Exploring the potential of small water bodies as an integrative management tool for fisheries production

***Christopher Mulanda Aura[a], Ruth Lewo Mwarabu[b], Chrisphine S. Nyamweya[a], Horace Owiti[a], Collins Onyango Ongore[a,c], Fredrick Guya[a], Safina Musa[d], Monica Owili[a], Sammy Macaria[e], Richard Oginga Abila[f], Andrew Lewis Marriott[g].**

[a]*Kenya Marine and Fisheries Research Institute P.O. Box 1881-40100, Kisumu, Kenya.*

[b]*Western Region Coordination Office, Aquaculture Business Development Programme (ABDP), Kisumu, Kenya.*

[c]*School of Biology, St. Andrews University, KY16 9ST. St. Andrews, Fife, Scotland.*

[d]*Kegati Aquaculture Research Center, Kenya Marine and Fisheries Research Institute, P.O. Box 3259-40200, Kisii, Kenya.*

[e]*National Programme Coordination Office, Aquaculture Business Development Programme (ABDP), P.O. Box 904-10100, Nyeri, Kenya.*

[f]*International Fund for Agricultural Development of the UN, Via Paolo di Dono, 44 00142, Rome, Italy.*

[g]*British Geological Survey, Centre for Environmental Geochemistry, NG12 5GG. Nottingham. England.*

*Corresponding author: Email: auramulanda@yahoo.com and/or aura.mulanda@gmail.com

Tel.: +254711233774.

Funding

We wish to thank the International Fund for Agricultural Development (IFAD) and The Government of Kenya through the Aquaculture Business Development Programme (ABDP) for funding the expeditions. Kenya Marine and Fisheries Research Institute provided logistics and facilitated the research activities.

Acknowledgements

We also wish to thank all the KMFRI, Kisumu, Kenya Fisheries Service - KeFS (Ms. Christine Etiegni, Mr. Stanley Tonui and Alice Hamisi), County Programme Coordinators (CPCs) and Fisheries Directors (from Nyeri, Kirinyaga, Meru, Tharaka Nithi, Embu, Kiambu, Kajiado, Machakos, Homa Bay, Migori, Kisii, Kisumu, Busia, Siaya and Kakamega), County administrative officers and dam management units for their valuable contributions.

Exploring the potential of small water bodies as an integrative management tool for fisheries production

Abstract

Understanding the potential of small water bodies (SWBs) will open greater opportunities in investment towards increased food and energy production. This study established the carrying capacity for fisheries development in SWBs in 8 counties in Central and 7 counties in Western Kenya. The carrying capacity of SWBs was calculated using socio-economic index (SI), trophic status index (TSI) and survey data from 74 SWBs. The central region had a potential of 72,447 metric tonnes (mt) in 37 sampled SWBs, while that of the western region had only 447 mt in a similar number of sampled sites. The higher potential in the central region is attributed to the relatively larger hydro-electric dams located in the area. To boost production in SWBs with low carrying capacities, restocking with native endemic fish species which require limited, or no supplementary feeding, is recommended. However, in SWBs where depths reach 3.0 m or more, cage culture reared fish coupled with a strong local community association would be recommended to provide both food security and assisted farm inputs from nearby hatcheries. The indexing holistic approach herein can form an integrative management tool for fisheries production in order to enhance global blue growth.

Keywords: Carrying capacity; ecology; socio-economic; integration; suitability; blue growth.

Introduction

Water resources such as small water bodies (SWBs) are vital to support biodiversity and provide socio-economic benefits to local communities (Hajkowkz, 2006). SWBs often represent examples of intact freshwater resources, such as dams, which are free from anthropogenic inputs, in that they remain unpolluted, and they are often a refuge for species which have all but disappeared from larger, more degraded and polluted water bodies (EPA, 2005; EEA ETC/ICM, 2009). SWBs and associated drainage ditches are essential elements of the agricultural landscape (Downing and Duarte, 2009). As ecosystems, they serve many important biocenotic, hydrlogical and economic functions (Fleischer et al., 1996). With the exclusion of ponds and rivers, SWBs are defined as standing waters that have been created as a result of erected barriers to stop or restrict the flow of water or underground streams (Haycock et al., 1996). In terms of their size, SWBs are usually greater than 1.0 ha, but are less than 100 ha (EPA, 2005; EEA ETC/ICM, 2009). SWBs differ in terms of their origin, with some formed naturally in dry depressions as a result of an accumulation of water from local surface runoff (Haycock et al., 1996), and being similar to that of morainal lakes. Artificially formed small water bodies of anthropogenic origin are mainly formed from peat borrow pits filled with water and are typically of regular form. The latter SWBs are frequently determined by the presence of shallow groundwater (European Commission, 2008).

