

## Research Application Summary

### **Phosphorus-based carrying capacity, and trophic state index of cage fish sites in the Kadimu Bay, Lake Victoria, Kenya**

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#### **Abstract**

Fish production in the Kadimu bay of Lake Victoria, Kenya through cage culture has the potential to increase the Phosphorus load to the aquatic ecosystem through fish feed waste. This increasing phosphorus levels in water may cause pollution leading to poor water quality that may be detrimental to fish farmers. This study focused on the calculation of the quantity of phosphorus the cage sites can accommodate and evaluation of water quality state by estimating the trophic state index for cage sites. Sampling for physicochemical parameters and nutrient load was conducted at five cage sites and a control. A replicate of water samples were collected at each site and the sites were selected because they were commercially viable cage fish farms within the Kadimu bay. The GPS of all the sites were recorded with a hand held GPS equipment. Water samples for chlorophyll-a (Chloro-a), total phosphorus (TP) and total nitrogen (TN) were taken to the Laboratory for analysis. The UV Photospectrometer was used for the analyses of TP, TN and Chloro-a. Water transparency at each sampling location were measured with a Secchi disk of approximately 20 cm diameter. The results showed that Kadimu bay had the capacity to accommodate more cages since total-P release from fish waste in to the environment was less than the total-P cage carrying capacity. Estimated Carlson trophic state index (TSI) values suggest light eutrophic state of the cage sites. This suggests a need for a precautionary approach to be adopted for sustainable management of Cage culture in the Kadimu Bay of Lake Victoria. For control and sustainability of fish cage culture within Kadimu bay, it is recommended for fish farmers to monitor physico-chemical parameters of the aquatic environment on a monthly basis, while a competent authority should monitor total-P and total-N on quarterly or annual basis.

**Keywords:** Aquaculture waste, Chlorophyll-a, eutrophication, floating cages, Kadimu Bay, phosphorus, Secchi disk

#### **Résumé**

La production de poisson dans la baie de Kadimu du lac Victoria, au Kenya, par le biais de la culture en cage, a le potentiel d'augmenter la charge de phosphore dans l'écosystème aquatique à travers les déchets d'aliments pour poissons. Cette augmentation des niveaux de phosphore dans l'eau peut entraîner une pollution entraînant une mauvaise qualité de l'eau qui peut être préjudiciable aux pisciculteurs. Cette étude s'est concentrée sur le calcul de la quantité de phosphore que les sites

de cages peuvent accueillir et l'évaluation de l'état de la qualité de l'eau en estimant l'indice d'état trophique des sites de cages. L'échantillonnage des paramètres physicochimiques et de la charge en éléments nutritifs a été effectué sur cinq sites de cages et un témoin. Une réplique d'échantillons d'eau a été prélevée sur chaque site et les sites ont été sélectionnés parce qu'il s'agissait de piscicultures en cage commercialement viables dans la baie de Kadimu. Le GPS de tous les sites a été enregistré avec un équipement GPS portatif. Des échantillons d'eau pour la chlorophylle-a (Chloro-a), le phosphore total (PT) et l'azote total (AT) ont été apportés au Laboratoire pour analyse. Le photospectromètre UV a été utilisé pour les analyses de PT, AT et Chloro-a. La transparence de l'eau à chaque point d'échantillonnage a été mesurée avec un disque de Secchi d'environ 20 cm de diamètre. Les résultats ont montré que la baie de Kadimu avait la capacité d'accueillir plus de cages puisque la libération totale de P des déchets de poisson dans l'environnement était inférieure à la capacité de charge totale des cages. Les valeurs estimées de l'indice d'état trophique (IET) de Carlson suggèrent un état eutrophique léger des sites des cages. Cela suggère la nécessité d'adopter une approche de précaution pour une gestion durable de la culture en cage dans la baie de Kadimu du lac Victoria. Pour le contrôle et la durabilité de la pisciculture en cage dans la baie de Kadimu, il est recommandé aux pisciculteurs de surveiller les paramètres physico-chimiques du milieu aquatique sur une base mensuelle, tandis qu'une autorité compétente devrait surveiller le P total et le N total sur une base trimestrielle ou annuelle.

