Promoting Environmentally Sustainable Commercial Aquaculture Project in Uganda
UG/FED/038-334

Final Site suitability and diurnal studies for establishment of appropriate cage designs for use in the Mwena Kalangala Cage Aquaculture Park

Report prepared for:

Ministry of Agriculture, Animal Industry and Fisheries (MAAIF),
the Directorate of Fisheries Resources (DiFR),
Department of Aquaculture Management & Development (DAMD)
Project Management Unit (PMU)

By

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Contents

List of Acronyms & Abbreviations

°C	Degrees centigrade
cm	Centimetres
DAMD	Department of Aquaculture Management & Development
DiFR	Directorate of Fishery Resources
DO	Dissolved Oxygen
EU	European Union
EUD	European Union Delegation, Kampala
GPS	Global Positioning System
m	Metres
m^3	Cubic metres
MAAIF	Ministry of Agriculture, Animal Industry & Fisheries
Mg	Milligrams
mg/l	Milligrams per litre
NaFIRRI	National Fisheries Resources Research Institute
NAO	National Authorising Officer
NARO	National Agricultural Research Organisation
pH	potential of Hydrogen (measure of acidity/alkalinity)
PMU	Project Management Unit
ppm	Parts per million
ppt	Parts per trillion
s	Second (time)
SD	Standard Deviation
SRP	Soluble Reactive Phosphorous
TSS	Total Suspended Solids
TAT	Technical Assistance Team
µs	micro-siemens (conductivity)
X	Mean

Introduction

The EU, through EDF 11, has availed the Government of Uganda funds for the "Promoting Environmentally Sustainable Commercial Aquaculture Project in Uganda". The Financial Agreement between the EU and the GoU, was signed by the Ministry of Finance, Planning & Economic Development (MoFPED), who are the National Authorising Officer (NAO) for the Project. The Supervisory Authority is MAAIF, through the Department of Aquaculture Management & Development (DAMD) where the Project Management Unit (OMU) for the project is located in Entebbe.

Under Result 2 of the Project, specifically Activities 2.8 to 2.10, the specific outputs are to be the establishment of two Aquaculture Parks (AquaParks) in Apac and Kalangala Districts.

This study is focused on the Mwena, Kalangala Aquapark site, where a water cage production AquaPark will be established. As a first step, the specific site suitability needs to be determined with regards to where cages will be located and the various water parameters that are integral to that process. A team was dispatched to undertaken this study using expertise from NaFIRRI and NARO and supported by DAMD.

Background

The current expansion fish farming world-over will continue to increase in the coming decades to meet the increasing demand for sea food (FAO 2012). Cage fish farming is one of the production systems that have been identified to have the potential to contribute to increase fish productivity. Much as cages through adoption of high stocking densities have the ability to contribute to increase fish productivity, if not well sited and managed can have damaging effects on the environment. These range from direct aesthetics impacts to direct impacts like environmental pollution and effects on biodiversity (Falconer et al., 2013). A number of environmental, infrastructure and visual characteristics have to be considered for optimized production from cage fish farming. Establishment of site suitability of an area for cage aquaculture based on bio-physico-chemical environmental parameters is of paramount importance since different cage designs have different specific environmental requirements to cope with varying weather conditions, water depth, and anchorage stability (Falconer et al., 2013). Ensuring that the cages are sited appropriately based on these engineering tolerances is of critical importance for sustainability of an operation while ensuring high profitability, safety of the operators and environmental sustainability (Falconer et al., 2013).

The technical suitability of a site for Aquaculture Park establishment draws from the suitability of any given site for aquaculture production activities in general and it critical in preventing any foreseeable negative environmental impacts. The determining parameters for suitability vary depending on whether the intended aquaculture production facility is land based (ponds) or water based (cages). The Lake Victoria site, having been proposed for water based Aquaculture Park, draws this study to determine the suitability of the Lake Victoria waters in the vicinity of Bugala Islands for Aquaculture Park establishment. The main suitability parameters of water bodies considered while establishing for cage aquaculture (or cage culture) production operations can be categorized into;

- *General environmental characteristic* which include; GPS location coordinates to be used for mapping out the evaluated sites, water column depth, to allow wastes and left over food to settle and decompose at safe distance without causing competition for oxygen between the cultured fish and the decomposition bacteria, secchi depth which is a measure of transparence of the evaluated waters, and water current flow rate which plays a critical role in clearing the uneaten feeds and fecal waste.

- *Physico-chemical characteristics* which include; dissolved oxygen (DO) which should be consistently supplied at the required concentrations to support fish production, temperature which is not only inversely proportional to the dissolved oxygen but all play a key role in influencing metabolic activities in the aquatic organisms, the pH is also critical to metabolic activities and the conductivity which play a role in boosting the aquatic animals' immune responses.

- *Nutrient characteristics* which include; ammonia-nitrogen (NH3-N), nitrite-nitrogen (NO2-N), nitrate-nitrogen (NO3-N), soluble reactive phosphorous (SRP) and Total suspended solids (TSS) all of which if high than the acceptable limits for aquaculture production can have deleterious effects on fish.

In selecting for aquaculture site suitability, it is important that type of cage culture system to be adopted is considered. The two commonly used cage types of cages for culturing finfish are the floating type and the stationery type. The floating cages have got an advantage of being movable and can be adopted for use in deep waters. The stationery cages are often used in relatively shallow waters and because of its low cost of construction they are commonly used by small-scale fish farmers.

It is therefore the aim of this study to collect the above information and data to be used to determine the engineering design and type of cages to be used in water base aquaculture park in the waters in the vicinity of Bugala island at Mweena and neighbouring bays in Kalangala district.

Assignment

In may 2018, a rapid validation assessment of the water quality of Mwena and neighboring bays in the vicinity of Bugala island was carried out by Department of Fisheries Resources (DiFR), Ministry of Agriculture Animal Industry and Fisheries (MAAIF) and National Fisheries Resources Research Institute (NaFIRRI), to re-examine suitability of the proposed cage aquaculture sites from the study conducted in 2013 which identified these waters as potential aquaculture parks sites. This was done because of the time lag between when these areas were identified in 2018 and the current implementation time of 2018. This assignment was aimed at generating data and information to guide on cage type, designs as well as diurnal variations in key physico-chemical parameters to in the establishment of a lake based aquaculture park.

General Objective

The general objective of this assignment was to collect data and information to be used in determining the cage types, designs, production potential, and diurnal variation in the key physico-chemical characteristics of the waters in Mwena and neighbouring bays which is the proposed site for the establishment of the lake based Aquaculture Park.

Specific Objectives

1. To collect the biophysical, chemical and general environmental characteristics of the waters in bays around Mwena landing site on Lake Victoria in District to be used in identifying the cage types and designs to be used in establishing the cage aquaculture park.
2. To collect data on the diurnal variations in key physico-chemical characteristics (temperature and Dissolved Oxygen) of the water in Mwena and neighbouring bays.
3. To provide a technical report with management recommendations on the different sites proposed for small, medium and large scale commercial aquaculture production in bays around Mwena landing site on Lake Victoria in Kalangala District in relation to a cage-based aquaculture park establishment.

