They are therefore in this way related to fish growth and yields. This chapter is devoted to the study of the physico-chemical parameters in Nyalenda wastewater lagoons, Kisumu, in relation to natural productivity and the survival of *Oreochromis niloticus* (Linnaeus). The wastewater lagoons are considered as shallow water bodies and since there are few studies on this topic in Kenya, their ecology is compared with the one of sewage ponds in Kenya and India and shallow waters of East and Central Africa.

Shallow waters are known to have a small buffering capacity to environmental changes (Williams and Ganf, 1981). For example, diurnal fluctuations of some physico-chemical parameters such as dissolved oxygen often exceed seasonal fluctuations. A detailed understanding of the variation of the physico-chemical and biological parameters in shallow waters in relation to fish survival is therefore necessary. Fish culture in wastewater lagoons therefore requires detailed information on (a) the interrelationships between the physico-chemical and biological parameters and their effects on the physiological needs of the cultured species (b) knowledge of pond management techniques such as provision of sufficient and regular wastewater flow and flushing, control of the growth of aquatic macrophytes and physical aeration (c) the type of species to be cultured and (d) the role played by algae and other aquatic life in fish survival and growth.

3.2 LITERATURE REVIEW

3.2.1 PHYSICO-CHEMICAL PARAMETERS

Tilapia sp are known to tolerate low dissolved oxygen concentrations (Lowe-McConnell 1959, Balarin and Haller, 1982) and sometimes can survive under anaerobic and dessicated conditions (Kutty, 1972; Majid and Babiker, 1975 and Donelly, 1978). However, fish kills result from low dissolved oxygen concentrations resulting from decaying organic matter being suspended by wind action which (i) consumes too much oxygen in the water column and (ii) clogs fish gills, thus suffocating them, or algae which consumes too much oxygen at night (Morgan, 1972; Leveque, 1979 and Kalk *et al.*, 1979). The lower lethal oxygen concentration for tilapia is about 3.0 mgl^{-1} though there are reports that they can survive at concentrations lower than this (Balarin and Haller, 1982). At such concentrations, the growth of tilapia (Alison *et al.*, 1976; Andren, 1976 and Coche, 1976) and feeding (Gruber, 1962; Payne, 1970 and Balarin and Haller, 1979) are adversely affected. Low dissolved oxygen conditions lead to mass fish kills, hence losses from fish cages and farms. It is therefore important to ensure that anaerobic or semi-anaerobic conditions do not develop in fish culture systems.

The ability of tilapia to survive in waters with low dissolved oxygen concentrations is due to the fact that their haemoglobin can load oxygen at low tensions and that the fish has a low metabolic rate. This has been observed in *Sarotherodon macrochir*, *S. esculenta* and *Orechromis mossambicus* (Perez and Maclean, 1975). The lethal concentrations of free carbon dioxide in water for tilapia are above 100 mgl^{-1} (Fish, 1956; Alabaster *et al.*, 1957 and Alabaster and Lloyd, 1982). Values above this cause distress and irreparable haemoglobin damage. Often, the cause of free carbon dioxide being lethal at concentrations below 100 mgl^{-1} is low pH (Jordan and Lloyd, 1964). This enhanced lethality is due to discharge of acid wastes into hard water which result in the release of carbon dioxide. This in turn becomes toxic at high concentrations (Alabaster and Lloyd, 1982).

The upper tolerance limits of temperature for most tilapia is 42°C for example *Oreochromis niloticus* and *Oreochromis mossambicus* (Balarin and Haller, 1982). The range for growth is 20 - 35°C, while the optimum temperature range is 28 - 30°C, for example for *O.*

niloticus (Balarin and Haller, 1982), *O. mossambicus* and *Sarotherodon hornorum* hybrid (Sufern *et al.*, 1978). It has been found that the tilapia exploit temperature fluctuations to enhance growth (Caulton, 1978). This theory has been put forward to explain diurnal migrations of the tilapia observed by (Welcomme, 1967; Moriarty and Moriarty, 1973a and Brutton and Boltt,1975). Despite these reports caged fish have little opportunity to exploit temperature fluctuations to enhance their growth as they are confined.

The lower lethal limit of pH is 5.0 below which the appetite is suppressed (Balarin and Haller, 1982), fish mortalities can occur and the natural productivity of the water is greatly reduced (Huet, 1975). In general, the entire growth of the fish is affected (Bardach *et al.*,1972 and Fruginin, 1975). Alabaster and Lloyd (1982) have noted that the suitable range of pH for any fishery is 5 - 9, whereas the one for maximum productivity is 6.5 - 8.5. The presence of other chemicals in the water makes this pH range toxic. Gruber, (1962) notes that higher pH stimulates feeding and that the species can tolerate pH as high as 12 (Reite *et al.*, 1973). Contrary to this, laboratory data show that the pH range 9 - 10 is lethal. Alabaster and Lloyd (1982) note the upper lethal range to be 9.2 - 10.8. Such high pH causes haemoglobin damage and impairs respiration (Huet, 1975).

Tilapias have been found to be tolerant to high alkalinity of the order 700 - 3000 mg $CaCO_3$ l^{-1}. At concentrations higher than this range, corneal damage results (Balarin and Haller, 1982).

Turbidity due to larger particle size in water causes gill damage and retards the ventilation efficiency of the fish (Roberts, 1979). The tilapia are renowned for their resistance to high turbidity range; as high as 1300mgl^{-1} (Morgan, 1972).

The toxic portion of ammonia in water is the unionized form, the NH_3. This portion increases in concentration with increasing temperature and the maximum tolerable limit by the tilapia is 3.4 mgl^{-1} (Redner and Stickney, 1979). At low dissolved oxygen concentrations and handling conditions, the lethal limit of unionized ammonia is 0.5 mgl^{-1}. Above this concentration, gill damage and mortality occurs (Balarin and Haller, 1979 and Muir and Roberts, 1982). The common sources of ammonia are sewage, agricultural and industrial effluents.

The biological breakdown of wastes in the sediments and to some extent in the water column releases other toxic materials such as nitrates. This is common in closed systems such as fish ponds. The maximum tolerable limit of nitrates by tilapia is 0.45 mgl^{-1} (Balarin and Haller, (1982).

3.2.2 NUTRIENTS

Nutrients are those substances which are required by algae and macrophytes to promote growth. They can be grouped into two categories: (a) those which are required in relatively larger amounts, the macronutrients and (b) those which are required in minute quantities, the micronutrients. The former constitute nutrients such as carbon, hydrogen, oxygen, nitrogen, potassium, magnesium, sulphur and phosphorus. The latter constitute nutrients such as iron, manganese, copper, zinc, boron, sodium, molybdenum, chlorine, vanadium and cobalt. Despite the fact that the micronutrients are required in trace amounts, they are just as essential as are the macronutrients. Therefore if they are absent or occur in even more minute quantities than are required for algal or plant growth, they can limit primary productivity to the same extent as the micronutrients (Odum, 1963). Thus nutrients must be available in sufficient quantities in the environment in order to promote primary productivity. Most nutrients however, such as carbon, sulphur, boron and chloride are always found in sufficient quantities in water (Schindler, 1971, 1974; Moss, 1980 and Welch, 1980). This is due to the fact that they are abundant in the rocks and soils from which they are derived. But some nutrients such as nitrates and phosphates are scarce either in the readily utilisable form in the case of both nutrients or due to low occurrence in the atmosphere in the case of phosphates. (Vallentyne, 1974; Canfield and Buchman, 1981 and Beveridge, 1984a). The two nutrients severely limit primary productivity and therefore fish production in water bodies.

The algal requirements for nitrogen are 16 times greater than those for phosphates as calculated by Welch (1980) and yet phosphates are in higher demand than nitrates. This is due to the fact that the phosphates (PO_4-P) readily react with other elements in nature (Fitzgerald,1970; Edzwald *et al* ., 1976; Furness and Breen, 1978; Hoyer and Jones, 1983) such that the utilisable form is not available. It adsorps on the surface of particulate organic matter and settles down to the bottom (Welch, 1980). These factors make it more limiting to primary productivity in natural waters other than those found in phosphorus rich volcanic soils. Earlier findings have shown that phosphorous is the major nutrient limiting primary productivity in the temparate lakes, while nitrogen plays the same role in the tropics (Goltermam,1975 and Kalff,1983). For example, fertilization experiments with nutrients carried out by Goldman (1960), Schindler (1971, 1974), Schindler and Fee, (1974) and Roberts and Southhall (1977), showed that phosphorus were more limiting than, nitrogen in temperate lakes. Recent findings contradict the above hypothesis. For example, Kalff (1983) notes that in a West Africa lagoon, there was a primary phosphorus limitation on primary productivity followed by an increasing nitrogen limitation during the dry season. Similarly, recent temperate studies have shown that there is highest phosphorous demand in the first half of the growing season, followed by an increasing nitrogen demand there after. Henry *et al* (1984) give examples of African fresh waters in which there is an alternating demand for both nutrients. For example, he notes that in the Roodeplaat and Vaal dams in Zimbabwe (Formerly Rhodesia), nutrient limitation by either nitrogen or phosphorous is seasonal. Muthuri (1985) has noted that nitrogen, phosphorus and sulphur can be at any given time the nutrients limiting primary productivity in African lakes. Beveridge (1984b) has discussed the importance of phosphorus in the metabolism and growth of fish.

3.2.3 BIOLOGICAL PARAMETERS

Primary productivity in natural waters depends on the availability of nutrients and solar energy. Fish production to some extent and sometimes entirely depends on primary productivity. Scientists working on the productivity of various water bodies have found that there is a positive relationship between fish yields and productivity (Hrbacek, 1969; Henderson *et al.*, 1973, Oglesby 1977; 1982; McConnell *et al.*, 1977; Heckey et al., 1981; Marten and Polovina, 1982 and Adams *et al.*, 1983). Generally the higher the productivity the higher the fish yields. The nutrients required in order to sustain high algal biomass are carbon, nitrates and phosphates (Talling *et al.*, 1973; Melack and Kilham, 1974; Vivier, 1977a;

Melack, 1979a and b). When occurring in sufficient quantities in water, sudden depletion of the nutrients is always associated with high algal biomass (Prowse and Talling 1958 and Ganf, 1974).

High algal biomass is usually encountered in shallow waters. In such situations, productivity is limited by high attenuation of light intensity down the water column by (a) dissolved organic and particulate organic matter and (b) biogenic turbidity. This greatly reduces the trophogenic zone and therefore limits primary productivity. The zone is further limited by photo-inhibition in which photosynthesis is reduced at the surface by oxidative destruction of algal enzymes by high incident solar radiation (Steeman, 1962 and Steeman and Jorgensen, 1962).

An important factor which has received little research attention is the contribution of photosynthetic bacteria towards total annual primary production. It has been found that bacterial photosynthesis contributes significantly to the annual production in eutrophic waters, for example in lakes with high inputs of allochthonous materials (Wetzel, 1973). In some cases, it has been found to exceed productivity of algae and macrophytes, for example in dimictic lakes (lakes with two seasonal periods of free circulation) and meromictic lakes (lakes which are permanently stratified as a result of chemical gradients in the hypo-and epilimnial waters)

(Odum, 1971). In lakes rich in hydrogen sulphide, particularly stagnant ones, they have been found to contribute about 25% of the total photosynthetic production (Wetzel, 1975).

3.3 MATERIALS AND METHODS

3.3.1. PHYSICO-CHEMICAL PARAMETERS

Physico-chemical parameters were monitored in a tertiary wastewater lagoon in which *Oreochromis niloticus* was being cultured. Measurements of temperature, pH, alkalinity, dissolved oxygen concentration, Secchi disc depth, conductivity and photosynthesis were conducted fortnightly for 1 1/2 years. Other measurements on nitrates (NO_3-N), phosphates (PO_4-P) and chlorophyll *a* concentration were measured similarly for 1 1/4 years. Further measurements of diel temperatures, light intensity and dissolved oxygen concentrations were measured during the months of August, October and December 1985.

Integrated samples collected with a plastic tube 2 m long by 2 cm wide (with a device attached to a string to close it when the sample has been enclosed) were used in the measurements of alkalinity, pH, conductivity, nitrates phosphates and chlorophyll *a* concentration. Temperature was measured using a mercury thermometer with a scale 0 - 50°C. Light intensity measurements were done by a photometer model Skye SKP 200. Conductivity was measured using a conductivity meter model Horizon 1484-10 at various temperatures, pH was measured using a pH meter, Cole Parmer Digi-Sense model 5985-40. The conductivity was converted to that at 25°C using the relationship:

$$K_{25^\circ c} = \text{Antilog} (\log K_t (\log 1.023) 25-t) \ \mu Scm^{-1}$$

(Mackereth *et al.* 1978). This is because conductivity readings are converted to that at 25°C to provide a basis for comparison for all the water bodies world wide.

Dissolved oxygen concentration was measured using the Azide modification of the Winker method as described in (APHA, 1985). To a lagoon water sample in a 300 ml bottle, 2 ml of manganese sulphate was added followed by 2 ml alkali-iodide-azide reagent. The bottle was stoppered and the contents mixed by gentle inversion. After the settlement of the precipitate and reshaking, 2 ml concentrated sulphuric acid was added, followed by mixing by gentle inversion until all the precipitate dissolved. Two hundred ml of this sample was titrated with a starch indicator using a 0.0250 N sodium thiosulphate solution to the end point (This volume was corrected for the reagents added by adding 3 ml to 200 ml.). Diel dissolved oxygen concentrations were measured using a calibrated oxygen meter model YSI 15 B. This method is better suited for diel measurements than the Winkler method because (a) the taking of many water samples on an hourly basis, causes considerable mixing particularly in shallow and small water bodies and (b) the use of the oxygen meter enables the readings to be taken rapidly, and the time interval between each set of readings to be kept constant at one hour. When the Winkler method is used, the readings taken do not represent a true picture of the distribution of oxygen down the water column, because of the disruption of the natural oxygen regime and the possibility of not being able to sample every hour, due to time involved in sampling and titrating many water samples. Total alkalinity was measured using phenolphthalein - methyl orange titration method (APHA, 1985). To 50 ml lagoon water, 0.1 ml of methyl orange was added. The sample was then titrated with 0.02N standard hydrochloric acid solution to the end point. The total alkalinity in the sample was calculated using the formula:

$$\text{Total alkalinity} = \frac{B \times N \times 50{,}000}{\text{ml sample}} \text{ (APHA,1985)}$$

Where B = volume (ml) of titrant used and N = normality of the acid (=0,02N.). The alkalinity readings were converted to meq l^{-1} by dividing mg$CaCO_3$ l^{-1} by 100. Free carbon dioxide was calculated from alkalinity (in meq l^{-1}) and pH and a free carbon dioxide factor "f2" and $[OH^-]$ obtained from a pH and alkalinity plot, (Talling 1985):-

$$\text{Free } CO_2 = f_2 \times (\text{alkalinity} - [OH^-]\ \mu \text{ mol } l^{-1}.$$

The Secchi disc depth was measured using a 25 cm diameter white wooden disc.

3.3.2 NUTRIENTS: NITRATES AND PHOSPHATES

Samples for the measurements of nitrates (NO_3-N) and phosphates (PO_4 - P) were filtered through a Whatman GF/C glass microfibre filters of diameter 47 mm using a vacuum pump at gentle pressure.

3.3.2.1 NITRATES

The nitrates were determined using the method described by Zahradnik (1981). A 1.0 litre stock solution containing 0.722g potassium nitrate was prepared (this solution contains 0.1 mg (NO_3 - N) ml^{-1}. Appropirate dilutions of this were made using distilled water to produce standards of 0.2, 0.4, 0.8, 1.6, 2.0, 2.4, 2.8, 4.0, 6.0, 8.0 and 10 mg NO_3 - N ml^{-1}

To 25 ml of filtered lagoon water, 1 ml sodium salicylate was added and the contents evaporated to dryness in an oven overnight at 100°C. The residue formed was dissolved in 1 ml concentrated sulphuric acid while the flask was still warm. This was followed by 7.0 ml sodium tartrate solution. The sample was made up to 1 litre by adding distilled water. After the development of a yellow colour, the absorbance of the sample was determined at 420 nm in 4cm cuvettes using pye-unicam spectrophotometers models SP6-250 and SP600 series 2. The standards were treated in the same way and a standard curve of concentration against the absorbances was plotted, from which the concentrations of analysed samples were determined using their respective absorbances.

3.3.2.2 PHOSPHATES

The concentration of phosphates in the samples was determined using the stannous chloride method described in APHA (1985). Standard solutions of 0.5, 1.0, 2.5 and 10 mg PO_4-Pl^{-1} were prepared and their absorbances determined using pye-unicam spectorphotometers models SP6-250 and SP600 series 2. A standard curve was plotted of the absorbances versus the concentrations. To 100 ml of filtered lagoon water, 1 drop of phenolphthalein was added to check for colour development. This was followed by 4.0 ml of molybdate reagent and then 0.5 ml stannous chloride solution. After a period of 10-12 minutes, the absorbance of the samples was determined at 690nm in 4cm cuvettes using pye-unicam spectrophotometers. The concentrations of all the samples which were analysed were determined from the standard curve using their respective absorbances.

3.4 BIOLOGICAL PARAMETERS: PHOTOSYNTHESIS

Photosynthesis rates were measured using the light and dark bottle technique described in Lieth and Whittaker (1975). Samples were taken using a Van-dorn bottle, initially just below 0 cm, then at 50 cm and 80-110 cm depths. During the measurements, it was realized that the euphotic zone does not extend even up to 50 cm deep. Further samples were then taken at 9, 20, 40, 60, 80, and 100 cm in the months of August, October and December 1985, and in February, April and June 1986. The light and dark bottles were incubated at the depths where the samples were taken from for a period of one hour. Concentrations of oxygen in the incubated and the initial bottles were determined using the azide modification of the Winkler method. Photosynthetic rates were calculated using the formulae presented in Lieth and Whittaker (1975):-

Net Photosynthesis (NP) = LB - IB $mgO_2 l^{-1} hr^{-1}$

Gross Photosynthesis (GP) = LB - DB " " "

where LB = Light bottle; IB = initial bottle and DB = dark bottle.

3.4.1. CHLOROPHYLL a CONCENTRATION

The chlorophyll a concentration was determined using the method described in Jones (1979) and Dick and Pitwell (1980). Integrated samples of lagoon water were filtered through a Whatman GF/C microfibre filter paper. The filter with the filtered algae was then inserted into a test tube containing 14 ml analytical grade methanol and placed in a water bath under subdued light. After the chlorophyll had been extracted in boiling methanol, the filter paper was removed and the remaining chlorophyll on it was squeezed into the test tube using a pair of forceps. The extract was then centrifuged at 3,500 revolutions per minute for 7-10 minutes using a Gallen-Kamp junior centrifuge. The clear chlorophyll overlying a precipitate was decanted into a 4 cm cuvette and after cooling in subdued light for 10 minutes, the absorbance of the chlorophyll was determined at 665 and 750 nm using pye-unicam spectrophotometers models SP6-250 and SP600 series 2. The concentration of chlorophyll *a* was calculated using the formula:

$$\text{Chl } a = \frac{Ve}{Vs} \cdot \frac{f}{l} \cdot A \text{ (Jones, 1979).}$$

Where Ve = total volume of solvent extract in ml,

Vs = Volume of the sample in litres,

A = Absorbance at 665nm corrected for that at 750nm, that is A665-A750

l = the pathlength of the cuvette used in cm and

f = a factor equivalent to the reciprocal of the specific absorption coefficient multiplied by 10^3.

Absorbances for calculating the relative degradation index of chlorophyll were taken at 410nm and 420nm. The index was calculated using the formula: A420/A410, that is, absorbance at 420 nm divided by that at 410nm. The amount of oxygen per μg chlorophyll *a* produced by the algae per hour (specific activity) was calculated using the formula:

$$\text{Specific activity} = \frac{mgO_2 l^{-1} hr^{-1}}{\mu g \text{Ch } a \, l^{-1}} \text{ (Talling, 1985)}$$

3.5 RESULTS

The data on the physico-chemical and biological parameters at the Nyalenda wastewater lagoons, Kisumu, are presented in Tables 2 and 3 and Figs. 6-10. The changes

TABLE 2 : THE PHYSICO-CHEMICAL AND BIOLOGICAL PARAMETERS AT NYALENDA WASTEWATER LAGOONS, KISUMU, FOR THE PERIOD DECEMBER 1984 - JUNE 1986

PARAMETER	WET SEASON			DRY SEASON			ANNUAL		
	RANGE	MEAN	DIFFERENCE	RANGE	MEAN	DIFFERENCE	RANGE	MEAN	DIFFERENCE
Dissolved Oxygen concentration $(mgl_2 l^{-1})$	3.6-9.5	6.64±0.232	5.9	4.5-7.2	5.833±0.163	2.7	3.6-9.5	6.3±0.21	5.9
Diel dissolved Oxygen concentration $(mgl_2 l^{-1})$	0.6-7.6	4.319±0.149	7.0	0.5-6.9	3.843±0.147	6.4	0.5-7.6	4.1±0.63	7.1
pH	7.4-9.7	9.148±0.143	2.3	7.7-9.15	8.26±0.091	1.45	7.4-9.7	8.7±0.66	2.30
Monthly subsurface temperature (^{o}C)	26.3-31.3	28.05-0.243	5.0	28.2-31.5	29.41±0.22	3.3	26.3-31.3	28.7±0.22	5.2
Diel subsurface temperature (^{o}C)	23.8-33.8	27.51±0.413	10.0	21.2-32.6	26.769±22.18	11.4	21.2-33.8	27.01±0.24	12.6
Alkalinity $(mgCaCO_3)$	130-480	267.45±22.30	350	182-480	338.28±22.18	298	130-480	299.7±22.61	350

TABLE 2: Contd.

PARAMETER	RANGE	MEAN	DIFFERENCE	RANGE	MEAN	DIFFERENCE	RANGE	MEAN	DIFFERENCE
Free Carbon dioxide (umol l^{-1})	0.175-712.8	76.192± 45.051	712.625	5.172-533.4	114,65±32.51	528.228	0.175-712.8	94.8±38.15	712.625
Secchi-disc depth (cm)	9.0-13.5	11.48±0.29	4.5	9.0-12.0	9.82±0.21	3.0	9.0-13.5	10.7±0.31	4.5
Diel light intensity (μmol $m^{-2}s^{-1}$)	11.5-217x103	120.48±0.96	14.4-200.2		120.6±19.030	185.8	0-217	17.06±8.68	217.0
Conductivity (μScm^{-1})	295.801-1224.616	518.05±75.79	928.815	446.684 - 1367.73	685.728±59.32	921.045	295.801 - 1367.73	543.2±56.92	928.815
Nitrates (NO_3 - N) (mgl^{-1})	0.76-7.6	3.03±0.47	6.84	4.97-7.15	6.213±0.187	2.18	0.76-7.6	4.306±0.58	6.84
Phosphates (PO_4 - P) mg^4l^{-1})	0.85-6.8	2.74±0.41	5.95	2.8-5.62	4.27±0.28	2.82	0.85-6.8	3.349±0.41	5.95
Chlorophyll a concentration (ugl^{-1})	426.3.83-1286.6	1042.118± 55.12	860.217	617.16±877.785	713.24±29.86	260.625	426.383-1286.6	926.8±65.996	860.217
Gross phytosynthesis ($mgO_2m^{-3}h^{-1}$)	933.33-2460	1695.19± 133.4	1526.67	480.0-1766.6	941.67±97.78	1286.67	480-2460	1393.778± 114.61	1980

TABLE 2: contd

PARAMETER	RANGE	MEAN	DIFFERENCE	RANGE	MEAN	DIFFERENCE	RANGE	MEAN	DIFFERENCE
Net Photo-synthesis ($mgO_2m^{-3}h^{-1}$)	233.3-1760	1077.41 ± 105.57	1526.67	233.3-1266.67	552.78±93.74	1033.34	233.3-1760	867.56±86.78	1526.67
Specific activity ($mgO_2m^{-3}h^{-1}$ μg chla l^{-1})	0.837-2.242	1.202±0.141	1.405	0.5-1.424	1.649±0.093	0.924	0.50-2.424	1.55±0.099	1.924
Chlorophyll a degradation index	0.963-1.o4	1.071±0.021	0.177	0.725-1.13	0.963±0.06	0.405	0.7301.14	1.024±0.03	0.41
(NO_3-N/PO_4-P) ratio	0.51-1.56	1.113±0.103	1.05	1.02-2.17	1.532±0.173	1.15	0.51-2.17	1.281±0.104	1.66

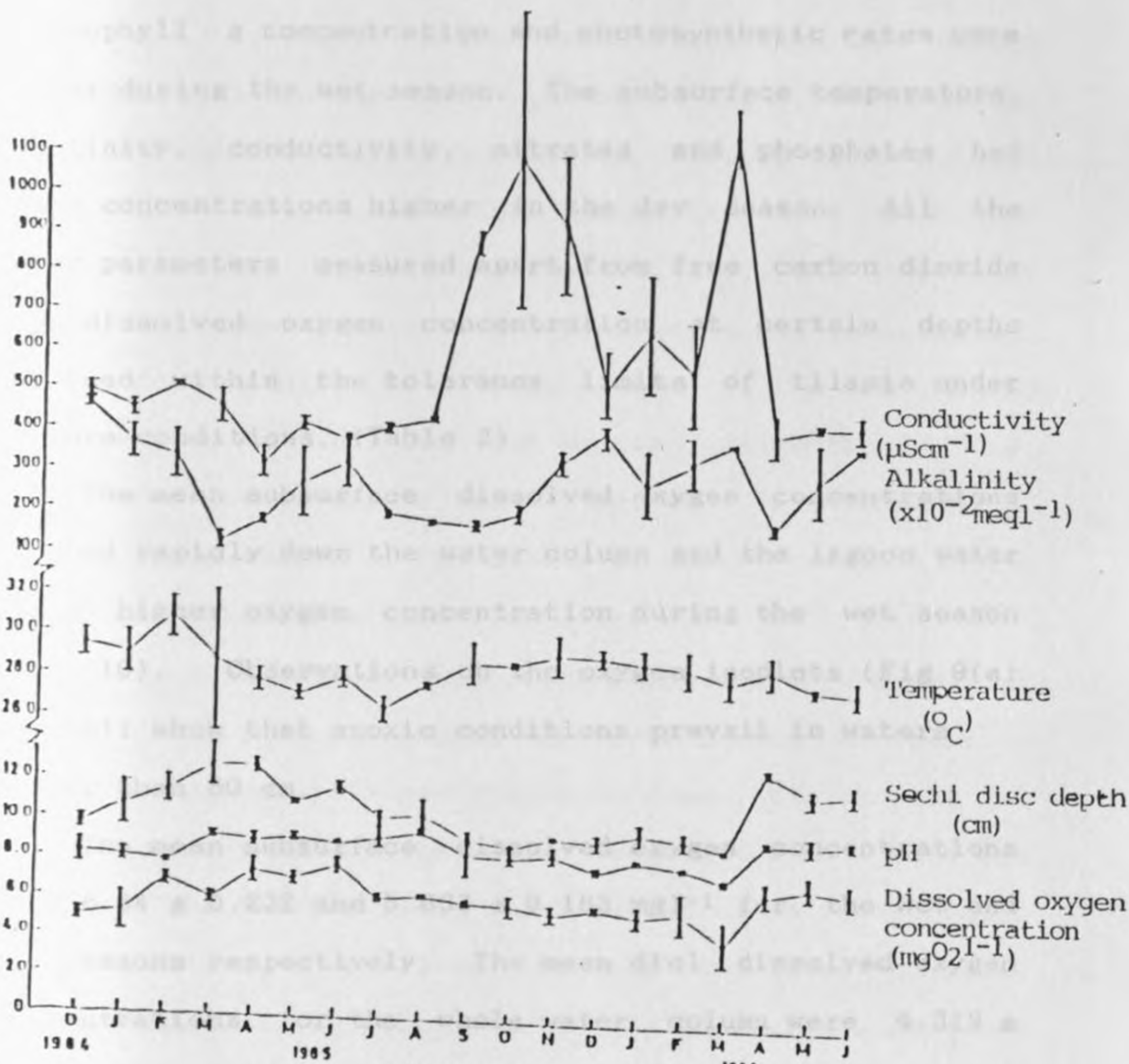

Fig 6. Mean monthly dissolved oxygen concentration, pH, Sechi disc depth, Temperature, Alkalinity and Conductivity in Nyalenda wastewater lagoons, Kisumu.

in diel dissolved oxygen concentration and diel temperatures were higher than seasonal changes. The pH, free carbon dioxide concentration, Secchi disc depth, chlorophyll *a* concentration and photosynthetic rates were higher during the wet season. The subsurface temperature, alkalinity, conductivity, nitrates and phosphates had their concentrations higher in the dry season. All the other parameters measured apart from free carbon dioxide and dissolved oxygen concentration at certain depths remained within the tolerance limits of tilapia under culture conditions, (Table 2).