Mots clés : Déchets d'aquaculture, Chlorophylle-a, eutrophisation, cages flottantes, Kadimu Bay, phosphore, disque de Secchi

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## Introduction

Current population growth and increase in per capita fish consumption will demand water resources to be more efficient in terms of food production on a global scale (Halwarth *et al.*, 2007). The rising demand is pushing fish farm expansion into new dimensions and Cage fish farming is one of the dimensions increasingly being used to enhance fish production especially in Africa (FAO, 2006). Cage fish farming uses ecosystem services for breakdown of organic matter, recycling of nutrient and supply of oxygen, but a certain level of fish biomass may exceed the system capacity to refine nutrients, leading to excessive eutrophication (David *et al.*, 2015). Phosphorus based carrying capacity, from ecosystem point of view aim at attaining resource use sustainability without damage to the ecosystem services of the waters beyond resilience (David *et al.*, 2015). Fishing pressure through cage farming and other gear exert pressure on the ecosystems to the extent that ecological services provided by ecosystems may be compromised (Ross *et al.*, 2013).

Cage fish farming is increasing extensively in African inland aquatic ecosystem and has the ability to close the gap between fish supply and demand deficit and improve other livelihoods benefits such as poverty alleviation, employment opportunities, and contribution to food security and Gross Domestic Product (Musinguzi *et al.*, 2019). However, there is need for measures to direct and control its activities for sustainability of production and ecological services of the waters (Byron *et al.*, 2011). The measures are necessary to avoid user conflict, pollution, disease, among other effects (Musinguzi *et al.*, 2019). Sustainable cage culture production requires periodic monitoring of water quality parameters of water bodies or cage sites for a profitable aquaculture investment (David *et al.*, 2015). Sustainable cage culture production should focus on estimating the quantity of aquaculture production that can be sustained by the environment without dramatic change of ecological processes, ecosystem services, species population and community structure (David *et al.*, 2015).

Biotic constituents of ecological systems are mostly utilized to breakdown the organic components,

recycle nutrients and produce oxygen in cage aquaculture while excess feeds may result into pollution effects and excess phosphorus from feeds would lead to eutrophication effects (David *et al.*, 2015). Mass balance models (Dillon and Rigler, 1975) have been used to determine the optimum feeding regimes in cage aquaculture and hence the carrying capacity of sites (Ross *et al.*, 2013; David *et al.*, 2015). In Lake Victoria, cage aquaculture is rapidly developing (Njiru *et al.*, 2018) but there have not been studies evaluating how cages fish farming affect water quality parameters at sites which is instrumental for sustainable production and environmental conservation. Furthermore, there is no existing study to evaluate the trophic state of cage sites in Kadimu Bay. Hence to address the information gap, this study evaluated phosphorus based carrying capacity for cage sites and compared with phosphorus emitted by fish waste from cages into the environment, examined the trophic state of the cage sites and recorded their potential impacts on fish production and other ecological services. It is hoped that the knowledge acquired in the current study can be used for surveillance and for improving procedural standards as reference points for the control of cage fish farming in the Kadimu Bay and in other similar ecosystems.

## Methods

**Study area.** The Winam Gulf lies at latitude 0° 14'24" S and longitude 34° 34'48"E with a tropical Rain Forest climate characterized with high rainfall year round. January is mostly dry with the highest rainfall in April, annual average precipitation is approximately 1. 388mm (54.6 inches) with average temperature of 22.9° C (World Weather Information Service, 2018). The Gulf is an important enlargement of northeastern Lake Victoria, into western Kenya. It has an inlet connected to the main Lake by the Rusinga channel approximately 3 miles (4.8 km) wide and is partly differentiated from the main body of the Lake by islands. The port of Kisumu, Kenya's third largest city is situated on its northeastern shore with an average width of 25 km (16 miles) and extend for a length of 64 km (40 miles) from Kisumu to the channel. The rivers Kisat, Nyamasaria, Nyando, Sondu-Miriu, Kuja, Awach, Yala and Nzoia drain in the Winam Gulf, bringing in a lot of sediment load (Mosongo *et al.*, 2005). Lake Victoria supports Africa's largest freshwater fishery with the major catch being the invasive Nile Perch, which was introduced in the 1950s. The increasing demand for the Nile Perch has caused a rise in the value of the fishery. The total number of boats by 2004 was 51,712 with a population of 153,066 fishermen. The fishery also brought in auxiliary employment in the form of fish processors, transporters, factory workers and other value chain addition (Geheb, 1997). Kadimu bay (Figure 1) is a shallow fresh water bay in Nyanza province, Kenya. The bay is situated between latitude 0° 5'10" S and longitude 34° 6' 40" E and lies within the tropical monsoon climate with temperatures ranging between 23°C and 24°C (Kotteck, 2006). The depth range of the bay is between 3 m to 12 m and it spans for a distance of 4.3 km (2.7 miles) making it a suitable site for cage fish farming.