Materials & Methods

Study Area

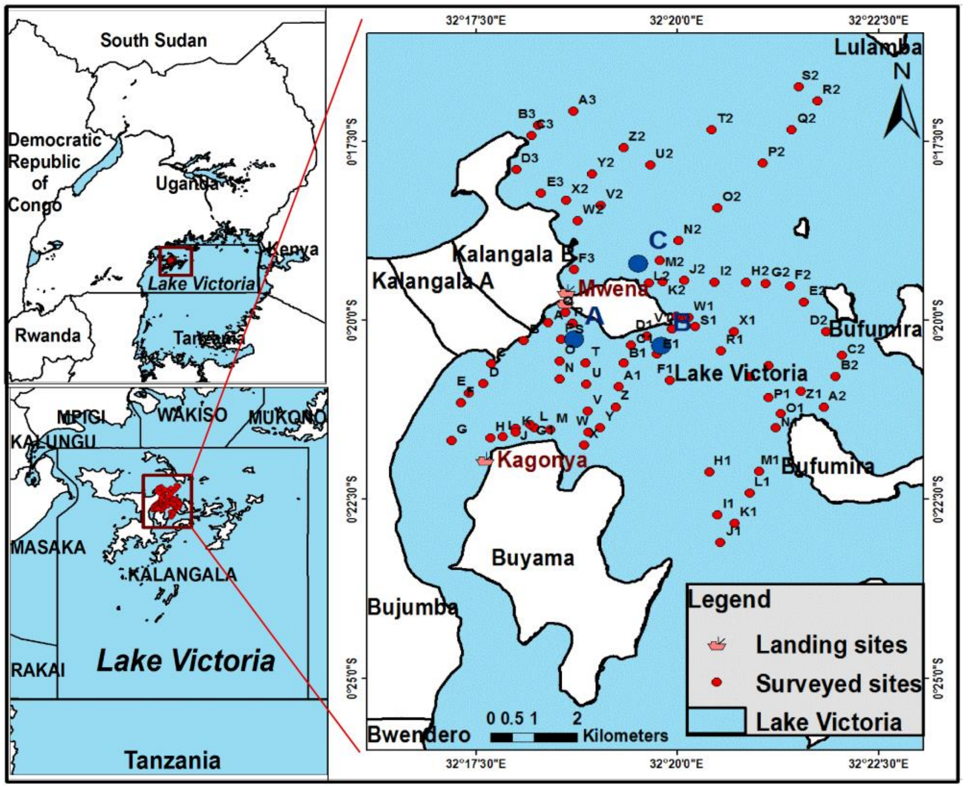

Figure 1: Map showing the location of the different sampled points of sample collection and in-situ measurement within the different bays around Mwena landing site on Lake Victoria in Kalangala District

Data Collection

This study was conducted at in September, 2018. It being a different season compared to the first suitability assessment conducted in May, 2018, this study also offers and opportunity to to assess seasonal variability in the water quality characteristics of these sites. Biophysical and chemical parameters specific to fresh water aquaculture were based on the Queensland Water Quality Guidelines, 2009; Water Quality and Water Quality Management in Aquaculture; Understanding Your Fish Pond Water Analysis Report by Nathan M. Stone and Hugh K. Thomforde, and Best Management Practices for Hawaiian Aquaculture, Centre for Tropical Aquaculture by Howerton Robert (2001).

The criteria for site selection and the acceptable ranges or standards are summarized in the table below;

Table 1. 1; Summary of Criteria for Cage Aquaculture Site Selection showing the acceptable standards for cage fish farming

Parameter		**Acceptable standard**
Topographical criteria		
Height of wave	- stationary cage	< 0.5 m
	- floating cage	< 1.0 m
Wind velocity	- stationary cage	< 5 knots
	- floating cage	< 10 knots
Depth	- stationary cage	min > 4, max < 8 m
	- floating cage	min > 5, max < 20 m
Physical criteria		
Current velocity		min > 10, max < 100 cm/sec
Suspended solid		> 10 mg/l
Water temperature	- tropical species	27–31 °C
	- temperature species	20–28 °C
Chemical criteria		
Dissolved oxygen	- pelagic fish	> 4 ppm
	- demersal fish	> 3 ppm
Salinity		15–30 ppt
Ammonia-nitrogen (NH_3-N)		< 0.5 ppm
Hydrogen ion index (pH)		7.0–8.5
Nitrate (NO_3-N)		< 200 mg/l
Nitrate (NO_2-N)		< 4 mg/l
Phosphate		< 70 mg/l
Chemical Oxygen Demand (COD)		< 3 mg/l
Biological Oxygen Demand (BOD)		< 5 mg/l
Biological criteria		
Bacteria count (E. coli)		< 3000 cell/ml

Chou and Lee (1997) suggest that water depth should be at least five meters so that floating net-cages possess at least two meters clearance from the bottom. A maximum water depth 50m is recommended although 100m is suggested by various researches. Wave height of less than 1m and tidal velocity of between 10 cm/s and 100 cm/s have been suggested to avoid straining the net-cages and distorting cage shape (ibid).

2.2.1 General Environment Assessment Criteria

The nature of the site (sheltered or open), bottom sediment type; Total Depth, Wave height and other users, (e.g. navigation, breeding / nursery ground, and capture fisheries), were used to assess suitability under the topographical and general environment criteria.

The sediment type was determined using a bottom grub. The total depth was measured using an echo sounder while wave height was estimated using visual observations. A Global Positioning System (GPS) unit (GARMIN 12XL), was used to take the GPS coordinates and height above sea (elevation) of the surveyed sites.

2.2.2 Physical Assessment Criteria

At each of the selected sample site, physical parameters; temperature, dissolved oxygen, and conductivity were measured in-situ using a water quality multi-probe from surface to a depths of 0.5m (surface), 2.5m, 5m and 10m where possible. A secchi disc was used to determine the secchi depth (transparency) of the water at the different sampled sites. The flow rate (cm/sec) was determined using a flow rate meter (Valeport, model: 0012/B). The pH was determined using an OAKTON pH Tester 30. The collected water samples were stored in cooler boxes in the field and later transported in the laboratory for nutrient analysis. At each of the sampling points, where applicable all the selected physical parameters were sampled from surface to bottom.

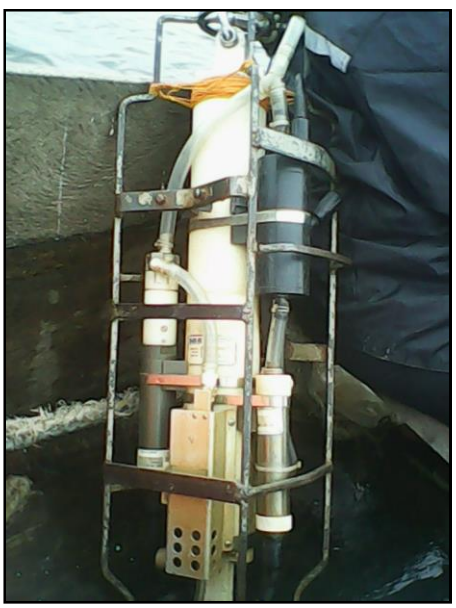

Figure 2: CTD water sampling probe used for taking Temperature, Dissolved Oxygen and Conductivity in the field

2.2.3 Chemical Assessment Criteria

Figure 3; Collecting water samples for chemical and nutrient analysis in the laboratory at National Fisheries Resources Research Institute (NaFIRRI)

Nitrite-Nitrogen (NO_2-N), Nitrate-Nitrogen (NO_3-N), Total Ammonia – Nitrogen (NH_4-N), Soluble Reactive Phosphorous (SRP) and Total Suspended Solids (TSS) were the chemical parameters which were determined in this study because of the high relevance and importance in aquaculture. Water samples were picked from various stations and depths by use of a Van Dorn water sampler. Water samples for dissolved nutrients; soluble reactive phosphorus (SRP), ammonia-nitrogen (NH_{3}-N) and nitrite-nitrogen (NO_{2}-N) were, filtered through 47mm pore Whatman GF/C filter papers and analysed by spectrophotometric methods following procedures by Stantoin *et. al*, 1977. Water samples were also analysed for total suspended solids (TSS). These were measured in mg/l for all the different parameter and compared with the acceptable ranges (table 1.1).

Data analysis and Interpretation

General Environment Assessment Criteria

The different general environmental assessment parameters considered in the different sites as given in 2.2.1 above were assessed according to their importance towards a given site being suitable for aquaculture. Where applicable the values in 2.2.1 above were compared with the recommended as well as the acceptable range for establishment of cage aquaculture (table 1.1). The topographical and general environment suitability assessment findings were summarized in Appendix 4 below.

Physical Assessment Criteria

The Means and Standard Deviations of the collected data for the different physical parameters measured as given in 2.2.2 above were calculated using MS Excel 2007. The calculated Means and their Standard Deviations for each of the surveyed sites were compared with both the recommended and acceptable ranges for aquaculture. Sites whose measured physical parameters were within the acceptable range were considered to be suitable. The acceptable ranges for the selected physical parameters are summarized in Table 1.1 above. The findings from the physical assessment criteria were summarized in Table 2 below.

