European Journal of Applied Sciences – Vol. 11, No. 6
Publication Date: December 25, 2023
DOI:10.14738/aivp.116.15199
Kaunda, E., Salima, C., Macuine, M. A., & Msiska, O. V. (2023). Feasibility of Cage Culture on Lake Malawi, Part 1: Physical, Chemical and Biological Processes. European Journal of Applied Sciences, Vol - 11(6). 294-316.

Feasibility of Cage Culture on Lake Malawi, Part 1: Physical, Chemical and Biological Processes

E Kaunda
Lilongwe University of Agriculture and Natural Resources

C. Salima
Lilongwe University of Agriculture and Natural Resources

M. A. Macuiane
Fundo de Desenvolvimento da Economia Azul,
IP. Av. Emilia Dausse, Nº591, RC, Maputo Mozambique

O. V. Msiska
WorldFish, P.O. Box 30294, Lilongwe, Malawi

ABSTRACT

The feasibility of cage culture in Malawi was fully evaluated using standard procedures involving a sub-model of dissolved oxygen and phosphorus budget models to compute carrying capacities in relation to bathymetric features. The central lakeshore district of Salima was used as a proxy for other parts of Lake Malawi. The values of carrying capacity varied from 4-5 tons for small cages (5 m diameter by 3 m depth) to 14-17 tons for large cages (10 m diameter x 6 m depth); this compares favorably with 18-22 tones from cages of 12 m diameter x 8 m depth produced by MALDECO Ltd. One site, Sani Maganga was found to be unsuitable because of an inverse relationship between dissolved oxygen and the water depth. On the other hand, values of 61-67 tons for medium cages and 79-86 tones for large cages, respectively, were computed using the phosphorus model, suggesting that this method may be inappropriate for Lake Malawi in its current form. The close correlation between actual and computed values in the dissolved oxygen model demonstrates its relevance. In future, dissolved oxygen should be measured at several depths with water temperature to determine oxygen saturation which is important to fish feed utilization. The phosphorus model needs to be fine-tuned, since it was derived on Trout fish farm modeling in temperate waters; water temperature/oxygen saturation and metabolic rates may be sources of variation. The recommended threshold of 70 ugL-1for phosphorus concentration could still be used. Unsuitable conditions at San Maganga, show that conditions vary from site to site and detailed studies are necessary. Therefore, current findings are not safe to generalize for the whole Lake Malawi.

Keywords: Cage Culture, Environmental Carrying Capacities, Lake Malawi-Salima. Physical Features, Nutrient status.

INTRODUCTION

While aquaculture production in Malawi has steadily increased from 800 tons in 2000s to 9, 900 tons in 2017, it is dominated by small-scale pond production and remains relatively low. Meanwhile, the rise in human population and decline in major food fish species has created a shortage of fish supply (Nhuong et al., 2022). Growth in the small holder sector is slow and not properly organized to respond to up-markets. Hence, the need to explore other means of production like cage culture has become more pressing. Tilapia production from capture fisheries has declined from 9, 400 tons to less than 1,500 tons in the 2020 (Nhuong et al., 2022). The few ventures that have been launched show that Lake Malawi provides opportunities for large scale commercial aquaculture. In Lake Victoria, a thriving cage culture industry has been established, therefore Lake Malawi is considered equally suited. Cage culture has also been experimented in Lake Volta, Ghana (Awity 2005 and Asmah et al. 2016) where the phosphorus model for estimating carrying capacity was applied. However, it is unlikely that all portions of Lake Malawi can be utilized for aquaculture, hence, the need for feasibility studies to provide guidance to prospective entrepreneurs. Given the differences among lakes of the Great Rift Valley, it is important that each gets specific attention. Funding by the African Bank Development Bank for Sustainable Fisheries Aquaculture Development Project provided an opportunity for conducting a feasibility study on Lake Malawi. The Malawi Press Corporation Limited company known as MALDECO Fisheries Ltd initiated cage culture on Lake Malawi in 2003 following observed increasing scarcity of Chambo in their catches. Screening of Oreochromis shiranus, Oreochromis karongae and Coptodon rendalli was conducted on-farm, where O. shiranus offered better prospects with respect to mortality and final biomass. Currently, 800-1,200 tones are annually produced in cages by the Company, well below a projection of 3,000 tones, meanwhile factors constraining production have been identified. The Government of Malawi has taken a precautionary approach to development of cage culture because of potential threats to biodiversity and genetic integrity of unique fish species in Lake Malawi. It is also the aim of Malawi Government to establish an environment which is conducive for poor fish farmers to enter the industry.

Globally, cage culture results in the accumulation of organic matter that leads to anoxic conditions from fish waste and uneaten foods causing environmental degradation and poor water quality. In Lake Malawi, there is an added fear that fish hybrids from escapees and alien fish species could interfere with high endemism and unique biodiversity of an estimate of 800-1,000 fish species; this led to the creation of Lake Malawi National Park in 1980 which was declared a UNESCO Heritage site in 1984 (https://whc.unesco.org/en/lis/289). Determining carrying capacities is critical to mitigate potential environmental impacts owing to building up of enriched nutrients such as Total-Phosphorus and Total-N with increased Chlorophyll-a biomass being the main symptom. Being of sedimentary origin, phosphorus in Lake Malawi is less labile than nitrogen; it does not quickly dissociate and is considered the most limiting nutrient in freshwater water bodies. It is required for fish growth, metabolism, and formation of phospholipids, entering the food chain as fish feed. Phosphorus is one of the reference points for determining carrying capacity since it transforms the trophic status of water bodies from oligotrophic to hypereutrophic (Vollenweider and Dillon 1974; Beveridge 1996) and in turn affects the dissolved oxygen cycle. Dissolved oxygen and currents are also successfully used in modeling for carrying capacity (Stigebrandt et al., 2004). Therefore, phosphorus and dissolved oxygen measurement were adopted to:

- Develop criteria and eventually designate zones for cage aquaculture;
- Development of practical, environmental carrying capacity models as recommended by (Beveridge and Jamu, 2010)
- Globally, cage aquaculture has contributed to food security, economic growth and employment; and it is generally believed that conditions exist in Lake Malawi to achieve successful implementation of the same.

OBJECTIVE

The overall objective of the proposed study is to identify zones on Lake Malawi in Salima for cage culture to facilitate its development taking into consideration other user rights and the integrity of the environment

Specific Objectives

To identify the size of area that can accommodate Cage Culture in Salima based on physical/biological requirements of the target species and environmental characteristics of the area (physical and production carrying capacity)

To determine factors that lead to optimum production, without causing adverse ecological impacts (Ecological carrying capacity).

METHODOLOGY

Description of Study Area

Lake Malawi lies between 9o 30'S and 14o 30'S on the western arm of the East African Rift Valley and is one of the southernmost lakes (Menz, 1995; Smith, 2000) (Figure 1). It is the third largest lake in Africa with an approximate length of 550 km, a mean width of 50-60 km and maximum recorded depth of 700 m. The total surface area and volume are 28,000 km2 and 8400 km3, respectively, giving an average depth of 292 m. Lake Malawi is significant to Malawi's economy because of its support to an important fisheries sector and acts as a destination for tourists, but more importantly for imparting ecological integrity on the country. The fisheries sector is the source of 60% of the total animal protein supply in the country with over 70% of Malawi's population depending on Lake Malawi and its catchment for other survival needs and livelihood (Chafota et al., 2005).

Lake Malawi has a catchment area –covering about 130,000 km2 and includes much of Malawi, the north-western corner of Mozambique and the south-western corner of Tanzania. It is a Global fish species rich lake harboring at least 800-1, 000 mostly cichlids that have evolved within the Great Rift Valley system of Africa, thus being of high biological significance (Chafota et al., 2005; Patterson and Kachinjika, 1995). Lake Malawi has been divided into segments called fishing areas to facilitate collection of catch assessment data allowing fish species to be geographically positioned.

Figure 1: Location of Lake Malawi in south-eastern Africa.

Specific Study Areas

The study was conducted in the central part of Lake Malawi of Salima district. A total of 15 sampling stations (Figure 2, Table 1); three at each site were sampled across five fish landing sites between 07th August 2022 and 12th August 2022.

Table 1: Sampling stations in Salima district, Malawi.