Sampling for physico-chemical parameters and nutrient load was conducted at five cage sites, Anyanga, Oele, Ugambe, Utonga, Uwaria and a control site (Figure1). The depth of the sites ranged from 3.048 m to 22.86 m, with an average of 12.95 m. Sampling was done three times a month and for a period of ten months. Three replicates of water samples were collected at each site and the sites were selected because they were commercially viable and had easily accessible cage fish farms within the Kadimu bay. The locations of all the sites were recorded with a hand-held GPS. Water samples for chlorophyll-a, total phosphorus (TP) and total nitrogen (TN) were collected monthly for a period of ten months from January, 2021 to October, 2021. During each sampling occasion, pH, Salinity, dissolved oxygen (DO), total dissolved solids (TDS), oxygen reduction potential (ORP), Conductivity, turbidity and temperature were measured in situ with a multiparameter water quality probe (YSI Pro Plus multiparameter). Water transparency at each sampling location was measured with a Secchi disk

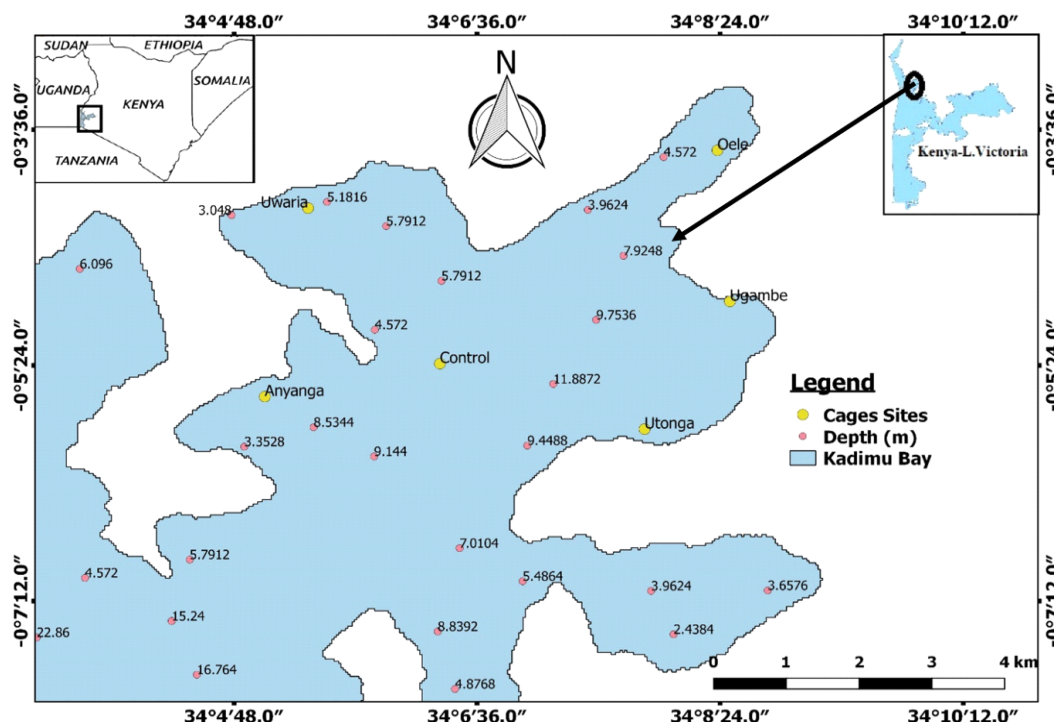


**Figure 1.** Map of Kadimu Bay (Lake Victoria, Kenya) showing sampling sites (Anyanga, Uwaria, Oele, Ugambe, Utonga and Control) Source: KMFRI, 2020)

of approximately 20cm diameter. The measured Secchi disk depth, the depth at which the Secchi disk goes out of vision were used to estimate the euphotic depth (zeu), the depth at which available radiation for primary production is 1% of the surface waters at each sampling location (Bartram and Balance, 1996).