Chemical Assessment Criteria

Nitrite-Nitrogen (NO_2-N), and Nitrate-Nitrogen (NO_3-N) were analysed following Wood *et al* (1967) Method, American Public Health Association (APHA). Total Ammonia – Nitrogen (NH_4-N), and Soluble Reactive Phosphorous (SRP) were analysed following Soloranzo (1969) APHA, and Murphy and Riley, 1962 (APHA) respectively. Total Suspended Solids (TSS) were analysed using following Wood *et al*., (1967) method, American Public Health Association (APHA). The Mean (X) and the Standard Deviation (SD) of the selected chemical parameters (nutrients) were calculated using MS Excel, 2007 and these were compared with the acceptable ranges for aquaculture. Sites whose chemical parameters were within the acceptable range were considered suitable.

Table 1.1 above gives a summary of the acceptable ranges for the selected chemical parameters (Nutrients) for aquaculture while table 3 below summarized the findings from the chemical assessment criteria.

Results

The sites referenced as S^1 (33.9m), K_1 (33.1m) and I_1 (30.1m) were found to be the deepest among all the sampled waters. B L_2 and D_3 were found to be the shallowest point with depth of 3.7m, 5.3m and 6.7m respectively. In all the different sampled the water flow rates ranged between 15.0 to 25.7cm/sec measured at J and W_1 respectively. The majority of the sampled points in the different waters were found to have rocky and sandy-rocky bottoms. A to Z appeared relatively shallow, relatively sheltered and more preferred for small scale Holder (SSH)cage aquaculture operations of cage bags of average depth not more than 5m deep. U2 to F3 were found to be slightly deeper and less sheltered and therefore more preferred for medium scale holder (MSH) aquaculture operations while those open un-shelter with cage bags depth ranging between 5 to 6m, deeper than 20m sites are more preferred for the Large scale holder (LSH) aquaculture operation with cage bags of average depth ranging between 8 to 10m. Transparency / secchi depth at the different sampled points in the surveyed bays ranged between 1.37 and 2.48m (appendix 3). All the different sampled bays were accessed via Mwena landing site.

Physical Assessment Criteria

Table 2; summary results (mean±sd) of the physical parameters of the waters from selected bays

Site	PH(-)	DO(mg/l)	Temp (°C)	Cond(µm/cm)
C	7.71±0.19	7.14±1.50	24.67±0.06	95.92±1.80
D	7.67±0.31	7.50±0.78	24.77±0.12	96.16±1.01
L	7.89±0.22	6.57±0.28	24.57±0.07	95.93±1.24
M	7.78±0.20	7.03±0.60	24.57±0.06	96.22±1.47
Q	7.68±0.28	7.49±0.42	24.63±0.06	95.55±0.95
T	7.95±0.23	7.37±0.78	24.73±0.06	97.88±1.27
Z	7.92±0.13	7.50±0.84	24.70±0.02	96.57±1.08
C_1	7.79±0.43	7.25±0.10	24.60±0.17	94.58±0.57
H_1	7.99±0.28	6.75±0.78	24.48±0.33	96.08±1.98
P_1	7.94±0.06	7.22±0.89	24.68±0.19	97.79±0.98
W_1	7.88±0.22	6.10±1.20	24.65±0.10	95.97±2.11
Y_1	7.99±0.14	6.90±0.32	24.87±0.21	96.58±1.89
D_2	7.71±0.27	6.44±0.62	24.83±0.21	96.11±0.63
H_2	8.07±0.20	6.14±0.47	24.98±0.28	95.56±1.10
J_2	7.82±0.28	6.29±1.03	25.1±0.37	95.67±2.62
O_2	7.62±0.24	6.73±1.07	25.13±0.55	96.49±1.69
U_2	7.93±0.43	6.39±0.92	25.57±1.08	96.97±0.57
X_2	7.95±0.24	6.86±0.72	25.28±0.64	97.29±2.13
E_3	7.94±0.15	6.86±1.13	25.63±0.79	95.94±0.52

The average measured Dissolved Oxygen DO in all the sampled points within the different bays ranged between 6.10± 1.20mg/l and 7.50±0.78mg/l. The average measured pH in all the different sampled points in these bays ranged between 7.62±0.24 and 8.07±0.20 measured at O_2 and H_2 respectively. In all the different sampled points within the different bays, the average measured conductivity was found to range between 94.58±0.57µs/cm and 97.88 ± 1.27µs/cm. The highest measured average temperature in all the different sampled points was 25.63±0.79˚C while the lowest measured average temperature was 24.57±0.06˚C among the different sampled points. (Table 2 above).

Chemical Assessment Criteria

Table 3: Summary of mean±SD of the nutrients and suspended solids in the water samples from different sampled bays

Station	**Nitrites-Nitrogen (mg/l)**	**Ammonia-Nitrogen (Mg/l)**	**Nitrates-Nitrogen(mg/l)**	**SRP(mg/l)**	**TSS(mg/l)**
C	0.01±0.00	0.08±0.02	0.03±0.01	0.01±0.00	2.75±0.35
H1	0.01±0.00	0.05±0.02	0.07±0.00	0.02±0.00	1.33±0.94
I	0.01±0.00	0.07±0.01	0.04±0.00	0.03±0.00	2.66±0.55
P1	0.01±0.00	0.06±0.03	0.04±0.03	0.02±0.01	2.92±1.02
N	0.01±0.00	0.05±0.01	0.05±0.01	0.03±0.02	5.21±3.01
T	0.01±0.00	0.06±0.02	0.05±0.04	0.03±0.03	2.94±0.55
Z	0.01±0.00	0.06±0.01	0.04±0.01	0.04±0.01	3.26±0.11
D2	0.01±0.00	0.06±0.00	0.07±0.00	0.02±0.00	3.02±1.27
E3	0.01±0.00	0.08±0.05	0.08±0.01	0.03±0.02	2.78±0.67
H2	0.01±0.00	0.04±0.01	0.10±0.01	0.01±0.00	2.79±0.97
X2	0.01±0.00	0.07±0.03	0.08±0.01	0.04±0.05	1.76±0.08
W1	0.01±0.00	0.05±0.02	0.06±0.03	0.05±0.05	1.26±0.34

The measured average NH_4-N, nitrite-nitrogen and nitrate-nitrogen concentration were all with acceptable ranges for aquaculture production as compared to the values given in table 1.1 above. The average maximum measured Soluble Reactive Phosphorous (SRP) from all the different sampled points within the different bays was 0.05±0.05mg/l while the measured average total suspended solids (TSS) ranged between 1.26±0.34 and 5.21±3.01mg/l (Table 3 above).

Diurnal variations in the physical chemical paramters within the different sampled bays

Dissolved Oxygen(mg/l) variations at the different depth(m) during the different sampling times