Sampling Beach	Sampling Station	Latitude	Longitude	Depth (m)
MAKUKUTA	Makukuta 1	-13.43936	34.39922	33.00
MAKUKUTA	Makukuta 2	-13.45452	34.38141	15.00
MAKUKUTA	Makukuta 3	-13.46671	34.36862	4.10
KAFUMU	Kafumu 1	-13.54804	34.45696	28.00
KAFUMU	Kafumu 2	-13.56284	34.44457	15.70
KAFUMU	Kafumu 3	-13.57076	34.43392	5.20
CHIGOLO	Chigolo 1	-13.59107	34.45045	6.00
CHIGOLO	Chigolo 2	-13.58089	34.45655	15.00
CHIGOLO	Chigolo 3	-13.55884	34.46338	25.00
SANIMAGANGA	SaniMaganga 1	-13.96816	34.51577	5.30
SANIMAGANGA	SaniMaganga 2	-13.96231	34.53462	12.50
SANIMAGANGA	SaniMaganga 3	-13.95265	34.53297	6.40
CHILAMBULA	Chilambula 1	-14.06028	34.57642	36.70
CHILAMBULA	Chilambula 2	-14.08347	34.56745	15.00
CHILAMBULA	Chilambula 3	-14.08402	34.55509	6.60

Figure 2. Map of Cage Zonation Sites in Salima.

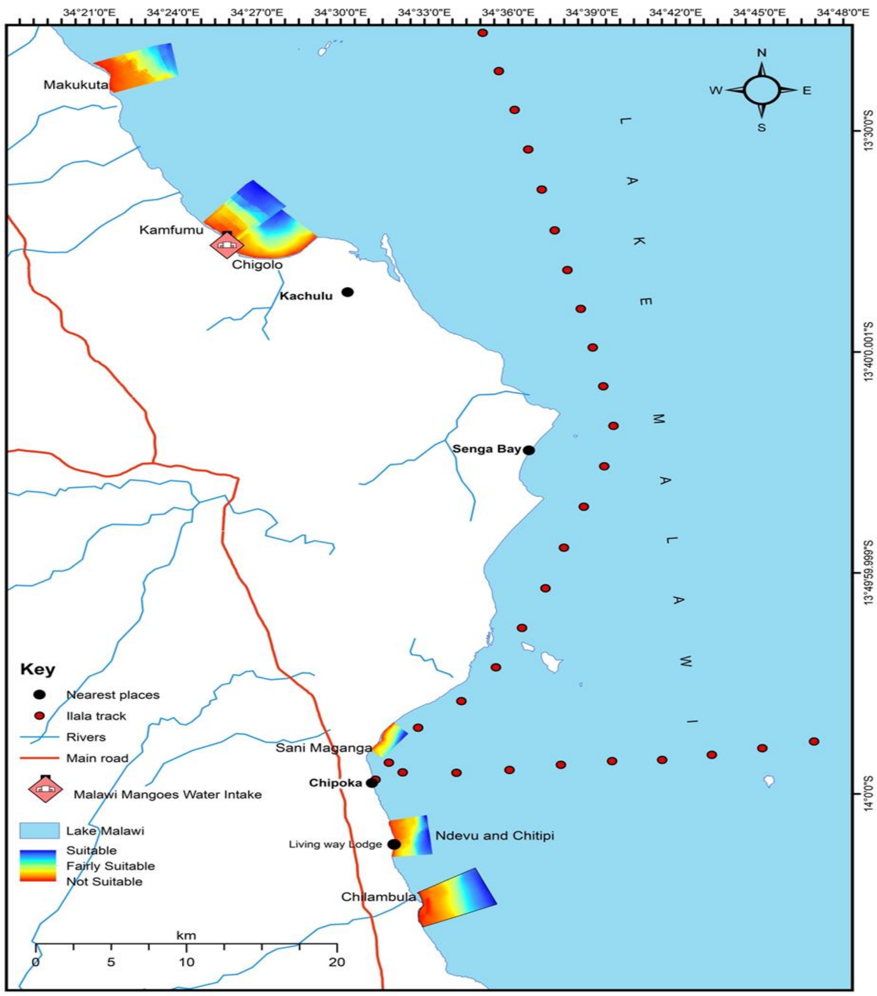

Figure 2: Location of Sampling Sites including Ndevu and Chitipi.

The Dissolved Oxygen Model for Carrying Capacity

Estimates of carrying capacities were done using the sub-model of water quality under the MOM (Modelling–On-growing fish farms–Monitoring) to determine the carrying capacities for cage culture in Salima. The MOM operates primarily at site level but may be linked to a more comprehensive management system which operates at higher geographical levels such as shoreline zones experiencing different human activities.

The sub-model of water quality computes the maximum fish production that keeps the oxygen concentration above critical value when the farm is at its minimum flushing rate. The model is based on production capacity and does not assume complete ownership of the lake. The main principle of the model is that farms must maintain sufficiently high oxygen concentrations and minimum ammonium concentrations to ensure successful fish farming (Stigebrandt et al., 2004). The study used dissolved oxygen concentration for two reasons. Firstly, oxygen concentrations are generally low in tropical lakes compared to temperate systems but fish metabolic rates and BOD rates are high so that the risk of low oxygen affecting fish growth is of concern. Secondly the sub-model applied requires relatively simple measurements, such as water currents, depth, size of the cages and the farm size which can be measured easily by farm owners using simple and less expensive instruments.

Explanation of the DO Carrying Capacity Model:
The carrying capacity was estimated based on oxygen consumption rates at the farm (OX1) and the rate of oxygen consumption per kg of fish production (OCR). For OX1, input parameters such as oxygen concentration flowing in O2IN (kg/m3) and out O2OUT (kg/m3) of the farm, the length of the farm LF (m); the depth of the cages D (m) were used with the condition that OOUT should not fall below O2MIN otherwise estimate of fish O2 consumption will be affected by oxygen stress. The minimum oxygen O2MIN was chosen as 3.0 kg/m3 from studies by Ross (2000). The minimum water currents UMIN recorded over a relatively long period was 0.004 m/s in the southeast arm of Lake Malawi with a 2D-ACM Falmouth Scientific Inc. The FSI acoustic water current meter was used. The rate of oxygen consumption of fish at the farm or at the cage OX1 (kg/h) = (O2IN - O2OUT) *LF*D* UMIN was estimated as shown below:

Carrying capacity/holding capacity (CC) was estimated as CC=OX1/OCR.

$$CC(Kg) = \frac{(\mathrm{O2IN} - \mathrm{O2MIN}) * LF * D * UMIN * PF}{OCR}$$

The Permeability of the farm (PF) describes the reduction in minimum current (UMIN) advised to be measured before the establishment of the farm. Knowledge of UMIN is important since the placement of cages reduce the water current flowing into the farm Ui(t); the resulting current flowing out of the farm Uo(t), as such estimates of PF (t) are less than 1, PF (0< PF <1). The study estimates the possible number cages that can be placed at a specific location based on estimated area and size of the cage and the space among cages. The suitability analysis was based on bathymetric parameters for cage farming in five locations was used to estimate local carrying capacities.

Model Assumptions:
Dissolved oxygen diffusion mechanisms through the lake surface and bottom are 'complex; they include fish-induced motions that may increase or reduce oxygen concentrations depending on standing fish biomass, water temperature, time of day and nature of bottom (Stigebrandt et al., 2004), these were not computed. The carrying capacity of the individual cage is determined using the same formulae as one used for the farm.

The Dillon and Rigler's Phosphorus Model for Carrying Capacity:
Various attempts to minimize environmental damage consider simple and complex models to minimize the impacts of cages. Africa has lagged behind and to date, there are no models specifically developed to regulate African cage aquaculture industry. Based on Beveridge (1996), all environmental capacity models should consider: (i) what determines the productivity of the lake, (ii) the feeds used in cage operations and wastes generated by the farmed fish during production cycle, (iii) the response of the receiving water body to waste loadings (organic and inorganic), (v) and how much production is permissible based on the intrinsic characteristics of a particular system.