The mean subsurface dissolved oxygen concentrations dropped rapidly down the water column and the lagoon water had a higher oxygen concentration during the wet season (Fig. 10). Observations on the oxygen isoplets (Fig 9(a) and (b)) show that anoxic conditions prevail in waters deeper than 80 cm.

The mean subsurface dissolved oxygen concentrations were 6.64 ± 0.232 and 5.833 ± 0.163 mgl^{-1} for the wet and dry seasons respectively. The mean diel dissolved oxygen concentrations for the whole water column were 4.319 ± 0.149 and 3.843 ± 0.147 $mgO_2\ l^{-1}$ for the wet and dry seasons respectively. The lower oxygen concentrations during the dry season concurred with dense algal blooms, reduced water depth, change in water colour (suggesting a change in the algal species), odours and reduced wastewater flow into the lagoons. On one occasion in

October 1985, during the dry season, the phenomenon coincided with fish kills. The same phenomenon was observed during a rainy period in November 1985. This was attributed to dense algal crops depleting the oxygen concentration in the water column at night. The depths with the optimum oxygen levels for tilapia under culture conditions were 43.8 ± 3.305 cm and 24.2 ± 2.596cm, for the wet and the dry seasons respectively. The depths at which the oxygen concentration fell below the lower lethal limit (for tilapia) of 3.0 mgl^{-1} were 71.7 ± 3.6 cm and 75.8 cm for the dry and wet seasons respectively (Fig. 10). Both these depths account for only less than 63.2% of the water column. The dissolved oxygen concentrations exhibited little variance (Table 2).

The mean annual subsurface temperature was 28.7 ± 1.20°C. Lower temperatures observed during the periods March to August 1985 and March to June 1986 in the wet season concurred with increased wastewater flow into the lagoons, the rainy periods and frequent cloud cover, which impeded solar energy from reaching the water surface. Higher temperatures occurring during the periods December 1984 to early March 1986 and September 1985 to February 1986 in the dry season concurred with reduced water flow, reduced water depth (frequently to about 0.8 m) and continuous sunshine during the day (Table 2 and Fig. 6). The small increases in temperature in June and April were attributed to the slowing down of the rains and the occurrence of short bursts of sunshine. X^2 test for the means of the wet and dry seasons showed no significant differences between the temperatures for the wet and dry seasons respectively ($X^2 = 3.84$; df $= 1$ p; < 0.05). The temperature remained within the range suitable for tilapia under culture conditions, that is, 20-35°C.

The temperature profiles (Fig. 10) show that the water column is warmer during the dry season than during the wet one. The mean temperature difference between the surface and the bottom of the lagoon was 2.9°C and 1.0°C for the dry and wet seasons respectively. The temperatures exhibited little variance throughout the culture period.

The mean annual pH at the lagoons was 8.7 ± 0.66 (Table 2) and was slightly alkaline. The pH values were higher during the wet season. Lower values in the dry season concurred with floating algal blooms, reduced water depth, low dissolved oxygen concentrations and a change in the water colour. Throughout the culture period, the pH remained within the suitable range for tilapia under culture conditions, that is, between 4.0 and 11.0. The pH exhibited little variance throughout the culture period.

The mean annual alkalinity was 2.997 ± 0.226 meql^{-1} (299.7 mg$CaCO_3$ l^{-1}). The values exhibited considerable variance (Table 2). The fluctuations were attributed to irregular discharge of alkaline effluent by factories such as Equator bottlers, which are known to discharge their wastewater into the lagoons. Despite this, the range of alkalinity measured remained within the limits tolerable to tilapia under culture conditions, that is, between 700-3000 mg$CaCO_3$ l^{-1}.

The mean annual free carbon dioxide concentration was 44.48 μmol l^{-1} as calculated from values obtained from the formula:

Free CO_2 = f_2 x (alkalinity (meq l^{-1}) [OH-]) μ mol l^{-1} (Talling 1985). The values exhibited a large variability ranging from as low as 0.7 μmol l^{-1} in April 1986 to 326.7 μ mol l^{-1} in March 1986. This range surpasses the upper lethal limit for tilapia under culture conditions, that is 50 - 100 μ mol l^{-1}.

The mean annual conductivity in the lagoons was 593.2 ± 56.92 μ S cm^{-1}. Like alkalinity, the conductivity exhibited significant variability ranging from 326.15 μS cm^{-1} in April 1985 to 1179.8 μScm^{-1} in March 1986. High conductivities were measured during the dry season when the water depth was much reduced, that is, between September and December 1985 and in March 1986 during the wet season when the flow into the lagoons was severely curtailed by a system breakdown (Table 2).

The mean annual nitrate concentrations at the lagoons was 4.306 ± 0.58 mg NO_3-N l^{-1} while that of phosphates was 3.349 ± 0.58 mg PO_4 - Pl^{-1}. Both nutrient concentrations were highest during the dry season. This concurred with low flow, reduced water depth, change

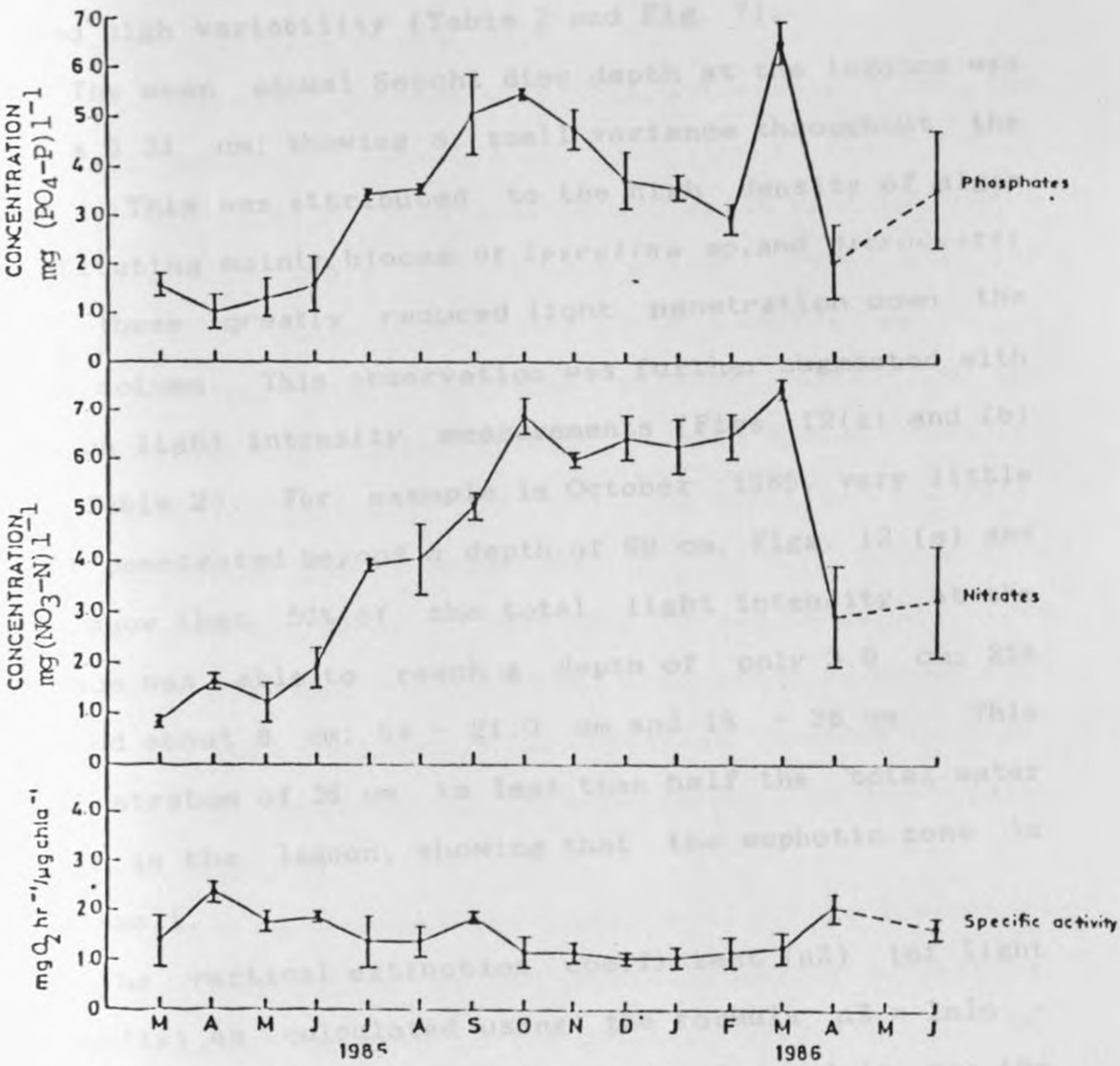

Fig 7. Mean monthly specific activity, nitrates (NO_3-N) and phosphates (PO_4-P) in Nyalenda wastewater lagoons. Kisumu.

in water colour and decaying algal blooms. Lower concentrations of the two nutrients occurred during the rainy season when the lagoons were full to capacity with much reduced algal blooms on the water surface. They showed high variability (Table 2 and Fig. 7).

The mean annual Secchi disc depth at the lagoons was 10.7 ± 0.31 cm; showing a small variance throughout the year. This was attributed to the high density of algae constituting mainly blooms of *Spirulina* sp.and *Microcystis* sp. These greatly reduced light penetration down the water column. This observation was further augmented with data on light intensity measurements (Figs. 12(a) and (b) and Table 2). For example in October 1985, very little light penetrated beyond a depth of 60 cm. Figs. 12 (a) and (b) show that 50% of the total light intensity at the surface was able to reach a depth of only 3.0 cm; 25% reached about 8 cm; 5% - 21.0 cm and 1% - 36 cm. This depth stratum of 36 cm is less than half the total water column in the lagoon, showing that the euphotic zone is very small.

The vertical extinction coefficient (nZ) (of light intensity) as calculated using the formula $nZ = \ln I_o - \ln I_z$ (Wetzel 1975) was 9.61151,where I_o and I_z are the light intensities in micromoles at the surface and at a given depth (z) respectifully. The percentile absorption (that is the dimunition of light energy with depth) as calculated using the formula $100\ (I_o - I_z)/I_o$ (Wetzel, 1975) of 99.989% was extremely high, showing a very high transformation of radiant energy into heat at a very shallow depth of 0.95 m. Measurements of light intensity using a photometer showed greater variability than readings taken by a Secchi disc.

The primary productivity characteristics of the Nyalenda wastewater lagoons are presented in Figs. 7,8,10 and 11 and Table 2. The mean annual gross photosynthetic rates were 1393.778 ± 114.61 $mgO_2\ m^{-3}hr^{-1}$. The mean for chlorophyll *a* concentration was 926.8 ± 65.996 µg chl. *a* l^{-1}. Both parameters exhibited greater variability and their values were higher during the wet season, that is, from March to September 1985 and from April to June 1986. They exhibited lower values during the dry season from October 1985 to February 1986 (Fig. 8 and Table 2). The low values measured for both the parameters in March 1986 (Fig. 8) were attributed to curtailed wastewater flow, caused by the breakdown of the main sewer line discharging into the lagoons.

The net result was the non-renewal of the wastewater and the deterioration of the physico-chemical parameters, which further resulted in low primary productivity. The decreases shown for both chlorophyll *a* concentration and gross photosynthesis in June 1985 are attributed to a temporary spell of unfavourable conditions in the lagoons in the course of the rainy season. Such conditions could result from collapse of the dense algal blooms with the

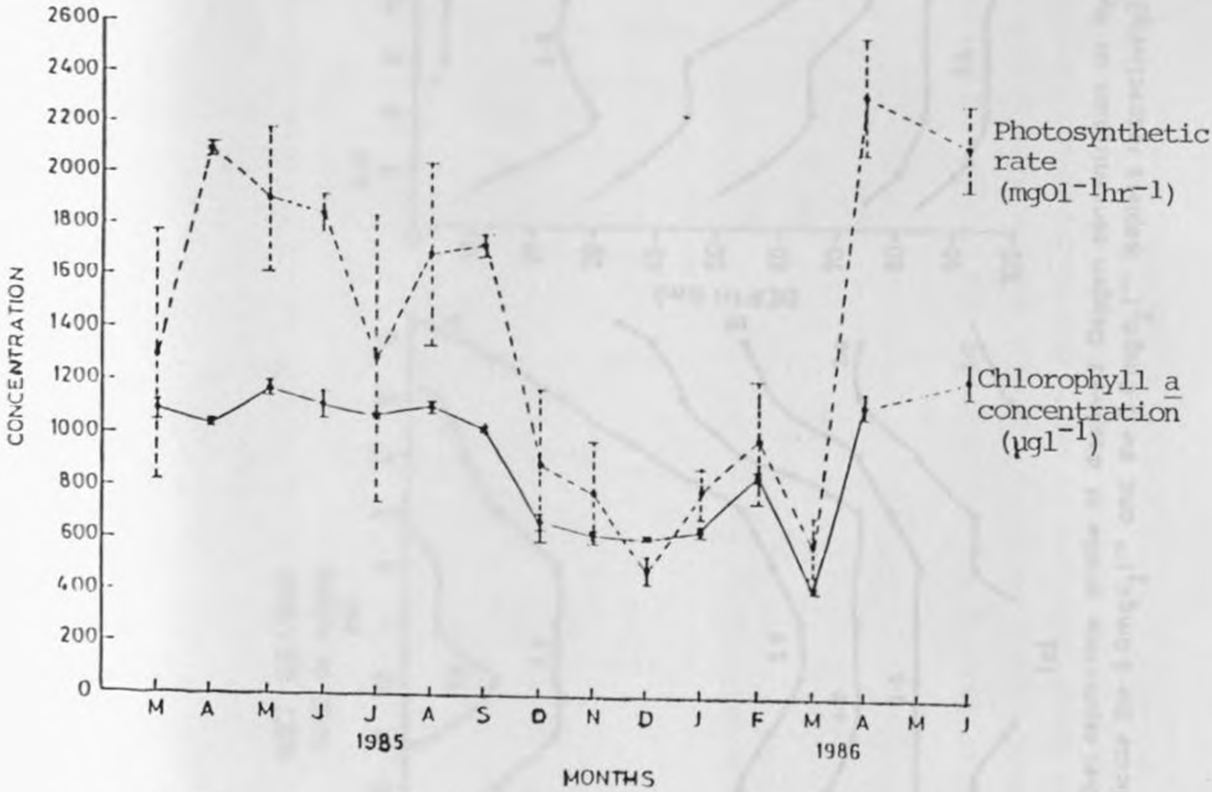

Fig.8. Mean monthly Chlorophyll, a concentration and photosynthetic rate in Nyalenda wastewater lagoons, Kisumu.

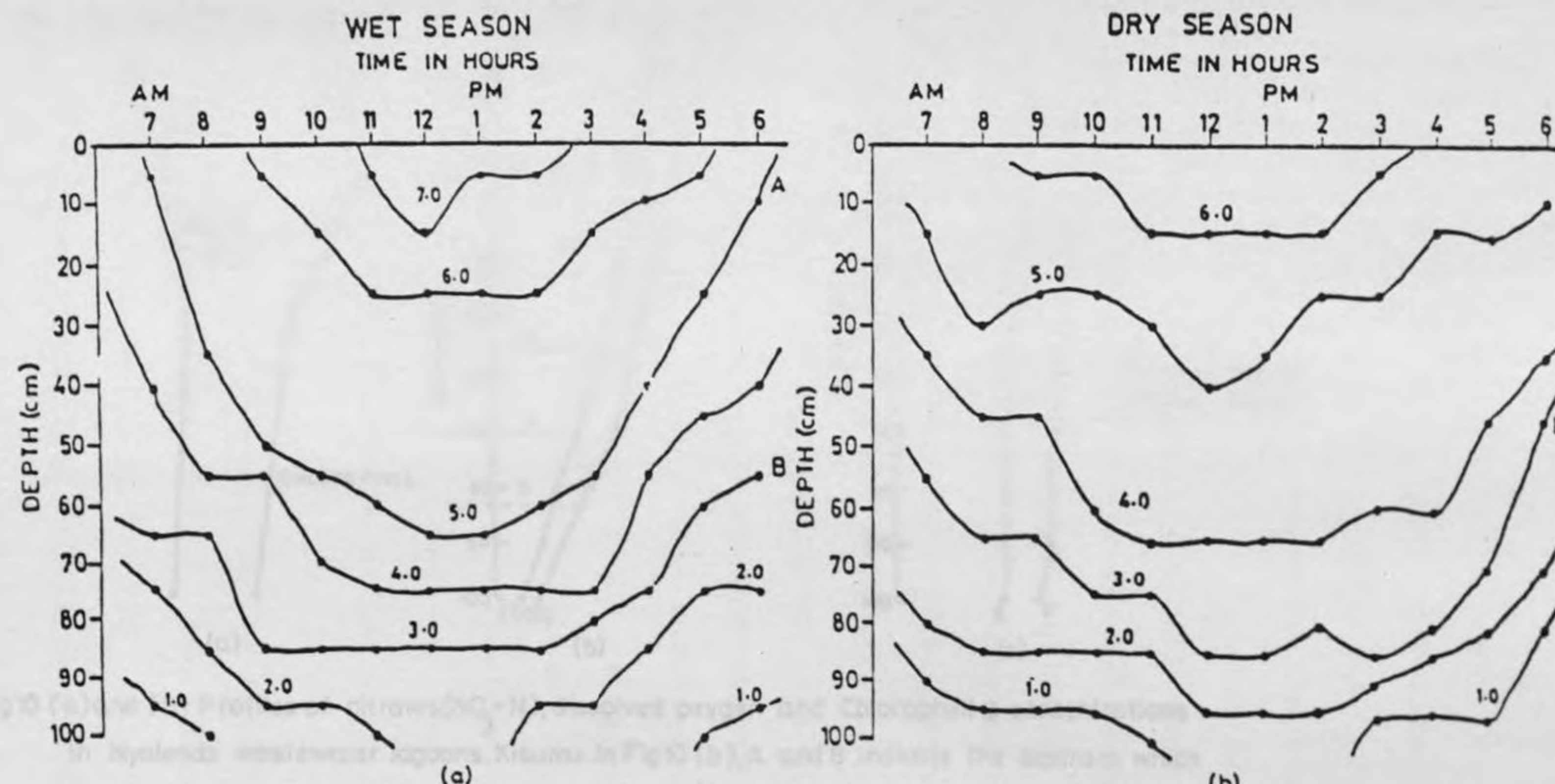

Fig. 9. (a) and (b); Diel depth-time profile of dissolved Oxygen concentration at Nyalenda ~~wastewater~~ lagoons, Kisumu. (A and B indicate the 5.0mgO_2 l^{-1} and the 3.0mgO_2 l^{-1} isoplets respectively)

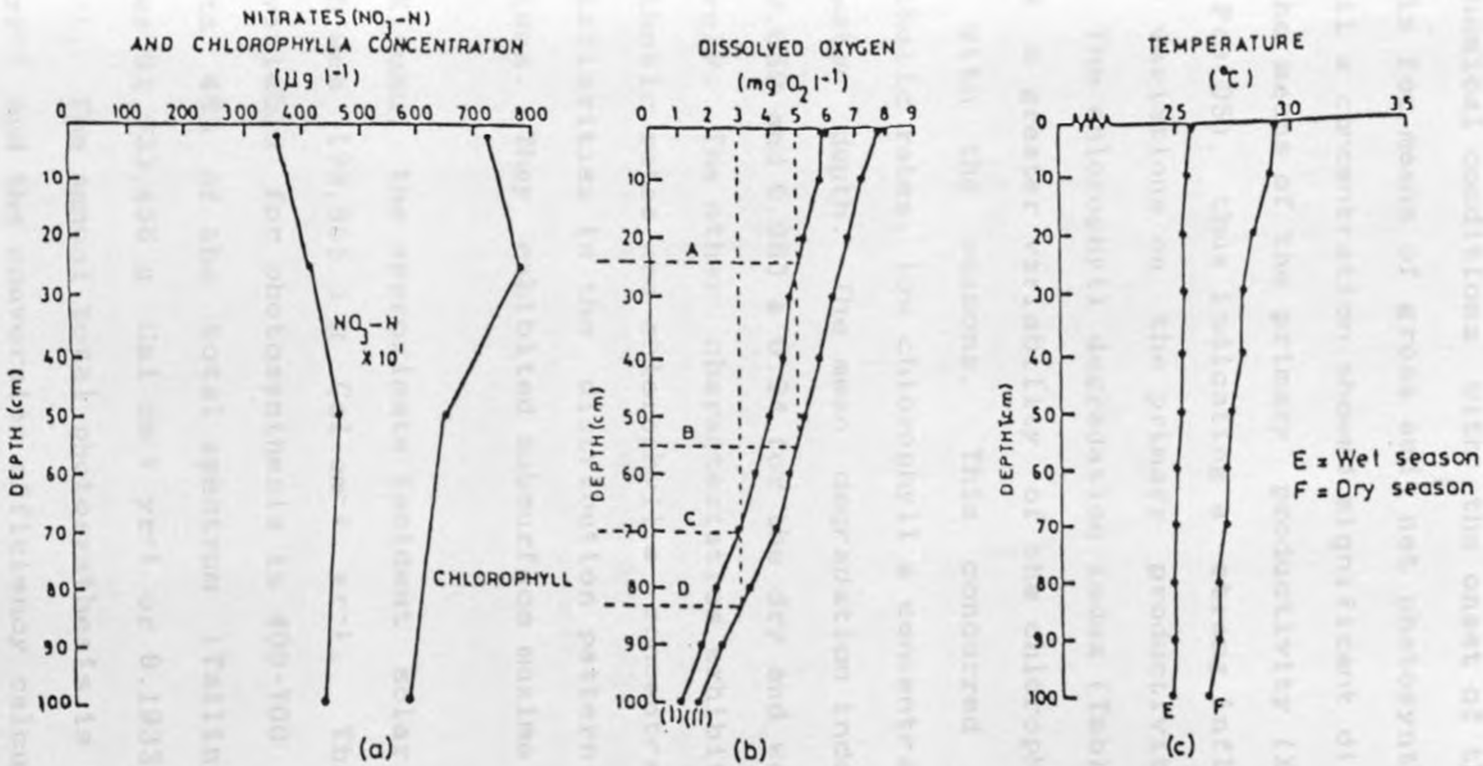

Fig 10. (a) and (b) Profiles of nitrates (NO_3-N), dissolved oxygen and Chlorophyll a concentrations in Nyalenda wastewater lagoons, Kisumu. In Fig 10 (b), A and B indicate the depths at which the dissolved oxygen concentration was 5.0 mgl^{-1} during the dry season (i) and the wet season (ii) and C and D, when the depths at which it was 3.0 ml^{-1} in both seasons respectively.

Fig 10 c. Temperature profiles at Nyalenda wastewater lagoons.

resultant depletion of oxygen in the water column. On the other hand, the slight increases in both parameters in February 1986 are attributed to the improvements of the physico-chemical conditions with the onset of the rains. X^2 analysis for means of gross and net photosynthesis and chlorophyll a concentration showed significant differences between the means of the primary productivity (X^2 = 3.84, df = 1, $P<0.05$), thus indicating a strong influence of seasonal variations on the primary productivity of the lagoons. The chlorophyll degradation index (Table 2) also indicated a greater variability of the chlorophyll being degraded with the seasons. This concurred with low photosynthetic rates, low chlorophyll a concentrations and reduced water depth. The mean degradation indecies were 1.071 ± 0.059 and 0.963 ± 0.34 for the dry and wet seasons respectively. The other characteristics exhibited by the photosynthetic rates and chlorophyll a concentrations are their similarities in the distribution pattern down the water column. They exhibited subsurface maxima (Figs. 10 and 11).