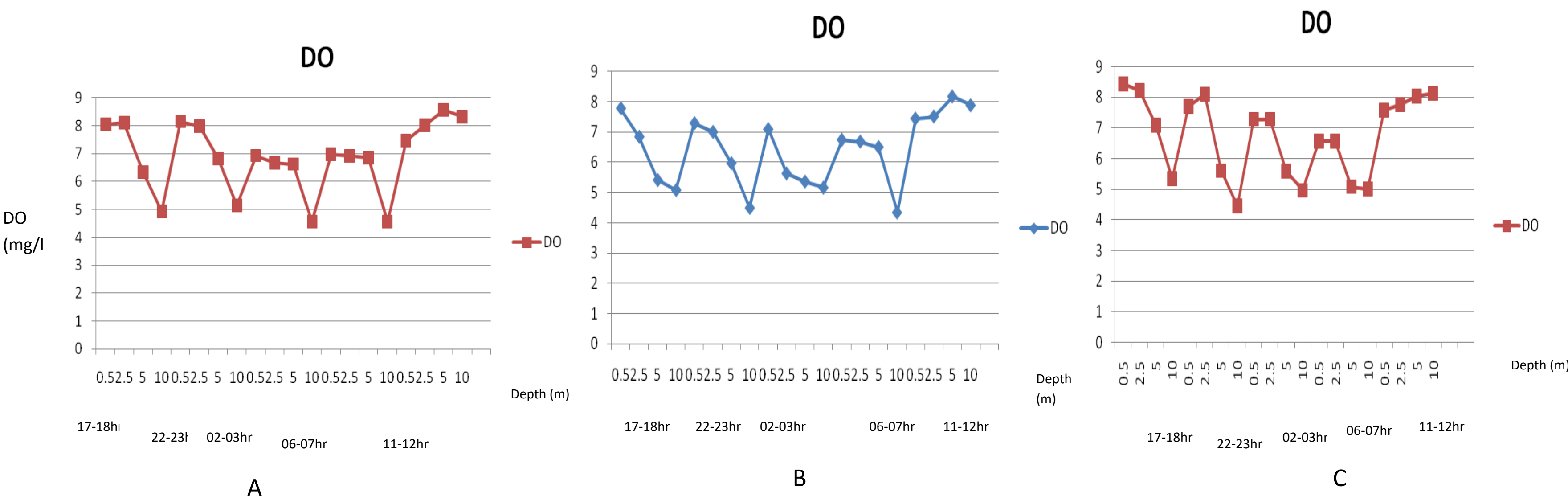

Figure 4; Diurnal Dissolved oxygen(mg/l) variation with depth at the different time of sampling at the three (3) pre-set sampling points

From all the three (3) pre-set sampling points, the dissolved oxygen levels decreased with increasing depth during the sampling times of 17-18hrs, 22-23hrs, 02-03hrs, and 06-07hrs. In all the three (3) pre-set sampling points, the dissolved oxygen increased with depth during the sampling time of 11-12hrs. The dissolved oxygen at a depth of 10m from the three pre-set sampling points during the sampling times of 17-18hrs, 22-23hrs, 02-03hrs, and 06-07hrs was found to be between 5 and 4mg/l which is very close to the lower critical range for supporting fish production in tropical warm water bodies.

Temperature variations at the different depth(m) during the different sampling times

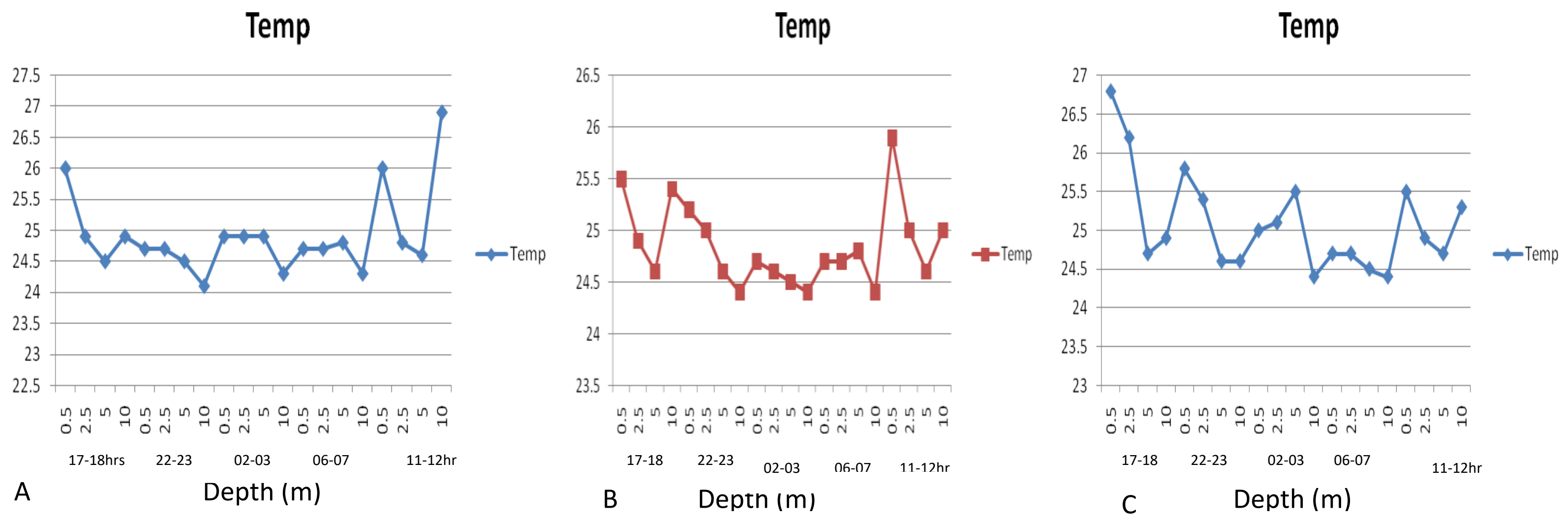

Figure 5; Dirunal variations in Temperature (°C) with depth at the different time of sampling at the three (3) pre-set sampling points

From all the three (3) pre-set sampling points where each point was in one bay for the diurnal variations, the temperature were taken at four hours interval as shown in figure 5 above. In all the different sampled points, temperature generally decreased with increasing depth with the highest temperatures observed in sampling points A and B during the 11-12hrs sampling time. At sampling point C the highest temperatures were observed during the sampling time of between 17-18hrs. The temperature remained within acceptable ranges from fish production at the pre-set sampling points at all the considered depth and sampling times.

Discussion

This suitability study captured the topographical and general environmental, physical and chemical parameters of the waters in bays around Mwena landing site between Bugala, Bunyama and Bufumira islands (Appendix 1 and figure 1). For environmental variability this data shall be compared with data collected in May, 2018 from these same sites. The topography and general environment assessment criteria, physical and chemical assessment criteria data collected in October, 2018 and May, 2018 were compared.

Topography and General Environment Assessment Criteria

Total depth

Small to medium holder cages of maximum depth not exceeding 3m are more preferred in the surveyed sites whose depth was found to be less than 6m. These can be cages of 5 X5 X 3m operated at a Low Volume High Density (LVHD) principle. The relatively shallow, well sheltered areas are good for the small and medium cages since such areas do not experiences the strong winds and waves. Such cages, if installed in open waters, are very prone to being destroyed by the strong winds and waves. For sites whose depth was more than 8m, relatively big, robust cages (figure 6) are preferable in such sites, since these offer better growth performance to the fish and are strong enough to withstand the winds in these relatively open waters. In waters exceeding 10m depth circular, square or rectangular cages with volumes of about 600m^3 can be used (figure 7). These can be operated on a principle of High Volume Low Density (HVLD). These are areas marked as small scale holders (SSH), medium scale holders (MSH), and Large Scale Holders (LSH) in appendix 3.

Figure 6; Square HDPE cages which can be operated in the open waters with depth higher than 6 to 8m

Figure 7; Circular HDPE cages which can be of diameter ranging between 10 to 20meter with a depth of 6 to 8m to used in Large Scale Holder operations

For optimal cage aquaculture productivity a water column to depth ration of 1:3 is preferred. Any areas with depth below 5m should be highly avoided. Cages established in sites whose depth is less than 5m deep cannot have enough space below them for water exchange and decomposition of faecal waste, as well as uneaten feeds. It is necessary to allow sufficient depth (at least 2.0m) for flushing out and water exchange under the cage in order to maximize water exchange, avoid oxygen depletion, accumulation of uneaten food, faeces and debris, disease infection, and build-up of some noxious gases such as H_2S generated by decomposition of the deposited wastes, a minimum depth of 4m of which 1m is space left between the cage and lake bottom is recommended for LVHD cages.

The clearance for a floating cage should be at least 2–3 m at the lowest low water of spring tide. But a stationary cage is allowed 1–2 m minimal clearance to minimize the costs of fixed poles. Also, because fixed cages are usually placed in the mouth of rivers, creeks and canals where the water flow is stronger than in other open areas in the lake. On the other hand, the maximum depth of the floating cage should preferably be less than 20 m, otherwise investment and maintenance costs will be higher as longer anchoring ropes and heavier anchor blocks are required. The maximum depth of a stationary cage should also not exceed 8 m since it is difficult to find sufficiently strong supporting posts longer than 8 m.