The intensity of cage farming system determines the type of model required for a particular system. For instance, extensive cage culture is a net consumer of primary production; semi-intensive cage culture may stimulate or reduce productivity while intensive cage culture stimulates productivity (Beveridge, 2004). The current research focuses on modelling carrying capacity for intensive cage culture in Lake Malawi, a system that uses complete diets with high nutrient content to ensure that fish grows to marketable size within a short period. The addition of fish meal and soybeans makes the diets rich in nitrogen and phosphorous. Phosphorous is an essential element for growth and development of fish (Lovell, 1989) and is also a limiting nutrient for phytoplankton growth in lakes. Not all phosphorous contained in diets is consumed by the fish, excess phosphorous is excreted, unavailable phosphorous is voided in the faeces, and uneaten food is a major source of phosphorous (Beveridge, 2004).

The potential increase of nutrients in the lake owing to cage culture activity in a given area is determined by knowing the base concentration of nutrients in the water, the amount of nutrients emanating from the cages per given time and residence time of the water (Håkanson et al., 1988).

Two methods (direct and indirect methods) have been employed to quantify the wastes emanating from the cages that reach the aquatic environment. The direct method of nutrient analysis involves the water column and sedimentation particulate material while the indirect method uses the mass balance approach (Beveridge, 2004) developed by Dillon and Rigler (1974). This model has been used in cage farming in many studies to assess the carrying capacities in inland waters (Beveridge, 1996; Håkanson et al., 1988). Beveridge produced a model that predicts the capacity of the lake to produce fish without exceeding the limits considered good in maintaining satisfactory water quality. The model is based on phosphorus loadings in unit area of the lake in a unit time. Such loadings should not overwhelm the intrinsic capacity of the lake to handle the loadings which can result in occurrence of eutrophication episodes and deleterious consequences in water quality. Dillon and Rigler's phosphorus budget model were used to estimate carrying capacities of 5 locations in Salima district of Lake Malawi.

Dillon and Rigler's Model Iterations:

Measure the steady-state Total-P concentration. In temperate waters this is best determined at the time of spring overturn, when the waters are well mixed.

The development capacity of lake or reservoir for intensive cage culture is the difference between the productivity of the water body prior to exploitation and the final desired/acceptable level of productivity.

The capacity of the water body for intensive cage fish culture is the difference, $\Delta[P]$, between $[P]$ prior to exploitation, $[P]i$, and the acceptable $[P]$ once fish culture is established, $[P]f$.

$$\Delta[P]\ (mg/m3) = [P]f - [P]i$$

ΔP is related to P loadings from the fish cages,

$$\Delta P = Lfish\ (1 - Rfish)\ z\rho$$

Lfish, the size of the lake, A, its flushing rate and the ability of the water body to handle the loadings.

$$Lfish = \Delta[P]\ z\rho / (1 - Rfish)$$

z can be calculated from hydrographic data, from the literature or from survey work.

$$Z = V/A$$

Where:

- V = volume of water body (m3)
- A = surface area (m2).

The flushing rate ρ (y-1) in volumes per year is equal to Q/V, where Q is the outflow (Km^3/s) e V (m3) is the volume of water. The current study used an outflow of 12 km3yr-1 (Hecky et al., 2003).

Rfish is the most difficult parameter to estimate. At least 45-55% of the Total-P wastes from cage Rainbow Trout are likely to be permanently lost to sediments as a result of solids deposition and calculated as:

$$Rfish = x + [(1 - x) R]$$

Where:

- x: the net proportion of Total-P lost permanently to the sediments as a result of solids deposition (0.45-0.55).
- R = the fraction of Total-P retained by the sediments;
- R = 1/ (1 + 0.747 ρ0.507)

Acceptable Total-P loading, La (ng/y^-1) is estimated by multiplying Lfish and lake surface area.

$$La = Lfish * Area$$

Intensive cage fish production (t y-1) can be estimated by dividing La by the average Total-P wastes per ton of fish production.

A simple mass balance was used to estimate phosphorus loading or phosphorus losses to environment from fish cages by subtracting phosphorus in fish flesh from phosphorus in feed as shown in equation as:

$$Pen = (Pfeed * FCR) - Pfish$$

Feed Conversion Rates (FCR) of 1.8 was applied for medium sized cages and FCR of 1.5 for large cages. Rainbow Trout data was used for phosphorus loadings, as such, phosphorus content in feed (Pfeed) was assumed to be 11.0 Kg in 1 ton of feed and phosphorus content in fish (Pfish) was assumed to be 2.2 kg t fish-1.

Suitability of Depth vs Cages Sizes

Carrying capacity estimates were done for medium and large cages from 5 locations in Lake Malawi in Salima district. Medium sized cages have a diameter of 5 m and 3 m depth size with an area of 47.1 m2 while larger cages are 10 m diameter and 6 m depth and occupy an area of 188.4 m2. The establishment of these cages had to follow a criterion established as for highly unsuitable to suitable based on size and depth (Table 2).

Table 1: Suitability of depth vs cages sizes

Factor	1 Highly unsuitable	2 Unsuitable	3 Fairly Suitable	4 Suitable
Medium cages 5m diameter, 3m depth	< 3	3 – 5	5-7	7-15
Large cages – Above 10m diameter, 6m depth	< 6	6-9	9-15	15-40

The rule of the thumb is that depth of the site below the cage should be at least 2 x times the depth of the cage.

Bathymetry

The bathymetric survey was conducted using hired boats from the selected landing sites (Kafumu, Chigolo, Makukuta, Sani Maganga and Chilambula) with different horsepower engines. An integrated Global Position System Garmin UHD 62CV transducer was used to collect depth (m) information and the corresponding position in decimal degrees of Longitude and Latitude. The transducer was set to automatically collect data at a distance of 50-meters. Data mining from the transducer/GPS was done using Garmin homeport software exported to Microsoft excel for analysis. Geostatistics were used to determine spatial extent of the lake to construct a depth surface map as outlined by Kaluzny et al, (1998). Experimental variograms were computed from sample points and then fitted with a spherical variogram model after which variogram parameters (sill, range and nugget) were estimated using a kriging sub-routine. Grid regression and map querying sub-routines were used to calculate the total surface area of the lake by depth gradation. ESRI's ArcGIS 10.5 and Microsoft Excel LTSC 2021 were used in data analyses.

Benthic Assessment

Benthic assessment studies were conducted to determine the substrate composition. These form the basis for siting of cages according to the size of the cage and how good the anchors hold to sustain the structures amidst strong and harsh weather conditions. To determine the bottom substrate composition of the potential sites, a Petite Ponar Grab Sampler of 16 cm x 16 cm, SST Scoops with plated steel arms and weights was used. Three composite samples were collected at each station for classification of soil composition; preservation was in alcohol and transported to Monkey Bay Fisheries Research Station Laboratory for further analysis.

Estimates Fish Composition and Abundance

Fish samples were collected from 5 landing sites namely: Chigolo, Chilambula, Kafumu, Makukuta and Chidzanje. Fish from different fishery and beaches were randomly sampled, identified and measured by weight and length to nearest gram (g) and millimetre (mm). Aall fish species caught in a particular area were identified according to Ad Konings (2003). Fish composition, diversity and fishing gears were identified and analysed using excel and displayed graphically.

Water Quality Assessment

Lake-wide water quality sampling was conducted using a plank boat powered by a 40HP outboard Yamaha engine. An integrated Global Positioning System (Garmin UHD 62CV GPS) fitted with a transducer was used to collect depth (m) information and corresponding position in decimal degrees of Longitude and Latitude. At each sampling station, pH, temperature, dissolved oxygen; salinity and conductivity were measured in-situ using a Hydrolab CTD MS5 series probe. Water clarity or transparency was determined by using a Secchi disk-of white and black disk with 30 cm diameter attached to measuring line. The Secchi disk was introduced in the water up to the depth at which it was no longer visible and then was pulled back after recording the depth. Water samples for analysis of phosphates, ammonia and Chlorophyll-a were collected using a Standard grey PVC (RAL 7011) 5L Niskin bottle with double sided stopper, and kept into 1000 ml sample collection bottles for laboratory analysis. At the laboratory, 1 to 2L of the sample was filtered onto a 47mm GF/F filter using a vacuum pump. The filtrate was used for the analysis of phosphates within 1 week after being collected following persulfate digestion and ascorbic acid methods (Wetzel and Likens, 2001; Stainton et al., 1977). A JANEWAY 7315 UV/visible spectrophotometer was used to measure absorption at 880nm. Ammonia was analyzed by spectrophotometry using a HACH spectrophotometer and in-built kits and chemical reagents. Residual particles on filter papers were then subjected to Chlorophyll an analysis. Extraction of chlorophyll a was done using a mixture of acetone and methanol (Stainton et al., 1977). Chlorophyll an analysis was conducted on a Turner Series 10 fluorometer.