In Kisumu, the approximate incident solar radiation for 1985 was 199,855.3 g Cal cm^{-2} yr^{-1}. The spectral region available for photosynthesis is 400-700 nm, which represents 46% of the total spectrum (Talling, 1965a). This gives 91,933.438 g Cal cm^{-1} yr^{-1} or 9.1933438 x 10^9 Kcal ha^{-1}. The annual total photosynthesis is 4513.382 ± gO_2m^{-2} yr^{-1} and the conversion efficiency calculated from

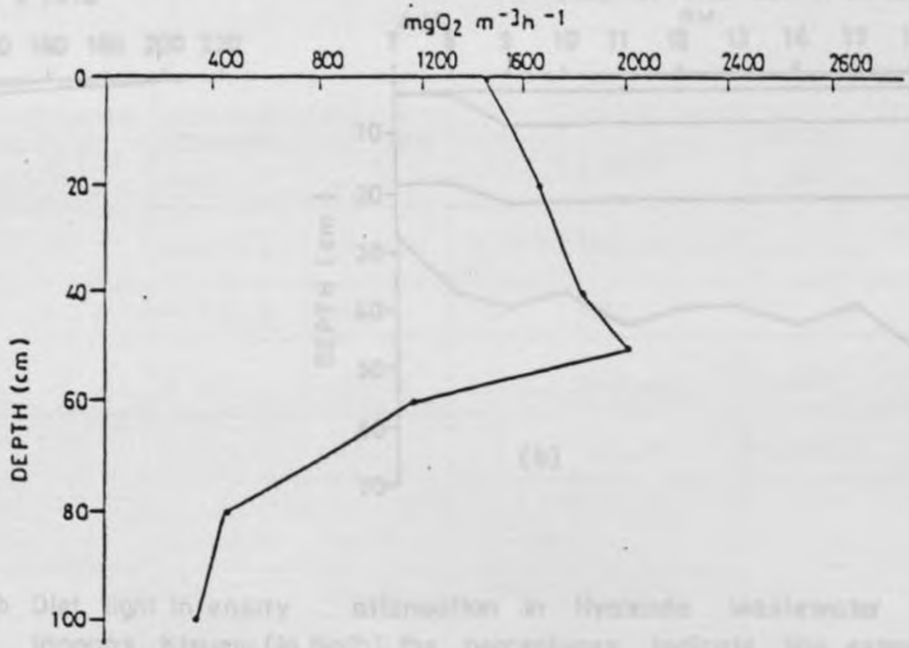

Fig 11. Mean gross photosynthetic rates in Nyalenda wastewater lagoons, Kisumu for the period December 1984 - June 1986 .

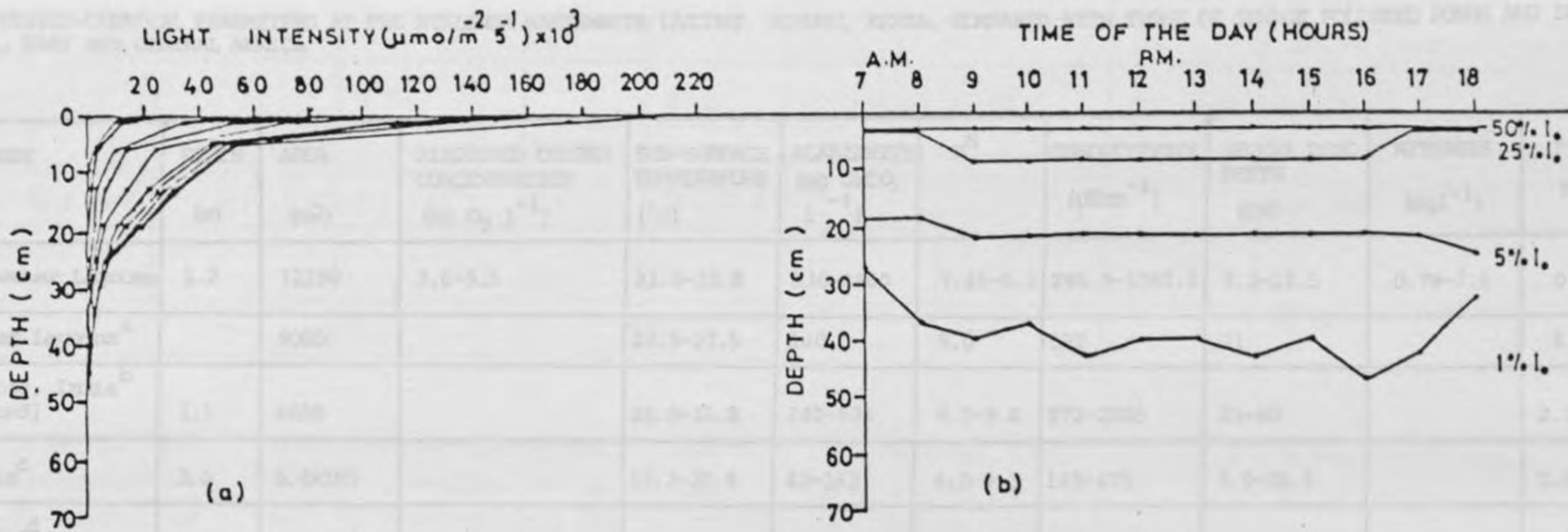

Fig.12.(a) and(b Diel light intensity attenuation in Nyalenda wastewater lagoons. Kisumu (In fig(b), the percentages indicate the extent to which the total intensity impinging at the surface(I_o) is reduced at various depths.

TABLE 3: THE PHYSICO-CHEMICAL PARAMETERS AT THE NYALENDA WASTEWATER LAGOONS, KISUMU, KENYA, COMPARED WITH THOSE OF SEWAGE POLLUTED PONDS AND SHALLOW LAKES IN INDIA, EAST AND CENTRAL AFRICA

WATER BODY	DEPTH (m)	AREA (m^2)	DISSOLVED OXYGEN CONCENTRATION ($mg\ O_2\ l^{-1}$)	SUB-SURFACE TEMPERATURE (°c)	ALKALINITY ($mg\ CaCO_3\ l^{-1}$)	P^H	CONDUCTIVITY (μScm^{-1})	SECCHI DISC DEPTH (cm)	NITRATES (mgl^{-1})	PHOSPHATES ($mg\ l^{-1}$)
1. Nyalenda wastewater Lagoons	1.2	12290	3.6-9.5	21.2-33.8	130-4800	7.45-9.7	295.8-1367.7	9.3-13.5	0.76-7.6	0.85-6.8
2. Thika Wastewater Lagoons[a]		9000		20.5-27.5	140	9.0	522	21		4.2
3. Foat Moat Vellore, India[b] (sewage polluted)	1.5	4800		26.0-31.8	240-536	8.3-9.6	972-2805	21-80		2.5-70
4. Ooty Lake, India[c]	3.0	3.4x105		17.3-20.6	42-163	6.8-9.3	145-475	3.0-10.5		0.0-0.1
5. Khordah sewagefed[d] fisheries ponds, India		6000-8000	2.0-18,7	19.2-32.75	174-460	7.6-9.0			Traces 140	2.0-20.0
6. Ayankulam pond, India[e]	3.0	1400		25-34.2	180-210	7.3-9.1	800-1900	30-60		
7. Lake George, Uganda[f]	2.4	2.5x108		25-35		9.0-9.7		30-35		0-250
8. Nyanza Gulf, Lake Victoria[g]	6	$1.3x10^9$	6.0-7.7	23.8-29	29-720	8.2-9.0	175	75-150	0.021-0.237	0.06-0.075
9. L. Victoria, Main Lake[h]	63	$4.1x10^{10}$	1.9-10.6	23-29		8.2-9.0	91-98	35-330		0.013
10. L. Naivasha[i]	7.3	$1.15x10^8$	6.9-7.35	19.1-22.0	126-194	8.8-9.0	282-975	100-150		0.0296

Table 3 Cont.

11. L. Sonachi[j]	5.5-6.5	$1.47\text{-}1.61 \times 10^{7}$	2.2-13.6	19.1-26.0	8680	9.8	5699-16470	30-55		0.200
12. L. Chad[k]	3.9	1.6×10^{10}		18.7-32.3		8.5	50-1000			1.780
13. L. Kanyaboli[l]	2.5	1.05×10^{7}	3.6-7.2	24-28.1	134-228	7.25-8.05	600-660	50-100	0.35-0.5	0.12-0.16
14. L. Sare[m]	5.0	6×10^{6}	4.9			6.8	106	100	0.8	0.4
15. L. Elementaita[n]	1.1	2.0×10^{7}		15-28	10800-80000	9.4-10.9	6500-3950	12-100		13.0
16. L Nakuru[o]	0.05-3.58	$0.2\text{-}4.9 \times 10^{7}$	6.5-13.5	19-22	2200-27500	9.8-10.3	162.5	30		13.6
17. Crescent Island Lake[p]	17	2.1×10^{6}	6.4	19.4-21.6				375-570		
18. Waters suitable for tilapia culture[q]			3.0	10.0-40		4.11				
19. L. Simbi[r]	13	2.9×10^{5}		26-30	26000	10.55		21-70		2.0

AUTHORS

a. Nyaga, 1981
b-e Sreenivansan, 1972
f - EAFFRO, 1952
g Melack, 1976
Melack, 1979 (b)
Welcomme. 1972

h - Talling and Talling, 1965 (b)
Talling, 1965 (a) and (b)
EAFFRO, 1952, 1954
i - Melack, 1979 (a)
j - Welcomme, 1972
Talling and Talling, 1965 (b)
Njuguna, 1982

k - Welcomme, 1972
l-m Okemwa, 1981
n - Melack, 1979 (a)
Tuite, 1981
Wandiga and Onyari, 1986

o - Mavuti, 1975, 1983
Tuite, 1981
Wandiga and Onyari, 1986
p - Melack, 1979 (a)
q - Balarin and Haller, 1982
r - Welcomme, 1972

this is 3.772%. This is a relatively high conversion efficiency.

3.5.1 DISCUSSION

The data on the physico-chemical and biological parameters of Nyalenda wastewater lagoons, Kisumu are compared with those of other wastewater lagoons in Kenya and India and with shallow waters in East and Central Africa (Tables 3 and 4). Most of the parameters such as dissolved oxygen concentration, subsurface temperature, alkalinity, pH and conductivity compare well with those of the other water bodies. The differences in primary productivity (Table 4) are brought about by differences in nutrient concentrations, radiant energy being received which is a function of the latitude and the nature and quantity of materials in the inflowing waters.

The observed rapid drop in dissolved oxygen concentrations towards dusk and dawn (Fig. 9(a) and (b)) suggests that the oxygen concentrations at night in the lagoons were much lower. This was attributed to the high algal biomass which consumes most of the oxygen at night. Further observations on the oxygen isoplets (Fig. 9(a) and (b)) show that at depths of 80-125 cm, oxygen concentrations were lower during the day than those required by tilapia under culture conditions. For example, in October 1985, the depth stratum with the optimum dissolved oxygen concentration required by tilapia

TABLE 4: PHYSICO - CHEMICAL AND BIOLOGICAL PARAMETERS IN NYALENDA WASTEWATER LAGOONS COMPARED WITH THOSE OF SEWAGE POLLUTED PONDS IN KENYA AND INDIA AND SHALLOW LAKES IN EAST AND CENTRAL AFRICA

WATER BODY		GROSS PHOTOSYNTHESIS ($mg\ O_2\ h^{-1}$)	NET PHOTO-SYNTHESIS ($mg\ O_2 h^{-1}$)	CHLOROPHYLL a CONCENTRATION ($\mu g l^{-1}$)	SPECIFIC ACTIVITY ($mgO_2/\mu gChla$)	MEAN LIGHT INTENSITY ($\mu molm^{-2}$)	CONVERSION EFFICIENCY (%)	AREAL GROSS PHOTOSYNTH. ($mgO_2 m^{-2}$)	FISH YIELDS	RADIATION ($jcm^{-2}\ yr^{-1}$)
Nyalenda wastewater Lagoons, Kenya	a	500 - 2340	2700-1476	4269 - 1286.6	0.5 - 2.247	1.70 - 0.24	3.772	480 - 2460	4.76-5.285 + kgm^{-3}	
Foat Meat Vellore India	b						2.845	1844.4	1607 $kg\ ha^{-1}$	32078.03
Oaty lake, India	c						1.553	1126.7	128 $kgha^{-1}$	35898.98
Khordah sewage fed Fisheries, India	d							37.5-353.1	7676 $kgha^{-1}$	
Ayankulam pond, India	e						4.027	2666.7	1438 $kgha^{-1}$	
L. George Uganda	f	1900 - 600	1000	400	0.8 - 4.3		3.6	1155.6-1688.9	152t	732.920-760.295
Nyanza Gulf L. Victoria	g	235 - 640		4.8 - 29.4				400-90	62t	840,008.4
Main Lake Victoria East Africa	h	43 - 132		44	14 - .35		3.1-10.2	822.2	42t	

Table 4 cont.

L. Naivasha Kenya	k	1470 - 2400		47.5	8-14		1.4-4.0	340 - 734	40t	
L. Sonachi Kenya	j	130 - 850		90-160	6-16	4.4-6.4	1.0-7.2	150-870		
L. Chad Central Africa	k	200 - 1300		700-1800				300-500	14t	
L. Nakuru Kenya	l				150-160		0.4-2	100-300		532.2-650.4
L. Elementaita Kenya	m	270 - 5540	1000-3500)	9.7		1.2-6.1 $gm^{-2}h^{-1}$	0.8-124	110-1740		

KEY:

* This is an average for the water column

+ This means yield obtained for five months has been doubled to get the annual yield per m

a This study

b. Sreenivansan, 1972

c. " "

d. " "

e. " "

f. Ganf - 1974, 1975
Welcomme, 1972

f. Dunn 1972
EAFFRO, 1952

g. Melack, 1976
Melack, 1979 (a)

h. Talling and Talling, 1965

Talling, 1965 a
EAFFRO, 1952, 1954

i. Melack, 1979

" 1979 a

j. Welcomme, 1972,
Talling and Talling, 1965

K. Welcomme, 1972

i. Okemwa, 1981

m. Melack, 1979 a
Tuite, 1981
Wandiga and Onyari., 1986

was reduced to a mere 10 cm by 6 p.m. in the evening (Fig. 9b). This has the effect that the number of fish raised per unit volume of water is reduced (See chapter 5). It can be further deduced that a greater part of the water column experienced prolonged periods of low dissolved oxygen concentrations, a factor which is not conducive to tilapia culture. Therefore the observation on the fish kills in the lagoons on some occasions, particularly during the dry season was attributed to deoxygenation by the dense algal crop and local winds resuspending anaerobic sediments which not only deplete the oxygen but also suffocates the fish by clogging their gills. Similar observations have been made by scientists working in shallow waters, for example Morgan (1972), Kalk *et al.* (1979) and Leveque (1979). In Lakes Chad and Chilwa, development of deoxygenated conditions in shallow water during the dry phase resulted in fish kills (Leveque, *op cit.* and Kalk *et al., op cit*). An example of fish kills in October 1966 when the water level was only 0.3 m resulted from winds which brought up anaerobic sediments. That such sediments can be resuspended at Nyalenda wastewater lagoons was evidenced from the soft nature of the bottom and the shallow depth of the lagoons which during the dry seasons was reduced to about 0.8m. This, apart from reducing the dissolved oxygen concentration, concentrates the various chemical components in the lagoon into a smaller volume of water and can make some of them toxic to fish. The low dissolved oxygen concentrations were further attributed to continuous irregular rates of wastewater flow containing organic materials with a high biological oxygen demand.

Wind mixing of the entire water column at night can therefore be disastrous, since by resuspending sediments with a high BOD, the already depleted oxygen concentrations will decline further.

The pH fluctuations though not very significant (Fig. 6) were attributed to a number of factors such as (i) discharge of effluents which alter the pH and (ii) development within the lagoons of anoxic conditions due to decaying algal blooms and resuspension of organic sediments by wind action. The low pH was also attributed to strong assimilation of carbon dioxide reserves in the water by the dense crop of phytoplankton with the net result that the pH was lowered. Alabaster and Lloyd (1982) have dealt with factors affecting the pH and causing it to be toxic at certain ranges.

During the dry phase, the water temperature at the lagoons become relatively high, with several degrees above 30°C. This was the major factor facilitating the decomposition process of algal blooms and other organic matter, particularly when the water depth was low, thus augmenting the oxygen depletion process. The subsurface water temperature was lower during the wet season due to cooling effect of rainwater, occasional stormwater and prolonged cloud cover.

The higher alkalinity values attained during the wet season were attributed to the discharge of an alkaline effluent by the Equator bottling factory at Kisumu. The fluctuations of the alkalinity are attributed both to the discharge of other materials through the sewage into the lagoon from the domestic sector and institutions in the town.

The free carbon dioxide concentrations computed from the factor "f2" determined from a pH and temperature plot and alkalinity (Talling, 1985) demonstrates how the interaction between two or more parameters which are not toxic can produce a parameter which is toxic. The free carbon dioxide levels exceeded the maximum tolerable limit for tilapia of 73-100 μ mol l^{-1} (Fish, 1956, Alabaster *et al.*, 1957 and Alabaster and Lloyd, 1982) on three different occasions, with values rising as high as 326.7 μ mol l^{-1}. This suggests that fish at the lagoons were subjected to undersirable levels of free carbon dioxide for long periods whose effects are distress and irreparable haemoglobin damage. Such high concentrations have their toxicity enhanced by discharge of acid wastes (Alabaster and Lloyd, 1982). The high variability in the free carbon dioxide concentrations at the lagoons reflected two causes: (i) the observed fluctuations in alkalinity and irregular wastewater flow and (ii) the interraction of a wide range of physico-chemical parameters including photosynthesis and acidic organic matter.

The conductivity and the nutrients (nitrates and phosphates) showed high variability with higher values measured during the dry season, when the water level in the lagoons dropped as a result of low and irregular flow, evapotranspiration and underground seepage, resulting from a high soil water demand. This served to concentrate the chemical components into a smaller volume of water with the effect that their concentrations were raised. Thus the conductivity and nutrient concentrations were high during the dry season. A similar effect could result from a wind action resuspending sediments rich in nutrients and chemicals with high electrical conductance. That wind action is an important factor in the alteration of the physico-chemical parameters at the wastewater lagoon, was witnessed in some days when most of the algal blooms were pushed to one side, the other portion of the lagoon remaining clear. This process reversed whenever the wind changed direction.

The low concentrations of the nutrients and conductivity measured during the wet season at the lagoon were as a result of dilution by increased flow of wastewater and rainfall during heavy storms. The dilution was further enhanced by leakage of floodwater into the sewage systems as some of the pipes are below the water table during the rainy season. These served to increase the water volume and cause dilution with the effect that the conductivity and nutrient concentrations were lowered. The relatively high nutrient concentration and conductivity supports the observation by other scientists in other water bodies that the higher these parameters, the higher the natural productivity.

The concentrations of nitrates and phosphates remained fairly high throughout the experimental period, (Fig. 7). The high concentrations are characteristic of wastewater lagoons and shallow water bodies. This is due to the fact that human wastes are rich in nutrients.

The observed higher concentrations of phosphates than nitrates on some occasions (normally nitrate concentrations are higher than those of phosphates) suggested that materials with high phosphate content such as detergents were being discharged into the lagoons. This was inferred from the dense white foam at the weirs when the lagoons were flushing, and from the wide usage of the detergents for cleaning purposes in homes and institutions in town, which discharge their wastewater into the lagoons. The decay of algal blooms and the defaecation of numerous birds into the lagoons, charge the water column with extra nutrients. As a result of the high fluxes of nutrients into the wastewater lagoons, the nitrate to phosphate ratio was low.

One consequence of the high nutrient concentration was the observed large biomass of phytoplankton at the lagoons. These formed an important source of food for *Oreochromis niloticus* (see chapter 4).

The differences between Nyalenda wastewater lagoons and the other sites presented in Table 3 can be explained in terms of the differences in morphometric characteristics, that is, depth and surface area, the nature and quantities of nutrients flowing into the different sites, the quantities of nutrients incorporated in the sediments; all these are affected by wind mixing and the physico-chemical characteristics prevailing in the sites. All these cannot be the same in the sites presented. It can be seen that the sewage ponds of Foat-Moat Vellore and Ayankulam are shallower and have smaller surface areas than Nyalenda wastewater lagoons. Their phosphate concentrations are higher than those of the other lagoons. The Nyalenda wastewater lagoons which are similarly shallower have higher nutrient concentrations than the other deeper and larger water bodies presented, Table 3. Ooty Lake in India on the other hand, though receiving sewage, has a large surface area and a slightly greater depth than any of the above-mentioned water bodies. It has a lower phosphate concentration than the other sewage ponds. All the other sites presented have greater surface areas and depth. The nutrient concentrations in them are lower than those of Nyalenda wastewater lagoons and the other sewage ponds of Foat-Moat Vellore and Ayankulam. Further-more, these three sewage-fed ponds more regularly receive large quantities of nutrients from the inflowing sewage as opposed to the other sites in which nutrient influxes may not be regular.

Wind mixing is much more pronounced and regular in shallower water bodies (Wetzel, 1973) (such as the sewage-fed ponds) than in the deeper water bodies. This results in a continuous resuspension of nutrients from the sediments, thus increasing their concentration in the water column (Williams and Ganf, 1981). Water at the bottom of such ponds or sites are nearly anaerobic or completely anaerobic due to the huge amounts of organic matter discharged into them in the form of sewage. This is augmented by the large amounts of dead algal cells and other organisms in "the plankton rain" which sinks to the bottom as a result of high natural productivity characteristic of such ponds. These promote nutrient release into the water column by bacterial decomposition of the organic matter. In some of the deeper water bodies presented such as Nyanza Gulf, Lakes Victoria and Simbi, the water may sometimes be stratified due to temperature differences between the top and bottom layers. Wind mixing is not easy and nutrients for most of the time are held at the bottom anoxic layers. Furthermore due to their larger volume, the dilution factor of the incoming nutrients and other ions is high, thus making their concentration per unit volume of water low.

Several comparisons can be made between some of the physico-chemical parameters and nutrient concentrations in the different sites presented in (Table 3). Ooty Lake has a lower alkalinity and pH range. Its phosphate concentration is lower than those of the other sewage ponds presented. Its temperature range is also lower than in other ponds. This implies that the rate of decomposition and therefore nutrient release may be lower than in the other sewage ponds. The Nyanza Gulf and Lake Kanyaboli have lower alkalinities than Nyalenda wastewater lagoons. Their nutrient levels on the other hand are also lower. Thus the differences between Nyalenda wastewater lagoons and the other sites presented in Table 3 can be attributed to differences in physico-chemical parameters: mainly surface area, volume, wind mixing regime, the quantities and nature of the inflowing nutrients and the regularity with which they are received.

However, it has been observed that when nutrients occur in large quantities, sudden depletion is associated with a significantly high increase in algal biomass (Prowse and Talling, 1958 and Ganf, 1974). Similar observations were made at Nyalenda wastewater lagoons during the rainy season, (Fig. 7 and Table 3) when the density of algae was high and the nutrient concentrations were lower.

The shallow Secchi disc depth and the high light intensity attenuation showed that the trophogenic zone was much reduced (Figs 6 and 12). This is also characteristic of sewage ponds of India and Kenya and shallow waters of East and Central Africa. The factors which were responsible for the reduced trophogenic zone were: (i) a high biogenic turbidity due to algal blooms of *Spirulina* sp. and *Microcystis* sp., (ii) a biogenic turbidity due to suspended inert materials brought in with wastewater, (iii) presence of dissolved organic matter which interferes with light penetration (Ganf, 1974), (iv) high alkalinity and (v) high pH. This is due to the fact that high alkalinity and pH favour dense phytoplankton growth which in turn causes self-shading. The net result is that the penetration of light into the water column is reduced, thus limiting the euphotic zone to a shallower depth (Huet, 1975). The effect of the wind also temporarily reduces the visibility in the reduced depth of water by resuspending bottom sediments into the water column. These act to reduce the photosynthetic rates.

The Secchi disc depth measurements at Nyalenda wastewater lagoons are only slightly lower than those of the Indian sewage polluted ponds of fort Moat Vellore and Ayankulam and also Ooty Lake, (Table 3). They also approach those of Lake Elementaita, but the range of the latter is much wider than that of the former and the other water bodies presented. Like the Nyalenda wastewater lagoons, all the other water bodies (Tables 3 and 4) are shallow and are characterized by high primary productivity, which is a consequence of their high nutrient content.

Photosynthetic rates and chlorophyll a concentrations were high during the wet season due to increased visibility in the water. This resulted from greater light penetration due to the dilution of the water by increased wastewater flow and rainfall. The lower values measured during the dry season were due to reduced light penetration caused mainly by high biogenic and abiogenic turbidities. The variability of the two parameters was further attributed to a number of other factors: (i) the occurrence of a degraded by-product of chlorophyll a, phaeophytin in water which is registered as chlorophyll a during absorbance measurements and (ii) the fact that at any given time, not all algae in a given water body are involved in photosynthesis. The presence of the by-product phaeophytin in water is known to cause fluctuations in chlorophyll a concentrations even on a 24 hour basis. Table 2 shows that chlorophyll degradation index in the lagoons was higher during the dry season. The variability in photosynthetic rates, that is for both net and gross photosynthesis (Table 2) was in particular attributed to the latter factor. Ganf (1974) notes that about 30% of the total algal concentration is involved in photosynthesis at a time.

The chlorophyll a concentration at the lagoons compares well with that at Thika wastewater lagoons, Kenya (Table 3). The Indian sewage ponds show slightly lower values of primary production due to the fact that they are situated in a more northerly latitude, primary productivity being generally lower in more northerly and southerly latitudes. With good management strategies such as provision of regular and adequate wastewater flow, removal of solids and algal blooms which on decaying deplete oxygen concentrations, removal of nuisance aquatic macrophytes at the lagoons such as *Ipomea* sp. and better maintenance of the whole sewage drainage system, the photosynthetic rates should exceed the current levels (Tables 3 and 4 and Figs 9 and 10). This means increased carrying capacity in terms of fish biomass per unit volume of water.

The photosynthetic rates showed depressed values at the surface and subsurface maximum at about 20-60 cm (Fig. 11). The same trend was exhibited by chlorophyll a concentration and nutrients (Fig. 10). This was attributed to photoinhibition at the surface (Steeman, 1962 and Steeman and Jorgensen, 1962). The shallow depth of 40-50 cm to which the maximum rate of photosynthesis is restricted reflected the strong light intensity attenuation at the lagoons (Figs. 12(a) and (b)).