The bottles used for collecting water samples were labelled, filled with samples collected randomly from stations at sites and placed in a cooler box at a temperature of approximately 4°C and transported to the laboratory. In the laboratory, water samples for Chlorophyll-a analysis were filtered with GFS filter papers before 24 hrs lapsed after collection. The filters were labelled after filtration and stored in a refrigerator at -20°C.

**Analytical procedures.** The UV Photo spectrometer was used for the analysis of TP, TN, nitrites, nitrates, ammonium, soluble reactive phosphorus (SRP), Chlorophyll-a and silicates following the methods of APHA (2005). The partitioning of Chlorophyll-a was done by the sonication method (APHA, 2005) and concentration measured by the Lorenzen equation (APHA, 2005) through the application of absorbance reading from the UV Spectrophotometer. The molybdenum blue procedure (APHA, 2005) was employed to estimate the soluble reactive phosphorus (SRP), while the dichloroisocyanurate-salicylate procedure (APHA, 2005) was used to estimate the ammonium ion concentration. The cadmium reduction procedure and the azo-dye complex method (APHA, 2005) were used to estimate the nitrates ( $\text{NO}_3^-$ ) and nitrites ( $\text{NO}_2^-$ ) concentration, respectively. The ascorbic reduction technique and the diazotization procedure were used to calculate the total phosphorus (TP) and total nitrogen (TN) concentrations, using water that was not filtered (APHA, 2005). The volumetric analysis technique was used to estimate total alkalinity, using tetraoxosulphate six acid ( $\text{H}_2\text{SO}_4$ ), phenolphthalein and methyl orange as indicators (APHA, 2005). The total suspended solids (TSS) and particulate organic matter (POM) were estimated by filtering a known volume of sample water using GFC filters. The GFC filter was weighed to obtain the initial weight and then used to filter a known volume of sample water and

weighed to obtain the final weight, followed by oven drying the filter to obtain the ashed weight. The TSS was estimated as final weight-initial weight/volume of filtered water\* 106, while the POM was estimated as final weight-ashed weight/volume of filtered water\* 106 (APHA, 2005).

**Data analysis.** The water quality parameters estimated at the various cage locations were compared to the water quality parameter standards set for fish growth by KMFRI. The one –way ANOVA was done to understand the effect of time (months) on water quality parameter for fish growth. The Carlson's trophic index was used to evaluate the trophic state of each cage site. The trophic state of each cage site was estimated using knowledge of the constrained nutrient requirements (total phosphorus), chlorophyll-a as a sign of primary productivity and water transparency as Secchi disk readings. The nutrient availability was estimated by accounting for the readily bio functional abiotic nutrients, total nitrogen, total phosphorus concentrations. The required limits for estimation of cage site trophic state was taken from the Organization for Economic Cooperation and Deve total phosphorus, chlorophyll-a, Secchi disk readings (Carlson and Simpson, 1996). The trophic state of each cage site (TSI) on the basis of specific parameters with a range of 0-100 was used in this study. The estimated TSI values quantified the trophic state of each cage site. The TSI was divided into five categories with 0-20 for hyper oligotrophic, 20-40 for oligotrophic, 40-60 for mesotrophic, 60-80 for eutrophic and 80-100 for hypereutrophic (Likens *et al.*, 1977).

The TSI value quantify the water quality state for fish rearing at cage sites, by estimating the productivity of the water based on algae biomass. The biomass of algae was calculated from the concentration of Chlorophyll-a, Secchi disk depth or water transparency and total phosphorus. The trophic state (TS) grouping using the TSI values is shown in Table1 (Carlson, 1977).

**Table 1. Carlson's trophic state classification**

| Carlson's trophic state index | Lake trophic state index | Attributes                                                                         |
|-------------------------------|--------------------------|------------------------------------------------------------------------------------|
| <30                           | ultra-oligotrophic       | Clear water, oxygen in hypolimnion throughout the annual cycle                     |
| 30-40                         | Oligotrophic             | Oligotrophy, but some shallow lakes may become anoxic during dry season            |
| 40-50                         | Mesotrophic              | Water moderately clear, but increasing occurrence of anoxia during dry season      |
| 50-60                         | Light eutrophic          | Decrease transparency, warm water fisheries only                                   |
| 60-70                         | Medium eutrophic         | Possibility of algae blooms during dry season tending towards hypereutrophic state |
| 70-80                         | Heavy eutrophic          | Decreasing macrophyte species, occurrence of alga scum, and loss of cultured fish  |
| >80                           | Hypereutrophic           | Increasing alga blooms, eutrophication of the water is evident                     |