Zooplankton

Samples for zooplankton were collected in a single haul using a 30 cm diameter Nitex plankton net with 80µm mesh suitable for zooplankton, connected to a 100ml bottle at the base. Water samples for zooplankton were immediately transferred into 250ml polypropylene bottles and fixed in 70% ethanol concentration before transporting to Senga Bay Fisheries wet laboratory for counting and classified to species level. Counting was done using a dissecting microscope. The volume of water filtered was determined by assuming that the net filtered the whole volume of water column traversed with a filtration efficiency of 0.93 (Irvine & Waya, 1995).

Data Analysis and Interpretation

A data set was created in SPSS which comprised of water quality measurements at each sampling station. Results are presented in form of tables and graphs.

RESULTS

Description on Study of Areas

The distance from the shore was measured to assess how far it will be to travel to the cage site for fish feeding or cage supervision. On each site, the last transect was maintained at a distance of roughly 5 kilometers.

Table 3: Depth range (minimum and maximum), average depth (m), area in square meters and hectares for sampled potential sites for cage culture.

Site	Min Depth	Max Depth	Mean Depth	Area (sq.m)	Area (Ha)
Chigolo	0	5	2.5	2,960,314.0	296.0
	6	9	7.5	2,784,351.3	278.4
	10	13	11.5	2,559,510.0	256.0
	14	18	16	2,918,336.0	291.8
	19	25	22	2,701,832.8	270.2
	Total			13,924,344.0	1,392.4
Chilambula	Min Depth	Max Depth	Mean Depth	Area (Sq.m)	Area (Ha)
	0	4	2	1,810,114.4	181.0
	5	9	7	2,140,102.5	214.0
	10	15	12.5	2,029,612.0	203.0
	16	22	19	1,740,038.3	174.0
	23	31	27	1,837,922.4	183.8
	32	38	35	2,769,675.3	277.0
	39	44	41.5	1,713,342.6	171.3
	Total			14,040,807.4	1,404.1
Kafumu	Min Depth	Max Depth	Mean Depth	Area (Sq.m)	Area (Ha)
	0	5	2.5	997,393.1	99.7
	6	9	7.5	2,084,021.8	208.4
	10	15	12.5	2,190,918.5	219.1
	16	20	18	2,076,120.6	207.6
	21	24	22.5	1,633,661.1	163.4
	25	27	26	2,933,153.8	293.3
	28	29	28.5	1,940,873.1	194.1
	Total			13,856,142.0	1,385.6
Sani Maganga	Min Depth	Max Depth	Mean Depth	Area (Sq.m)	Area (Ha)
	0	3	1.5	495494.8	49.5
	4	5	4.5	734430.9	73.4
	6	8	7	967180.4	96.7
	9	11	10	533083.4	53.3
	12	14	13	426504.3	42.7
	Total			3156693.9	315.7
Makutuka	Min Depth	Max Depth	Mean Depth	Area (Sq.m)	Area (Ha)
	0	5	2.5	2781291.3	278.1
	6	10	8	3445232.0	344.5
	11	16	13.5	1907582.9	190.8
	17	25	21	2432140.5	243.2
	26	36	31	2629438.5	262.9
	Total			13195685.1	1319.6
	Min depth	Max depth	Mean Depth	Area (Sq. m)	Area (Ha)

Chitipi and Ndevu cage site (Data taken From Lenzie Mills study)	0	4	2	2380346.6	238.0
	5	7	6	2336720.59	233.7
	8	10	9	906755.09	90.7
	11	14	12.5	978981.73	97.9
	15	17	16	1661125.18	166.1
	Total			8263929.19	826.4

Areas Suitable for Cage Culture Based on Bathymetry

Classification of the areas based on the bathymetry for different cage sizes: medium (5m diameter 3m depth) and large cages (10 m diameter, 6m depth) are presented in Figures. For medium scale cages, the guidelines stipulate that for small cage farming should occupy depth range of 5-15m. This depth range covers both the fairly suitable (5-7 m) and most suitable area (7-15 m) while for large scale cages, the suitable area covers a depth range of 9m to 40m, where 9-15m is fairly suitable while 15-40m is most suitable. The unsuitable areas are either shallow or too deep.

The estimated suitable area for medium-scale cages in Chigolo area is 7,094,402.2 square meters (709.4 ha), and the distance from the landing site is 0.3 km (300 m). In Chilambula, there are 3,918,522.97 square meters (391.8 ha) and the distance from the landing site to the 5-meter mark, which is the minimum depth for a fairly suitable area is 970 m. The calculated area in the Kafumu area representing the fairly suitable and suitable area for medium cages is 4,026,030.20 square meters (402.6 ha), and the distance from the shore at the Kafumu landing site to the 5 m depth mark is 940 m. However, the shortest distance to the 5 m depth contour was noted to be from the Malawi Mangoes Company water intake pump, and covering a distance of 250 m.

Sani Maganga's estimated area for medium cages is 2,166,599.58 square meters (216.6 ha), lying between 5 m and 14 m depth. The distance from the shore to the 5 m depth contour is 0. 46 kilometers. Sani Maganga, unlike the other surveyed areas, was partly restricted because it also happens to be a route for the passenger vessel Ilala. However, from the map, it can be noted that the only area for large cages is from the 9-meter contour mark to just over the 13-meter contour. Due to this limitation, the total distance that was covered at Sani Maganga was short—only 1.3 km. The calculated area for medium cage culture and fairly suitable cage culture is 4,825,747.5 square meters (482.6 ha). The estimated distance from the Makukuta shore to the 5 m depth contour is 940 m, and the shortest distance to the 5 m depth contour was 880 m, from the next landing site called Mwanjowa. Data from Chitipi and Ndevu were collected together because the two sites were very close to each other. The area estimated for medium-scale cages in Chitipi and Ndevu was 4, 684, 322.27 square meters (468.4 ha), which lies between 5 and 15 meters. The distance from the shore to the potential cage site for the medium cages is 0.39 kilometers.