In most developing countries, SWBs remain among the least investigated part of the water environment and are largely excluded from fisheries management planning (European Commission, 2008; Fisheries Annual Statistics Bulletin, 2016). For example, while there are at least 1000 dams in Kenya, many of which are stocked with fish, national statistics capture only three main small water bodies in their studies, i.e. Jipe, Tana and Turkwel (Fisheries Annual Statistics Bulletin, 2016; Aura et al., 2020b). Understanding of these resources has now changed, with most governments and private sectors focusing on fisheries and aquaculture as key drivers of the blue economy for sustainability and food security. It is however imperative that the promotion of sustainable fisheries development does not degrade the environment and takes into account all sectors and resource users involved with the inclusion of the SWBs (EEA ETC/ICM, 2009).

While there can be found several dams and small reservoirs in most developing nations and mainly in Africa,there is the potential to increase fisheries production using SWBs at local levels to bridge the fish consumption deficit per capita of 10 kg / person / year nationally (FAO, 2019). Owing to their relatively small size, and being either state-owned or communal property, these SWBs fisheries could be easily managed by local governments or dependent communities to enhance their productivity (Bolgrien et al., 2009). With the observed reduction in fisheries contribution to most Gross Domestic Products (GDPs) due to declines in capture fisheries (Aura et al., 2020b), the utilisation of SWBs (dams, pans and reservoirs) for fisheries production could significantly increase productivity, fisheries yield, and therefore reduce food insecurity and malnutrition (FAO, 2019). For example, in Kenya, the lower fish consumption per capita has been cited as a major contributor to high malnutrition prevalence in most parts of rural Kenya (Ogello and Munguti, 2016). In the fish production debate, fisheries cultivation has been shown to have the potential to bridge the fish supply gap and enhance national fish consumption per capita (Musa et al., 2014; FAO, 2019).

With proper management and husbandary, SWBs can promote community-aquaculture initiatives to increase fish production and availability in rural areas (Gibbs, 2004). The SWBs can also be used for rural irrigation to promote the production of other food sources as an additional dietary supplement. To this end, SWBs appear to be a neglected “hot spot” for rural fisheries production, hence the need for effective management strategies. Such strategies on effective management of SWBs is an initiative that resonates with the Sustainable Development Goals i.e. SDG1 – no poverty; SDG2 - zero hunger, SDG3 - good health and well-being; SDG 13 – climate action and SDG 14 - life below water (Government of Kenya Report, 2007). The strategies also support the Africa's agenda 2063 on rural food production and other national pillars targeting food and nutrition security (ICES, 2005; FAO, 2019).

Given the two most common fisheries innovations for SWBs compromise of stocking and cage culture, fish stocking is probably the oldest and most successful intervention from a fishery development perspective, when used in the right manner and in the right location (Aura et al., 2013). Cage culture is less preferable as an alternative innovative technology due to the relative shallowness of water depths observed in SWBs which can lead to floatation challenges for cages during lean seasons and more importantly problems associated with enhanced eutrophication (Aura et al., 2018; Njiru et al., 2019). However, proper management stocking of juvenile fish can maintain fish populations or supplement those produced naturally, thereby increasing fish abundance and fisheries yields (Musinguzi et al., 2019). However, care must be taken with regards fisheries stocking, in that some instances, these introductions could be counter-productive or may exhibiting undesirable impacts such as disruption of native fish communities, loss of wild strains and reduced genetic diversity (Read and Fernandes, 2003; Newell, 2004; Aura et al., 2013).

Nonetheless, before undertaking the stocking of SWBs, there are several precautionary approaches that need to be carefully considered in order to mitigate against adverse impacts on the environment, biota and livelihoods of riparian communities (Souchu et al., 2001). The assessment of socio-ecologically sustainable fisheries production in SWBs poses a major challenge, given the range of issues that must be taken into account. They include the interactions betweennatural and social components, and the coupling between the small water body basin and the watershed (Inglis et al., 2000; ICES 2005; Whitall et al., 2007). Along with biodiversity loss, environmental pollution, and resource exhaustion induced by rapid economic development and population growth, sustainable development concerns have spawned the concept of carrying capacity (Arrow et al., 1995). Policy recommendations are being made to encourage nations to produce fish species through cultivation as an environmentally sound activity (Gibbs, 2004). If we are to exploit a small water body, the concept of carrying capacity has to be prioritised and addressed (Raillard and Ménesguen, 1994).

According to a report by GESAMP (1986), carrying capacity refers to the ability of the environment to accommodate a particular activity or rate of activity without unacceptable impact. Several authors have developed various carrying capacities on different activities. For example, ecological carrying capacity (Monte-Luna et al., 2004), environmental carrying capacity (Liu and Borthwick, 2011), land carrying capacity (Cheng et al., 2016), agricultural carrying capacity (Peters et al., 2007), tourism carrying capacity (Bera et al., 2015), and mineral carrying capacity (Wang et al., 2016).