The measured transparency / secchi depth, at all the sampled points within the different bays, were higher than the upper acceptable limit for cage fish farming (Table 1.1). Clear transparent waters can be an indication of waters with a low nutrient input, offering more visibility to fish feeds in cases where artificial feeds are used. A relatively low micro-organism population, to a secchi disc reading of between 80 – 200 cm, as this will ensure a biomass balance in favour of the cage farming activities, when keeping environmental impact in check. In such cases the recommendation is that the production system should be based entirely on artificially formulated feeds.

Water flow rates

The average measured water flow rates in all the sampled points were found to be on the lower side of the acceptable ranges for cage Aquaculture of 10 – 100cm/sec (Table 1.1). It is important that low stocking densities are deployed in areas whose flow rates are less than 50cm/sec. In this validation activity the surveyed sites all had water flow rates less than 50cm/sec. This implies that relatively low stocking densities should be operated in these bays if environmental sustainability is to be ensured. The water column also serves as a guard against disease transfer from the decomposing substances to the fish while the water current flow rate effectively washes away fish wastes and un-eaten food through and out of the cage. It is preferred that the clearing of the uneated feeds and fecal waste is done continuously at a rate which ensures optimum water quality balance for best production results.

High stocking densities can only be adopted in areas whose flow rates are higher than 50cm/sec. The water flow rate currents bring fresh oxygenated water to and remove waste from the cage. A large tidal range generally indicates better conditions for high stocking density of fish. On the other hand, strong currents will generate excessive strain on the raft anchoring system or fixed poles, distortion of the nets and cage structures, slow growth of fish caused by too much expense of energy in swimming against the current, and food losses. If the fish is unable to swim against the current, then stress will occur, from being impacted on one side of the net. The direction of current is also a major criterion to be followed when positioning a cage on a grid line or raft. To minimize the strain on the anchoring system resulting from strong currents, the rectangular raft should be in a direction parallel to the current. This is opposite to the weak current areas where a cage needs to be positioned against the current for a better water flow.

Physical Assessment Criteria

Dissolved Oxygen (DO)

The DO levels were found to range between 6.10± 1.20mg/l and 7.50±0.84mg/l. This is well above the recommended acceptable minimum of 4mg/l and 3mg/l for pelagic and demersal fishes respectively (table 1.1) which makes waters in these bays good for farming of various aquatic organisms including fish. The problem of dissolved oxygen for net-cage culture is not as serious as in pond culture due to current movements. At night, planktonic algae play contribute to the depletion of dissolved oxygen due to respiration and cessation of photosynthesis. In conjunction with oxygen consumption of fish at high stocking densities in the cages, and limited water circulation caused by excessive fouling, can severely lower the dissolved oxygen content of the water surrounding the cage. In the case of cage culture in shallow areas, benthic organisms and settleable solid wastes may also reduce the oxygen level. Solubility of oxygen in water declines with increasing temperature and salinity. Hence depletion of DO always occurs during night time at neap tide in summer.

pH

The pH is all the different sampled points in the different bays ranged between 6.80±1.40 and 8.90±0.40, a range that is well within the acceptable range of 6.5 – 8.5 for aquaculture (Robert, 2001). Extreme values of pH can directly damage gill surfaces, leading to death (McDonald, 1983). Normally, seawater is alkaline with pH values of 7.5– 8.5. At this level, water also acts as buffer to prevent pH changes caused by other factors. An exceptional case is in estuarine areas where seawater is mixed by freshwater influx during heavy rains. The pH of freshwater may have a greater variation from 3 to 11 caused by acid rain or limestone rocks. In estuarine area, phytoplankton population, for example *Chlorella* spp., may elevate pH value in water due to its waste. However, pH is also important because it affects the toxicity of several common pollutants such as ammonia cyanide and heavy metals like Aluminium (Malcolm, 1987).

Conductivity

The conductivity measured in all the sampled points was found to be within the acceptable range of 30 – 3000µs/cm. Conductivity plays an important role in boosting the animals' immune system. At low conductivity levels farmed fish become more susceptible to diseases, while at high conductivity levels above 1000µs/cm fish have shown to have a higher immunity. It also gives an indication on the levels of water hardness. If the conductivity is low then water is not hard while high conductivity may indicate the waters being hard and very rich in salts.

Temperature

The measured temperature at all the different sampled points within these bays were also within the acceptable range for aquaculture of 24 – 32˚C (Robert, 2001). The temperature ranges at a proposed site for cage fish farm do affect the metabolic activities of the fish, oxygen consumption, ammonia and carbon dioxide production, feeding rate, food conversion, as well as fish growth. Water temperature normally changes with climatic condition, with a wide range occurring in temperature areas. Solar radiation is also important with regard to heat transfer to the top layers of the water column. Since low water movement causes mixing in neap tides, it may be found that water temperature is higher than normal in shallow areas. Temperature change in coastal areas is mainly influenced by land runoff, i.e. colder in winter/cold season and warmer in summer. Strong wind also affects temperature change by bringing up the colder water from the bottom to the surface and reducing the heating up of surface waters. Although some fish can survive in such temperature ranges, growth is usually inhibited. The best solution is to select fast-growing species (not more than 8 months) and avoid having the culture period running into the months with unsuitable temperature.

Chemical Assessment Criteria

Ammonium –Nitrogen (NH_4-N)

For all the sampled points in the different bays, the Ammonium-Nitrogen was with the acceptable range of less than 0.5mg/l (FAO, 1989). In shallow water cage culture, the ammonia level in water caused by the decomposition of uneaten food and debris at the bottom can have serious adverse effects on the fish. Normally in coastal areas, sewage discharge and industrial pollution are the main sources of higher levels of ammonia in a number of aquatic systems.

Nitrite – Nitrogen (NO_2-N) and Nitrate –Nitrogen (NO_3-N)

The average measured nitrite-Nitrogen and nitrate-Nitrogen in all the sampled points were well within the acceptable range of less than 4mg/l and 200mg/l for nitrite-nitrogen and nitrate-nitrogen respectively. The excessive amount of nitrite in water becomes toxic to fish due to oxidation of iron in haemoglobin from ferrous to ferric state (Tiensongrusmee, 1986). It will cause hypoxia in fish because haemoglobin molecules cannot bind with oxygen. Nitrate can also cause methemoglobinemia, but it is not as strong as oxidation by nitrite. Nitrate also serves as fertilizer for phytoplankton, which could bloom excessively. For a suitable area, nitrite level should not exceed 4 mg/litre while nitrate level should be below 200 mg/litre.

Soluble Reactive Phosphorous (SRP)

The highest average SRP measured in the different sampled points with the different bays was 0.05±0.05mg/l. This implies that the SRP levels in all the sampled bays were within the acceptable range of less than 70mg/l (FAO, 1989). The total phosphate content in natural water may range from 0.01 to more than 200 mg/litre (Tiensongrusmee, 1986). An excessive level of phosphate in water will trigger an over-bloom of phytoplankton, which causes the depletion of oxygen levels in water. A good site for cage culture should have phosphate level not higher than 70 mg/litre.

Total Suspended Solids (TSS)

All the sampled points in with the different bays were within the acceptable range for aquaculture of less than 10mg/l (FAO, 1989). Turbid water, which is normally caused by freshwater run-off during rainy season, is not suitable for cage culture. Organic and inorganic solids are suspended in the water column as a result of soil erosion. Run-off also brings some heavy metals leached from the catchment area, as well as other industrial effluents; it also reduces salinity at the site. Sedimented material from the usually soft muddy bottom of estuarine areas causing more solids to deposit on the nets. These sediments act as a substrate for the growth of fouling organisms. Suspended solids in turbid waters with strong currents from freshwater run-off will also stir up already, which prevent proper water circulation. In addition, suspended sediments tend to clog fish gills, which may lead to mortality from asphyxiation or cause gill epithelial tissues to proliferate and thicken. The presence of suspended solids also relates to some disease such as "fin-rot" caused by Mycobacteria (Herbert and Merkens, 1961; Herbert and Richards, 1963). The visibility of fish to the feeds will also be reduced which may lead to feed loss and impair fish growth.