Adapted from AACL Bioflux, 2019 volume 12 issue 5.<http://www.bioflux.com.ro/aac>

$$TSI = 60 - 14.41 \ln(SD)$$

$$TSI(Chloro - a) = 30.6 + 9.81 \ln(Chloro - a)$$

$$TSI(TP) = 4.15 + 14.42 \ln(TP)$$

$$Site\ TSI = \frac{TSI(SD) + TSI(Chloro - a) + TSI(TP)}{3}$$

Where (SD) is Secchi disk depth or water transparency in (m); (Chloro-a) is chlorophyll-a concentration in  $\mu\text{gL}^{-1}$ ; (TP) is total phosphorus concentration in  $\mu\text{gL}^{-1}$ .

**Calculation of phosphorus-based carrying capacity method.** The parameters for the estimation of phosphorus-based carrying capacity for the sites is shown in Table 2. The surface area and water volume at each site were estimated by the planimetry method (KMFRI, 2020). The average depth at sites were recorded using the depth finder device. The Cage Site Carrying Capacity of total-phosphorus estimated from each cage site is shown in Table 2. The water debit average for this study was drawn from Literature (Mahmudi et al., 2019). Palatsu (2003) quantify the proportion of total-P dispersed permanently in sediments as 0.5 which lead to the estimation of total-P in sediments due to floating net cages.

**Table 2. Variable used in deriving Phosphorous-based carrying capacity (Mahmudi et al., 2019)**

| Variable                                                         | Symbol            | Formula                                             | Unit                               |
|------------------------------------------------------------------|-------------------|-----------------------------------------------------|------------------------------------|
| volume                                                           | V                 | -                                                   | $\text{m}^3$                       |
| Surface Area                                                     | A                 | -                                                   | $\text{m}^2$                       |
| Average Depth                                                    | Z                 | $Z=V/A$                                             | m                                  |
| Water debit average                                              | Q                 | -                                                   | $\text{m}^3\text{year}^{-1}$       |
| Flushing Coefficient                                             | p                 | $P=Q/V$                                             | $\text{year}^{-1}$                 |
| Feed conversion rate                                             | FCR               | Total feed given/Total fish production              |                                    |
| Total P allocation load                                          | [P]               | $\Delta[P] = [P]_i - [P]_c$                         | $\text{mgm}^{-3}$                  |
| Standard total P for fish culture                                | $[P]_i$           | -                                                   | $\text{mgm}^{-3}$                  |
| P measured at each cage site                                     | $[P]_c$           | -                                                   | $\text{mgm}^{-3}$                  |
| Proportion of total-p left in sediments                          | R                 | $R = (1 + 0.747p^{0.507})^{-1}$                     | $\text{g m}^{-3}$                  |
| Proportion of total-p left in sediments due to floating net cage | $R_{\text{fish}}$ | $R_{\text{fish}} = X + (1-X)R$                      | $\text{g m}^{-3}$                  |
| Proportion of total-p dispersed permanently in sediments         | X                 | -                                                   | -                                  |
| Cage site carrying capacity on total-P from cages                | $L_{\text{fish}}$ | $L_{\text{fish}} = \Delta[P]Zp/1 - R_{\text{fish}}$ | $\text{g m}^{-2} \text{year}^{-1}$ |

Also, the equation to estimate the quantity of total-P discharged by fish aquaculture waste proportional to fish production was as illustrated below:

$$Plp = FCR * (P_{feed} - P_{fish})$$

Where:

Plp = total-P release by fish cage in (kg ton<sup>-1</sup>)

FCR = Feed conversion rate

P<sub>feed</sub> = total-P in feeds in (kg ton<sup>-1</sup>)

P<sub>fish</sub> = total-P eaten by fish in (kg ton<sup>-1</sup>)

## Results

**Characteristics of Cage Sites:** Table 3 shows the characteristics of the various cage locations sampled in the Kadimu bay of Lake Victoria, Kenya.