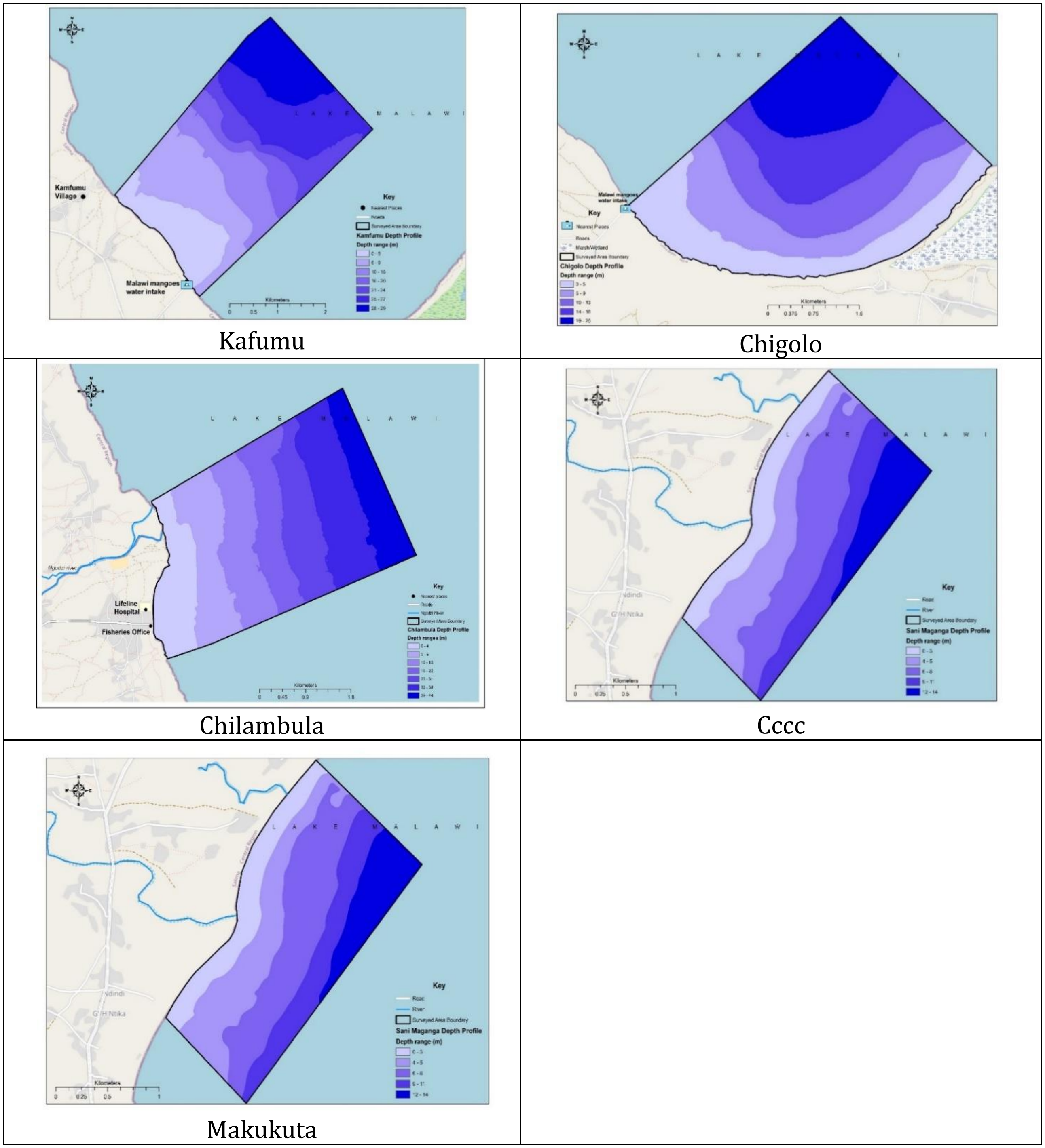

Figure 3: Depth Profiles of Sampling Sites in Salima district.

To confirm suitability of the sites, bottom profiles for installation of cage fish farms, surface area, depth range, and distance from shore were computed based on assumptions from Table 2. The resulting bathymetry maps are displayed in Figures 3 and 4. A total of 5,817.40 hectares were surveyed and an additional 826.39 hectares under the area designated for Lenzie Mills Company in Chitipi-Ndevu area. All of the sampled sites are shallow, with a gentle slope towards the lakeside; depth of 7 m and 15 m covered surface area of 2, 529 ha.

Large Scale Cages

The area suitable for large-scale cage culture is estimated to be 8,103,494.2 square meters (810.3 ha). The distance from the shore at the Chigolo landing site to the suitable area for large-scale cages is 740 m and 1.77 kilometers from the Malawi mangoes water intake station. The recommended guideline depth for large cage farming is 9–15 m for fairly suitable and 15–40 m for suitable. The total distance covered from the shore to the farthest end of the survey transect was 4.6 kilometers. Chilambula is 9,1920,93.79 square meters (919.2 ha). The shortest distance from the shore to the 9-meter depth is 1.64 kilometers. A total distance of 5 kilometers is from the shore to the last transect at Chilambula. At Kafumu, the area suitable for large cage culture is estimated to be 8,938,679.85 square meters (893.8 ha), covering from 9 m to 29 m depth. The distance from the shore at the Kafumu landing site to the fairly suitable area for large cages is about 1.86 kilometers (1860 m). The shortest distance was from Malawi Mangoes' water intake pump is 1.42 kilometers from the 9-meter depth contour. At Kafumu, the last transect from the shore was a distance of 5 km. The total area for large cage cultured are Makututa is 7, 260,145.4 square meters (726.9 ha). Further, the estimated distance from the beach to the 9-meter depth mark contour is 2.54 kilometers (2,540 m) from Mwanjowa beach and 1.51 kilometers (1,510 m) from the Makukuta landing site. Makukuta is longest distance of 5.3 km from the shore to the last transect off shore.

Carrying Capacity Estimates

The carrying capacity estimates was done for medium and large cages from 5 locations in Lake Malawi in Salima district (Table 2). Medium sized cages have a diameter of 5 m and 3 m depth size with an area of 47.1 m2 while larger cages are 10 m diameter and 6 m depth and occupy an area of 188.4 m2. For a single cage ranged between 4,148 kg and 4,400 Kg for medium scale cages. The carrying capacity estimates for large cages from 5 locations in Lake Malawi in Salima district for a single cage ranged between 16,590 Kg and 17,599 Kg. When placed at different locations, the same cage assumes different carrying capacities owing to differences in dissolved oxygen recorded from specific locations, designated as oxygen flowing into the farm or cage.

The carrying capacity estimates for five locations for the establishment of medium (Tables 3) and large cages (Tables 4) show a high production capacity potential ranging from a minimum for 202,330,097 Kg in Sani Maganga from 45,987 cages to a maximum of 624,692,272 Kg from 150,616 cages. According to the criteria specified, Sani Maganga was not a suitable site for cage culture.

The Dillion and Rigler's model produced carrying capacity estimates for the establishment of medium and large cages (Tables 4 and 5) which ranged between 61,073.55 tones in Sani Maganga and 66,122.73 tonnes for medium sized cages in Chigolo and between 79,469.44 tons in Kafumu and 85,958.70 tons for large sized cages in Chilambula. Dillon and Rigler's generated far in excess than practically used in Lake Malawi. As a benchmark, MALDECO Fisheries Company has achieved 18-22 tones using cages of 12-meter diamer and 8 meters depth (personal observation). Therefore, the phosphorus model should can only be applied after establishing new assumptions; it's validation needs more field data.

Table 2: Carrying capacity estimates for single medium (47.1 m2) and single large cage (188.4 m2) in Lake Malawi.

Location	O2IN (mg/l)	Carrying Capacity (Kg)	
		Medium	Large
Makukuta	8.12	4,164	16,655
Kafumu	8.16	4,196	16,786
Chigolo	8.1	4,148	16,590
Sani Maganga	8.41	4,400	17,599
Chilambula	8.33	4,335	17,339

Table 3: Carrying capacity estimates for medium scale cages in Lake Malawi.

Location	Suitable Area (m2)	Number of cages	Carrying Capacity (Kg)
Makukuta	4,826,000	102,463	426,640,473
Kafumu	4,026,000	85,478	358,697,414
Chigolo	7,094,000	150,616	624,692,272
Sani Maganga	2,166,000	45,987	202,330,097
Chilambula	3,918,000	83,185	360,575,666

Table 4: Carrying capacity estimates for large scale cages in Lake Malawi

Location	Suitable Area (m2)	Number of cages	Carrying Capacity (Kg)
Makukuta	7,260,000	38535	641,817,205
Kafumu	8,938,000	47442	796,333,205
Chigolo	8,103,000	43010	713,544,049
SaniMaganga	-	-	-
Chilambula	9,192,000	48790	845,944,747

Benthic Area

The bottom substrate was mostly made by components of sandy clay or silty soil particles. Overall, the Makukuta site is characterized by sandy clay particles and a high sandy composition at Station 1 with maximum depth of 34 meters. Kafumu is characterized by sandy clay (silt) particles with high sand composition observed at station 3, and recorded a maximum depth of 5 meters. The Chigolo site is characterized by sand clay (silt particles), while Chilambula and Sani Maganga are both characterized by clay and sandy particles. Notwithstanding some sites having more clay, overall, the sites were found suitable for cage sitting. The sandy clay (silt) soils and clayey loam soils are conducive environments for primary production. The sandy soil deposits in both Sani Maganga and Kafumu's shallower stations are unsuitable for proper anchorage. However, the presence of clay at the other stations within these two sites suggests that there may be a considerable sand bed on top of sandy clay and silt particles, which is ideal for firm anchorage.