Sustainable carrying capacity for fisheries production has four components, categorised according to physical, production, ecological and social aspects (Inglis et al., 2000; McKindsey et al., 2006). These four components can be modulated by scaling, usually considered to be either system-scale (i.e., small water body), or local scale (invested small water body through restocking to co-create a farm). Furthermore, socio-economics as a component might be analysed in terms of resource use classification (system-scale), whereas farm siting might draw on space availability for competing uses (physical), food availability (production), and local biodiversity concerns (ecological) (Inglis et al., 2000; McKindsey et al., 2006). However, there is limited information addressing the carrying capacity of SWBs before fisheries production at a local, regional and global level. Yet, it is important to assess the carrying capacity of an area prior to the establishment of any form of cultivation, to ensure an adequate food supply for the anticipated production and to avoid or mitigate any ecological impacts (Gngery et al., 2001; Nunes et al., 2003).

The current paper undertook the estimation of carrying capacity for SWBs, with specific reference to inland systems. This is because, within an ecosystem-based management approach, carrying capacity (expressed in metric tonnes, mt) has been identified as the key consideration which helps to set the upper limits of production given the environmental limits and social acceptability (Cross, 2013). Notably, this preliminary study will be used to estimate the carrying capacity potential of SWBs with specific reference to 15 counties found in the Kenyan inland systems and used as a decision-support-tool for investment in fisheries production. This study takes a first step towards providing the evidence base that is needed to support sustainable utilization of SWBs in the Kenyan inland systems by addressing the following research questions:

i. Where is high fish production potential using ecological and socio-economic factors that affect fisheries management?
ii. What is the type of fisheries development to be undertaken is specific SWBs?
iii. What are the possible strategies to boost blue economic investment in SWBs?

Materials and Methods

Study area

This study was conducted in eight counties in the central eco-region of Nyeri, Kirinyaga, Meru, Tharaka Nithi, Embu, Kiambu, Kajiado, and Machakos) and seven counties in western eco-region of Migori, Kisii, Homabay, Kisumu, Siaya, Busia, and Kakamega in Kenya (Figure 1). The two regions are major multifunctional ecosystms with an interesting connection between conflict and food security (Aura et al., 2017). The target counties were those with high concentrations of aquaculture activity, high production, existing sectoral infrastructure (processing, marketing and research), adequate water resources and marketing potential (Munguti et al., 2014; ABDP Aquaculture Blue Book, 2021). They contain the highest number of SWBs in the country, however a recent survey found both regions to be 65 - 79% food insecure with an incidence of poverty at 62 - 71% (Government of Kenya Report, 2007). Furthermore, both regions comprise several areas of rivers, forests, woodland and grassland which are minor centers for species endemism (IUCN, 2012).

Determination of the potential of small water bodies

Figure 2 shows a summarized procedure towards the development of carrying capacities of SWBs. The methodology was divided into the establishment of socio-economic characteristics, selected water quality and SWB's morphology parameters, existing fisheries and the calculation and validation of the estimated carrying capacities.

Socio-economic characteristics

A multistage sampling approach was adopted in the socio-economics survey entailing either an inclusion and/or exclusion criteria within clusters and elements of the sampling frame to accord representative samples (Sedgwick, 2015). Sampling was based on the features of the SWBs for which a benchmark for selection was set. A sample survey was preferred to a complete assessment of all the SWBs within the target counties, due to financial constraints, logistics, time and quality benefits. The selection criteria took into account sub-county representation, dam acreage (preferably $\geq$ 5 acres), permanence of the water source and ownership status (mostly communal or government owned) to exclude or include dams in the assessment. Various data collection methods and visualizations were adopted to capture socioeconomics data as summarised in table 1.

Observations on the general environmental conditions of the small water body catchment including the land use patterns, substrate types, basin vegetation cover and the climatic elements, were recorded immediately on arrival at the site. The format for the questionnaire survey was built from Aura et al. (2021) community index approach, but with modifications to collect 5-Likert point perceptions on water usage, resource use conflicts, gender and group dynamics, climate risks, ancillary services, social acceptability and investment scale. Coding of the data was done to allow for thematic analyses that involved identification of patterned meaning in the dataset (Aura et al., 2021).

Water quality and small water body parameters

Assessment of water characteristics followed published standard methods for aquatic environmental studies (APHA, 2000). Portable water physico-chemical electronic sensor-based probes were used to take measurements at every SWB's sampling site in triplicate.

i) Physico-chemical parameters

The main physical and chemical parameters measured were: column depth (m), temperature (°C), dissolved oxygen (D.O. mg L^{-1}), and pH. Water transparency measured as Secchi depth (photic depth) was undertaken using a standard Secchi disk of 20 cm diameter.