**Table 3. Characteristics of cage location**

| Site    | Surface Area(m <sup>2</sup> ) | FCR | Volume (m <sup>3</sup> ) | Depth (m) |
|---------|-------------------------------|-----|--------------------------|-----------|
| Anyanga | 617,509m <sup>2</sup>         | 1.4 | 4,328,738.09             | 7.01      |
| Oele    | 22,458m <sup>2</sup>          | 1.4 | 95,895.66                | 4.27      |
| Ugambe  | 9,250m <sup>2</sup>           | 1.4 | 81,770.00                | 8.84      |
| Utonga  | 29,122m <sup>2</sup>          | 1.4 | 310,731.74               | 10.67     |
| Uwaria  | 137,022m <sup>2</sup>         | 1.4 | 644,003.4                | 4.7       |
| Control | -                             | -   | -                        | -         |

**Phosphorous-based carrying capacity.** The occurrence of floating cages for fish production in Kadimu bay has the potential to increase the phosphorus concentration in the lake. However, some of the key factors that provide lake ability to consume the phosphorus load are volume (V) and surface area (A). Orina *et al.* (2018) reported the occurrence of 2,160 cages at the Anyanga cage site, 170 cages at Ugambe, 20 cages at Oele, 16 cages at Uwaria and 9 cages at Utonga with annual production of approximately 1000 kg. The content of total-P in fish feed used by farmers was estimated at 21.75 kg ton<sup>-1</sup>, while the content of total-P in fish biomass was estimated at 3.5 kg ton<sup>-1</sup> at the Kenya Marine and Fisheries Research Institute (KMFRI) Laboratory Kisumu branch. Total-P release by fish waste in kg ton<sup>-1</sup> (PLP) was estimated as 25.55 kg ton<sup>-1</sup>. The results from this study are shown in Tables 4-8.

**Table 4. Cage Site Phosphorous-based carrying capacity calculations**

| Site    | Surface Area (m <sup>2</sup> ) | FCR | Volume (m <sup>3</sup> ) | Depth (m) | Total P allocation load (mg m <sup>-3</sup> ) | Flushing Coefficient (year <sup>-1</sup> ) | Proportion of total-p left in sediments (g m <sup>-3</sup> ) | Proportion of total-p left in sediments due to floating net cage (g m <sup>-3</sup> ) | Cage site carrying capacity on total-P from cages (kg year <sup>-1</sup> ) |
|---------|--------------------------------|-----|--------------------------|-----------|-----------------------------------------------|--------------------------------------------|--------------------------------------------------------------|---------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Anyanga | 617,509                        | 1.4 | 4,328,738.09             | 7.01      | 113.44                                        | 0.72                                       | 0.613                                                        | 0.81                                                                                  | 1,860,828,817.00                                                           |
| Oele    | 22,458                         | 1.4 | 95,895.66                | 4.27      | 103.39                                        | 0.74                                       | 0.609                                                        | 0.8                                                                                   | 36, 684,213.50                                                             |
| Ugambe  | 9,250                          | 1.4 | 81,770.00                | 8.84      | 102.62                                        | 0.74                                       | 0.609                                                        | 0.8                                                                                   | 31, 047,578.40                                                             |
| Utonga  | 29,122                         | 1.4 | 310,731.74               | 10.67     | 117.07                                        | 0.72                                       | 0.613                                                        | 0.81                                                                                  | 137, 851,066.60                                                            |
| Uwaria  | 137,022                        | 1.4 | 644,00 3.40              | 4.7       | 44.84                                         | 0.67                                       | 0.621                                                        | 0.81                                                                                  | 101, 829,817.60                                                            |
| Control | -                              | -   | -                        | -         |                                               |                                            |                                                              |                                                                                       |                                                                            |

**Table 5. Phosphorus load discharge in the environment from Cages**

| Site    | FCR | P <sub>feed</sub> (kg ton <sup>-1</sup> ) | P <sub>fish</sub> (kg ton <sup>-1</sup> ) | PLp(kg ton <sup>-1</sup> ) | Number of Cages | Annual production per cage (kg) | P-discharge in Environment (kg year <sup>-1</sup> ) |
|---------|-----|-------------------------------------------|-------------------------------------------|----------------------------|-----------------|---------------------------------|-----------------------------------------------------|
| Anyanga | 1.4 | 21.75                                     | 3.5                                       | 25.55                      | 2160            | 1000                            | 55188000                                            |
| Oele    | 1.4 | 21.75                                     | 3.5                                       | 25.55                      | 20              | 1000                            | 511000                                              |
| Ugambe  | 1.4 | 21.75                                     | 3.5                                       | 25.55                      | 170             | 1000                            | 4343500                                             |
| Utonga  | 1.4 | 21.75                                     | 3.5                                       | 25.55                      | 9               | 1000                            | 229950                                              |
| Uwaria  | 1.4 | 21.75                                     | 3.5                                       | 25.55                      | 16              | 1000                            | 408800                                              |