Suspended solids in a suitable site for net-cage culture should not exceed 10 mg/l. But its effect also depends on the exposure time and current speed. In estuarine site during flood periods, the turbidity can be higher than 100 mg/l but the exposure time is only at low tide and the current is also rapid enough to prevent the sedimentation of solid matters.

Diurnal variations in the physico-chemical water quality parameters

Temperature and Dissolved oxygen being very critical to fish production, they were the main physico-chemical parameters which were considered under the diurnal variation studies. The main source of oxygen being the dissolved oxygen from the atmosphere during the evening, night and morning, this could probably explain the trend of dissolved oxygen levels decreased with increasing depth during the sampling times of 17-18hrs, 22-23hrs, 02-03hrs, and 06-07hrs. Photosynthesis which is another oxygen contributing process being a light dependant process, and with light intensity decreasing with increasing depth could be another explanation for the decreasing in DO with increasing depth. The observed dissolved oxygen increase with depth during the sampling time of 11-12hrs, could be explained by the mixing of the waters during the day. It is important that cage bags adopted in these bays don not exceed 8m deep since the DO reduces to critical levels after 10m depth. The decrease in temperature with increasing depth could be attributed to the sun being the main source of heat. The temperatures remaining within acceptable ranges for fish production at the pre-set sampling points at all the considered depth and sampling times, implies that there is no need for additional interventions for improving temperature.

Socio-Economic Assessment criteria

In addition to the general requirements for water based aquaculture establishment, an Aquaculture Park, being a large commercial entity there has to additionally consider; Close proximity to land that is suitably profiled for; Fish landing, Construction of support facilities such as a hatchery and / or nursery, feed store, net making and mending workshop among others. The current existing infrastructure at Mwena landing site will require some expansion if it is to accommodate support structures for feed storage, net mending and accommodation. As for the hatchery, it is important a site with appropriate water quality, enough land and proximal to the aquaculture park has to be identified.

The current fish handling facility can be used as a marketing outlet within some modifications, improvement and enhancement in the current ice production, cold room and live fish handling facility. It is important fish products from capture fisheries and aquaculture are handled separately to avoid conflict. This would require making provisional establishment for handling catches from capture fisheries or gazetting the handling of capture and aquaculture products on different days.

The current existing access road need to be improved to match the required standards as well as improving the transport network between the different components of the aquaculture park. The power access to Mwena landing will need enhancing to match required voltage for the machinery and equipment within the aquaculture park establishment.

Conclusion

Topography and general environmental Assessment Criteria

Bays around Mwena landing site were found to be suitable for both Low Volume High Density (LVHD) and High-Volume Low-Density (HVLD) cages. It is important that cage bags used in these sites are designed based on the depth characteristics of the site where the cages are to be installed (cage bags of not more than 8m deep). These cage bags should allow for enough space below the cages for auto-euperation. Moderate stocking density (not exceeding 70 kg of fish/m^3) in the small to medium cages should be deployed while in the big HVLD cages stocking densities not exceeding 54kg/m^3 are adopted since the measured flow rates in these bays were found to be on the lower side of the acceptable range.

Physical Assessment Criteria

From the physical assessment criteria, all the considered parameters at the different sampled points within the different bays were within the acceptable ranges for aquaculture except the transparencies (secchi depth). It is recommended that production is completely based on artificial feeds since the transparency was higher than the recommended ranges, an implication that there is not enough primary production along the river in the different surveyed points to provide enough food for the fish. It is recommended that floating feeds are used for ease of recovery of the uneaten feeds. This implies that this site can be used for cage fish farming.

Chemical Assessment Criteria

Since all the considered chemical parameters were within the acceptable range for all the surveyed points, then based on the chemical criteria all the surveyed points are considered suitable for cage aquaculture.

Diurnal variations

Much as during the day the dissolved oxygen levels at depth as high as 10m is still within acceptable ranges, it is important the designed cage bags do not exceed 8m deep because DO drops to critical levels during the night. Although temperature drops were observed during the night, the temperature still remained within acceptable range for tropical warm water fish production. This is has an implication of there being no special requirement for temperature manipulation in this aquaculture park establishment.

Management Recommendations

It is of extreme importance that a diurnal sampling is done for the different seasons since the observed variations in this sampling which was done in the rain season might not be a true reflection of what happens in the dry season in these areas.

It is important that floating feeds are used in any aquaculture operations in these bays, and nursing of larvae and fingerlings should be strictly done on land since the measured flow rates were on the lower side of the acceptable range.

It is important that continuous monitoring is done in these areas to ensure that seasonal variability in the above measured parameters can be captured.

Even after the commencement of cage aquaculture, it is recommended that continuous monitoring is done to ensure that any changes in the bio-physical and chemical parameters are captured before exposing the farmed fish to negative effects. This shall also help the AquaPark management to know the effects of cage aquaculture on the water environment.

It is also important that further studies are done to establish the cage densities and carrying capacities which can be accommodated in these sites so as to avoid over loading which might result into eutrophication.