Optimal levels of nutrients (nitrogen and phosphorus) are important for autotroph productivity that forms the primary source of energy for the heterotroph predators (Aura et al., 2020). Elevated or reduced nutrient levels would lead to a shift in habitat characteristics with consequential impact on biotic health, structure, abundance and overall change to ecological processes (Masese et al., 2013). The shifts from optimal levels will ultimately result in reduced fish productivity in the water body (Aura et al., 2020b). Therefore the present study also investigated the levels of ammonium-NH_4^+-N and total nitrogen - TN) and total phosphorus (TP) (Kundu et al., 2017). Three sites were identified and sampled where possible, two at the littoral areas and one at the centre of the small water body. The samples were then composited to make one sample. Water samples were collected using a Van Dorn water sampler at the surface. The water samples for soluble nutrient fractions were then filtered and stored in polyethylene bottles under refrigeration at about 4°C for further laboratory analyses. Samples for TN and TP were refrigerated without filtration (APHA, 2000).

Chlorophyll-a as a measure of levels of primary production was also measured, by filtering with GF/C filters securely wrapped in aluminium foil before refrigeration ≈4 °C. Samples were then transported to the laboratory and analysed according to methods adopted from APHA (2000).

ii) Total and fecal coliforms

Microbiology analysis for total and faecal coliforms was undertaken according to methods described in APHA (2000). Water samples were collected and analysed in the field using a portable incubator test kit Wagtech Potalab +(M). The Membrane Filtration method was used to determine the total coliforms and faecal coliforms at 37°C and 44°C, respectively. Total and faecal coliforms were detected and quantified using selective and differential culture media. Lauryl Sulphate Broth was used for cultivation of the organisms, where three composite samples were analysed for each SWB. Sample volumes depended on the water turbidity of the sampled dam.

iii) Phytoplankton

Water samples were taken using a horizontal 2.2 L Van Dorn sampler from subsurface depth of about 0.5 m. A portion of the sample (25 ml) was preserved in acidic Lugol's solution. Utermöhl sedimentation chamber was used to process the samples ahead of microscopic examination.

Phytoplankton cells were identified to species level where possible and counted using a Zeiss Axiovert 35 inverted microscope. The taxa were identified using the methods of Huber – Pestalozzi (1938). Phytoplankton diversity and abundance reflect a small water body's ecosystem health and productivity. For example, phytoplankton are important bio-indicators of heavy metal pollution in aquatic ecosystems due to their capacity to eliminate them from the water, and to accumulate and store them over long periods even when the concentrations in the water are low (Kundu et al., 2017; Aura et al., 2020a).

Fisheries

Fish samples were collected and assessed as per methods described by Kundu et al. (2017) using a beach seine net 50 m long with a depth of 3 m and a stretched mesh size of 2.54 cm (1 inch). The data collected was supplemented with commercial catches from fishermen where possible. Fish specimens were identified to species level. Fisheries and aquaculture restocking possibilities were evaluated using a semi-structured questionnaire which was administered to community leaderships, surrounding communities, aquaculture systems farmers, hatchery owners and feed processing owners.

Calculation of carrying capacity

Figure 3 depicts a possible simulation of a SWB with the interaction of various parameters involved in the estimation of fisheries carrying capacity. A composite Socio-economics index (SI) was calculated as a measure of the general socio-economics carrying capacity acceptable for any fisheries development interventions in the SWBs. This percentage score was derived from weighted averages of the specific ordinal scores subject to the Likert scale ratings of various socio-economics perception indicators (Aura et al., 2021). The overall socio-metric scale was segmented as follows: 0 ≤ Unsuitable < 0.2; 0.2 ≤ Subsistence < 0.4; 0.4 ≤ Low-scale commercial < 0.6; 0.6 ≤ Medium-scale commercial < 0.8; and 0.8 ≤ Large-scale commercial < 1.0 (FAO, 2019).

Additionally, biological productivity of any given water body can be limited by either light or nutrient availability (Aura et al., 2020a). Light irradiance in the water column would therefore be influenced by algal or suspended sediment turbidity. Trophic status of SWBs was assessed to understand the consequences of restocking and management actions and the importance of ecological processes. Trophic status index (TSI; Carlson, 1977) is an indicator of algal biomass in limnological systems as a response to nutrient concentrations, light availability, and/or other factors influencing primary production. Biomass surrogates that were used to calculate TSI were chlorophyll (Chl-a), Secchi depth (SD), total nitrogen (TN), and total phosphorus (TP). Trophic status index averages range from ultra-oligotrophic (approximately TSI = 0) to hyper-eutrophic (TSI > 1.0) (USEPA, 1998).

The calculation of trophic state index (TSI) therefore took into consideration the Secchi Depth (SD) measurement and concentration levels of Total Nitrogen (TN), Total Phosphorus (TP) and Chlorophyll-a (Chl-a). The TSI was first calculated for individual parameters before calculating the average value of all the parameters according to Carlson (1977) and Carlson et al. (2005) but with slight modifications to suit local conditions.