The possibility of photosynthetic bacteria contributing to the photosynthesis in the lagoons cannot be assumed. They are known to be present in very productive lakes at depths with light intensity levels less than 10% of the total impinging at the surface. (Fig.

12(a)and (b)) show that over 80% of the total water column at Nyalenda wastewater lagoons received less than 10% of the total light intensity impinging at the surface). The photosynthetic bacteria are also known to be present in stagnant lakes rich in hydrogen sulphide (Odum, 1971) and also in lakes receiving a lot of allochthonous inputs. All these characteristics are present in the lagoons.

The conversion efficiency of light energy into photosynthesis at the lagoons of 3.772% is relatively high when compared with those of the Indian sewage ponds and shallow waters of East and Central Africa (Tables 3 and 4). Other scientists have found higher efficiencies. For example Sreenivansan (1972), has noted an efficiency of 6%; Teal (1962), 6%. Oswald and Golueke (1960) found an average efficiency of 6.2% in very shallow sewage oxidation ponds. The main factors which ensure higher conversion efficiencies are the good distribution of algae and low biogenic turbidity. For example in the Ayankulam pond, India, the well dispersed algal population resulted in a higher conversion efficiency while in Fort-Moat Vellore which is sewage polluted, the efficiency was slightly lower due to self-shading by algae.

CHAPTER 4

THE FOOD COMPOSITION AND SELECTION OF *OREOCHROMIS NILOTICUS* IN WASTEWATER LAGOONS.

4.1 INTRODUCTION

Fish need food for survival and growth. In nature, they feed on a great diversity of food items such as phytoplankton, zooplankton, benthic and non-benthic invertebrates,benthic deposits, other fish and aquatic macrophytes. They also absorb nutrients extra-enterally such as glucose and calcium for scale and bone formation.

Little research has been conducted on the diet of the species extensively cultured in enclosures such as cages. The culture of algivorous species such as *Tilapia zillii* and *Oreochromis niloticus* requires that the algal types and production are known so that appropriate stocking densities can be estimated and used. This will ensure optimum utilization of the water and better yields per unit area. The knowledge on the types of natural fish foods is important in formulating the dietary needs of species used in both intensive and extensive culture. This chapter is devoted to the study of the composition of different natural foods eaten by *Oreochromis niloticus* and their level of selection in wastewater lagoons.

4.2 LITERATURE REVIEW

The feeding habits of *Oreochromis niloticus* qualifies it as a suitable culture specimen in wastewater lagoons.

Observations in the natural habitat, show that the fish prefers plant material in its diet and that it ingests a great variety of feeds (Lowe, 1958; Yashuov and Chervinski, 1960; 1961). Moriarty *et al.* (1973) found in Lake George, Uganda, that the fish readily digests blue-green algae, contrary to previous reports. They made further observations that the young initially feed on a variety of plant and animal material including "aufwuchs", detritus, rotifers, copepods, hydracarines and various insects and later when adult turn to a predominantly algal diet. Further observations showed that *Microcystis* sp., filamentous algae such as *Lyngbya* sp. and *Melosira* sp. were positively selected, while the blue-green algae *Anabaenopsis* sp. and the diatom *Synedra* sp. were negatively selected based on Ivlev's index of electivity. The reason why less zooplankton are taken during adult life is that the fish changes its mode of feeding, which is by gulping the water within its vicinity. The zooplankton detect the feeding current and swim away to avoid being swallowed (Moriarty *et al.*, 1973). Earlier studies conducted by Fish (1951), Fryer and Iles (1972) and Moriarty and Moriarty (1973b) show that *Oreochromis niloticus* feeds on bottom deposits, derived from the plankton rain and other sources. Beveridge (1984a) notes that *Oreochromis niloticus* is onmivorous, but feeds predominantly on phytoplankton and can utilize blue-green algae, while juveniles consume a wide range of food items.

Oreochromis niloticus like all the other tilapia, is a herbivore (Jauncey and Ross, 1982) and its diet under natural conditions is restricted to phytoplankton (Moriarty, 1973 and Moriarty and Moriarty, 1973b). But in organically fertilized ponds, where the principal flow of energy is through the detritus pathway and where interspecific competition for food can be severe, the fish feeds and grows well on organic manures (Wohlfarth and Schroeder, 1979). In this case, the nutritive value is not derived from the detritus but from the micro-organisms which cover the surface of the particles (Kerns and Roelofs, 1977 and Schroeder, 1978). In Lake Kivu, it feeds on very small particles in the water, including bacteria (Fryer and Iles, 1972).

Moriarty and Moriarty (1973a) studied the daily rate of algal ingestion in *Oreochromis niloticus* in lake George, Uganda and expressed it as a linear relationship between the dry weight of the phytoplankton ingested (Y) and the weight (X) of the fish and obtained the following equation:

$$Y = 271 + 13.3X.$$

The rates are affected by the times at which individual fish start to feed and the amount of algae accumulated in the stomach.

The assimilation efficiences for various types of algae consumed by some tilapia species have been studied by Bowen (1982). For *Oreochromis niloticus*, the assimilation efficiencies for the algae are: *Microcystis* sp. 70%, *Anabaena* sp. 75%, *Nitzschia* sp. 79%, *Chlorella* sp. 19% and the Lake George suspended matter, 43%. These may not necessarily be the same in different water bodies. The majority of these food items are abundant in wastewater lagoons. However, reports on their assimilation efficiencies together with the feeding habits of *O. niloticus* in wastewater lagoons are scanty.

Whereas fish in the wild are free to move and graze on the algae and exploit all other available resources, caged fish are not. They rely largely on a passive food supply brought by water movements. They do not have the opportunity to graze on benthic material which in *Oreochromis niloticus* constitutes a significant proportion of the material ingested. This may reduce the yields per unit volume of water in extensive fish culture practices.

4.3 MATERIALS AND METHODS

Fish were caught by total seining of two tertiary wastewater lagoons M4 and M6 (Fig 2) during the wet season in April 1985 and during the dry season in November 1985. A beach seine of mesh size 4cm stretch measure was used. The standard lengths and weights of the specimens caught were measured to one decimal place in cm and nearest g respectively. They were then dissected in the field and the degree of stomach fullness was assigned an index ranging from 0-4; whereby 0 = empty stomach and 4 a full stomach and 1,2 and 3, the gradations in order of fullness between 0 and 4 (Craig, 1978). The total gut lengths of the November sample were measured. The stomachs were carefully removed and put in glass specimen bottles containing 4% formalin for later analysis in the laboratory.

At the same time of fish collection, integrated water samples for plankton analysis were taken using a plastic tube. The number of algae and other food items in the stomachs of the fish and in the lagoons were estimated using a sedgewick rafter-cell mounted on a compound microscope. The percentage abundance of the food items in both the stomachs and the lagoons were calculated. Three measures of food selection namely, the forage ratio (FR), Ivlev's index of electivity (E) and the Linear food index (L) as reviewed by Strauss, (1979) were used to compare food selection in *Oreochromis niloticus*. They were computed thus:

(i) Forage ratio (FR) = ri/pi

Log_{10} FR = Log_{10} (ri/pi)

(ii) Ivlev's index of electivity (E) = (ri-Pi)/(ri+Pi)

(iii) Linear food index (L) = ri - pi

Where ri and pi are the relative ambundances of the food items in the stomach and environment respectively.

The benthic materials for the estimation of food composition and selection indecies were collected using an Ekman bottom grab of area 240 cm ^{2}. The calculation of the electivity indecies of benthic fauna was considered separately from those of algae and zooplankton as the methods of sampling were different in both cases.

4.4 RESULTS

The size distribution and stomach fullness of *Oreochromis niloticus* analysed are presented in Fig.13. The larger sizes were fewer due to the fact that the fish rarely grows to sizes greater than 30 cm in ponds. This is attributed to the phenomenon of stunting (Fryer and Iles, 1972). The sizes ranged from 0-32 cm. For the size range 0.0 - 9.9 cm, 117 fish were analysed; for the size range 10.0 - 19.9, 90 fish, for the size range 20.0 - 29.9 cm, 37 fish and for sizes greater than 30.0cm, only two specimens were analysed. Fig. 14 shows the percentage contribution of the specimens analysed to various degrees of stomach fullness: 2.149% had empty stomachs; 12.09% had 1/4-full stomachs; 26.210% had 1/2 full stomachs; 27.016% had 3/4 full stomachs and 32.2% had completely full stomachs. This shows that most of the fish had already fed when they were collected for analysis, that is between ten in the morning and two o'clock in the afternoon.

Regression analysis of gut length (GL) on standard length (SL) revealed a linear relationship (Fig.15), which is described by the following equation:

$$SL = 25.78 + 8.144\ GL;\ r = 0.856\ (n = 117)$$

Standard length was used instead of total length because a

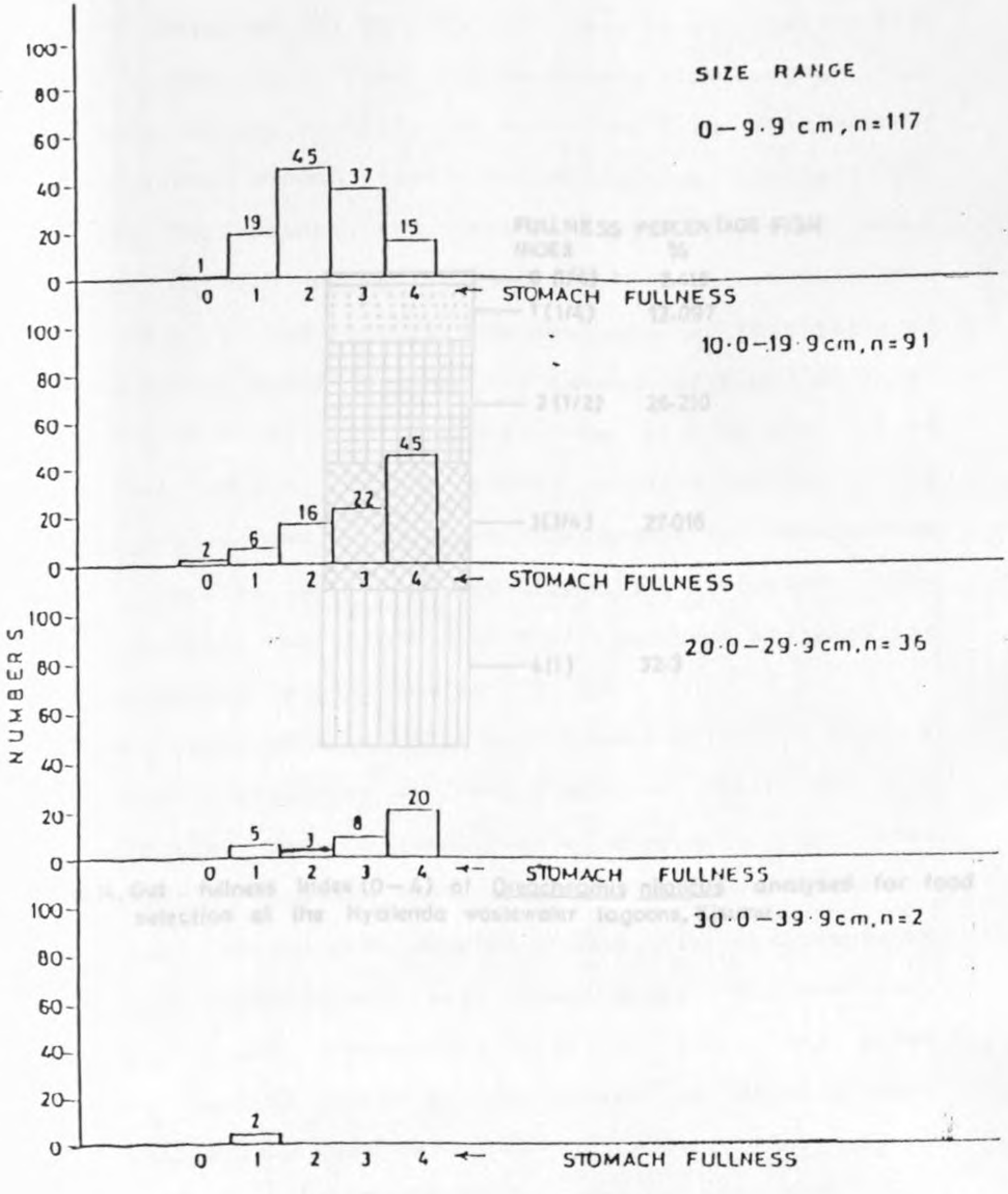

Fig.13 Size distribution and stomach fullness index of <u>Oreochromis niloticus</u> specimen analysed for food selection studies from Nyalenda wastewater lagoons, Kisumu.

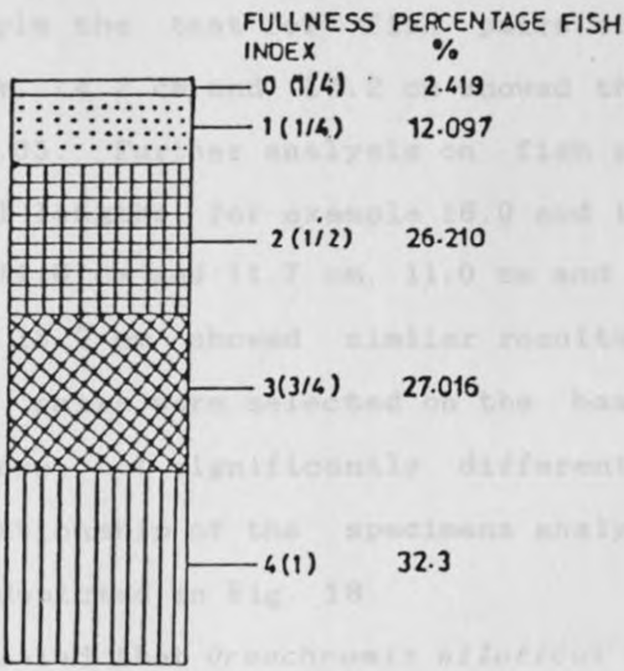

Fig. 14. Gut fullness index (0 – 4) of Oreochromis niloticus analysed for food selection at the Nyalenda wastewater lagoons, Kisumu.

significant proportion of fish had partly destroyed caudal fins. Observations on the gut lengths of similar fish sizes showed significant intraspecific differences (Fig. 15). Chi-square analysis on pairs of fish specimens of equal lengths showed significant differences in their gut lengths. For example the test for fish pairs of equal lengths of 13.0 cm, 14.2 cm and 17.2 cm showed that X^2 = 3.84, df = 1, $p<0.05$. Further analysis on fish pairs of approximately equal lengths, for example 16.0 and 16.1 cm, 15.4 and 15.6 cm, 11.6 cm and 11.7 cm, 11.0 cm and 11.1 cm and 18.1 cm and 18.2 cm showed similar results. The latter set of fish pairs were selected on the basis that their lengths were not significantly different. The length-weight relationship of the specimens analysed for food selection is depicted in Fig. 18.

The study revealed that *Oreochromis niloticus* ingests five major categories of food items, of which four are quantifiable. The non-quantifiable component constituted of the bottom deposits which occurred in over 50% of the specimens. Bottom grab samples showed it to constitute of loose mud interspersed with green algae, Chironomidae, Oligochaeta and decomposing bits of grass and plant material such as *Carex* sp. and *Ipomea* sp. growing along the edges of the lagoons. Due to the fact that some of the detrital particles were so minute that they were suspended in the water film of the sedgewick rafter-cell, while some formed fine hues at various positions in the

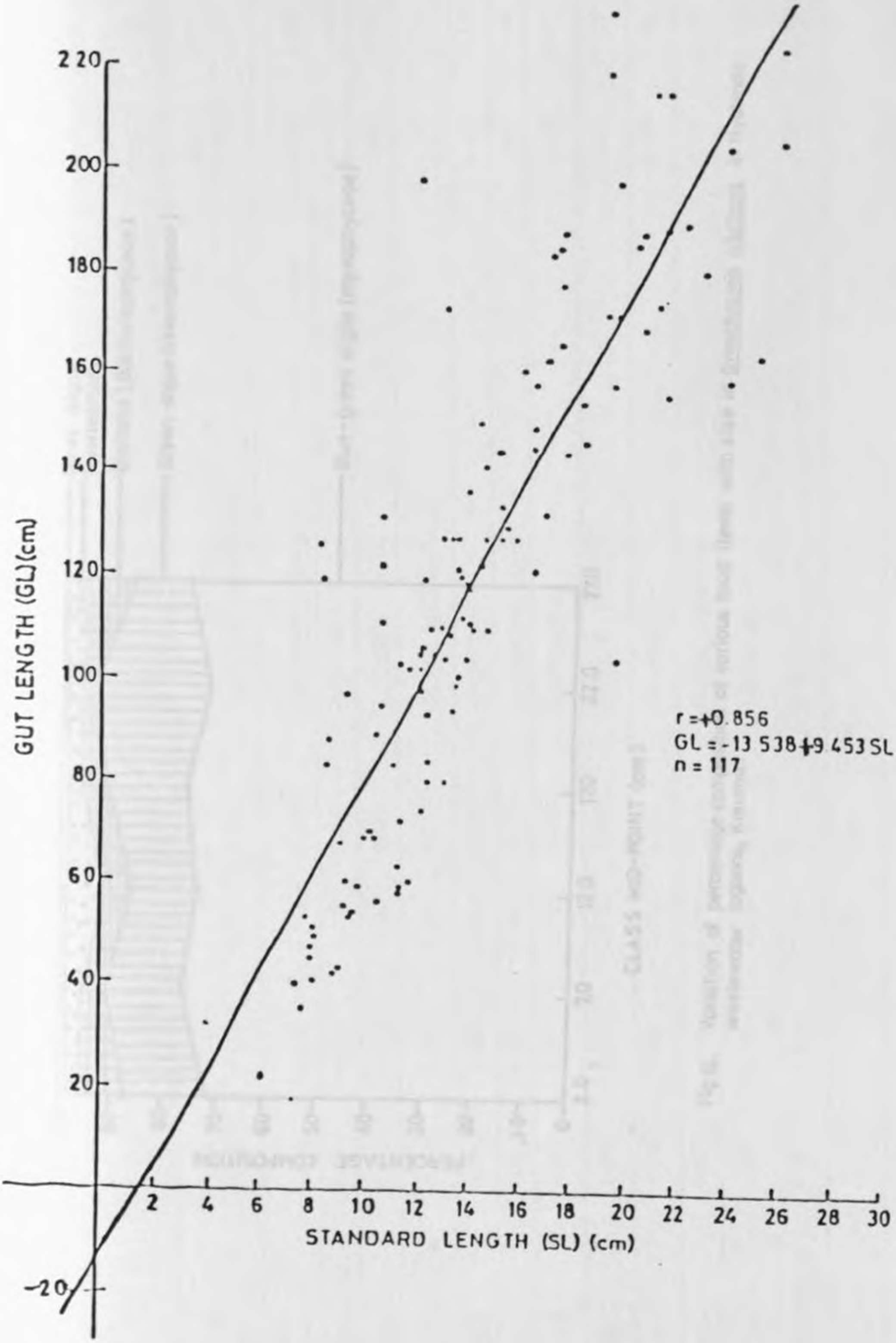

Fig.15. Relationship between gut length and standard length of <u>Oreochromis niloticus</u> at Nyalenda wastewater lagoons, Kisumu.

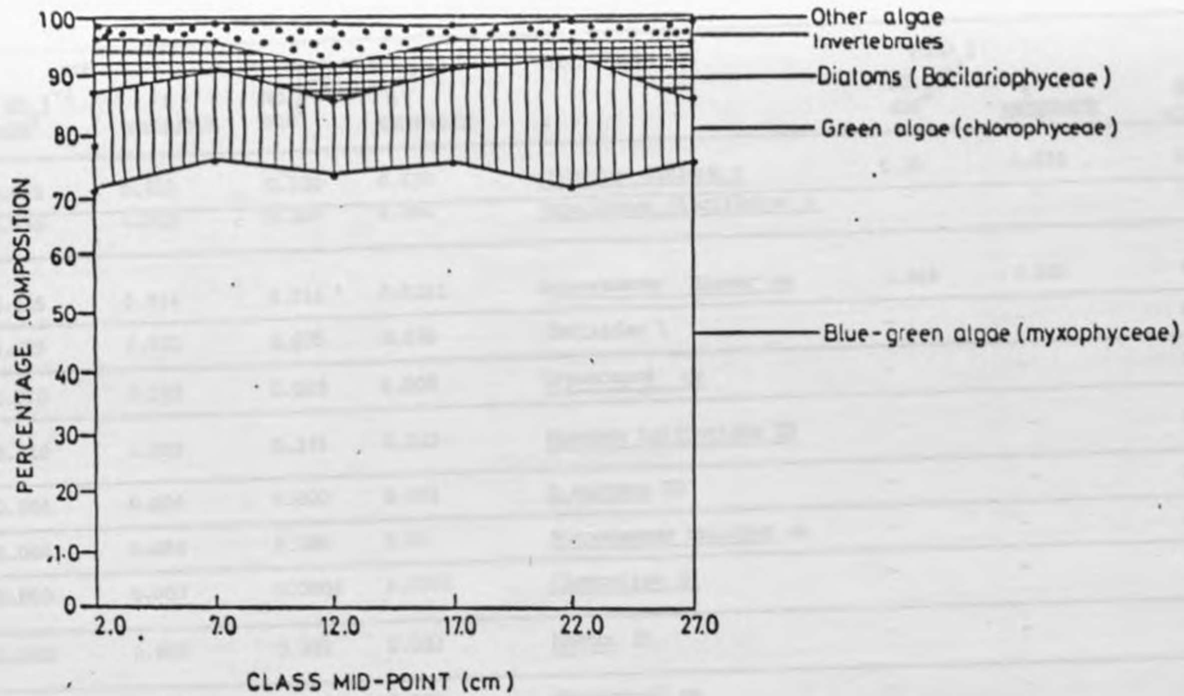

Fig 16. Variation of percentage composition of various food items with size in Oreochromis niloticus in Nyalenda wastewater lagoons, Kisumu.

TABLE 5. THE CONCENTRATIONS OF ALGAE, ZOOPLANKTON AND LARGER INVERTEBRATES IN NYALENDA WASTEWATER LAGOONS, KENYA

FOOD ITEM	POND 1		POND 2		FOOD ITEM	POND 1		POND 2	
	NO. l^{-1} $x10^6$	% ABUNDANCE	No. l^{-1} $X10^6$	% ABUNDANCE		NO. l^{-1} $x10^6$	% ABUNDANCE	NO. l^{-1} $x10^6$	% ABUNDANCE
Anabaena fi	0.445	0.415	0.510	0.430	Colacium minimum z	0.35	0.033	0.06	0.51
Filinia z	0.020	0.019	0.100	0.084	Brachionus claciflorus z	-	-	0.0035	0.003
Cyclopoid Copepods z	0.015	0.014	0.016	0.0163	Scenedesmus dispar ce	0.048	0.045	0.035	0.030
Brachionus sp. z	0.025	0.023	0.035	0.030	Corixidae l	-	-	0.0033	0.0003
B. Caudatus z	0.010	0.009	0.009	0.008	Crysocapsa ce	-	-	0.062	0.052
Disctyosphaerium ce	0.010	0.009	0.276	0.233	Diatoma balfouriana CD	-	-	0.021	0.18
Epiphanes z	0.004	0.004	0.002	0.002	D.vulgare CD	-	-	0.09	0.076
Testudinella z	0.004	0.004	0.000	0.00	Scenedesmus obliquus ce	-	-	0.09	0.076
Trichocerca z	0.003	0.003	0.0005	0.0004	Closterium ce	-	-	0.730	0.165
Polyathra	0.003	0.003	0.002	0.002	Nostoc fi	-	-	0.018	0.015
Moina Z	0.006	0.006	0.006	0.005	Crytomonas ce	-	-	0.455	0.384
Synchaeta z	0.003	0.003	0.002	0.002	Heterochromonas ce	-	-	0.990	0.835
Actinastrum ce	0.280	0.261	0.180	0.152	Diatoma sp. CD	-	-	0.019	0.016
Scenedesmus sp. ce	0.70	0.690	0.915	0.771	Others M	7.896	8.008	10.543	8.887
Surirella CD	-	-	0.017	0.14	-	-	-	-	-
Diaptomid copepods z	0.00005	0.000006	0.0002	0.0002	Navicula CD	0.415	0.075	0.075	0.063
Asplanchna z	0.0002	0.0002	0.0002	0.0002	Scenedesmus bijugatus ce	0.440	0.410	0.006	0.005

Table 5: Cont.

	POND 1 No. l^{-1} $x10^6$	POND 1 % ABUNDANCE	POND 2 No. l^{-1} $x10^6$	POND 2 % ABUNDANCE		POND 1 No. l^{-1} $x10^6$	POND 1 % ABUNDANCE	POND 2 No. l^{-1} $x10^6$	POND 2 % ABUNDANCE
Notonecta I	0.000002	0.000002	0.000007	0.000006	Gomphosphaeria ce	0.550	0.513	0.255	0.190
Spirulina fi	29.02	27.01	28.46	23.99	Oscillatoria fl	0.630	0.588	0.375	0.316
Synechocystis co	18.50	17.257	24.14	20.348	Chlamydomonas ce	0.415	0.387	0.710	0.598
Microcystis co	13.645	12.729	14.600	12.307	Nitzschia CD	0.475	0.443	0.193	0.163
Stichococcus CO	5.335	4.977	10.47	8.826	Phacus ce	0.315	0.294	0.045	0.038
Chlorella co	4.520	4.216	5.576	4.699	Scenedesmus brasiliensis ce	0.310	0.289	0.540	0.455
Scenedesmus quadricauda ce	5.930	5.504	4.225	3.587	Cymbella CD	0.200	0.187	0.085	0.072
Trachelomonas ce	2.150	2.006	0.675	0.569	Phacus contortus cc	0.170	0.158	0.015	0.013
Euglena ce	1.615	1.507	2.465	2.087	Cocomyxa ce	0.170	0.158	0.03	0.025
Ankistrodesmus fi	1.435	1.339	1.125	0.948	Protozoans z	0.105	0.098	2.620	2.208
Chroococcus ce	1.960	1.828	2.905	2.449	Aphanocapsa ce	0.185	0.173	0.016	0.013
Synedra CD	1.070	0.998	1.425	1.201	Scenedesmus arcuatus ce	0.123	0.115	0.080	0.067
Lyngbya fi	0.705	0.658	0.375	0.316	Pediastrum ce	0.060	0.056	0.080	0.067
Coelosphaerium ce	0.665	0.620	0.115	0.097	Scenedesmus dispar ce	0.048	0.045	0.035	0.030
Oocystis ce	0.655	0.611	0.460	0.388	Melosira fd	0.605	0.564	0.295	0.249
Scenedesmus linearlis ce	0.450	0.420	0.145	0.135					

KEY:
ce = Cellular alga
co = Colonial alga
z = Zooplankter
CD= Cellular diatom
I = Invertebrates
fi= Filamentours alga
fd= Filamentous diatom
m = mixed

rafter-cell where they occurred, it was not possible to enumerate them. Microscopic examination revealed part of the bottom deposits to constitute of diatoms such as *Diatoma* sp., *Navicula* sp. and *Melosira* sp. and algae such as *Merismopedia* sp., *Scenedesmus* sp. and *Spirulina* sp., attached either to organic particles or to the colonies of the alga *Microcystis*. Other forms of organisms and phytoflagellates such as protozoa and Phacus sp. were also observed amongst the detritus. Table 5 shows the concentrations of the different food items eaten by *O. niloticus* in Nyalenda wastewater lagoons.