Table 5: Benthic substrate characterization

Site name	Station ID	Depth (m)	Bottom substrate type
Makukuta	1	34	Sandy soils
	2	15	Sandy + Clay soils
	3	4.1	Clay + Sandy particles with rocks
Kafumu	1	28	Clay + Silt particles

	2	15	Clay + Sandy particles
	3	5	Sandy soils
Chigolo	1	6	Clay + Silt particles
	2	15	Clay + Silt particles
	3	24	Loamy + Silt particles
Chilambul	1	37	Sandy + loamy particles
	2	15	Clay + Sandy particles
	3	6	Clay + Sandy particles
Sani Maganga	1	5.3	Sandy particles
	2	12.5	Clay + Silt particles
	3	6.4	Clay + Silt particles

Fish Catches and Fishing Gear Types

The Chibolo fish landing site registered a wider range of gears (7) including Chilimira, Gillnets (MF), Kandwindwi, Kambuzi seine, Nkacha, Long lines and Fish traps. Chidzanje/Sani Maganga beach registered 5 gears including: Chilimira, Long lines, Ngongongo, Kambuzi seine and Gillnets. While Chilambula registered 4 gears Chilimira, Gillnets, long lines and Kandwindwi. Makukuta and Kafumu landing sites had the least number of gears of Chilimira, Long line, and Gillnets while Makukuta registered Chilimira, Ngongongo and Long lines.

At Chigolo, the fish catch comprised of fish families Cichlidae 88.71%, Claridae 0.37%, Cyprinidae 9.20%, and Mochokidae1.72%, dominated by Cichlids. At Chilambula, fish catches were composed of two fish families; Cichlidae 48.04% and Cyprinidae 51.96% with Cyprinids dominating. In Kisumu, the fish catch had fish families Cichlidae 89.69%, Cyprinidae 8.59%, Mochokidae1.72% with the cichlids dominating. At Chidzanje/Sani Maganga, the fish catches comprised of five fish families Cichlidae 63.14%, Claridae 2.35%, Cyprinidae 34.12%, Mochokidae 0.39% and the Cichlids dominated. At Makukuta, fish catch comprised of families Cichlidae 91.23%, Claridae 3.12%, Cyprinidae 0.75%, Mochokidae 4.87% with the cichlids dominating. The presence of Oreochromis karongae justified it as a candidate species for cage culture, pending further research on dissolved oxygen demands (Msiska 1999). Thew dominant fish species were of less economic values compared to the targeted species for cage culture such as Oreochromis shiranus, Coptodon rendalli and Oreochromis karongae. The presence of Oreochromis karongae and Oreochromis shiranus in most of the sampled areas is an indication that environmental conditions support growth and production of these species, their abundance is an assurance that rearing these species in captivity could yield good results.

Water Quality Results

Results of the most critical water quality parameters that may affect fish production as indicators are given in Table 7. They include water temperature, dissolved oxygen, water pH, phytoplankton biomass, transparency and zooplankton density. Physical-chemical and biological water quality parameters for the five assessed sites pose no threat to fish.

Transparency and Total Suspended Solids:

Water transparency which is the measure of the ability of light to pass through the water column did not vary across the sampled sites. Water transparency depends on the amount of particles in the water which can be inorganic (silt and sediments) or organic such as phytoplankton. In the present study transparency ranged between 2.3-7.1 m at Makukuta site, 4.3-7 m at Kisumu, 5.1-6.6 m at Cigolo, 3.5-5.8 m at Sani Maganga and 5.2-9.3 m at Chilambula. Overall, the highest average Secchi depth/transparency of 7.9 m was recorded at Chilambula followed by Cigolo with 5.7 m and the least Secchi depth of 4.7 m was recorded at Sani Maganga. The TSS ranged between 3.00-6.00 mg/L at Makukuta, 3-7 mg/L at Kisumu, 1.00-2.0 mg/L at Cigolo, 3-19 mg/L at Sani Maganga and 3-7 mg/L at Chilambula. The highest average TSS of 9 mg/L was recorded at Sani Maganga and the least average TSS of 1.67 mg/L was recorded at Cigolo (Table 7).

Electrical Conductivity:
Conductivity which is a measure of dissolved solids and ions in the water ranged between 245.33 µS/cm-246.33µS/cm (Table 7), with the highest average conductivity being registered at Sani Maganga and the lowest average conductivity registered at Makukuta and Chilambula. Conductivity directly affects fish physiological activities such as growth of fry, egg fertilisation and hatching. Conductivity of freshwater varies between 30 and 5000 µS/cm (Stone et al, 2013). The average conductivity recorded in the present survey (Table 7) falls within the acceptable range ideal for survival and growth of the cultured fish species.

Water Temperature:
Water temperature is one of the most significant physical parameters which greatly influences fish production in aquatic environments. The surface water temperatures ranged between 23.69°C-24.2°C at Makututa, 24.0°C-24.37°C at Kisumu, 23.92°C-23.94°C at Cibolo, 23.84°C-24.06°C at Sani Magana and 23.62°C-24.29°C at Chilambula. Overall, the highest average surface water temperature of 24.19°C was recorded at Kisumu followed by Chilambula with average surface water temperature of 24.06°C and then Sani Maganga recorded average water temperature of 23.95°C (Table 7). Makukuta and Chigolo registered average surface water temperature of 23.93°C.

Dissolved Oxygen:
The surface dissolved oxygen was between 8.09 mg/L-8.15mg/L at Makututa, 8.12mg/L-8.2mg/L at Kisumu, 8.08mg/L-8.14mg/L at Cibolo, 8.29mg/L-8.49mg/L at Sani Maganga and ranged 8.23mg/L-8.42mg/L at Chilambula. Sani Maganga registered the highest average dissolved oxygen of 8.4mg/L followed by Chilambula with average dissolved oxygen concentration of 8.35mg/L while the least surface dissolved oxygen concentration of 8.10mg/L was registered at Cibolo (Table 7). In all sites, except for Sani Maganga, dissolved oxygen profile followed a decreasing pattern with the highest dissolved oxygen observed at the surface and the lowest dissolved oxygen registered at the bottom (Table 7). The scenario was different at Sani Maganga where the highest dissolved oxygen was registered at the maximum sampled depth of 10 m and the lowest observed close to surface.

Water pH:
The surface water pH ranged between 8.25-8.43 at Makukuta, 8.27-8.31 at Kisumu, 8.3-8.32 at Cibolo, 8,3-8.38 at Sani Magana and 8.23-8.42 at Chilambula (Table 7). Overall, Chilambula and Makukuta each registered the highest average pH of 8.35 while Kisumu registered the lowest average surface water pH of 8.3. Figure 5 shows that water pH decreased with increasing depth at Kisumu, Cibolo and Chilambula while at Sani Maganga water pH remained almost constant

with increasing depth. The pH profile at Makukuta had no pattern due to strong water waves which were encountered.

Water Nutrients:

Dissolved inorganic nutrients affect the pelagic ecosystems increasing lake's primary productivity and causing algal blooms (Olsen & Olsen, 2008). In this study, total phosphorous ranged 6.01µg/L-6.34µg/L at Makututa, 6.72µg/L-6.98µg/L at Kisumu (Table 5), 5.5µg/L-6.3µg/L at Cibolo, 6.3µg/L-8.17µg/L at Sani Magana and was 6.67µg/L-9.13µg/L at Chilambula. Chilambula registered the highest average total phosphorus concentration of 7.95µg/L followed by Sani Maganga with an average phosphorus concentration of 7.14µg/L. The Cigolo site registered the least average total phosphorus concentration of 5.89µg/L. Regarding soluble reactive phosphorus, Chilumbula site registered the highest average SRP concentration 0f 6.02µg/L followed by Sani Maganga and Kafumu with the least average SRP concentration of 4.25µg/L (Table 7).

Table 7: Summary results for the physicochemical water quality parameters (Mean± Standard deviation) and acceptable standards for cage culture.