TSI (SD) = 10*(6 – ( )……………………………………………(1)

TSI (Chl-a.) = 10*(6 – ……………………………(2)

TSI (TP) = 10*…………………………………………………..(3)

TSI (TN) = 54.45 + 14.43 ln(TN)……………………………………(4)

TSI = (TSI (SD) + TSI (Chl-a.) + TSI (TP) + TSI (TN))/4……….(5)

Therefore, the carrying capacity takes into account the socio-economics index, trophic state index and physical size (area and euphotic depth) of the system (Cross, 2013). The estimated carrying capacity was scaled down by 30% to mitigate against overestimation given that SWBs' physical-chemical attributes exhibit huge seasonal variability (GESAMP, 1986; Cross, 2013).

$$C = ((A*D\_e *SD)*SI*TSI) \times 30\% \qquad (6)$$

Where C = Carrying capacity (mt), A = area of small water body, D_e = Euphotic depth, SD = Stocking density of fish in kg m^{-1} SI = Socio-economics index, and TSI = Trophic status index. The carrying capacity was further classified into low (≤ 30 mt), medium (31 – 100 mt) and high (≥ 100 mt) levels based on the estimations obtained.

The study employed the use of SPSS version 21 (SPSS Inc., Chicago, IL, USA) and R version 3.5.0 (R Core team 2014) for statistical analyses. The level of significance was estimated at $p < 0.05$.

Results and Discussion

Water quality and SWBs parameters

Significant variations ($p < 0.05$) were noted between western and central regions for dissolved oxygen, ammonium, TN, TP, Chlophyll-a, total and faecal coliforms which could be attributed to varying anthropogenic activities surrounding the sampled SWBs (Table 2). The western region had a relatively higher extent of human activities than the central counterpart which included but not limited to wetland reclamations, increased discharges of domestic and industrial wastes, fertilizer runoff from agricultural-based farms, and sediment transported by rivers (Lung'ayia et al., 2001). Furthermore, the fluctuations in such physio-chemical parameters are typical of SWBs (Catalan et al., 2006).

The physiological analysis revealed the occurrence of six phytoplankton groups (Figure 4). Quantitative analysis revealed a predominance of diatoms in the central region which are adaptive to lower temperatures, reminiscent of this region, and are usually replaced by cyanobacteria were least abundant with increased temperatures (Nowrouzi and Valavi, 2011). With no significant differences ($p > 0.05$) in water temperature compared to the central region, the concentration of diatoms (52.96 Ind. L) in the western region was ranked second after Euglenophyceae (68.59 Ind. L^{-1}). However, diatoms are used as indicators of both fertile and contaminated water (Trobajo et al., 2009); a scenario that could be associated with the presence of total and faecal coliforms within the SWBs surveyed, and the presence of moderate concentrations of cyanobacteria. The increased presence of chlorophyceae especially in the central region's SWBs which was predominated by a species in the order chlorococcales, indicating the likelihood of an ambient primary productivity and which has been shown to increase in the presence of shallow aquatic systems (Tavernini et al., 2009). Environmental management of these SWBs, combining enhanced conservation measures such as afforestation and strict adherence to contaminant and discharge regulations, alongside investment in fisheries production management is necessary if we are to reduce or moreover prevent water quality degradation.

Fisheries

The survey recorded a total of 28 fish species in 74 SWBs (Table 3). The central region had the highest proportion of fish abundance (66.67%) when compared to western Kenya's fish abundance (33.33%). The differences in proportions in both regions were linked to a healthier water quality being exhibited in the central region when compared with the western region. Water quality has been known to be the main determinant of biota occurrence in aquatic systems, with fish also used as an indicator of water quality due to their sensitivity to pollution in the water bodies where they reside (Mora et al., 2003, 2008; Masese et al., 2020). One species the Nile tilapia (*Oreochromis niloticus*) was observed to dominate SWBs within both regions. This dominance based on the ambient water quality observed could partly be due to *O. niloticus* having a high tolerance for poor quality waters (Masese et al., 2020). This resilience combined with its fast growth rate, tolerance for over-stocking (high stocking densities), adaptability to differing culture systems and its high market value, make this fish ideal for re-stocking in locations of SWBs where it is already endemic (Musa et al., 2014).

Socio-economics index (SI)

The socio-economic carrying capacity indicators significantly varied ($p < 0.05$) across the SWBs in western and central regions (Figure 5). The central region exhibited a relatively higher carrying capacity compared to the western region. This implies that, based on the socio-economic environment, fisheries development in SWBs within the central region was more viably productive than within the western region. Since the recent uptake and growth of aquaculture this carrying capacity has continued to be relatively higher in the central compared to the western region (Ochieng', 2017). One main reason identified is that the western region and its communities are largely linked to Lake Victoria, the largest open-access capture fishery in Kenya. This factor, in having direct access to fish on your "door step" could be attributable to why most communities in this region do not perceive fisheries or culture would be more viable in SWBs (Shitote et al., 2013).