The variations of the percentage contribution of the four quantifiable categories of food items with the size of *Oreochromis niloticus* is depicted in Fig.16. The blue-green algae (Myxophyceae) constituted by far the most abundant food item, contributing 73.1% followed by the green algae (Chlorophyceae) 13.7%, then the diatoms, (Bacilariophyceae) 7.3%, then the invertebrates 4.2% and lastly other forms of algae 1.8%. The percentage contribution by the blue-green algae ingested ranged from 71.7% in fish with a mean size of 2.0 cm to 77.1% in fish with a mean size 27.0 cm. This shows that larger fish consumed slightly larger amounts of blue-green algae than smaller fish. The green algae ingested ranged from 11.4% in fish with a mean size of 27.0 cm to 19.0% in fish with a mean size of 22.0 cm. The diatoms eaten varied from 4.78% in fish with a mean size of 22.0 cm to 10.93% in fish with a mean size of 2.0 cm. The invertebrates ingested ranged from 2.69% in fish with a mean size of 17.0 cm to 6.96% in fish with a mean size of 12.0 cm. The percentage contributions of the other food items ingested ranged from 1.24% in fish with a mean size of 22.0 cm to 2.15 - 2.44% in fish with a mean size of 12.0 - 17.0 cm. Chi-square analysis indicated no significant differences in the variation of the percentage contribution of the different food items ingested with fish size (X^2 = 11.070, df = 5, $P < 0.05$)

The major genera of food items taken by *Oreochromis niloticus* and their percentage occurrences in the specimens analysed are presented in Table 6. Those contributed by the blue-green algae were Spirulina sp., *Microcystis* sp., *Synechocystis* sp., *Merismopedia* sp., *Lyngbya* sp., *Chroococcus* sp., and *Coelosphaerium* sp. Those belonging to the green algae were *Chlorella* sp., *Scenedesmus* sp., *Oocystis* sp., *Pediastrum simplex*, while the diatoms constituted of *Melosira* sp., *Navicula* sp., *Nitzschia* sp., *Diatoma vulgare* and *Synedra* sp. The invertebrates mainly constituted of the Cladocera; *Moina* sp., Rotifera, Chironomidae and Oligochaeta.

The algal genera with the highest percentage occurrences in the stomachs of *Oreochromis niloticus* were *Microcystis* sp., which occurred in 97.5% of the specimens; *Spirulina* sp., 97.09%, *Chlorella*, 91.75%; *Scenedesmus quadricauda* 86.53%; *Merismospedia tennuissima*, 71.25%:

TABLE 6: PERCENTAGE OCCURRENCE OF VARIOUS FOOD ITEMS IN THE STOMACHS OF OREOCHROMIS NILOTICUS AT NYALENDA WASTEWATER LAGOONS

FOOD ITEM	X %	S	FOOD ITEM	X %	S
1. Chironomidae	53.54	±9.71	19. Navicula	18.86	±7.52
2. Spirulina	97.09	±4.12	20. Moina	43.97	±11.50
3. Microcystis	97.50	±3.54	21. Euglena	14.27	±4.86
4. Nitzschia	44.150	±2.33	22. Merismopedia tenuissima	71.25	±5.30
5. S. quadricauda	86.55	±5.73	23. Brachionus sp.	12.61	±7.220
6. Melosira	39.92	±4.83	24. S. obliquus	18.86	±7.52
7. Aphanocapsa	3.97	±2.64	25. Pediastrum	12.17	±1.89
8. S. braisiliensis	12.30	±2.65	26. Genicularia	1.25	±1.77
9. Epihanes	13.02	±11.05	27. Cymatopleura	1.36	±0.45
10. Chlorella	91.75	±6.01	28. Oligochaeta	14.19	±3.56
11. Phacus	29.82	±2.10	29. Anabaena	22.20	±0.42
12. Synechocystis	55.40	±4.10	30. Scenedesmus sp.	31.99	±35.80
13. S. acumunatus	2.50	±1.77	31. Closterium	4.89	±2.52
14. Chroococcus	15.00	±3.54	32. Coelosphaerium	9.50	±2.83
15. Cymbella	9.29	±0.16	33. Ankistrodesmus	3.64	±0.76
16. Lyngbya	54.19	±0.02	34. Gomphosphaeria	6.77	±2.21
17. Oocystis	26.25	±1.77	35. Surirella	11.17	±0.47
18. Diatoma	16.15	±6.63	36. B. calciflorus	3.22	±0.16

Table 6. Contd.

	FOOD ITEM	X%	S	
37.	S. ecornis	0.94	± 0.15	55.
38.	Colacium minimum	1.36	± 0.45	56.
39.	Synedra	1.88	± 0.29	57.
40.	S. nanus	3.34	± 1.18	58.
41.	Dimorphococcus	2.40	± 1.03	59.
42.	Merismopedia sp.	12.19	± 3.97	60.
43.	Oscillatoria	16.57	± 10.46	61.
44.	Asplanchna	6.88	± 5.01	62.
45.	S. linearlis	8.65	± 7.81	63.
46.	Dictyosphaerium	3.77	± 0.62	64.
47.	B. caudatus	2.72	± 0.87	65.
48.	Frustularia	0.42	± 0.59	66.
49.	Chlorobium	1.25	± 1.77	67.
50.	Chlamydomonas	3.65	± 0.74	68.
51.	Daphnia	1.36	± 0.45	69.
52.	D. vulgare	13.67	± 14.62	70.
53.	S. arcuatus	3.65	± 0.74	71.
54.	Pinularia	1.36	± 0.45	72.

Key

$\bar{X}$ % = Mean percentage occurrence
S = standard deviation

Synechocystis sp. 55.40% and *Lyngbya* sp. 54.19%. Other algae with moderately low percentage occurrences were the diatoms such as *Diatoma* sp. 16.15%; *Navicula* sp. 18.86%; *Surirella* sp. 11.17% and *Diatoma vulgare* 13.67%. Among the invertebrates, the Chironomidae and the Cladocera, *Moina* sp. had fairly high percentage occurrences, that is 53.54% and 43.97% respectively. Other invertebrates had moderately low percentage occurrences: for example *Brachionus* sp. had 12.6%, *Epiphanes* sp. 13.02% and Oligochaeta 14.19%.

Table 7 presents the electivity indecies (E), the linear food indecies (L) and the logarithm to base ten of the forage ratio (Log_{10} FR). The logarithm of the forage ratio was used because it is more normally distributed than the plain ratio, hence its suitability for statistical comparisons. The forage ratio (FR) and Ivlev's index of electivity show that some of the algae particularly the diatoms and some invertebrate genera such as the Cladocera and Rotifera had high positive values, showing high selectivity. For example *Surirella* sp. had an electivity index (E) of + 0.934; *Merismopedia* sp. + 0.930; *Diatoma* sp., + 0.850; *Pediastrum simplex*, 0.86; *Melosira* sp.+ 0.838; *Scenedesmus dispar*, + 0.810; *S. arcuatus* + 0.835; *Aphanocapsa* sp. + 0.856; *D. vulgare*. + 0.797; *Merismopedia tennuissima* + 0.720 and *Lyngbya* sp. + 0.556. Among the invertebrates, the Cladocera, *Moina* sp. had a mean electivity index (E) of + 0.949; the

TABLE 7: THE MEAN VALUES OF THE PERCENTAGE ABUNDANCE, ELECTIVITY INDEX (E), THE FORAGE RATIO ($LOG_{10}FR$) AND THE LINEAR FOOD INDEX (L) OF THE FOOD ITEMS EATEN BY OREOCHROMIS NILOTICUS IN NYALENDA WASTEWATER LAGOONS, KISUMU

FOOD ITEM	ALGAL MORPHOLOGY	PERCENTAGE ABUNDANCE IN THE LAGOONS	E	$LOG_{10}FR$	L
Spirulina	fi	25.5	+0.124	+0.101	+0.144
Microcystis	ce	12.518	+0.391	0.445	+0.240
Chlorella	ce	4.458	-0.071	-0.081	-0.240
Scenedesmus quadricauda	ce	4.546	-0.164	-0.192	-0.004
Melosira	fd	0.407	+0.838	+1.474	+0.084
Merismopedia	co	2.023	+0.720	+1.298	+0.018
Lyngbya	fi	0.487	+0.556	0.755	+0.024
Synechocystis	ce	18.803	-0.620	-0.801	-0.108
Nitzschia	cd	0.303	+0.292	+0.471	+0.014
Oocystis	ce	0.500	+0.418	+0.463	+0.009
Phacus	ce	0.126	+0.563	+0.771	+0.008
Moina	z	0.006	+0.949	+2.365	+0.029
Navicula	cd	0.225	+0.549	+0.088	+0.017
Chroococcus	ce	2.139	-0.327	-0.359	-0.005

TABLE 7: CONTD

FOOD ITEM	ALGAL MORPHOLOGY	PERCENTAGE ABUNDANCE IN THE LAGOONS	E	$Log_{10}FR$	L
Anabaena	fi	0.423	+0.273	+0.435	-0.028
Diatoma	cd	0.016	+0.85	+1.631	+0.040
Oscillatoria	fi	0.452	+0.648	+0.667	+0.026
Scenedesmus sp.	ce	0.731	+0.325	+0.600	+0.017
S. obliquus	ce	0.076	+0.459	0.644	+0.011
S. linearlis	ce	0.778	+0.672	+0.907	+0.017
S. brasiliensis	ce	0.372	+0.438	+0.955	+0.005
Cymatopleura	cd	-	+0.962	+1.309	+0.008
S. dispar	ce	0.038	+0.810	+1.190	+0.006
S. arcuatus	ce	0.091	+0.838	+1.608	+0.018
Euglena	ce	1.793	-0.273	-0.316	-0.002
Epiphanes	z	0.003	+0.964	+2.051	+0.008
Filinia	z	0.052	+0.648	+0.188	+0.021
Brachionus	z	0.027	+0.817	+2.274	+0.019
Asplanchna	z	0.0002	+0.994	+2.953	+0.018
Brachionus caudatus	z	0.009	+0.966	+2.145	+0.017

TABLE 7: CONTD

FOOD ITEM	ALGAL MORPHOLOGY	PERCENTAGE ABUNDANCE IN THE LAGOONS	E	$Log_{10}FR$	L
Trichocerca	z	0.002	+0.990	+2.879	+0.007
Strichococcus	z	6.902	−0.233	−0.305	−0.018
Pediastrum simplex	cd	0.032	+0.856	+1.483	+0.011
Cymbella	cd	0.130	+0.396	+0.460	+0.013
Gomphosphaeria	ce	0.352	+0.545	+0.694	+0.021
Surirella	cd	0.017	+0.934	+1.593	+0.008
Ankistrodesmus	fi	1.144	+0.499	−0.190	−0.0002
Diatoma vulgare	cd	0.076	+0.797	+1.114	+0.010
Coelophaerium	ce	0.359	+0.218	+0.274	+0.0094
Aphanocapsa	ce	0.093	+0.856	+2.242	+0.016
Chlamydomonas	ce	0.493	−0.098	−0.251	−0.019
Dictyosphaerium	ce	0.121	+0.0594	+1.371	+0.010
Protozoans	z	1.153	+0.269	+0.156	+0.009
Other algae	m	8.448	−0.691	−0.929	−0.060

KEY:

ce = Cellular
m = mixed
fe = filamentous
cd = cellular diatom
co = colonial
fd = filamentous diatom
z = zooplankter

rotifer *Epiphanes* had + 0.964; *Filinia* sp. + 0.648 and *Brachionus* sp. + 0.917. Despite the high levels of selection, most of the food items were not abundant in the lagoons (Table 5). Others such as *Melosira* sp., *Merismopedia* sp. and *Lyngbya* sp. had fairly high percentage occurrences and high positive indecies. Those algae with highest percentage occurrences both in the stomachs of the fish and in the lagoons had moderate to low electivity indecies. For example *Microcystis* sp. had an electivity index (E) of + 0.391; *Spirulina* sp. + 0.124; *Scenedesmus quadricauda* - 0.164, *Chlorella* sp. - 0.071 and *Synechocystis* sp. - 0.620. Other less occurring algae with negative electivity indecies were *Euglena* sp. - 0.273; *Stichococcus* sp. - 0.233 and *Ankistrodesmus* sp - 0.499.

Food selection as studied using the linear food index (L) showed a slightly different pattern from the other two measures: the forage ratio (FR) and Ivlev's index of electivity (E). The linear food index methods are regarded as more appropriate than the other two methods. This is due to the fact that the two indecies are significantly biased when the sizes of prey samples from the gut of the predator and the habitat are unequal. Furthermore, the linear food index (L) avoids most of the statistical and mathematical inadequacies of the other two measures of food selection (Strauss,1979). Therefore, for further nutrition studies, the linear food index should be used to select the best algae for raising *Oreochromis niloticus* and other fish. Using this index, the algal species with relatively high positive selection indecies were *Microcytis* sp. + 0.240; *Spirulina* sp. + 0.144; *Melosira* sp. + 0.084; *Diatoma* sp. + 0.040, *Anabaena* sp. + 0.028; *Oscillatoria* sp. + 0.026 and *Lyngbya* sp. + 0.024. Among the invertebrates, the ones with high linear food indecies were: *Moina* sp. + 0.029; *Brachionus caudatus* + 0.017; *Filinia* sp. + 0.021 and *Brachionus* sp. + 0.021. The food items with negative linear food indecies were: *Synechocystis* sp. - 0.108; *S. quadricauda* - 0.004; *Chlorella* sp. -0.240; *Chroococcus* sp. - 0.005 and *Stichococcus* sp. The linear food indecies are smaller in magnitude than those of the other two measures because in the computation of the linear food index, proportions rather than percentages are used.

Due to the wide range of food items eaten by *Oreochromis niloticus* in the lagoon, which number over 70 genera, the variations in the forage ratio and indecies of selection of the individual food items with size are complex. Fryer and Iles (1972) note that due to the method used by the tilapia in collecting food; that is by mucus entanglement and filtration by microbranchiospines in the gills, and due to the minuteness of the particles taken, selection of what is collected is impossible. Despite this, some authors, for example Moriarty *et al.* (1973), have attempted studies on food selection in *Oreochromis* *niloticus* and a similar attempt was used in this study. Fig.17, therefore presents the general trend of the variations of the electivity index (E) of common food genera with fish size. The Cladocera *Moina* sp. and the algae *Merismopedia* sp. and diatoms had fairly consistent mean electivity indecies (E) throughout all the sizes analysed. *Melosira* sp. maintained strong positive selection for fish in the size range 0-22 cm and fell to a moderate positive selection at sizes greater than this range. *Synechocystis* sp. maintained a strong negative selection. Selection for *Microcytis* sp. remained positively moderate over the whole fish size ranges (Fig.17).

Most of the food items had low percentage occurrence in the environment and were absent from the stomachs of some fish size ranges. Plots of the variation of their electivities with fish size was therefore not possible. Their mean selection values are presented in Table 6.

Quantitative observations done on the feeding behaviour of *Oreochromis niloticus* at the wastewater lagoons showed that fish which had fed on bottom deposits had fewer algae in terms of genera and numbers. In such fish the volume of the Chironomidae and Oligochaeta as judged by eye, was more than that of algae. It was further observed that the fish which were held in floating cages had no access to the bottom deposits, an important food resource for the tilapia.

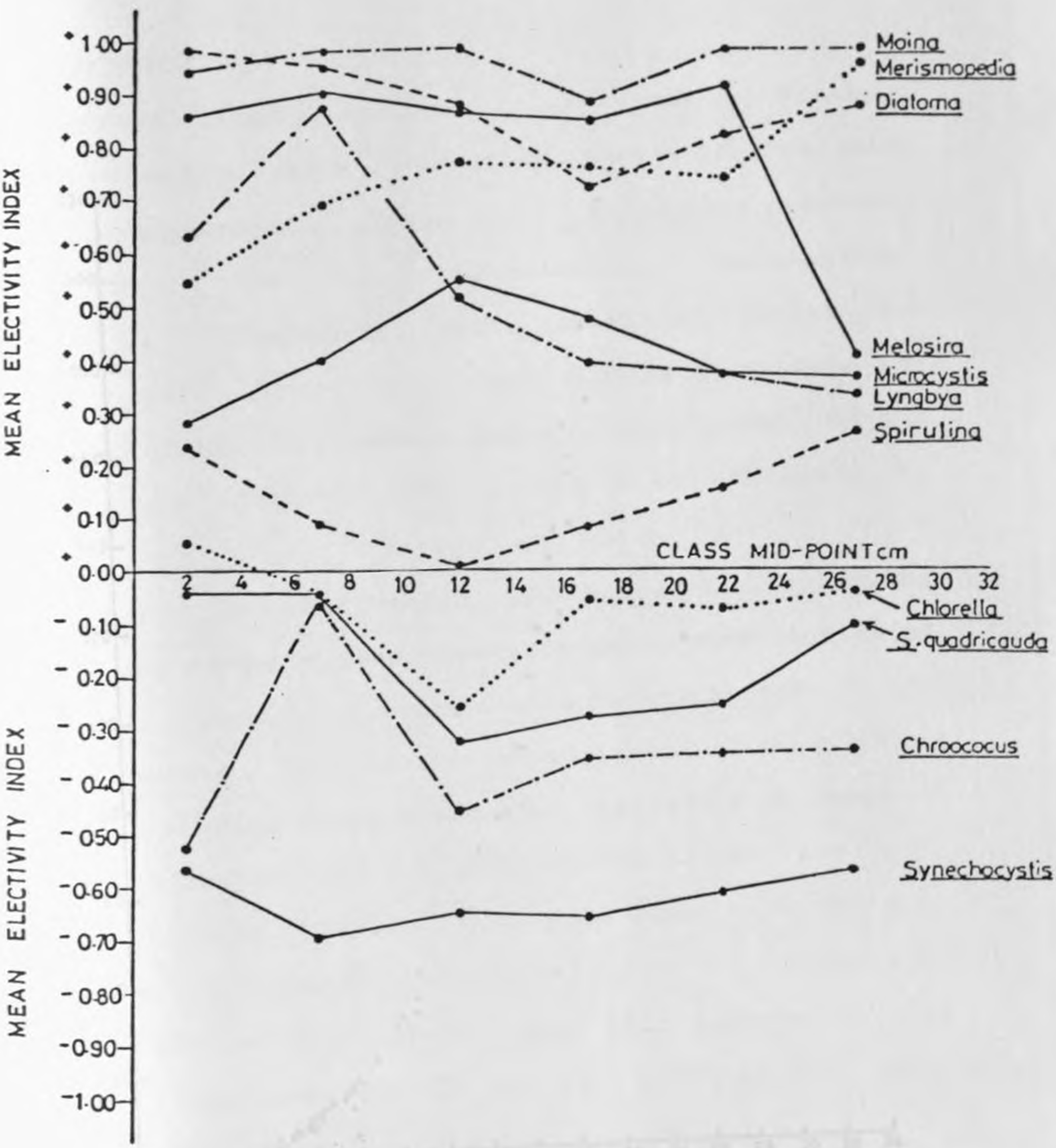

Fig 17. Variation of mean electivity indices of common food items injested with size of Oreochromis niloticus in Nyalenda wastewater lagoons, Kisumu.

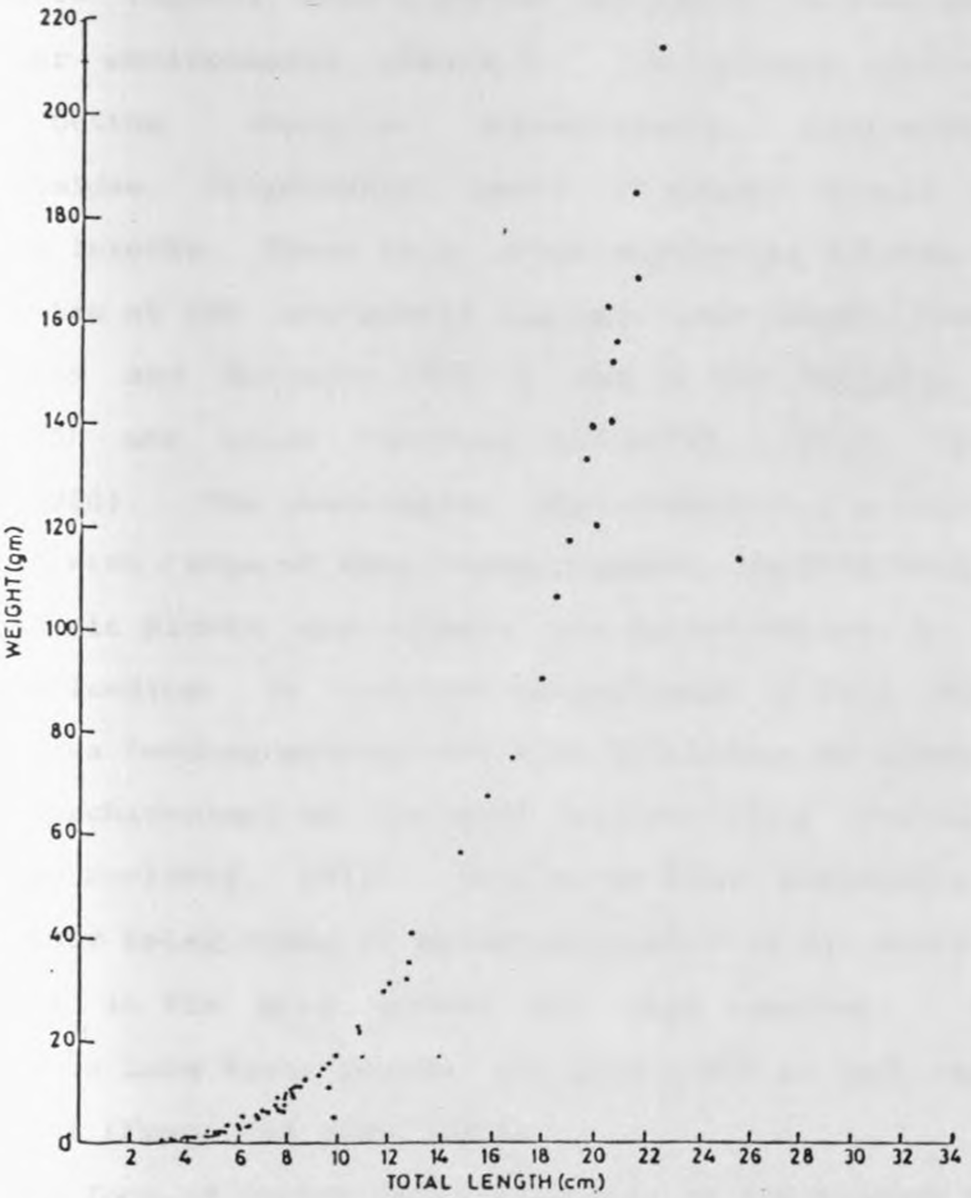

Fig.18. Length-weight relationship of a sample of Oreochromis niloticus analysed for food selection studies at Nyalenda wastewater lagoons, Kisumu

4.5 DISCUSSION

The food eaten by *Oreochromis niloticus* at Nyalenda wastewater lagoons, bore a marked similarity to that eaten in other environments. (Table 8). It includes nutrient-rich bottom deposits, phytoplankton, zooplankton, Chironomidae, Oligochaeta, parts of higher plants and aquatic insects. There is a great similarity between the food eaten at the wastewater lagoons, Lake George, Uganda (Moriarty and Moriarty 1973 a and b and Moriarty *et al.*,1973) and Lakes Tiberias and Huleh, Israel (Ben-Tuvia,1960). The observation that *Oreochromis niloticus* takes a wide range of food items, largely constituting of microscopic plants and animals can be attributed to its mode of feeding. It involves entanglement of food items in a mucus feeding current and also filtration by bands of microbranchiospines on the gill arches (Fryer and Iles, 1972 and Moriarty, 1973). This means that everything in the water being taken is either entangled in the mucus or filtered at the gill arches and then ingested. For example in Lake Kivu, Uganda, the fish feeds on very small particles (Fryer and Iles, 1972)

The food of *Oreochromis niloticus* at the lagoons has been shown to be dominated by the blue-green algae constituting largely of *Microcystis* sp. and *Spirulina* sp. Earlier reports by Fish (1951) and Lowe (1958) indicated that the fish cannot digest blue-green algae in some East African waters, while it was able to do so in others, such

TABLE 8: THE FOOD OF *OREOCHROMIS NILOTICUS* EATEN IN VARIOUS ENVIRONMENTS COMPARED TO THAT EATEN IN WASTEWATER LAGOONS. (Note that for wastewater lagoons, other food items are presented in Tables 6 and 7 .