	Makukuta	Kafumu	Chigolo	Sanimaganga	Chilambula	Acceptable Standards
Max Depth (m)	17.37±14.59	16.3±11.41	15.33±9.50	8.07±3.88	19.43±15.53	
Secchi Depth (m)	5.1±2.50	5.53±1.37	5.57±0.81	4.7±1.15	7.9±2.34	>0.75m
Max Wind (m/s)	5.63±0.90	2.87±0.55	4.23±2.93	3.33±0.74	2.5±2.94	
Avg Wind (m/2)	3.47±0.75	2.33±0.35	3.33±2.55	2.03±0.49	1.1±1.56	
DO (mg/L)	8.12±0.03	8.16±0.04	8.10±0.03	8.41±0.09	8.33±0.09	≥4mg/L
Temperature (°C)	23.93±0.26	24.19±0.19	23.93±0.01	23.95±0.11	24.06±0.44	
Water pH	8.35±0.09	8.30±0.02	8.31±0.01	8.33±0.04	8.35±0.10	7.0 - 8.5
Salinity (mg/L)	120±0.00	120±0.00	120±0.00	120±0.00	120±0.00	
EC (µS/cm)	245.33±0.58	245.67±0.58	246±0.00	246.33±0.58	245.33±0.58	30 - 5000
Chl-a (µg/L)	0.71±0.30	0.60±0.14	0.55±0.05	1.03±0.24	0.73±0.25	
TP (µg/L)	6.20±0.17	6.84±0.13	5.89±0.40	7.41±0.99	7.95±1.23	
SRP (µg/L)	4.57±0.35	4.25±0.60	4.60±1.06	5.29±0.39	6.02±1.71	<70
Ammonia (mg/L)	0.12±0.01	0.15±0.01	0.15±0.02	0.17±0.07	0.14±0.02	<0.5
TSS (mg/L)	4.33±1.53	5.00±2.00	1.67±0.58	9.00±8.20	5.00±2.0	10-15

Ammonium-nitrogen was below the acceptable threshold of 0.5mg/L. Ammonia ranged between 0.12mg/L-0.13mg/L at Makututa, 0.14mg/L-0.15mg/L at Kisumu, 0.13mg/L-0.16mg/L at Cibolo, 0.12mg/L-0.25mg/L at Sani Maganga and was 0.12mg/L-0.15mg/L at Chilambula. Sani Maganga registered the highest average ammonia concentration of 0.17mg/L while Makukuta site had the least ammonia concentration of 0.15 (Table 7).

Biological Parameters:

Phytoplankton Biomass:

Chlorophyll 'a' concentration was used as a proxy of phytoplankton biomass. Phytoplankton forms the base of food webs in aquatic ecosystems and are the main food sources for fish juveniles and larvae. Phytoplankton biomass was 0.38-0.98µg/L at Makukuta, 0.51-0.76µg/L at Kisumu, 0.52-0.61µg/L at Cigolo, 0.76-1.21µg/L at Sani Maganga and 0.51-1.00µg/L at Chilambula (Tabela 5). The highest average phytoplankton biomass of 1.03µg/L was recorded at Sani Maganga followed by Chilambula with phytoplankton biomass of 0.73µg/L and the least phytoplankton biomass of 0.55µg/L was recorded at Cigolo (Tabela 5).

Zooplankton Community:
Zooplankton community are good indicators of water quality and play an important role in aquatic ecosystem trophic dynamics as secondary consumers. This survey showed a zooplankton species richness number of 7 across all sites. The highest zooplankton abundance of 15,763.08ind./m^3 was registered at Makukuta followed by Chigolo site with density of 14,682.43ind./m3, Chilambula with density of 14,366.01, Kafumu with density of 10,199.07ind./m^3 and the least total zooplankton density of 1,472.01ind./m3 was registered at Sani Maganga (Figure 6). The study showed that Nauplii dominated in zooplankton density in all the sampled sites followed by T. neglectus. The contributions of Diaphanosoma spp, M. aeq. Aequatorialis, T. cunningtoni were insignificant in all the sites with total zooplankton density of below 500ind./m^3. Zooplanktons not only act as food for fish, but they also play role in ameliorating water quality by grazing on phytoplankton and other fouling organisms.

DISCUSSION

In order to establish the feasibility of cage fish farming on Lake Malawi, many factors needed to be assessed covering bathymetric, biological, chemical analyses and benthic factors. The original plan to cover the whole Lake Malawi was impractical during the project time scale. All the sites covered in Salima were found to be suitable except Sani Maganga; the latter registered high phytoplankton biomass, high total suspended solids and an inverse surface-depth dissolved oxygen profile. This unusual dissolved oxygen profile implies that there is self-shading at the site not allowing light to penetrate to great depth. This also occurs where there is overproduction of algae at the surface.

The success of aquaculture operations would largely depend on water quality at each level of biomass. Water temperature is of utmost importance since it influences fish production in aquatic environment, and most importantly it influences oxygen saturation (Boyd 1990). It exerts influence on fish metabolic activities, oxygen consumption, feeding rate, food conversion and fish growth (Piccolotii & Lovatelli, 2013). Fishes experience poor growth and become susceptible to diseases if temperature is suboptimal (Joseph et al., 1993). Boyd (1990) reported that water temperature of 26.06oC to 31.97oC is preferable for warm water fish culture, however, oxygen saturation is equally critical. Other research has also shown a similar temperature range of 25oC-32oC to be ideal (Bolorunduro & Abdulla, 1996). Water temperature profiles of the assessed sites were within the tropical fish tolerance range of 18oC-33oC; this is within acceptable limits for the target fish,

The average dissolved oxygen concentration was higher than 3.0 mgL-1, generally regarded as a minimum in catfish raceways and tilapia farming (Ross, 2000). Masser (1997) and FAO (1989) reported that dissolved oxygen concentration of 4mg/L or greater is conducive for tilapia growth to achieve acceptable feed conversion. However, while oxygen is satisfactory, it is important to compute oxygen saturation which is influenced by temperature. As fish biomass increase dissolved oxygen can decrease and affect fish growth. For practical purposes, each site will have to be monitored separately, and as fish biomass increases with time, aeration equipment needs to be on standby for remedial oxygen supplementation.

The pH values in all the assessed sites were within the range of 7.0-8.5, which is ideal for the cultured tilapia fish species as recommended by FAO (1989). The average blood pH of fish is 7.4 hence, any deviations will be harmful to fish. In acidic waters of low pH, fish become stressed and susceptible to opportunistic pathogens. Most fish species thrive well within the pH range of 6.5 and 9.0. At pH lower than 4 or and above 11, most fish species do not survive (Lawson, 1995).

The dominant zooplankton were the larvae forms, nauplius, which could act as supplementary food for good growth and survival of juvenile fish. In aquatic food webs, zooplankton communities occupy an intermediate trophic position, making them key mediators of energy and material fluxes (Sterner, 2009, Hamdy Abo-Taleb, 2019).

Except for Sani Maganga, the sites registered average phytoplankton biomass of less than 1µg/L; typical for oligotrophic Lake Malawi. This is an indication that the sites were not highly impacted by excessive nutrients. Aquaculture increases levels of available nutrients in tropical lakes, resulting into changes in limnological variables (Degefu et al., 2011). Phosphate is critical factor as it is produced by the fish farm into the environment (Kelly, 1993). The soluble reactive phosphorus from all sites was below 70µg/L; an acceptable threshold (FAO,1989). The primary route by which phosphorus enters the aquatic environment is through fish feed (Gavine et al., 1995). Excessive nutrient load can lead to eutrophication and excessive growth of phytoplankton and other aquatic weeds. High phytoplankton growth causes dissolved oxygen depletion through respiration, especially at night and leads to the production of ammonia and other toxins. Levels of phosphorus from all sites were within acceptable limits. Similarly, the ammonium-nitrogen was less than the threshold of 0.5mg/L prescribed FAO (1989).

The carrying capacity for small cages measuring 5 m diameter by 3m depth was estimated at 4,148-4, 440 kg. For large cages of 10 m diameter by 6 m depth, the carrying capacity was 16, 540 -17, 599 kg. Since this compares favorably with production at MALDECO Fisheries Limited (18 -22 tons) from cages of 12 m diameter vs 8 m depth; therefore, dissolved oxygen model was the most suitable for estimating carrying capacity.

The phosphorus model produced very high carrying capacity figures which appear to be unrealistic for Lake Malawi; the model was derived from data obtained in a temperate environment where dissolved oxygen is inherently high in support of fish such as Rainbow Trout. Validation of this model will require further field studies in Lake Malawi. Carpenter (1981) observed that; "rate of accretion of colonizable sediment is relatively insensitive to changes in the influx of phosphorus and dry matter to the lake from the watershed". The values of reactive phosphorus were below 7.0 ugL-1, considered by FAO (1989) to be within acceptable limits since it is one of the drivers of eutrophication. The presence of zooplankton is welcome as they graze on phytoplankton while acting as food for fish. Although this study recommends many cages per site, it is not advisable to fill up all spaces so that in case incidences like low oxygen or disease outbreak occur, rotation should be possible to relocate cages and allow original sites to recover.