These findings relate well with insights from Stiftung (2012), which indicated that central Kenya as an eco-region is much more developed in terms of physical infrastructure e.g. social amenities and the availability of ancillary services than was observed in the western region. Furnished with good road infrastructures and communication networks, growing industries and numerous fish processing factories, the central Kenya region provides a perfect environment for growth in both fish aquaculture markets and its associated inputs (ABDP Aquaculture Blue Book, 2021). Overall, this study has indicated that the central region (when compared to its western counter-part) has shown potential for investment and development in understanding the socio-economic benefits beyond the prevailing development.

The specific mainstay of local livelihoods and cultural eating habits was also found to shape the interest and participation of the local communities in fisheries development initiatives within the dams (Requier et al., 2020). Generally, it was found that livestock and farm-based agricultural communities' perceived fishing and fish farming as less important entrepreneurial ventures within their socio-cultural backgrounds. This statement could imply that there is a requirement for improved communication and discussions, in order to understand the potential of SWBs fisheries investments as a viable livelihood alternative to the induced socio-cultural orientations.

Furthermore, some dams provided more prospects for livelihood improvement from other socio-economic activities other than capture or culture fisheries development. For instance, most urban dams were suited for eco-tourism activities. Adaptation to the socio-economic dynamics of the dam's situation, such as developing sport fishing in a tour-centric location (Smucker and Detenbeck, 2014) or cage culture and irrigation provided significant prospects for multiple livelihood activities in these SWBs. Using these socio-economic dynamics in an integrated approach, would improve the management and scale of the potential fisheries development and conversely this would then not impinge on livelihoods and activities based in and on the SWB.

Most dams in the present study performed poorly (< 15%) on group formation and integration dynamics, conflict resolution and gender mainstreaming. The low indications of community-based group formation and lower social acceptability score, generally compromise the scale of potential investment achievable (Stephenson et al., 2020). As such, capacity building initiatives meant to promote group cohesion and skills, coupled with a proper community engagement and involvement framework, is required for these SWBs in order to improve fisheries development prospects.

Trophic status index (TSI)

There were significant variations ($p = 0.04$; $F = 110$) in the TSI across all the surveyed SWBs (Table 4). The TSI ranged between 0.14 – 0.68 that revealed eutrophic state of SWBs but at different levels of nutrient enrichment. Those SWBs with TSI > 0.5 was indicative of highly fertile systems (USEPA, 1998) with increased concentrations of TN, TP and total and faecal coliforms. Unlike central Kenya, all the surveyed SWBs in western Kenya had TSI ≥ 0.50 which was indicative of increased nutrient enrichment. Runoff from agricultural land, inputs of industrial and settlement effluent, the predominantly urban setting, and the nature of its inflows into the SWBs may have generated these eutrophic patterns (Mwambri, 2016).

Carrying capacity

The surveyed SWBs had a carrying capacity of about 72,894 mt of fish potential, out of which Masinga dam constituted about 51,217 mt, followed by Kamburu (15,135 mt), Kindaruma (2,409 mt), and Gitaru (2,351 mt) (Table 4). All these four dams are in Embu County and within the River Tana system with depths of > 3.5 m that are ideal for cage culture due to their improved water exchange (Aura et al., 2018; Njiru et al., 2019). However, dams that had high carrying capacities (> 100 mt) are not accessible to local communities, which raises the possibility of the need to agree memoranda of understanding between KenGen – a national government power generating company, and the local associations to have an integrated system. Other dams with substantial carrying capacity were Kiserian (522.95 mt, Kajiado County) and Chinga (396.90 mt, Nyeri

County). Generally, these estimates show the need to invest in SWBs and enable such systems to be integrated in the mainstream fisheries production for blue growth. These efforts would help supplement capture fisheries sources that are being over fished and are on the decline (Fisheries Annual Statistics Bulletin, 2016).

In the western Kenya region, Yao Kosiga Dam in Homa Bay County exhibited the highest potential (47.0 mt). This was followed by Olasi (41.98 mt) and Karamu (39.46); both of which are in Migori County. Migori and Kakamega Counties have the potential for increased water retention that could favour aquaculture production e.g. topography ansoil type (Musa et al., 2014; ABDP Aquaculture Blue Book, 2021). The SWBs with shallow depths and with low estimated fish carrying capacities (≤ 30 mt), constituted 81% of those surveyed and were found to be common in the western region. These SWBs were recommended for wild-restocking with endemic fish species with limited or no supplementary feeding to avoid effects of acclimatisation and adaptation with new environments (Fleischer et al., 1996). Additionally, those SWBs classified with medium capacities could require semi-intensive fisheries production with a moderate supplementary feeding regime (Musinguzi et al., 2019).

The inventory of the sampled fish species from each surveyed county was shared with the respective directorates of fisheries to inform and support possible restocking activities. Furthermore, table 5 shows an example of an advisory framework that was shared with the county fisheries officers and the national fisheries authorities as a decision-support-tool for possible fisheries investment in each viable small water body.