LAKE GEORGE Moriarty and Moriarty, 1973 Burgis *et al*., 1973 Moriarty, 1973)	LAKES TIBERIAS AND HULEH Ben-Tuvia 1960	E.A. LAKES AND WATERS Lowe (1958) Fryer & Iles (1972)	WASTE WATER LAGOONS This study (1985/86)	RIVERS IN WEST AFRICA Ben-Tuvia, 1960	NIGER Ben-Tuvia, 1960
Microcystis	*Peridinium*	*Microcystis*	*Microcystis*	Phytoplankton	*Cosmarium*
Chlorella	*Pediastrum*	*Anabaenopsis*	*Spirulina*	Benthon	*Lyngbya*
Anabaena	*Scenedesmus*	*Spirulina*	*S. quadricauda*	Bottom mud	*Anabaena*
Nitzschia	*Staurastrum*	Bacteria	*Synechocystis*		*Anabaenopsis*
Chaoborus	*Spondylosium*	Bottom deposits	*Chroococcus*		*Surirella*
Anabaenopsis	*Synedra*	Epiphytic diatoms	*Merismopedia*		*Melosira*
Lyngbya	*Melosira*	Zooplankton	*Aphanocapsa*		
Aphanocapsa	*Cyclotella*	Lakefly corpses	*Synedra*		
Chroococcus	Higher plants		*Navicula*		
Synedra	*Navicula*		*Diatoma*		
Pediastrum	*Surirella*		*Oocystis*		
Benthic material			*Scenedesmus*		
Scenedesmus			*Anabaena*		
Hydracarines			*Pediastrum*		
Kirchneriella			Chironomidae		
Plant material			Oligochaeta		
Melosira			*Moina*		
Thermocyclops			Cyclopoid copepods		

WASTE WATER LAGOONS	RIVERS IN AFRICA	NIGER
<u>Filinia</u>		
<u>Brachionus</u>		
<u>Melosira</u>		
<u>Lyngbya</u>		
<u>Oscillatoria</u>		
Bottom deposits		

as Lake Turkana (Rudolf) (Fryer and Iles, 1972). Moriarty and Moriarty (1973b) and Moriarty (1973) however demonstrated that the fish is capable of digesting blue-green algae at low pH of about 1.4 in its stomach. Thus the great abundance of the blue-green algae and the observation that *Oreochromis niloticus* extensively feeds on it means sufficient food for the fish. This makes it a suitable specimen for culture in wastewater lagoons. Research by Edwards *et al.* (1985) showed that *O. niloticus* raised on a monoculture of the blue-green alga Microcystis sp. registered higher growth rates than those reported from waste-fed tilapia culture in earthen ponds. The relatively high growth rates of the fish observed at the Nyalenda wastewater lagoons, Kisumu (Chapter 5) may be due to the abundant *Microcystis* sp. and other blue-green algae such as *Spirulina* sp.. The abundance of the blue-green algae at the lagoons which forms over 70% of the food of *Oreochromis niloticus* was attributed to the fairly high temperature, high pH and alkalinity, factors which are also responsible of high natural productivity in water bodies (Chapter 3). The digestibility of the blue-green algae is therefore not due to the presence of chemicals in the water as proposed by Fryer and Iles (1972) and Fish (1955), but due to the ability of the fish to digest it at low pH in its stomach.

The feeding of the fish on a large number of genera of algae and invertebrates enables it to derive a wide range of nutrients. The works of Moriarty and Moriarty (1973b) and Pantastico *et al.* (1985) show that different algal genera have different assimilation efficiencies and levels of percentage crude protein content respectively.

The selection of algae as food by *Oreochromis niloticus* in the lagoons shows that some genera were positively selected and others negatively (Fig.17 and Table 6). Scientists who have worked on this subject have put forward explanations to this. Moriarty *et al.* (1973) suggest that the selection of a food item depends on its size and shape, but the observation on the great diversity of food items eaten by the fish at Nyalenda wastewater lagoons showed that it consumed all sizes and shapes of plankton and other food items. Pantastico *et al.* (1985) have explained the acceptability of the algae Chroococcus sp. and *Navicula* sp. by *O. niloticus* in terms of gastric acid excretion by the fish, that is, the algae are readily digested under acidic conditions. This also applies to diatoms (Bowen, 1976). Pantastico *et al.* (1985) further explain the poor acceptability of other algal genera, namely, *Chlorella* sp., *Euglena* sp. and *Oscillatoria* sp. to factors such as toxicity (of the algae) and cell wall composition: that is, the cell wall being impermeable to digestive juices of the fish (Fryer and Iles, 1972).

Existing reports indicate that most of the food items with high positive indecies in the wastewater lagoons have high assimilation efficiences and percentage crude protein content. Moriarty and Moriarty (1973b) have shown that the algal genera *Microcystis* sp., *Anabaena* sp. and *Navicula* sp. have higher assimilation efficiencies and percentage crude protein content than *Chlorella* sp. The former algae had positive selection at Nyalenda wastewater lagoons while the latter had negative. Euglena sp. had a lower assimilation efficiency but the highest percentage crude protein content. In the wastewater lagoon samples, it had negative selectivity due to its low assimilation efficiency and percentage crude protein content. This study shows that *Chlorella* sp. had negative selection in the lagoons.

The other factors which can affect the selection of a food item are (i) its abundance in the environment (ii) the species composition of the food items and (iii) the age of the algae: older algae being unpalatable due to loss of nutrients by leaching. The most abundant food item in the environment has a higher probability of being taken and sometimes accidentally than a less abundant one with equal selection potential.

The alga *Melosira* sp. showed almost an identical selection pattern with fish size in both Nyalenda wastewater lagoons and Lake George, Uganda (Fig.17). The other algae, namely, *Microcystis* sp. and *Lyngbya* sp. showed a more or less similar selection as in Lake George, but the level of selection in the wastewater lagoons is lower.

The species composition in the environment determines the extent and nature of selection of a food item. For example, the composition of food items used by *Oreochromis niloticus* at the Nyalenda wastewater lagoons is different from that at Lake George, Uganda. In the wastewater lagoons, the dominant genera were *Spirulina* sp., *Synechocystis* sp., *Microcystis* sp., *Scenedesmus quadricauda* and *Chlorella* sp. (Table 5). In Lake George, they were: *Microcystis* sp., *Anabaenopsis* sp., *Lyngbya* sp., *Aphanocapsa* sp. and *Chroococcus* sp., in that order (Burgis *et al.*, 1973 and Moriarty and Moriarty, 1973 a and b). This could explain the marked similarities in the selection of the same genera in both environments; for example *Melosira* sp.,*Lyngbya* sp. and *Microcystis* sp. had positive electivity indecies in both environments.

The electivity index of a particular food item can be affected by that of another one of equal selection potential. This means that in the absence or scarcity of one, the presence of the other is as good. This was observed to be the case between the algae *Spirulina* sp. and *Microcystis* sp. in Nyalenda wastewater lagoons. Fish which had picked a lot of *Spirulina* picked less *Microcystis* sp. and vice versa (Fig.17). The food selection of an item can further be affected by the feeding habit of the fish. By *Oreochromis niloticus* feeding on the bottom deposits, the algae in the water column are accorded a lesser probability of being selected.

Another factor affecting the electivity indecies of the food items is patchy distribution. Patchiness which is either natural or induced due to intense predation or grazing, affects the probability of a food item being eaten (Strauss,1979). Where as a result of patchiness, the organisms occur in very low concentrations or are absent, the accessibility of the prey item to the fish is low. This results in a low percentage occurrence of the item in the fish stomach. The calculated electivity index under such a condition is low. In Nyalenda wastewater lagoons, several prey items were absent from at least one of the three sampling sites in each of the two tertiary lagoons studied. Examples are *Scenedesmus dispar*, *Navicula* sp., *Chroococcus* sp., *Merismopedia* sp., *Cymbella* sp., Chironomidae and Oligochaeta. The low indecies of these food items (Table 7) can be attributed to patchy distribution in the lagoons. The fact that some fish which had fed on benthic material contained only Oligochaeta and no Chironomidae and vice versa further lends support to the speculation that these food items are patchily distributed in the lagoons and this had the effect of lowering their electivity indecies, (Table 7).

CHAPTER 5

THE EFFECTS OF STOCKING DENSITY ON THE GROWTH RATE, CONDITION FACTOR AND NET YIELD OF *OREOCHROMIS NILOTICUS* IN WASTEWATER LAGOONS.

5.1 INTRODUCTION

There has been little research on the extensive culture of Oreochromis niloticus in wastewater lagoons. The scanty data on extensive cage culture comes mainly from the Philippines freshwater lakes. Balarin and Haller (1979) suggest that extensive cage culture of tilapia in wastewater lagoons is an opportunity worth exploiting in the future. This is further supported by the high yields obtained in Costa Rica (Echandi, 1982) and Tennessee, U.S.A. in sewage ponds (Sufern *et al.*, 1978). The advantages of culturing fish in wastewater lagoons are two fold (i) to improve the waste treatment capacity and (ii) to procure the much needed fish protein. The improvement of the water quality is effected through the utilization of algae as food by the fish which when the biomass is high leads to the production of a poor effluent. This entails that microphagous species such as *Oreochromis niloticus*, *O. mossambicus* and *O. aureas* be used. This chapter is devoted to the study of the effect of the stocking densities on the growth rate, condition factor and yield of *Oreochromis niloticus* in wastewater lagoons.

The stocking densities at which maximum yields can be obtained are largely unknown. They are determined by (a) the physico-chemical nature of the habitat and (b) the primary productivity.

5.2 LITERATURE REVIEW

Edwards *et al.* (1981) observed that the mean weight of *Oreochromis niloticus* cultured in a sewage effluent fell as the stocking density increased but the final yield increased. Similar observations have been made on caged fish, predominantly tilapia (Coche, 1976, Muthukumarana and Weerakoon, 1985 and Edwards *et al.*,1986). The decline in the biomass is attributed to a number of factors such as overcrowding at high densities, low dissolved oxygen and some growth inhibitor in the sediments beneath the cages (Balarin and Haller, 1979). Anon (1978) reports the stunting of cage stocks in Lake Calibato in the Philippines and attributed this to overstocking of the lake with cages.

Studies on the growth rates of *O. niloticus* at different stocking rates particularly in wastewater lagoons is scanty. At Thika wastewater lagoons in Kenya, *O. niloticus* stocked at 30 and 50 fish 0.81m^{-2} cage survived for 132 days and attained daily growth rates of 0.55 and 0.33g respectively without supplemental feeding. After this, there was 100% mortality whose cause was not known (Nyaga, 1981). In Lake George, Uganda, *O.*

niloticus kept in open mesh cages grew from fry to a maximum of 19.6 cm, with an average length increment of 1.6 cm month^{-1} (Moriarty and Moriarty,1973a). In Lake Victoria, East Africa, caged *O. niloticus* grew from mean lengths of 4.3, 6.3 and 7.9 cm to 7.7, 9.2 and 10.2 cm respectively, which represent mean growth rates of 1.8,3.1,3.5 and 1.7cm month^{-1} (Rinne, 1975). Coche (1976) notes that at equal stocking densities, the individual size increase is dependent on feed availability.

The yields from extensive cage culture furnished by scientists working in the Philippine freshwater lakes are low when compared with those realized in intensive cage culture. They range from 0.04-1.9kg month^{-1} (Mane,1979, Alvarez,1981 and Guerrero, 1983 all quoted by Beveridge, 1984b). Further, it has been observed there that there is a steady decline in fish yields corresponding to a decline in natural productivity. The consequences have been the drop in the stocking densities and the extension of the culture period from 4 to 6-9 months (Coche, 1982; Guerrero, 1983 and Beveridge 1984b). This shows the dependence of fish yields on the level of natural productivity. Balarin and Haller (1979) report that without supplementary feeding,yields of 25-500 tonnes ha^{-1} yr^{-1} have been achieved in Tennessee, U.S.A.

Yields from intensive cage culture are higher. For example at Kossou Lake, Ivory Coast, cage cultured *O. niloticus* at stocking densities of 215-488m^{-3} yielded up to 76 kgm^{-2} in a period of 3-5.5 months (Coche, 1977). Balarin and Haller (1979) note that yields up to 94 kg m^{-3} are possible. Since there is no intensive feeding in extensive culture, the yield per unit area of water is lower.

The setting of cages in a water body has been found to affect growth rates. Cages set too near the bottom exhibited low growth rates. While those set at about 0.2m from the bottom exhibited better growth rates (Balarin and Haller, 1979). This has been largely attributed to deoxygenation resulting from the decomposing organic matter near the bottom and to some growth inhibitory factor in the sediments (Muir and Roberts, 1982). It is therefore, recommended that cages should be set at least 3 m from the bottom (Balarin and Haller, *op cit*).

There have been few studies on the relationship between yields obtained in extensive cage culture and the natural productivity of the habitat. Scientists not directly involved in cage culture have demonstrated that annual fish yields and natural productivity are positively related (Hrbacek, 1969; Adams *et al*.,1983; Melack, 1976; McConnell *et al*., 1977; Oglesby, 1977, 1982; Heckey *et al*., 1981 and Marten and Polovina, 1982). A similar relationship has been shown to hold for extensive cage culture (Beveridge, 1984b).

In some water bodies, it is not easy to draw a good correlation between fish yields and natural productivity.

A number of factors which contribute to the total amount of energy fixed interfere with the relationship. These are (i) autochthonous production from periphyton and macrophytes (Moss, 1980) and (ii) allochthonous inputs particularly in small aquatic systems (Oglesby, 1977 and Yap, 1983). This causes the yields to be higher than those predicted from the primary productivity in some environments.

The increase in fish yields in relation to natural productivity does not continue indefinitely. At higher levels of production, algae are inefficiently utilized by fish leading to energy wastes. This lowers the P/B (productivity to biomass) ratio. At a primary production of about 2,500 g C m^{-2} yr^{-1} , further increases lead to small increments in fish yields (Liang *et al.*, 1981).

5.3 MATERIALS AND METHODS

Four pairs of 1 m^3 cages were constructed from wooden frames of 5.1 x 5.1 x 5.1 cm and a plastic netting material of mesh size 19 cm. The cages were provided with lockable doors. The main frames of the cages were reinforced with small wooden brackets, while the doors were supported by larger brackets, fixed to the main frame at the door opening (Fig. 19). The cages were used to culture *Oreochromis niloticus* in a tertiary wastewater lagoon. At the lagoon, the cages were anchored to the bottom using manila strings attached to stones of about 5 kg.

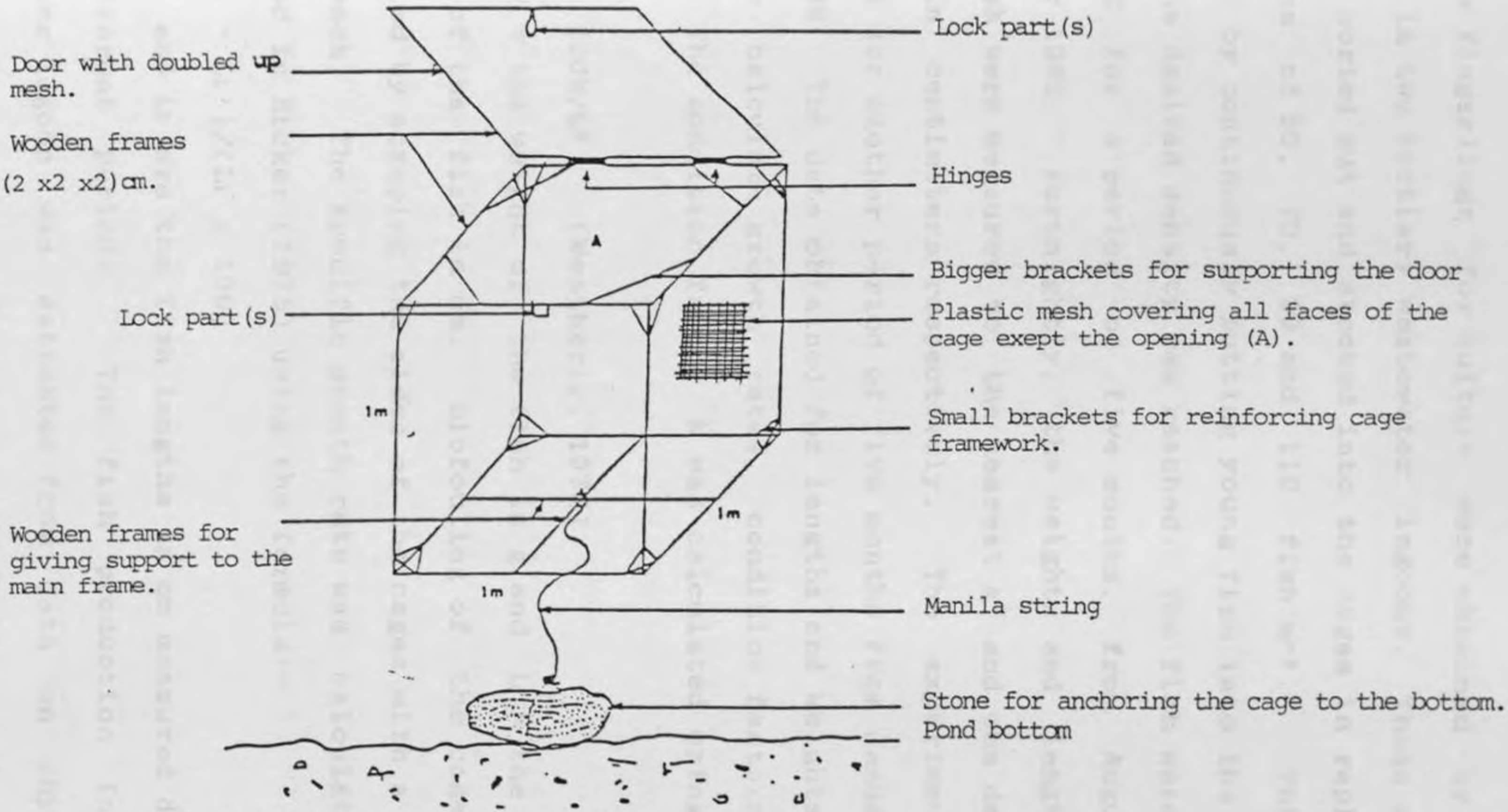

Fig. 19. The type of cage used to culture Oreochromis niloticus in wastewater lagoons, Nyalenda, Kisumu.

The fingerlings for culture were obtained by beach seining in two tertiary wastewater lagoons. Those of 6-7 cm were sorted out and stocked into the cages in replicate densities of 50, 70, 90 and 110 fish m^{-3}. This was achieved by continuously putting young fish into the cages until the desired density was reached. The fish were then cultured for a period of five months, from August to December 1985. Fortnightly, the weights and lengths of the fish were measured to the nearest g and one decimal place in centimeters respectively. The experiment was repeated for another period of five months from January to June 1986. The data obtained for lengths and weights were used to calculate growth rates, condition factors and yields. The condition factor K was calculated using the formula:-

$K = 100W/L^3$ (Weatherly, 1972),

where W = the weight of the fish in g and L = the total length of the fish in cm. Biofouling of the cages was controlled by scraping the sides of the cages with a brush once a week. The specific growth rate was calculated as described in Ricker (1975) using the formula:-

$(L_2 - L_1)/(L_1 \times 100)$

where L_1 and L_2 are the fish lengths in cm measured during two different periods. The fish production in the wastewater lagoon was estimated from data on physico-chemical parameters and primary production using the methods described in Huet (1975) and Sreenivansan (1972).

The formula for calculating the annual fish production for artificial ponds as expressed in Huet (*op cit.*) is:-

$$K = Na/10 \times B \times k.$$

where K is the annual fish production in kilograms, Na is the size of the pond in ares, B is the biogenic capacity (nutritive value) of the water in the pond and k is the coefficient of productivity. k is a product of four sub-coefficients namely; k_1 for temperature, k_2 for acidity or alkalinity, k_3 for fish species and k_4 for the age of the fish.

The biogenic capacity (B) is expressed on a scale ranging from I for water with the lowest nutritive value to X for water with the highest nutritive value. The four sub-coefficients of productivity are expressed thus:- for 10°C, k_1 = 1.0; for 16.0°C, k_1 = 2.0; for 22°C, k_1 = 3.0 and for 25°C, k_1 = 3.5. k_2 for acid water is 1.0 while that for alkaline water is 1.5. k_3 is 1.0 for cold water species and 2.0 for warmwater species and k_4 is 1.5 for fish of less than 6 months and 1.0 for those of greater than 6 months. For the computation of fish production at Nyalenda wastewater lagoons, the following values were used:

$$Na/10=B=10,\ K = 3.5,\ K = 1.5,\ K = 2.0,\ K = 1.5$$

The annual production computed was converted to that representing five months; a period equivalent to the one used to culture fish in the lagoons.

The method explained in Sreenivansan (1972) utilizes the net primary production to estimate fish production. The following conversion rates were used as is required by the method:_

(i) 1 g oxygen (photosynthetic)= 0.375g carbon.

(ii)1 g carbon = 10g of fish (wet weight).

Nine hours as suggested (Prowse, 1972) were used to compute the daily fish production. The monthly fish production was computed by multiplying by 30 days. This was similarly converted to that representing five months for comparison purposes with the previous method and the fish yields for the five-month culture period.

5.4 RESULTS

The overall means of the growth rates, maximum sizes, stocking densities and net and gross yields attained by *Oreochromis niloticus* in the cages are presented in Tables 9, 10 and 11. The growth rates at an initial stocking density of 50 fish m^{-3} were slightly higher than those at higher stocking densities. The overall mean growth rate ranged from 2.479 cm (29.825 g) at an initial stocking density of 110 fish m^{-3} to 2.821 cm (36.256 g) at an initial stocking density of 50 fish m^{-3}. The growth rates in cm and g are presented in Figs.20 and 21.

The initial rapid growth rates in the 0th-8th weeks of culture occurred during periods of regular and adequate wastewater flow and high primary productivity. The decline in the growth rates in the 8th-10th weeks of

TABLE 9: THE RESULTS OF THE FIRST CULTURE EXPERIMENT ON <u>OREOCHROMIS NILOTICUS</u> IN NYALENDA WASTEWATER LAGOONS, KISUMU.

NO. OF FISH m^{-3}	MEAN LENGTH (cm)	MEAN WEIGHT (g)	TOTAL WEIGHT (Kg)	RESULTS AFTER FIVE MONTHS OF CULTURE: GROWTH RATES ($cm\ fish^{-1}$)	GROWTH RATES ($g\ fish^{-1}$)	MEAN FINAL LENGTH (cm)	MEAN FINAL WEIGHT (g)	NO. OF FISH m^{-3}	TOTAL WEIGHTS (Kg)	NET WEIGHT (Kg)
50	6.98	7.01	0.351	2.692	33.471	20.44	174.365	17	2.967	2.616
70	6.96	7.013	0.491	2.536	29.890	19.64	156.465	17	2.707	2.216
90	7.02	7.022	0.632	2.496	29.151	19.50	152.779	17	2.599	1.967
110	7.17	7.336	0.807	2.418	28.044	19.26	147.556	19	2.8015	1.9945

TABLE 10. RESULTS OF THE SECOND CULTURE EXPERIMENT ON <u>OREOCHROMIS NILOTICUS</u> IN NYALENDA WASTEWATER LAGOONS, KISUMU.

NO. OF FISH m^{-3}	MEAN LENGTH (cm)	MEAN WEIGHT (g)	TOTAL WEIGHT ($Kg\ m^{-3}$)	RESULTS AFTER FIVE MONTHS OF CULTURE: GROWTH RATES MEAN LENGTH ($cm\ Fish^{-1}$)	GROWTH RATES MEAN WEIGHT ($g Fish^{-1}$)	MEAN FINAL LENGTH (cm)	MEAN FINAL WEIGHT (g)	MEAN NO. FISH m^{-3}	TOTAL WEIGHT ($Kg\ m^{-3}$)	NET YIELD ($Kg\ m^{-3}$)
50	6.771	6.93	0.341	2.951	39.041	21.524	202.135	12	2.321	1.980
70	6.820	6.99	0.494	2.810	36.695	20.871	190.465	13	2.476	1.982
90	6.830	6.879	0.619	2.709	34.708	20.377	180.42	12	2.161	1.542
110	6.913	7.455	0.82	2.539	31.609	19.609	165.498	14	2.321	1.501

TABLE 11. COMBINED RESULTS OF THE FIRST AND SECOND CULTURE EXPERIMENTS ON OREOCHROMIS NILOTICUS IN NYALENDA WASTEWATER LAGOONS, KISUMU.

INITIAL STOCKING RATES				RESULTS AFTER FIVE MONTHS OF CULTURE						
				GROWTH RATES						
NO. OF FISH m^{-3}	MEAN LENGTH (cm)	MEAN WEIGHT (g)	TOTAL WEIGHT (Kg)	MEAN LENGTH (cm $Fish^{-1}$)	MEAN WEIGHT (g $Fish^{-1}$)	MEAN FINAL LENGTH (cm)	MEAN FINAL WEIGHT (g)	MEAN NO.FISH m^{-3}	TOTAL WEIGHT (Kgm^{-3})	NET YIELD (Kgm^{-3})
50	6.876	6.97	0.346	2.821	36.256	20.982 ± 0.767	188.25 ±19.636	14.5	2.644 ±0.457	2.298 ±0.450
70	6.89	7.002	0.493	2.673	33.293	20.256 ±0.870	173.465 ±24.042	15.0	2.592 ±0.163	2.099 ±0.165
90	6.925	6.951	0.626	2.603	31.930	19.939 ±0.620	166.600 ±19.545	14.5	2.380 ±0.310	1.755 ±0.301
110	7.042	7.400	0.814	2.479	29.825	19.435 ±0.247	156.527 ±12.687	16.5	2.561 ±0.340	1.748 ±0.349

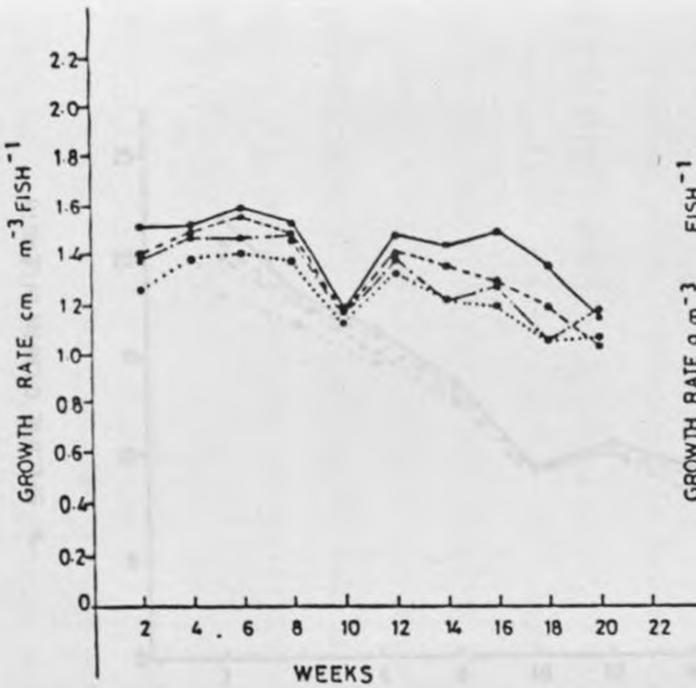

Fig 20 Mean growth rate of caged *Oreochromis niloticus* in Nyalenda wastewater lagoons, Kisumu..