**Table 6. Cage site carrying capacity of total-P and total-P discharge in the environment from cages**

| Site    | Cage site carrying capacity of total-P (kg year <sup>-1</sup> ) | p-discharge in Environment (kg year <sup>-1</sup> ) |
|---------|-----------------------------------------------------------------|-----------------------------------------------------|
| Anyanga | 1, 860, 828,817.00                                              | 55188000                                            |
| Oele    | 36, 684,213.50                                                  | 511000                                              |
| Ugambe  | 31, 047,578.40                                                  | 4343500                                             |
| Utonga  | 137, 851,066.60                                                 | 229950                                              |
| Uwaria  | 101, 829,817.60                                                 | 408800                                              |

**Trophic state estimation of cage sites:** The trophic state index (TSI) was estimated using the quantity of Chlorophyll-a (Chloro-a) concentration, total phosphorus (TP) and water transparency or Secchi disk (SD) reading at cage sites. It is assumed that (Carlson, 1977), these parameters are closely related to each other. The calculated trophic state index values for Chloro-a, TP and SD, TP, Chloro-a and CTSI are shown in Table 8.

**Table 7. Calculated trophic state index values for fish cage site in the Kadimu bay, Lake Victoria, Kenya from January, 2021 to October, 2021**

| Months  | TSI (SD) m | TSI (TP) $\mu\text{g}^{-1}$ | TSI (Chloro-a) $\mu\text{g}^{-1}$ | CTSI $\mu\text{g}^{-1}$ | Eutrophic status |
|---------|------------|-----------------------------|-----------------------------------|-------------------------|------------------|
| Jan     | 54.18±0.78 | 73.73±6.76                  | 42.11±11.74                       | 56.67±5.92              | Light eutrophic  |
| Feb     | 52.97±1.08 | 67.81±2.38                  | 42.92±1.42                        | 54.59±0.42              | Light eutrophic  |
| Mar     | 53.78±1.05 | 73.63±6.02                  | 46.46±7.84                        | 57.96±4.79              | Light eutrophic  |
| Apr     | 52.97±1.08 | 68.2±0.82                   | 36.98±1.12                        | 52.72±0.64              | Light eutrophic  |
| MaY     | 53.04±2.23 | 68.57±1.09                  | 39.1±5.59                         | 53.56±2.16              | Light eutrophic  |
| Jun     | 53.11±2.29 | 68.94±1.36                  | 41.22±10.05                       | 54.43±3.68              | Light eutrophic  |
| Jul     | 53.3±1.47  | 69.92±0.72                  | 35.72±3.55                        | 52.98±1.08              | Light eutrophic  |
| Aug     | 53.25±0.73 | 68.75±6.72                  | 46.35±2.49                        | 55.93±0.76              | Light eutrophic  |
| Sep     | 53.89±1.15 | 67.64±1.24                  | 42.42±2.39                        | 59.65±0.82              | Light eutrophic  |
| Oct     | 54.18±0.78 | 67.57±0.63                  | 41.47±0.56                        | 54.41±0.26              | Light eutrophic  |
| P-Value | 0.897      | 0.42                        | 0.771                             | 0.801                   |                  |
| F-Value | 0.44       | 1.01                        | 0.61                              | 0.57                    |                  |

The Carlson trophic state index suggest a light eutrophic state of the cage sites in the Kadimu bay throughout the study period with no significance difference at  $P < 0.05$ . However, the highest of the three indicators of all sites comes from total phosphorus (TSI-TP).