Conclusions and Recommendations

The results of this study revealed that the central region had a potential of 72,447 mt while that of the western region was only 447 mt. The comparatively high potential in the central region is attributable to the huge hydro-electric dams which are not accessible by local communities due to the management structure and ownership by KenGen – a power-producing company. The top four dams in terms of carrying capacity are in Embu County nd are within the River Tana system. The SWBs with shallow depths and carrying capacities that were common in the western region are recommended for restocking with endemic fish species with limited or no supplementary feeding. Cage culture is recommended for SWBs with depths of ≥ 3.0 m and strong community associations to provide security and farm inputs from nearby hatcheries. However, most of the surveyed SWBs had multiple socio-economic uses - a possible recipe for conflict among resource users. To avoid conflicts and improve on performance, the development of SWBs strategy would be recommended. The strategy will among other things detail: potential investments under the blue economy precipice; optimization of operation by re-defining the SWBs objectives; economic analysis, rehabilitation, rebranding and upgrading of the SWBs; SWBs safety; sedimentation; and research. Further studies on the carrying capacity predictions based on the introduced investment opportunities could improve the methodological approach identified in the present study for further fisheries management growth and improved conservation management of the systems.

Acknowledgements

The International Fund for Agricultural Development (IFAD) and The Government of Kenya through the Aquaculture Business Development Programme (ABDP) funded the expeditions. Kenya Marine and Fisheries Research Institute provided logistics and facilitated the research activities. KMFRI, Kisumu, Kenya Fisheries Service - KeFS (Ms. Christine Etiegni, Mr. Stanley Tonui and Alice Hamisi), County Programme Coordinators (CPCs) and Fisheries Directors (from Nyeri, Kirinyaga, Meru, Tharaka Nithi, Embu, Kiambu, Kajiado, Machakos, Homa Bay, Migori,

Kisii, Kisumu, Busia, Siaya and Kakamega), County administrative officers and dam management units provided valuable contributions.

References

APHA (2000). Standard methods for the analysis of water and wastewater, 15th ed. American Public Health Association and Water Pollution Control Federation. Washington DC, USA. 12- 56Pp.

ABDP Aquaculture Blue Book (2021). Final report – an assessment of the aquaculture value chain players in the ABDP implementing counties. Aquaculture Business Development Programme (ABDP), P. O Box 904 – 10100, Nyeri, Kenya. 223pp.

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C.S., & Pimentel, D. (1995). Economic growth, carrying capacity, and the environment. *Ecol. Econ*., 15(2), 91-95.

Aura, M. C., Musa, S., Njiru, J., Ogello, E. O. & Kundu, R. (2013). Fish-Restocking of Lakes in Kenya: Should solemnly be an Environmental Issue, 39-60pp. In: Adoyo, W. A. & Wangai, C. I. African Political, Social and Economic Issues: Kenya Political, Social and Environmental Issues. NOVA Science Publishers, Inc. NewYork. ISBN: 978-1-62081-085-9.

Aura, M.C., Kimani, E.N., Musa, S., Kundu, R., & Njiru, J.M. (2017). Spatio-temporal macroinvertebrate multi-index of biotic integrity (MMiBI) for a coastal river basin: a case study of River Tana, Kenya. *Ecohydrology and Hydrobiology*, 17, 113-124.

Aura, M.C., Musa, S., Yongo, E., Okechi, J., Njiru, J.M., Ogari, Z., Wanyama, R., Charo-Harrison, H., Mbugua, H., Kidera, S., Ombwa, V., & Abwao, J. (2018). Integration of mapping and socio-economic status of cage culture: Towards balancing lake-use and culture fisheries in

Lake Victoria, Kenya. *Aquaculture Research*,9(1), 532-545. https://doi.org/10.1111/are.13484.

Aura, M.C., Odoli, C., Nyamweya, C., Njiru, J.M., Musa, S., Miruka, J.B., Owili, M.O., Omondi, R., Raburu, P., Mwamburi, J., Ogari, Z., & Mbaru, E. (2020a). Application of phytoplankton community structure in the ranking of major riverine catchments that influence pollution status of a lake basin. *Lakes & Reservoirs: Science, Policy and Management for Sustainable Use*, 25, 3-17. https://doi.org/10.1111/lre.12307.

Aura, M.C., Nyamweya, C.S., Owili, M., Gichuru, N., Kundu, R., Njiru, J.M., & Ntiba, M.J. (2020b). Checking the pulse of the major commercial fisheries of Lake Victoria Kenya, for sustainable management. *Fish Manag Ecol*., 27, 314–324. https://doi.org/10.1111/fme.12414.