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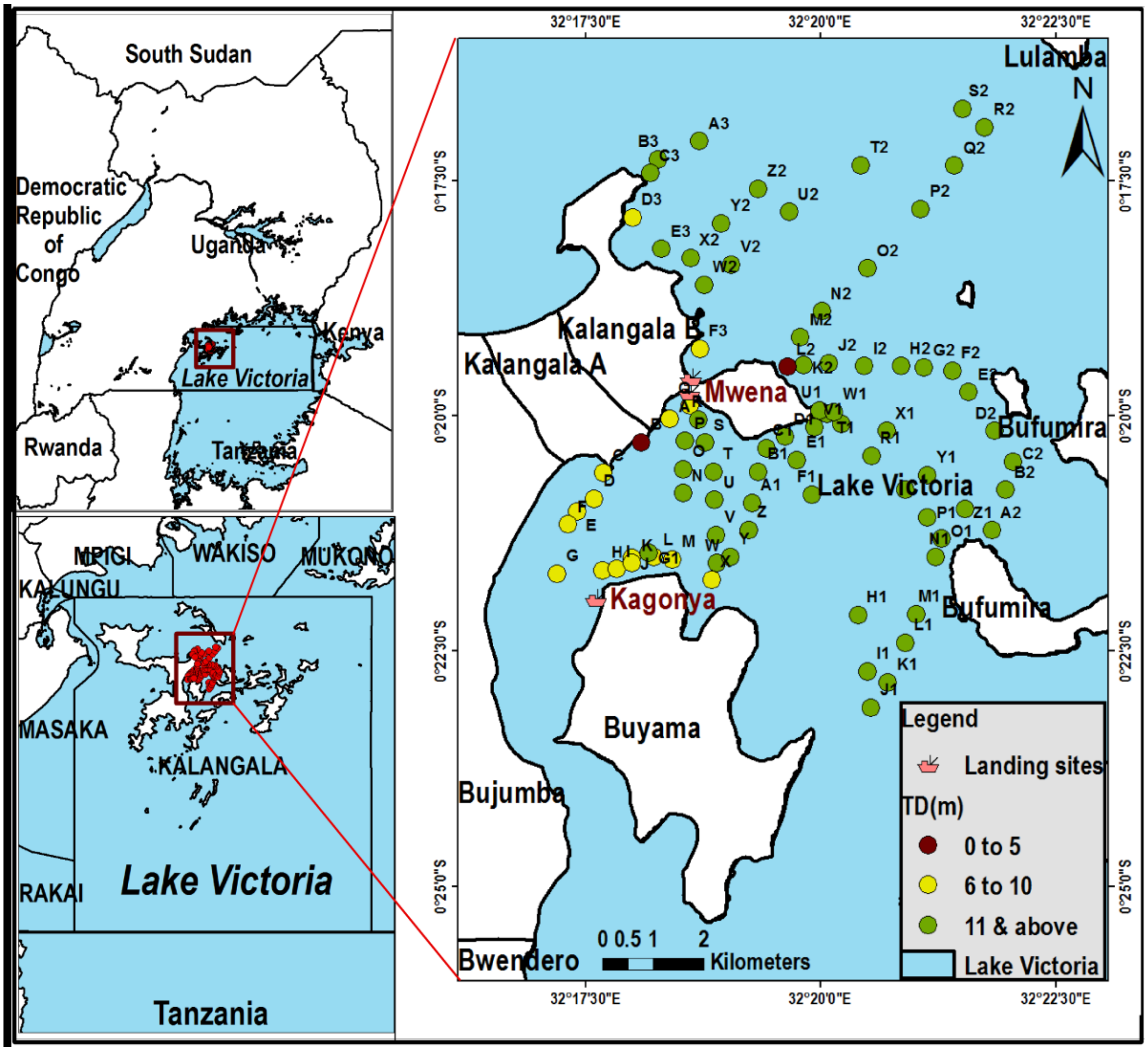
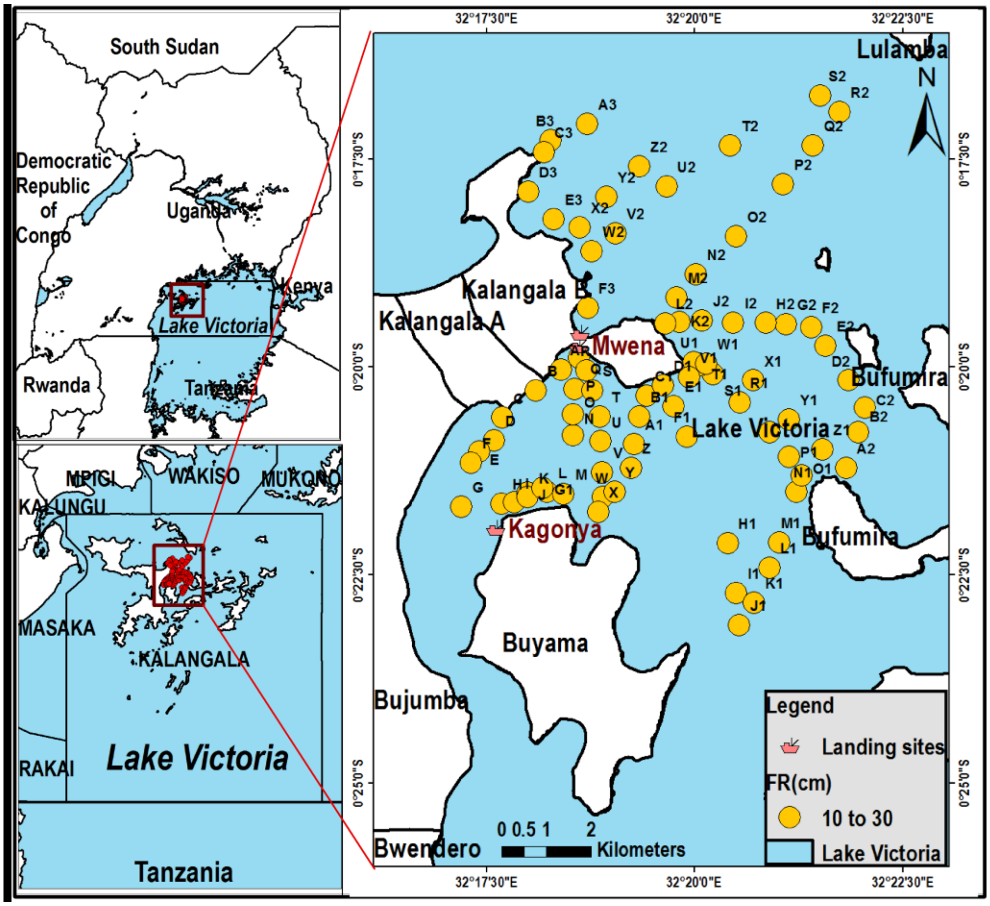
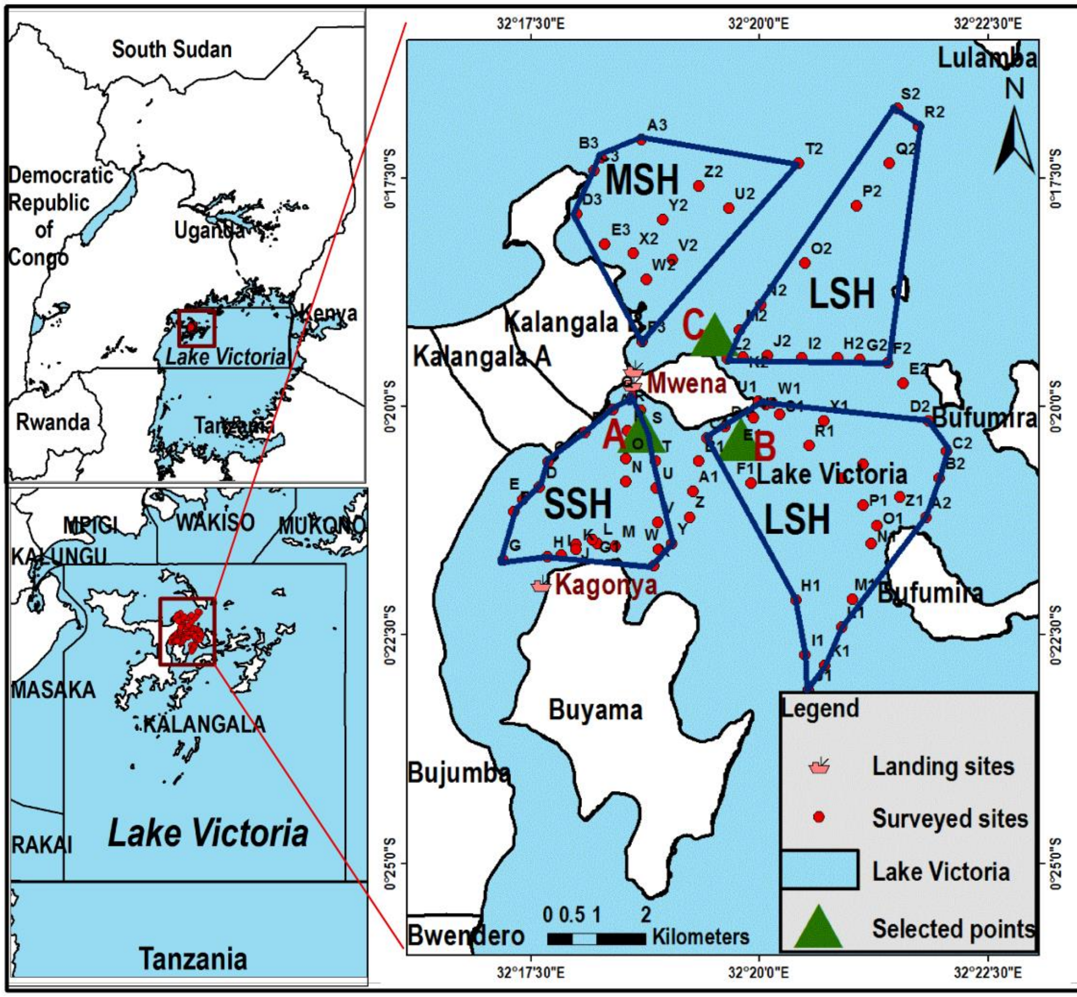
Appendix: 1: Map showing the variation ranges in depth **at the different sampling points in the waters around Mwena and neighboring bays on Lake Victoria, Kalangala District.**



Appendix 2; Map showing the variation in water flow rates **at the different sampling points in the waters around Mwena and neighboring bays on Lake Victoria, Kalangala District.**



Appendix 3; Map showing the different proposed blocks for small, medium and large scale cage operations


South Sudan
Democratic Republic of Congo
Uganda
Kenya
Lake Victoria
Rwanda
Tanzania
MPIGI
WAKISO
MUKONO
KALUNGU
MASAKA
KALANGALA
RAKAI
Lake Victoria
Tanzania
32°17'30"E
32°20'0"E
32°22'30"E
0°17'30"S
0°20'0"S
0°22'30"S
0°25'0"S
Lulamba
N
MSH
LSH
SSH
LSH
Kalangala B
Kalangala A
Mwena
Kagonya
Lake Victoria
Bufumira
Bufumira
Buyama
Bujumba
Bwendero
0 0.5 1 2 Kilometers
Legend
Landing sites
Surveyed sites
Lake Victoria
Selected points