**Table 8. Calculated trophic state index values for fish cage site in the Kadimu bay, Lake Victoria, Kenya**

| SITE    | TSI (SD) m       | TSI (TP) $\mu\text{g}^{-1}$ | TSI(CHLORO-A) $\mu\text{g}^{-1}$ | CTSI $\mu\text{g}^{-1}$ | Eutrophic state |
|---------|------------------|-----------------------------|----------------------------------|-------------------------|-----------------|
| Anyanga | 53.44 $\pm$ 1.08 | 68.46 $\pm$ 0.394           | 39.37 $\pm$ 4.86                 | 53.76 $\pm$ 11.87       | Light eutrophic |
| Uwaria  | 54.02 $\pm$ 1.29 | 73.38 $\pm$ 7.53            | 52.06 $\pm$ 6.61                 | 59.82 $\pm$ 9.62        | Light eutrophic |
| Oele    | 53.63 $\pm$ 1.58 | 69.43 $\pm$ 1.43            | 39.13 $\pm$ 4.93                 | 54.06 $\pm$ 12.37       | Light eutrophic |
| Ugambe  | 52.58 $\pm$ 0.71 | 69.42 $\pm$ 1.54            | 40.19 $\pm$ 3.32                 | 54.06 $\pm$ 11.97       | Light eutrophic |
| Utonga  | 53.50 $\pm$ 1.14 | 68.12 $\pm$ 1.79            | 40.08 $\pm$ 3.04                 | 53.9 $\pm$ 11.54        | Light eutrophic |
| Control | 53.77 $\pm$ 1.51 | 67.69 $\pm$ 1.22            | 38.25 $\pm$ 4.90                 | 53.23 $\pm$ 12.02       | Light eutrophic |

The Carlson trophic state index suggest a light eutrophic state of the cage sites in the Kadimu bay, Lake Victoria, Kenya. There is no difference in eutrophic state of cage sites and the control, the Carlson classification suggest both the cage sites and control being light eutrophic.

### Discussions

Results of the study showed that, the total-P release by fish waste in the environment was less than the total-p cage site carrying capacity, meaning the cage sites had not reached their optimum carrying capacity. Hence addition of new cages at the sites could still be encouraged with a precautionary approach. Mahmuti *et al.* (2019) reported that reducing phosphorus discharge from fish cages prevent eutrophication of Lakes. Thus maintaining Phosphorus discharge within safe limits from fish cages is a good approach toward sustainability of cage fish farming. However, maintenance of Phosphorus discharge from fish cage can only be achieved through timely feed application to avoid uneaten feed contributing to Phosphorus discharge. According to Shoji (2009) uneaten feed are the ultimate source of pollutants in cage fish farming, suggesting the significance of feed utilization and controlling feed ingredients based on nutrient composition.

For a sustainable development of cage fish culture, it is necessary to keep feed application and pollution load below site carrying capacity based on phosphorus load. The difference in total-P discharge by fish cage in the environment and total-p cage site carrying capacity can be related to the number of cages at each site. Thus, Anyanga recorded large values because of its large surface area as well as the higher number of cages. Even though the Ugambe cage fish site had the smallest surface area, the total-P discharge by fish cage in the environment was relatively high compared to in Oele cage fish site because of the high number of cages it contain. Therefore, the number of cages per site is critical for the discharge of total-P from fish cages in the environment. While the number of cages per site is important for the release of total-p from fish cage in the environment, the site surface area is a significant factor that determined the total-P cage site carrying capacity. Thus, there is relationship between the number of cages and total-P discharge from fish cages into the environment as well as cage site surface area and total-P cage site carrying capacity. According to Mahmuti *et al.* (2019) light eutrophic to medium eutrophic is not a threat to eutrophication. Hence, the calculated TSI values suggesting light eutrophication of cage sites implies eutrophication was not a threat to fish cage aquaculture in the Kadimu bay of Lake Victoria, Kenya. Nevertheless, the increasing contribution of TSI-TP to the light eutrophic State

of cage sites in the Kadimu bay (Mahmuti *et al.*, 2019) suggests that the other two indicators, TSI-Chlorophyll-a and TSI-SD are generally less affected by increasing phosphorus concentration in the water. Results of Carlson's trophic state index values for fish cage site (Anyanga, Uwaria, Oele, Ugambe, Utonga and Control) all suggest a light eutrophic state, meaning eutrophication is not a threat to cage fish farming in the Kadimu bay, Lake Victoria, Kenya.

## Conclusion

All the cage sites in the Kadimu bay of Lake Victoria, Kenya have the potential to accommodate more cages for sustainable fish production. However, a precautionary approach need be adopted for sustainable management of Cage culture in the Kadimu Bay of Lake Victoria Kenya. Thus, for control and sustainability of fish cage culture within Kadimu bay, it is recommended for fish farmers to monitor physico-chemical parameters of the water on monthly basis, while a competent authority should monitor total-P and total-N on quarterly or annual basis.

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