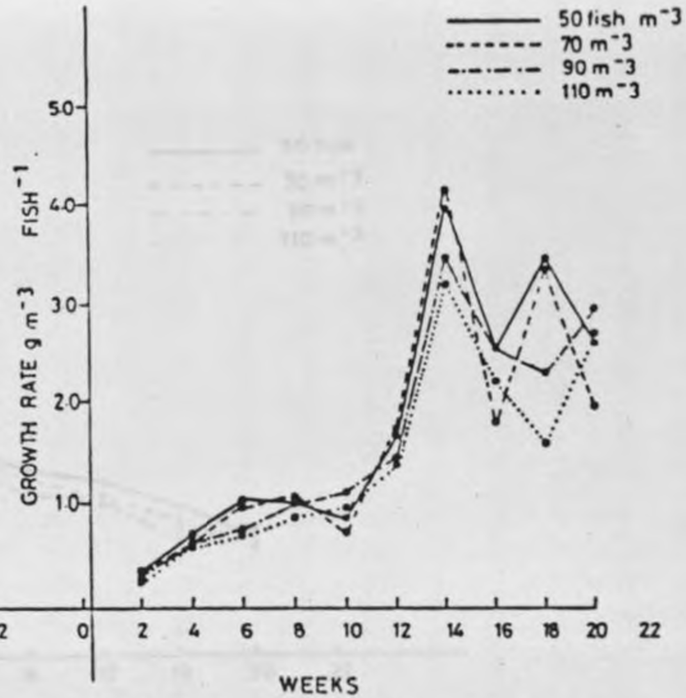

Fig 21. Mean growth rate of caged *Oreochromis niloticus* in Nyalenda wastewater lagoons.

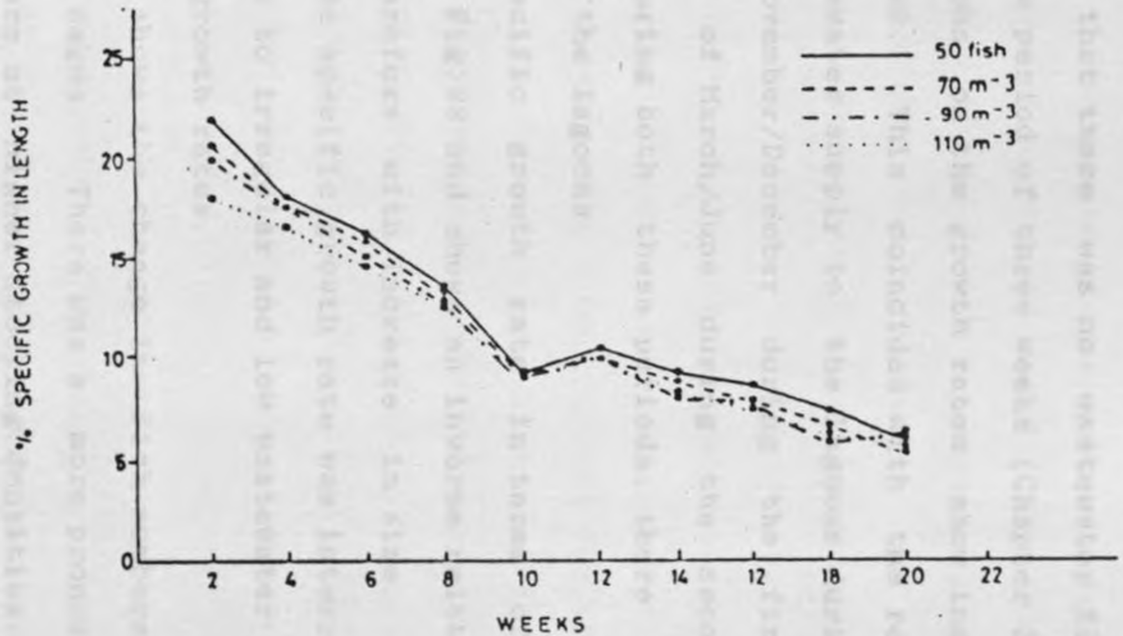

Fig. 22. Percentage specific growth of <u>Oreochromis</u> <u>niloticus</u> in Nyalenda wastewater lagoons, Kisumu.

culture following the rapid initial growth rates occurred during periods of irregular and reduced wastewater flow into the lagoons. In the second phase of culture, the poor growth rate also coincided with a period when there was a major breakdown of the sewage system, in March 1986 coincidentally also in the 8th-10th weeks of culture to the extent that there was no wastewater flow into the lagoons for a period of three weeks (Chapter 3).

The graphs on the growth rates show increases after the 10th week. This coincided with the resumption of regular wastewater supply to the lagoons during the later rains of November/December during the first phase of culture and of March/June during the second phase of culture. During both these periods, there were regular flushings of the lagoons.

The specific growth rate in terms of length is presented in Fig.22 and shows an inverse relationship with time and therefore with increase in size. The smooth decline in the specific growth rate was interrupted in the 10th week due to irregular and low wastewater supply which reduced the growth rates.

Fig.24 shows the change in fish numbers per m^3 with time in the cages. There was a more pronounced initial drop in numbers at higher stocking densities. There was another drop in the 10th week which coincided with poor growth rates. The drop at higher stocking densities of 90 and 110 fish m^{-3}, resulted in a big reduction in the weight to the extent that the net yield was negative during the initial stages (Fig.23).

The mean overall sizes attained by *Oreochromis niloticus* ranged from 19.435 ± 0.247 cm (156.527 ± 12.687g) at an initial stocking density of 110 fish m^{-3} to 20.982 ± 0.767cm (188 ± 19.636g) at an initial density of 50 fish m^{-3}. The growth in mean length and weight with time is presented in Figs.25 and 26. The mean sizes at a stocking density of 50 fish m^{-3} remained slightly above those at greater stocking densities.

The overall biomass in the cages ranged from 2.380 ± 0.310 kg m^{-3} at an initial stocking density of 90 fish m^{-3} to 2.644 ± 0.45 kg m^{-3} at an initial stocking density of 50 fish m^{-3}. Fig.28 shows the variation of the total fish biomass in the cages with time. Except for that at 50 and 70 fish m^{-3}, the other stocking densities shows a drop in the biomass corresponding to the initial drop in numbers (Figs.24 and 28). Single factor analysis of variance was used to find out whether there were any significant differences between the gross yields attained at different stocking densities. The F value calculated for F0.05 (1) 3, 12 = 3.49 was 0.384 showing that there were no significant differences. The total biomass starts to increase after the second week during the phase of high growth rate (Figs.20 and 21) and then slows down between the 8th and 12 week, a period when there was reduced water flow and depth at the lagoons. The rapid increase is

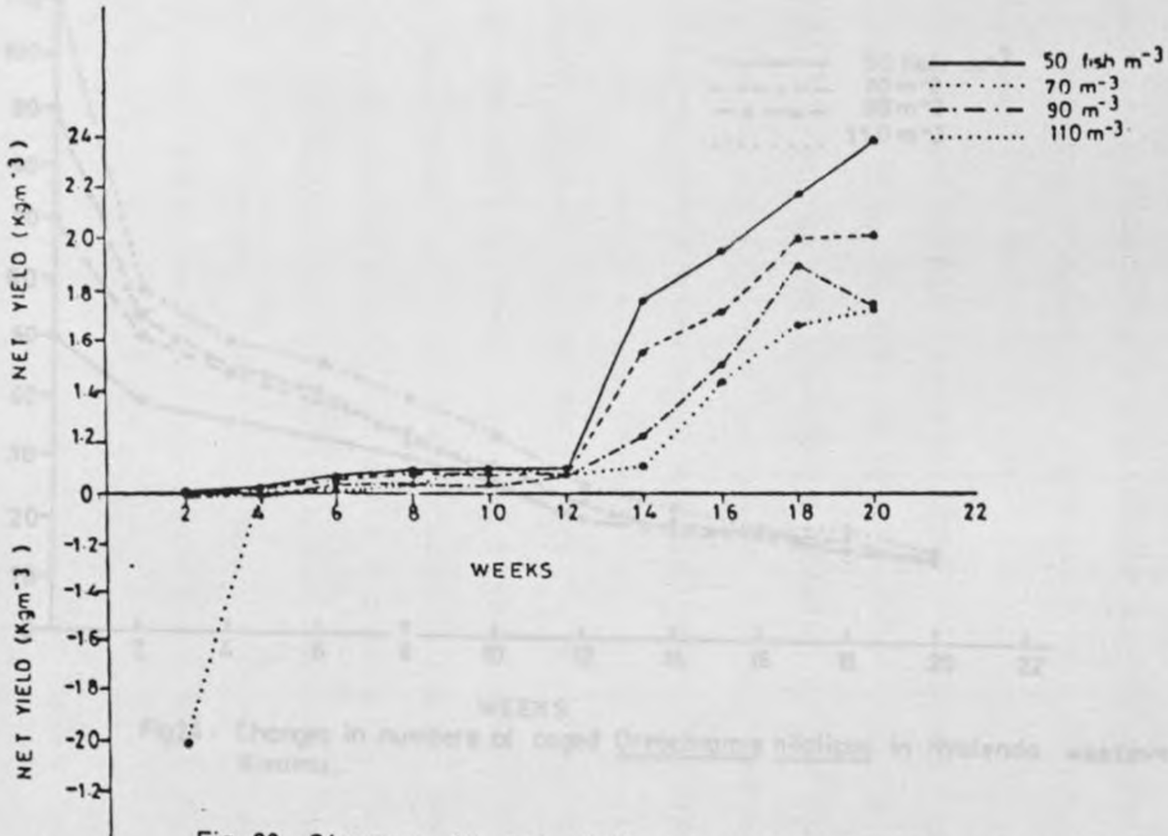

Fig. 23. Changes in net yield of caged Oreochromis niloticus in Nyalenda wastewater lagoons, Kisumu.

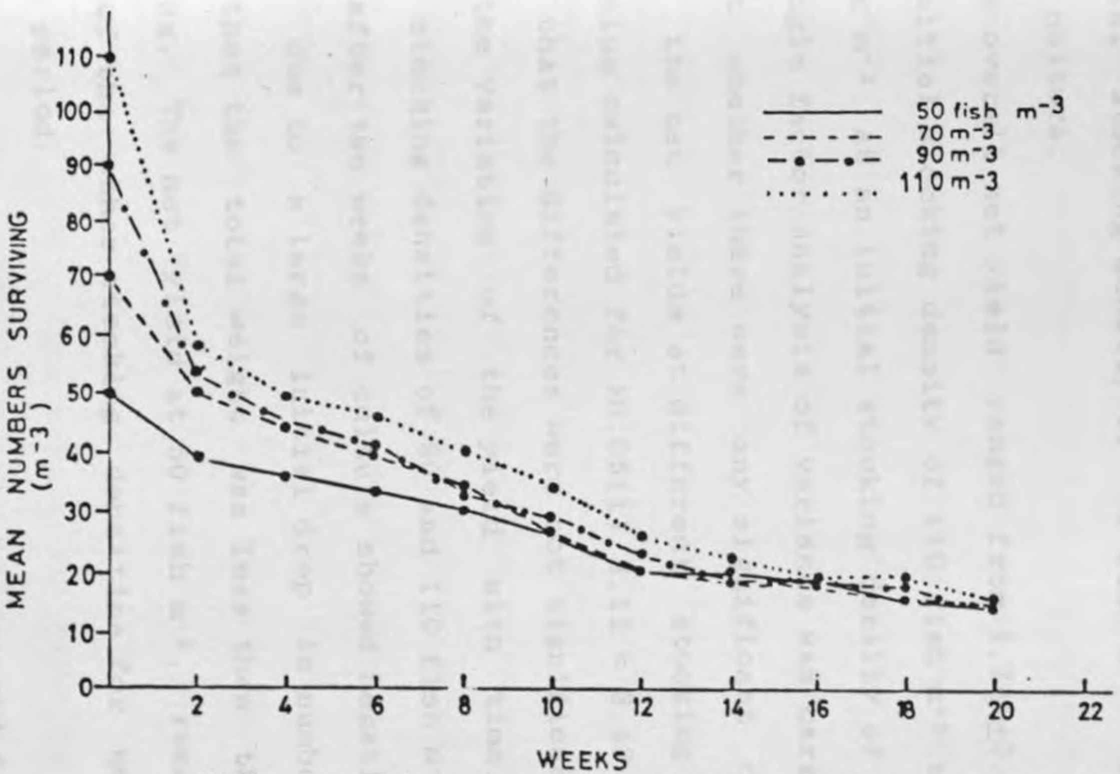

Fig24. Changes in numbers of caged Oreochromis niloticus in Nyalenda wastewater lagoons, Kisumu.

followed by the slackening of the growth rate as the fish approach bigger sizes. The total fish biomass in cages with higher stocking densities was higher than that in lower stocking densities initially but declined as the numbers decreased, (Fig.28), for example in the cages with an initial stocking density of 90 fish m^{-3} in the 14th week of culture.

The overall net yield ranged from 1.748±0.349 kg m^{-3} at an initial stocking density of 110 fish m^{-3} to 2.298 ± 0.450 kg m^{-3} at an initial stocking density of 50 fish m^{-3}. Single factor analysis of variance was carried out to find out whether there were any significant differences between the net yields at different stocking densities. The F value calculated for $F_{0.05(1)\ 3,12} = 3.49$ was 2.056, showing that the differences were not significant. Fig.23 shows the variation of the yield with time. At the initial stocking densities of 90 and 110 fish m^{-3}, the net yields after two weeks of culture showed negative values. This is due to a large initial drop in numbers to the extent that the total weight was less than that at the beginning. The net yield at 50 fish m^{-3}, remained above those of the other stocking densities for most of the culture period.

The overall specific growth rate ranged from 0.108 ± 0.044 at an initial stocking density of 110 fish m^{-3} to 0.120 ± 0.053 per fortnight, at an initial stocking density of 50 fish m^{-3}. Fig.27 shows that the specific growth rate in terms of length was higher at lower stocking densities.

The overall condition factor ranged from 2.041 ± 0.050 at a stocking density of 50 fish m^{-3} to 2.124 ± 0.100 at an initial stocking density of 110 fish m^{-3}. Fig.27 shows that the condition factor generally dropped between the 0th and the 12th week of culture and this corresponds with the period of the rapid decline in fish numbers in the cages. The increase in the condition factor after the 12th week corresponds to the low densities attained in the cages, almost stabilising.

Fish production was also estimated in the lagoons using the physico-chemical and biological characteristics presented in Chapter 3. The methods employed were those of Huet (1975) in which the biogenic capacity, temperature, pH, age and species of the fish are used, and of Sreenivansan (1972) in which the primary productivity as measured in g O_2 m^{-2} yr^{-1} is converted to g C m^{-2} yr^{-1} by a factor of 0.375 and then the g C m^{-2} yr^{-1} is converted to fish production (wet weight) by a factor of 10. Huet's method gave an estimate of 1.9398 kg fish m^{-2} yr^{-1} (wet weight), while Sreenivansan's method gave 10.176 kg fish m^{-2} (wet weight). Assuming two equal crops per year as suggested by the results on cage culture, then Huet's method gives 0.969 kg fish m^{-2} and Sreenivansan's gives 5.088 kg fish m^{-2}. If five months are considered as in the cage culture experiments, then

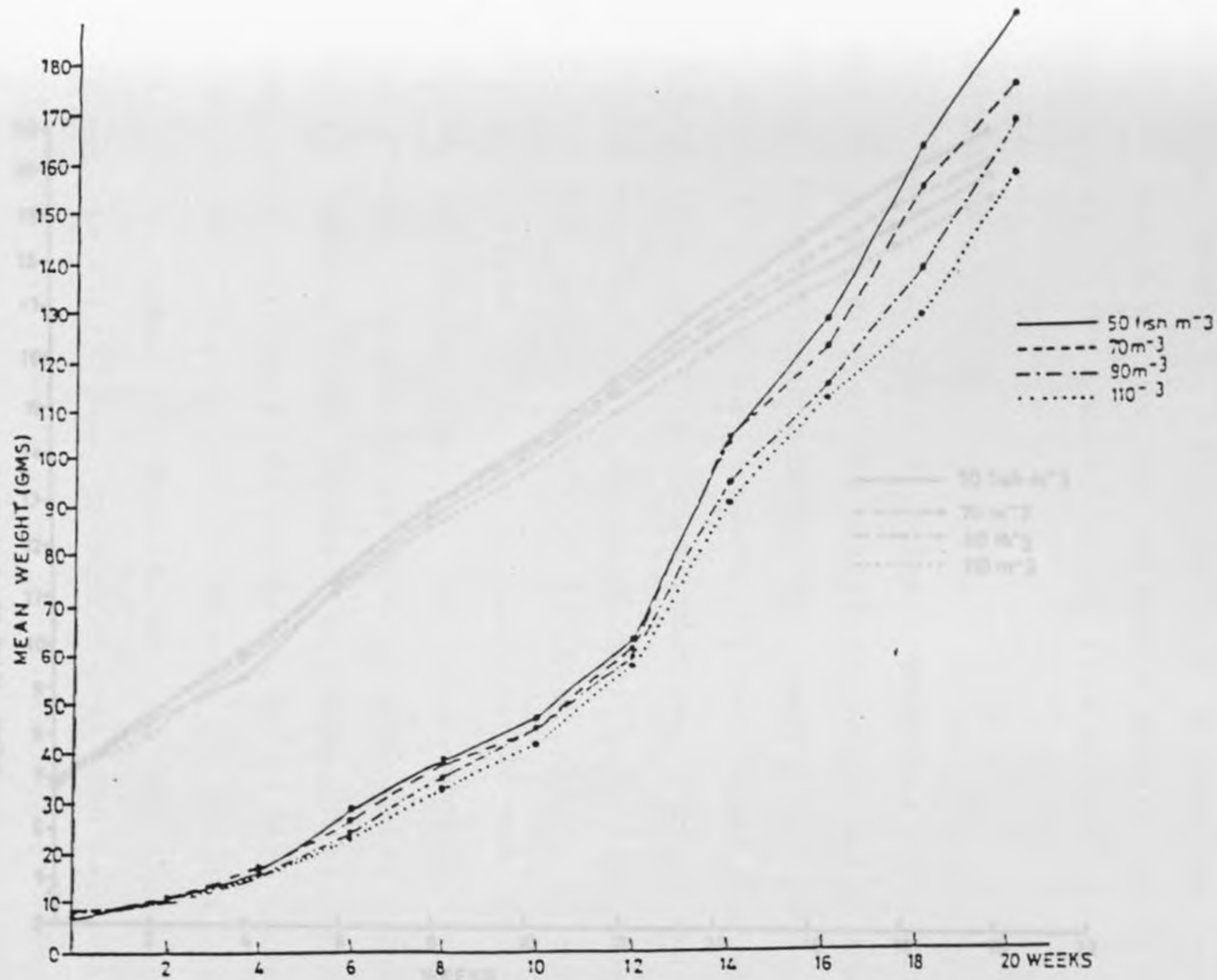

Fig.25 Growth in mean weight of caged Oreochromis niloticus in Nyalenda lagoons, Kisumu.

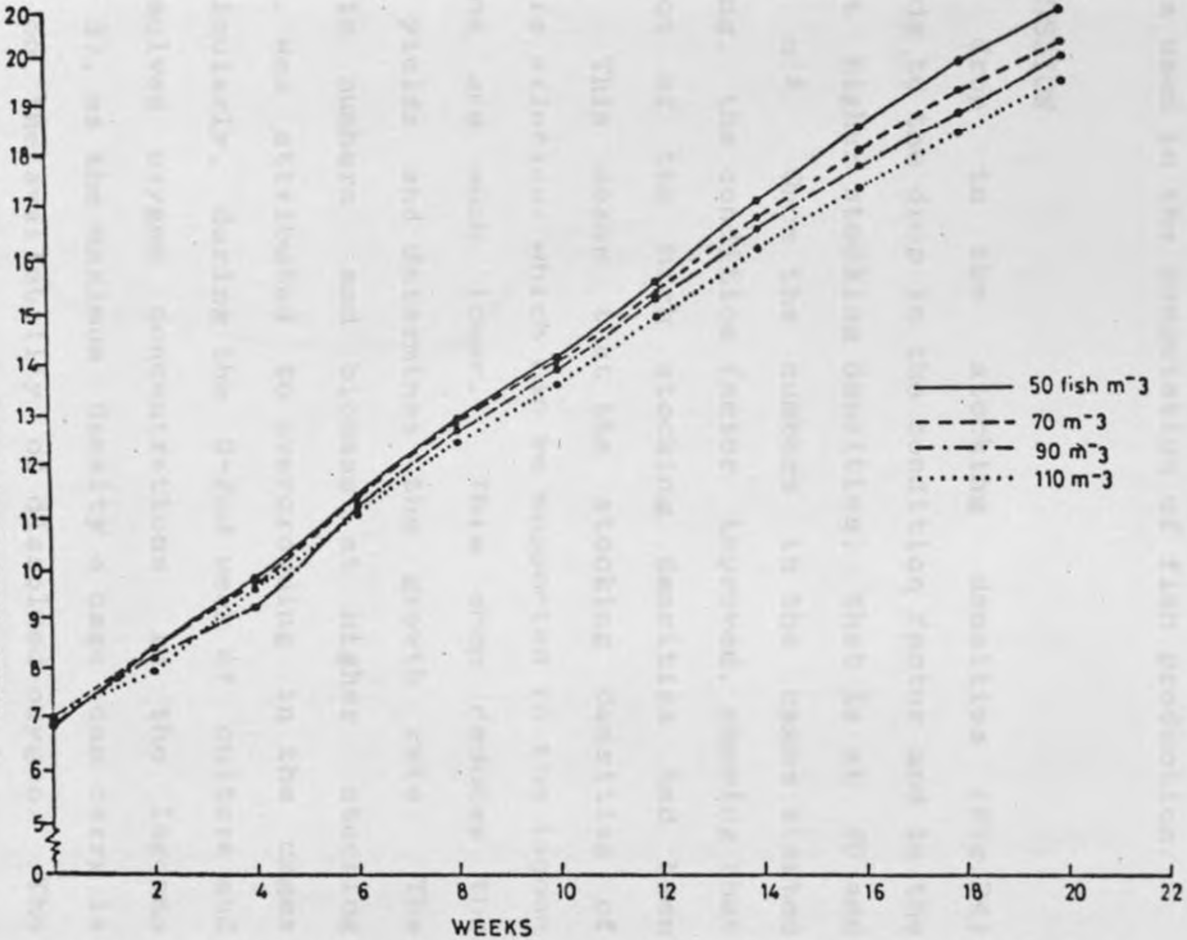

Fig 26 Growth in mean length of caged *Oreochromis niloticus* in Nyalenda wastewater lagoons, Kisumu.

Huet's method gives 0.8075 kg fish m^{-2} and Sreenivansan's gives 4.24 kg fish m^{-2}. The disparity between the two methods is attributed to the different physico-chemical parameters used in the computation of fish production.

5.5 DISCUSSION

The drop in the stocking densities (Fig.24) corresponds to the drop in the condition factor and in the biomass at higher stocking densities; that is at 90 and 110 fish m^{-3}. Once the numbers in the cages started stabilising, the condition factor improved, showing that the effect of the high stocking densities had been reduced. This means that the stocking densities of *Oreochromis niloticus* which can be supported in the lagoon environment are much lower. This drop reduces the expected yields and determines the growth rate. The decline in numbers and biomass at higher stocking densities, was attributed to overcrowding in the cages more particularly, during the 0-2nd week of culture and low dissolved oxygen concentrations in the lagoons (Chapter 3), as the maximum density a cage can carry is dependent on the availability of dissolved oxygen. The low dissolved oxygen concentration was attributed to three factors. (i) waste materials produced as result of overcrowding in the cages which locally affected the water quality, (ii) presence of organic matter in the lagoons which on decomposing consumed dissolved oxygen and (ii)

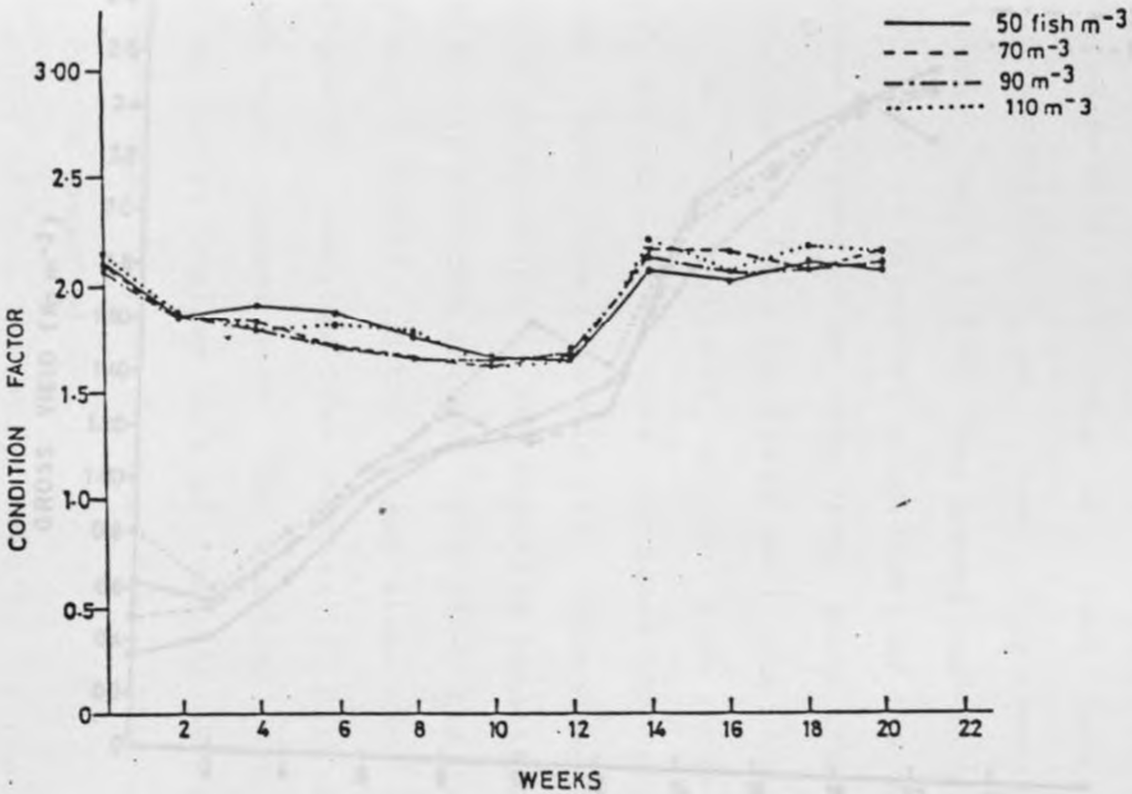

Fig 27. Changes in the condition factors of caged Oreochromis niloticus in Nyalenda wastewater lagoons, Kisumu.