Appendix 4: Topographical and General Environment suitability **findings for the selected sampled points within Bays around Mwena landing site on Lake Victoria**

	Site	Southings	Eastings	Altitude (m)	TD(m)	SD(m)	FR(cm/sec)	COMMENT
Mwena	landing site	S00^0 19.741'	S32^0 18.599'	1135				ADB fish holding facility
Mwena	landing site	S00^0 19.584'	S32^0 18.616'	1133				
	A	S00^0 20.031'	E32^0 18.399'	1134	10.7	2.03	20.5	soft flocculent mud
	B	S00^0 20.284'	E32^0 18.095'	1133	3.7			wave height less 0.65m
	C	S00^0 20.612'	E32^0 17.690'	1134	8.1	1.89		
	D	S00^0 20.885'	E32^0 17.594'	1134	9.4	2.03	21	
	E	S00^0 21.015'	E32^0 17.408'	1137	9.8	1.89	24.5	
	F	S00^0 21.155'	E32^0 17.314'	1133	9.3			bottom type sandy
	G	S00^0 21.681'	E32^0 17.199'	1130	8.8	1.37	19.5	
	H	S00^0 21.645'	E32^0 17.681'	1134	10.1			traffic route
	I	S00^0 21.631'	E32^0 17.837'	1133	9.4			water sample taken
	J	S00^0 21.514'	E32^0 17.991'	1133	9.3	2.04	15	
	K	S00^0 21.569'	E32^0 17.997'	1132	9.3			
	L	S00^0 21.506'	E32^0 18.225'	1130	9.8			bottom sandy

M	S00^0 21.529'	E32^0 18.427'	1134	10.3	2.4	23.55	
N	S00^0 20.824'	E32^0 18.535'	1134	13.7			
O	S00^0 20.568'	E32^0 18.542'	1129	14.6			
P	S00^0 20.270'	E32^0 18.561'	1131	14.8			
Q	S00^0 19.893'	E32^0 18.612'	1133	9	1.8	19	
R	S00^0 20.041'	E32^0 18.701'	1134	14.4			
S	S00^0 20.287'	E32^0 18.768'	1132	15.6	1.95	18	
T	S00^0 20.596'	E32^0 18.860'	1133	17.6	2.135	23.9	sandy rocky
U	S00^0 20.898'	E32^0 18.873'	1133	15.3			
V	S00^0 21.269'	E32^0 18.890'	1133	14.4			
W	S00^0 21.568'	E32^0 18.896'	1133	12		18.2	
X	S00^0 21.744'	E32^0 18.843'	1133	10.8	2.215		wave height less 0.55m
Y	S00^0 21.503'	E32^0 19.040'	1135	13.3			
Z	S00^0 21.212'	E32^0 19.235'	1134	15.9		19.7	
A_1	S00^0 20.927'	E32^0 19.275'	1137	18	2.33	28	
B_1	S00^0 20.595'	E32^0 19.338'	1136	20.9			Rocky
C_1	S00^0 20.344'	E32^0 19.430'	1134	21.2		21.15	
D_1	S00^0 20.225'	E32^0 19.621'	1134	20.9			
E_1	S00^0 20.470'	E32^0 19.751'	1136	25			
F_1	S00^0 20.838'	E32^0 19.907'	1135	25.3		24.5	

G$_1$	S00^0 21.461'	E32^0 18.177'	1132	27.7	2.48		
H$_1$	S00^0 22.120'	E32^0 20.397'	1133	29.6		22.85	
I$_1$	S00^0 22.716'	E32^0 20.503'	1138	30.1			
J$_1$	S00^0 23.103'	E32^0 20.539'	1136	29.7			
K$_1$	S00^0 22.834'	E32^0 20.716'	1135	33.1			
L$_1$	S00^0 22.414'	E32^0 20.900'	1135	28.4			
M$_1$	S00^0 22.107'	E32^0 21.015'	1134	25.6	1.99	26	
N$_1$	S00^0 21.502'	E320 21.224'	1135	14.5			
O$_1$	S00^0 21.302'	E32^0 21.284'	1138	13.9			
P$_1$	S00^0 21.085'	E32^0 21.133'	1136	19.6			Cloudy evening
Q$_1$	S00^0 20.787'	E32^0 20.905'	1134	20.5			
R$_1$	S00^0 20.427'	E32^0 20.543'	1134	25.1			
S^1	S00^0 20.086'	E32^0 20.224'	1133	33.9			
T$_1$	S00^0 19.983'	E32^0 20.068'	1133	30.7			Rocky near stones
U$_1$	S00^0 19.946'	E32^0 19.991'	1131	23.7			
V$_1$	S00^0 20.122'	E32^0 19.939'	1133	28.7			
W$_1$	S00^0 19.961'	E32^0 20.143'	1137	31.4	2.06	25.75	
X$_1$	S00^0 20.164'	E32^0 20.702'	1135	25			
Y$_1$	S00^0 20.635'	E32^0 21.137'	1135	18.5	1.83		
Z$_1$	S00^0 20.994'	E32^0 21.538'	1139	13.5			
A$_2$	S00^0 21.218'	E32^0 21.819'	1140	12.5		17	
B$_2$	S00^0 20.790'	E32^0 21.967'	1135	12.9			traffic route to kitobo
C$_2$	S00^0 20.493'	E32^0 22.051'	1136	13.5			traffic route to kitobo

D_2	S00^0 20.164'	E32^0 21.852'	1136	17.5	2.04		
E_2	S00^0 19.750'	E32^0 21.572'	1135	18.6			
F_2	S00^0 19.525'	E32^0 21.401'	1134	20.9			traffic route
G_2	S00^0 19.492'	E32^0 21.101'	1133	20.9			
H_2	S00^0 19.475'	E32^0 20.855'	1133	22.4	2.11	21.1	
I_2	S00^0 19.473'	E32^0 20.467'	1138	26.3			
J_2	S00^0 19.444'	E32^0 20.090'	1136	26.5	2.09		
K_2	S00^0 19.464'	E32^0 19.819'	1139	18.1			
L_2	S00^0 19.482'	E32^0 19.647'	1137	5.3			Sandy rocky bottom
M_2	S00^0 19.169'	E32^0 19.786'	1135	19.2			
N_2	S00^0 18.891'	E32^0 20.016'	1137	21.2			
O_2	S00^0 18.436'	E32^0 20.499'	1137	25	1.65	18.4	Water hyacinth
P_2	S00^0 17.803'	E32^0 21.061'	1135	22.1			
Q_2	S00^0 17.343'	E32^0 21.423'	1137	21.8			
R_2	S00^0 16.937'	E32^0 21.747'	1134	24			
S_2	S00^0 16.742'	E32^0 21.510'	1132	22.8			
T_2	S00^0 17.339'	E32^0 20.430'	1132	21.1			
U_2	S00^0 17.835'	E32^0 19.665'	1133	18	1.78		
V_2	S00^0 18.394'	E32^0 19.052'	1134	15.2			
W_2	S00^0 18.612'	E32^0 18.763'	1134	14.1			
X_2	S00^0 18.324'	E32^0 18.616'	1132	14.4	1.7	17.1	
Y_2	S00^0 17.957'	E32^0 18.943'	1131	18.5			
Z_2	S00^0 17.592'	E32^0 19.339'	1131	17.7	1.275		
A_3	S00^0 17.084'	E32^0 18.712'	1130	16.3			
B_3	S00^0 17.277'	E32^0 18.270'	1131	14.8			
C_3	S00^0 17.424'	E32^0 18.188'	1133	16.3			

	D_3	S00^0 17.895'	E32^0 18.000'	1133	6.7			
	E_3	S00^0 18.229'	E32^0 18.310'	1137	12	1.785	13.85	Bloom from palm trees
	F_3	S00^0 19.292'	E32^0 18.717'	1130	9.3			Near I fish cages