On Lake Malawi, dissolved oxygen follows a certain predictable pattern such that at a depth below 100-150 meters, dissolved oxygen is almost non-existent, so this is out of range of cage farming. However, it is possible that accumulation of uneaten foods and faeces might further compromise this normal phenomenon. As cage farming develops wild fish are likely to congregate around cages to feed off awfuchs and uneaten feed.

Socially, smaller cages could prove ideal for low-income members of society, or they might opt to work in cooperatives to spread the risks and costs, thereby creating more cohesive communities. Conflict with fishing activities is not anticipated because most fish species that were caught by fishermen occur offshore in much deeper waters of the pelagic zones. On the other hand, inshore species like Oreochromis shiranus and Oreochromis karongae, could inbreed with improved fish varieties and create hybrids, if escapees occur.

ACKNOWEDGEMENTS

We wish to thank the African Development Bank for funding and guidance through Dr. Ahmed S. Khan, Chief Fisheries Officer, the Coordinator of the Project Implementation unit in Malawi Dr. Robert Kafakoma and Dr. Victor Siamudaala, Regional Director of WorldFish, Zambia, and many others whose inputs have made this study possible.

References

Asmah, R., Karikari, A., Falconer, L., Telfer, T.C. and Ross, L.G. 2016 Cage aquaculture in Lake Volta, Ghana: Guidelines for a sustainable future. CSIR Water Research Institute, Ghana and University of Stirling, Stirling UK. 112 pp.

Awity, L. 2005. National Aquaculture Sector Overview-Ghana. National Aquaculture Sector Overview Fact Sheets. In: FAO Fisheries and Aquaculture Department [online]. Rome. Accessed September 03, 2021.

Beveridge. MCM and DM Jamu. 2010. Cage Aquaculture in Malawi. Briefing Note 2119.The WorldFish Center, Malawi, August 2010.

Beveridge, MCM. 1996. Cage Aquaculture. Fishing News Ltd, UK.

Beveridge, MCM. 2004. Cage Aquaculture, 3rd Edition, Wiley-Blackwell, UK.

Boyd, CE. 1990. Water quality in ponds for aquaculture, Agriculture Experiment Station, Auburn University, Alabama. 482p.

Bolorunduro, P. I., & Abdulla, A. Y. 1996. Water Quality Management in Fish Culture. National Agricultural Extension and Research Liason Services, Extension Bulletin No.98.

Carpenter, SR. 1981. Submerged vegetation: An Internal Factor in Lake Ecosystem Succession. The American Naturalist, Volume 118, No 3, Sept. 1981. Doi/epdf/10.1086/283829.

Chafota, J. Burgess, N., Thieme, M. and Johnson, Sthey. 2005. Priority conservation areas and vision for biodiversity conservation. Lake Malawi/Niassa/Nyasa Ecoregion Conservation Programme. WWF SARPO: Karonga, Malawi.

Degefu F, Mengistu S, Schagerl, M 2011. Influence of fish cage farming on water quality and plankton in fish ponds: a case study in the Rift Valley and North Shoa reservoirs, Ethiopia. Aquaculture 316:129-135.

Dillon and Rigler.1974. The phosphorus-chlorophyll relationship in Lakes. 3imnology and Oceanography. Vol. 19, 5ssue 5: 767-773.

FAO. 1989. Site Selection Criteria for Marine Finfish Net Cage Culture in Asia. Retrieved November 27, 2020, from http://www.fao.org/3/AC262E/AC262E00.html

Gavine, F. M., Phillips, M. J., & Murray, A. 1995. Influence of Improved Feed Quality and Food Conversion Ratios on Phosphorous Loadings from Cage Culture of Rainbow trout, Oncorhynchusmykiss (Walbaum), in Freshwater Lakes. Aquaculture Research; 26, 483-495.

Håkanson, L., Ervik, A., Makinen, T. and Moller, B. 1988. Basic concepts concerning assessments of environmental effects of marine fish farms. Nordic Council of Ministries. Nord 1988:90.

Hamdy Abo-Taleb. 2019. Importance of Plankton to Fish Community, Biological Research in Aquatic Science, Yusuf Bozkurt, IntechOpen, DOI:10.5772/intechopen.85769.

Stainton, MP, MJ Capel and FAY, Amstrong. 1977. The Chemical Analysis of Freshwater. Miscellaneous Special Publication No. 25, 2nd Edition, Winnipeg, Manitoba, Canada.

Stigebrandt, A., Aure, J., Ervik, A. and Hansen, P. K. 2004. Regulating the local environmental impact of intensive marine fish farming III. A model for estimation of the holding capacity in the Modelling-Ongrowing fish farm-Monitoring system. Aquaculture, 234, 239-261.

Menz, A. (ed.) 1995. The fisheries potential and productivity of the pelagic zone of Lake Malawi Nyasa. Scientific Report of the UK/ SADC Pelagic Fish Resource Assessment Project. Chatham, UK: Natural Resource Institute. Hobbs the Printers Ltd. Totton, Hampshire,386 pp.

Nhuong Tran, Jeffrey Peart, U-Primo E. Roddriguez, Chin Yee Chan, Yan Hoong, Victor Siamudaala, Friday Njaya and Robert Kafakoma. 2022. The future of fish supply-demand in Malawi and implications for nutrition security and poverty reduction. Penang, Malaysia: WorldFish. Working Paper: 2022-21

Patterson, G. and Kachinjika, O. 1995. Limnology and Phytoplankton Ecology. In The Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa. Menz, A. (Ed). Chatham; Natural Resources Institute.

Kaluzny, S.P., Vega, S.C., Cardoso, T.P. and Shelly, A.A. (1998), S+SpatialStats: User's Manual for Windows and UNIX, Vol. 1, Springer Science & Business Media.

Kelly, L. A. 1993. Release Rates and Biological Availability of Phosphorus Released from Sediments Receiving Aquaculture Wastes. Hydrobiologia 253 (1-3), 367-372.

Konings, Ad. 2003. Back to Nature: Guide to Malawi Cichlids. Fohrman Aquaristik AB.

Smith, L.W. 2000. The reproductive biology of an open-water spawning Lake Malawi cichlid, Copadichriomis chrysonotus. African Zoology 35(2):151-164. (Accessed 27 April 2013) http://africanzoology.journals.ac.za.

Irvine, K., & Waya, R. (1995). The zooplankton: general sampling methods and estimation of biomass and development rates. In A. Menz, The Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa. (pp. 69-83). Chatham, UK: Natural Resources Institute.

Soil Survey Staff. (2011), Soil Survey Laboratory Information Manual Report No. 45. Soil Survey Investigations Report No. 45, U.S. Department of Agriculture, Natural Resources Conservation Service.

Joseph, K. B., Soderberg, R. W., & Terlizzi, D. E. (1993). An Introduction to Water Chemistry in Freswater Aquaculture. NRCA Fact Sheet No.170.

Lawson T.B. 1995. Fundamentals of Aquacultural Engineering. Chapman & Hall, New York. 355 p.

Lovell, RT. 1989. Nutrition and Feeding Fish. Van Nostrand Reinhold, New York, USA.

Masser, M. P. 1997. Cage Culture Site Selection and Water Quality. Southern Regional Aquaculture Center, Publication No.161.

Msiska, O.V. 1998. Reproductive Biology and Growth of Oreochromis (Nyasalapia) karongae in ponds and open waters in Malawi. PhD Thesis, University of Malawi, 196p.

Piccolotii, F., & Lovatelli, A. 2013. Construction and Installation of hexagonal wooden cages for fish farming. A Technical manual, FAO Fisheries and Aquaculture, Technical Paper No.576. Rome, FAO, p. 76.

Ross, L. G. (2000). Environmental Physiology and Energetics. In M. C. Beveridge, & B. J. McAndrew, Tilapias: Biology and Exploitation, Fish and Fisheries Series 25 (pp. 89-128). Dordrecht, Netherlands: Kluwer Academic Publishers.

Vollenweider, RA and PJ Dillon. 1974. The application of the phosphorus loading concept to eutrophication research. NRCC 13690, Nat. Res. Counc, Can. 42p.