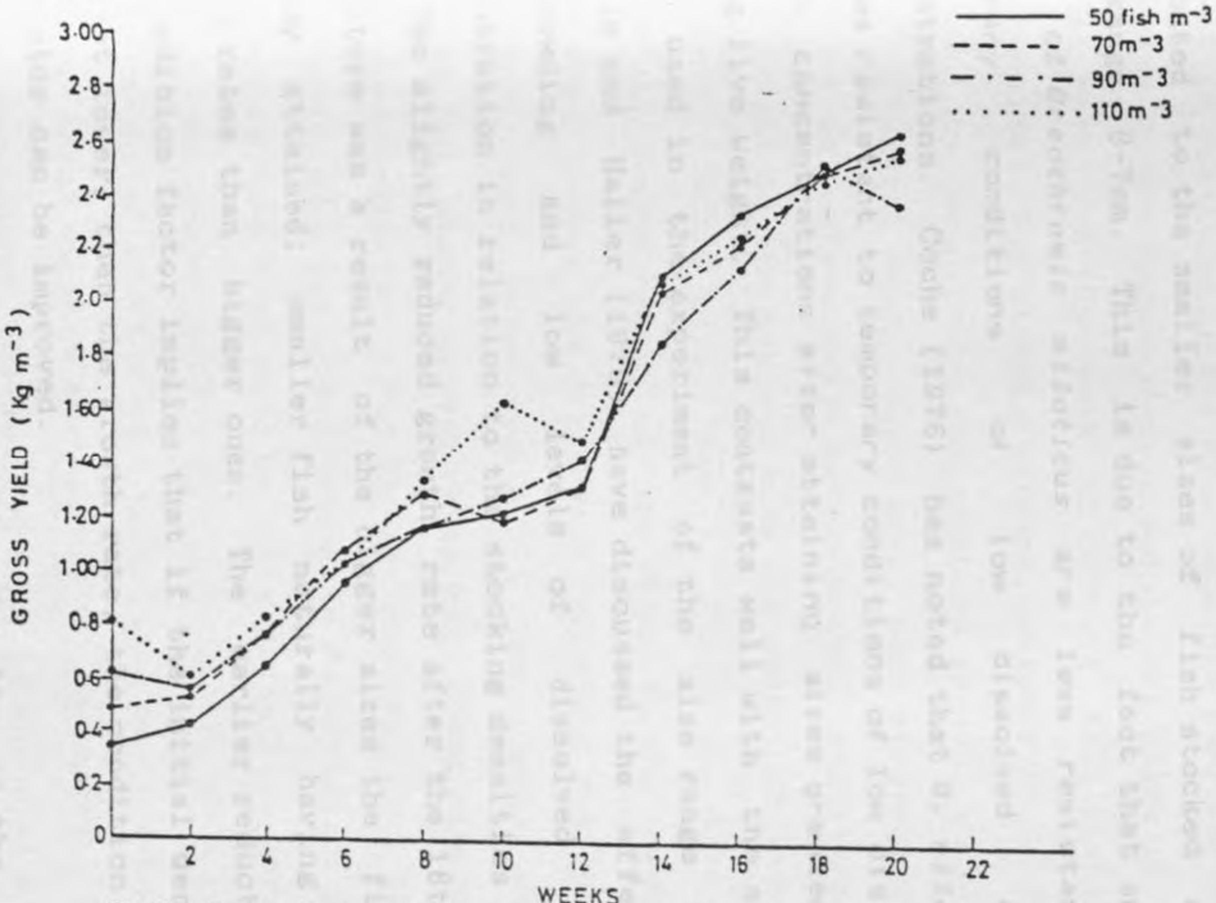

Fig 28. Changes in total biomass of caged *Oreochromis niloticus* in Nyalenda wastewater lagoons, Kisumu.

dense algal crops present in the lagoons which depleted oxygen reserves at night. The decline was more pronounced at higher stocking densities of 110 and 90 fish m^{-3}. The high mortality observed in the initial stages was also attributed to the smaller sizes of fish stocked of the size range 6-7cm. This is due to the fact that smaller sizes of *Oreochromis niloticus* are less resistant to temporary conditions of low dissolved oxygen concentrations. Coche (1976) has noted that *O. niloticus* becomes resistant to temporary conditions of low dissolved oxygen concentrations after attaining sizes greater than 20-30g live weight. This contrasts well with the smaller sizes used in the experiment of the size range 6-8 g. Balarin and Haller (1979) have discussed the effects of overcrowding and low levels of dissolved oxygen concentration in relation to the stocking densities used.

The slightly reduced growth rate after the 16th week of culture was a result of the bigger sizes the fish had already attained; smaller fish naturally having faster growth rates than bigger ones. The earlier reduction of the condition factor implies that if the initial densities are kept lower, then the growth rate, the condition factor and yields can be improved.

The effect of the stocking density on the growth rate, condition factor and net yield can be evaluated between the 0th and the 12th week when density differences in the cages were big enough to warrant the assessment.

The initial growth rate during the 0th-2nd week was relatively lower than that of the following week up to the 12th week. This was attributed to overcrowding in the cages which after the 2nd week was eased as a result of the drop in densities, (Fig.24). All the physico-chemical parameters in the lagoon during the latter phase of growth that is, from 2nd-12th week of culture fell within the range required for tilapia culture,(Chapter 3). Tilapia are known to demonstrate compensatory growth whereby the growth potential which might have been surpressed as a result of an unfavourable environmental condition might reveal itself to the maximum with the onset of favourable conditions (Dadzie pers. comm.). Therefore during this phase, the growth rates of the fish in the cages were higher than during the dry season when the environmental conditions were unfavourable. The lower stocking densities had higher growth rates but lower biomass than the higher densities (Fig.20, 21 and 28); but the net yield was higher at lower stocking densities. Similar observations have been made by other scientists working on cage culture (Coche, 1977).

No detailed studies were undertaken on disease as the causative agent of fish mortalities in the cages. However casual observations showed that most of the fish died due to lack of oxygen. This was evidenced from their wide open mouths and raised gill covers with gill filaments far apart. During the 0th-2nd week of culture, some of the dead specimens had partly destroyed fins particularly the caudal fins. This suggests that they had an infection of fin-rot or that the fins had probably been bitten off by other fish in the cages and then secondarily infected with bacteria. Other observations in October 1985 revealed that some of the dead specimens had inflammed guts which were dark-brown in colour. Their livers were unusually elongated, pale-brown in colour and irregular in shape particularly on the lower half. Fin-rot, inflamed guts and unusually elongated and infected liver conditions were also observed in some of the non-caged specimens taken from the lagoons in October for food selection studies. Thus the mortality of the fish in the cages during the culture period can also be attributed to disease.

After the 12th week, a comparison of the effects of the stocking densities on the growth rate, condition factor and net yield cannot be made as the densities in the cages approached close ranges (Fig.24). This is reflected in the haphazardness in the growth rates after the 12th week. It can be realized that the earlier effect on the different stocking densities that is, the larger differences in fish numbers per m^3, had a long term effect on the yield giving rise to low yields and moderate condition factors.

The generally fast growth rate in all the cages during the initial stages of culture was due to the presence of suitable environmental factors resulting from a good rate of wastewater renewal through flushing and the presence of abundant fish food in the form of phytoplankton and invertebrates (Chapter 4). The presence of abundant *Microcystis* sp. and *Spirulina* sp. could be one of the reasons why the fish attained such fast growth rates. The fish extensively fed on these two algae in the lagoons. Experiments in which the alga *Microcystis* sp. has been harvested and fed to *Oreochromis niloticus* produced the fastest growth rates surpassing the highest reported from waste-fed tilapia culture in earthen ponds (Edwards *et al.*,1985). Rhyne *et al.* (1985) have shown that the alga *Spirulina* sp. meets certain criteria necessary in an integrated fish-mariculture system as fish feed. The two algae have been demonstrated to have a high percentage of crude protein content in their cells, an important consideration in selecting fish feeds. Lee Boon Yang *et al.* (1980) report that the growth rates, weight gain and general health of fish fed on algae were equal or superior to fish fed on standard commercial feeds. Hence since the physico-chemical conditions fell within tolerance limits of tilapia culture and there was abundant food during this phase, the differences in the growth rates and the condition factor can be attributed to the differences in the stocking densities, the sizes already attained and sex.

The reduction in numbers and of the growth rates observed during the dry phase resulting from low or no sewage flows into the lagoons led to the reduction in the biomass in the cages. The reduction in the growth rates was due to the reduction of the water depth to the extent that the cages were resting at the bottom of the pond. During the dry season, there was deoxygenation and production of odours due to the decaying of algal blooms and the concentration of substances into the reduced water depth (Chapter 3). The non-flushing and low rate of water renewal at the wastewater lagoons does not ensure optimum dissolved oxygen concentrations necessary for better growth rates. Hence in the management of wastewater lagoon fish culture, there has to be a reliable and adequate flow of water to sustain suitable depths and also proper maintainance of the whole sewage system. This will ensure water renewal and the keeping of physico-chemical conditions within the suitable range for fish culture. Furthermore, the reduced growth rates during the dry phase are attributed to poor physico-chemical conditions interfering with the normal feeding process of the fish. Olah *et al.* (1986) observed that the daily and therefore regular introduction of sewage in Hungarian ponds made stable the environment which supported healthy growth of fish, while in Indian ponds where sewage introduction was irregular, the environment was unstable for fish growth.

A comparison of fish production using extensive and intensive culture in selected tropical lakes and lagoons is presented in Table 12. Better levels of production

TABLE 12: RESULTS OF CAGE CULTURE OF O. NILOTICUS AT NYALENDA WASTEWATER LAGOONS COMPARED WITH THOSE OF OTHER TROPICAL LAKES AND LAGOONS. OVER 90% OF THE EXAMPLES GIVEN ARE ON EXTENSIVE CULTURE

LOCALITY	DATE	SPECIES	CAGE SIZE M^3	STOCKING DENSITY (No. M^{-3})	SIZE AT STOCKING (g)	CULTURE PERIOD (MONTHS)	SIZE AT HARVEST (g)	PRODUCTION Kg m^3 $month^{-1}$	AUTHORS
Nyalenda Waste water lagoons, Kenya	1985-1986	Oreochromis niloticus	1 m^3	50-110	6.97-7.400	5-5.25	147.6-2.021	0.286-0.523	This Study 1985/86
Thika wastewater lagoons, Kenya	1981	O. niloticus	0.81m^3	30 and 60	12-150	4.4	—	0.330-0.568	Nyaga 1981
Lake Victoria, Kenya	1975	O. niloticus	1.5x1.0x 3.0 m^3	12 30 20	2.9 5.6 12.1	1.25 1.5 1.0	4.4 16.6 24.3	0.0012 0.0074 0.0012	Rinne 1975
Kossou Lake, Ivory Coast	1974	O. niloticus	1 m^3	2.5-488 INTENSIVE	9-55	3-5.5	157-271	35-76	Coche 1977
Laguna de Bay Philippines	1983 1978	Tilapia O. niloticus	5x10x3 10.20x5m^3 138-2900 m^2	4-8 7.4	1	4-5 6.3	100 119	0.07-0.18 0.14	Mahe 1979 Lazaga & Loa 1983
Bato Lake Philippines	1983	O.niloticus		50		4	160	1.90	Beveridge, 1984

The production in Kg m^{-3} has been calculated from the graphs presented by Nyaga 1981.

TABLE 12 Contd.

Lake Victoria Tanzania	1975	T. zilii	3.5x3.5x3.5	83	2.6	3	15.6	0.417	Ibrahim, Nozawa and Lema 1975
		O.esculentus	5x5x5 m^3	19	19	6	46.6	0.14	
		O.leucosticus		22	16.3	5	83.1	0.348	
Lake Bunot Philippines	1980	Tilapia	20x25x5 m^3	4 extensive		4	250	0.24	Alvarez.(1981)
Taal Lake Philippines	1983	Tilapia	10x5x3 m^3	50		4	100	1.25	Guerrero (1983)
Buiuan Lake Philippines	1982 to 1983	Tilapia	5x10x5 m^3	10	1	5	200	0.40	Oliva (1983)
Sampaloc Lake Philippines	1983	Tilapia	10x50x9 25x20x9 m^3	1.6-2.0	12.5-16.0	6-9	225-300	0.05-0.08	Guerrero.(1983)
Lagoons, Kenya	1974	S. spilurus S.nigra T.zillii	0.7 m^3	71	32.0	5.9	236.8	1.79	Haller (1974)

seem to come from environments where the stocking density is low for example the Taal and Bato Lakes in the Philippines, the lagoons at the Coast of Kenya and at Thika. But some of the stocking densities used at the Nyalenda wastewater lagoons approximate those used in the environments presented. Thus the rapid drop in numbers in the wastewater lagoon experiments confirm the findings that the use of high densities in extensive fish culture is not possible as the yields can be low. That the other environments exhibit low levels of production despite the low stocking densities is due to low natural productivity. This also depends on the sex and the species of fish and the size of the cages used.

The lower levels of fish production, that is in the range 0.286 - 0.523 kg m^{-3} $month^{-1}$ exhibited at the Nyalenda wastewater lagoons in comparison to some of the other environments presented in Table 12 is attributed to poor physico-chemical conditions resulting from low and irregular wastewater flow and the higher stocking densities used.

CONCLUSIONS AND RECOMMENDATIONS

1. The main constraint to the culture of fish in wastewater treatment lagoons was found to be the low and irregular wastewater flow. This particularly affected the dissolved oxygen concentrations which resulted in low fish growth rates and the production of a poor water quality

effluent. It is recommended that aerators be used to improve the oxygen regime and that of other physico-chemical parameters. In this way, the fish stocking densities and yields per unit area of water will be increased. This will also ensure a good water quality effluent.

2. The removal of floating algal scums and aquatic macrophytes particularly *Ipomea* sp. which proliferate into the lagoons will also improve the oxygen regime. Animals such as burrowing fish and tortoises which introduce extra channels of water loss should be eliminated physically.

3. Food for *Oreochromis niloticus* at the lagoons is not a major problem as the phytoplankton and small aquatic invertebrates are abundant. There is need to carry out research into the nutritive value of the different food items to the fish in terms of percentage proteins, fats, carbohydrates and vitamin content and on assimilation efficiencies. Direct measurements on the biomass of algae is possible and this will enable the determination of primary productivity in terms of wet weight algae to be made.

4. The growth rates and yields of *O. niloticus* obtained from the wastewater lagoons are reasonable when compared with those obtained in other environments. It is recommended that in the presence of predatory fishes such as *Protopterus aethiopicus* and *Clarias mossambicus*

cages should be used to curtail predatory losses. This will also enable the usage of appropriate stocking densities to efficiently graze on the algae and produce a good quality effluent.

5. The existence of large numbers of wild ducks in the lagoons is a point worth considering. They assist in cropping up the algae thus reducing its density and in this way assist in the waste treatment process. In view of this,trials to determine the practicality and economics of fish-duck-sewage treatment should be tundertaken.

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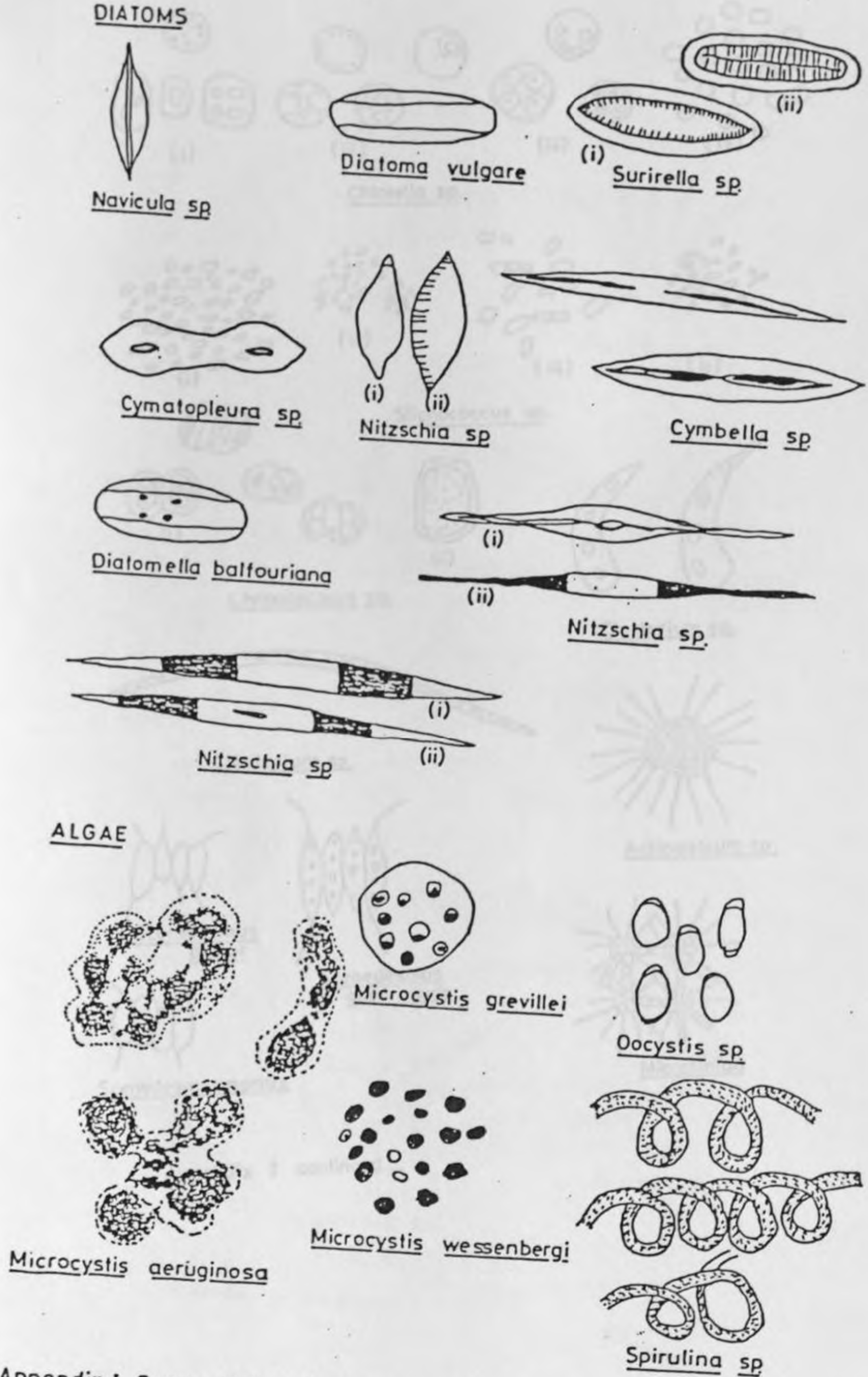
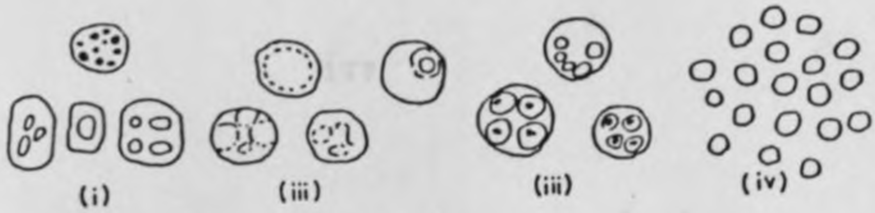
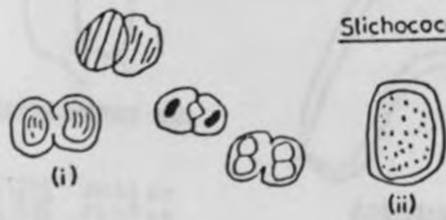


Appendix I. Some of the food items eaten by *Oreochromis niloticus* in Nyalenda waste-water lagoons, Kisumu.



Chlorella sp.

Slichococcus sp.

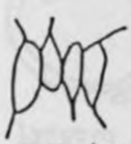


Chroococcus sp.

Closterium sp.

Closterium sp.

Actinastrum sp.



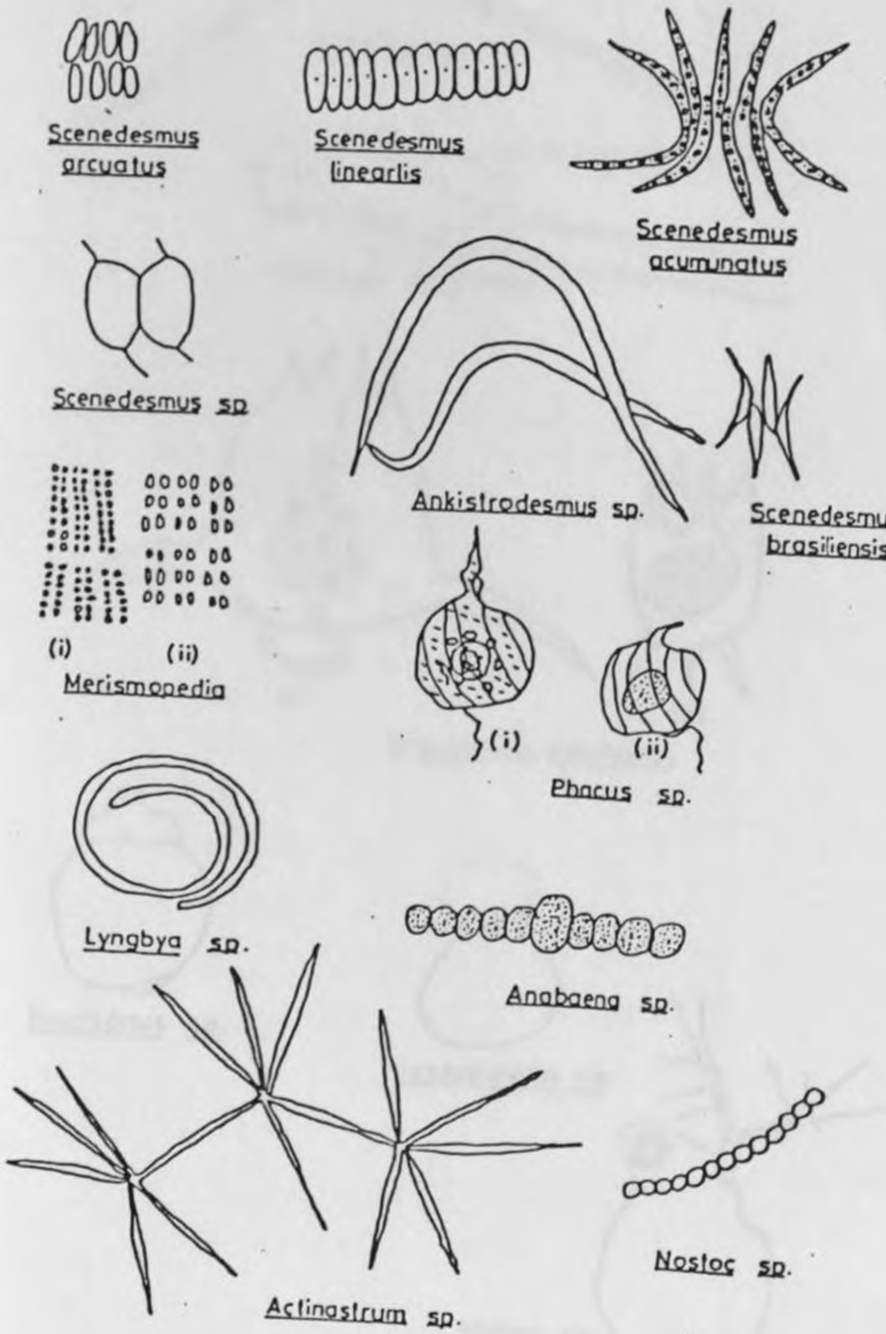
Scenedesmus dispar

Scenedesmus quadricauda

Scenedesmus nanus

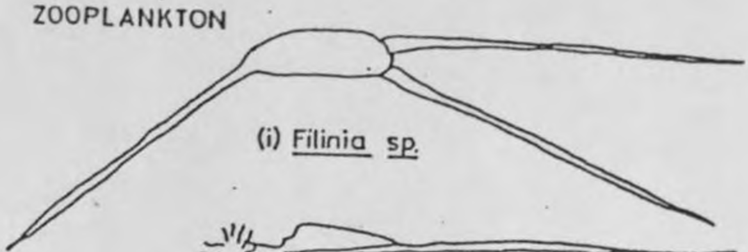
Micratiniun

Appendix I continued....



Appendix 1 Continued.

ZOOPLANKTON



(i) Filinia sp.

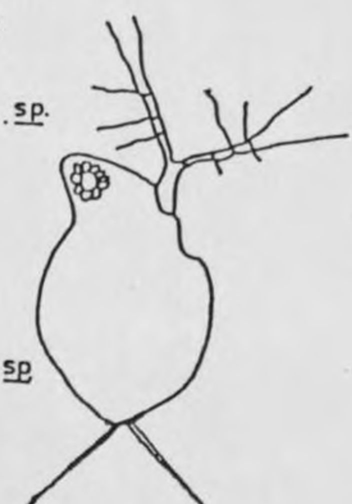
(ii) Filinia longisetta

(i) (ii)

Brachionus calciflorus

Brachionus sp.

Testudinella sp.



Moina sp

Appendix I continued ....