Aura, M.C., Nyamweya, C.S., Owiti, H., Odoli, C., Musa, S., Njiru, J.M., Nyakeya, K., & Masese, F. (2021). Citizen science for bio-indication: development of a community-based index of ecosystem integrity for assessing the status of Afrotropical riverine ecosystems. *Front. Water*, 2, 609215. 10.3389/frwa.2020.609215.

Bera, S., Majumdar, D.D., & Paul, A.K. (2015). Estimation of tourism carrying capacity for Neil Island, South Andaman, India. *J. Coastal. Sci*., 2 (2), 46-53.

Bolgrien, D.W., Scharold, J.V., Angradi, T.R., Corry, T.D., Schwieger, E.W., & Kelly, J.R. (2009). Trophic status of three large Missouri River reservoirs. *Lake and Reservoir Management*, 25(2), 176-190.

Carlson, R.E. (1977). A trophic state index for lakes. *Limnol. Oceanogr*., 22, 361-369.

Carlson, R.E., & Havens, K.E. (2005). Simple graphical methods for the interpretation of relationships between trophic state variables. *Lake Reserv. Manage*., 21, 107-118.

Catalan, J., Camarero, L., Felip, M., Pla, S., Ventura, M., Buchaca, T., Bartumeus, F., De Mendoza, G., Miro, A., & Casamayor, E.O. (2006). High mountain lakes: extreme habitats and witnesses of environmental changes. *Limnetica*, 25 (1-2), 551-584.

Cheng, K., Fu, Q., Cui, S., Li, T.X., Pei, W., Liu, D., & Meng, J. (2016). Evaluation of the land carrying capacity of major grain-producing areas and the identification of risk factors. *Nat. Hazards*, 1–18 https://doi.org/10.1007/s11069-016-2686-1.

Cross, S. (2013). Carrying capacity (mt) and site selection tools for use in the implementation of an ecosystem-based approach to aquaculture in Canada: a case study. In L.G. Ross, T.C. Telfer, L. Falconer, D. Soto & J. Aguilar-Manjarrez, eds. Site selection and carrying capacities for inland and coastal aquaculture, pp. 253–262. FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, 6–8 December 2010. Stirling, the United Kingdom of Great Britain and Northern Ireland. FAO Fisheries and Aquaculture Proceedings No. 21. Rome, FAO. 282 pp.

Downing, J.A., & Duarte, C.M. (2009). Abundance and size distribution of lakes, ponds, and impoundments. In: Likens G.E., editor. *Encyclopedia of Inland Waters*, 2009, 469-478. DOI: 10.1016/B978-012370626-3.00025-9.

EEA ETC/ICM (2009). Small water bodies assessment of status and threats of standing small water bodies. Report published by the EEA European Topic Center on inland, coastal and marine waters. Available at http://icm.eionet.europa.eu/ETC_Reports/Assessment%20of%20status%20and%20threats%20of%20standing%20small20water%20bodies.pdf, (last accessed 17 March 2021).

EPA (2005). The characterisation and analysis of Ireland's River Basin Districts in accordance with Section 7(2 & 3) of the European Communities (Water Policy) Regulations 2003 (SI

722 of 2003) National Summary Report (Ireland) 2005. Available at http://www.wfdireland.ie/Documents/CharacterisationReport/Ireland_Article_5_WFD.pdf (last accessed 14th March 2021).

European Commission (2008). Commission decision of 30 October 2008 establishing, pursuant to Directive 127 ASSESSMENT OF SMALL WATER BODIES 2000/60/EC of the European Parliamnt and of the Council, the values of the Member State monitoring system classifications as a result of the Inter-calibration Exercise (notified Un. L 332/20 EN Official Journal of the European Union 10.12.2008).

FAO (2019). Kenya: High aquaculture growth needed to improve food security and nutrition. WAPI Policy Brief, CA4693EN/1/05.19. Available at: http://www.fao.org/3/ca4693en/ca4693en.pdf.

Fisheries Annual Statistics Bulletin (2016). State Department for Fisheries, Aquaculture and the Blue Economy (SDFA&BE), Ministry of Agriculture, Livestock and Fisheries, Nairobi, Kenya. 66pp.

Fleischer, S., Joelsson, A., & Stibe, L. (1996). The potential role of ponds as buffer zones. In: Buffer Zones: their processes and potential in water protection. Haycock NE, Burt TP, Goulding WT, Pinay G, editors. Harpenden, UK: Quest Environmental.

Gangnery, A., Bacher, C., & Buestel, D. (2001). Assessing the production and the impact of cultivated oysters in the Thau lagoon (Méditerranée, France) with a population dynamics model. *Can. J. Fish Aquat. Sci*., 58, 1-9.

GESAMP (1986). Environmental Capacity, An Approach to Marine Pollution Prevention. GESAMP Reports and Studies No. 30. 62 pp. Available at:

www.gesamp.org/data/gesamp/files/media/Publications/Reports_and_studies_30/gallery_1263/object_1271_large.pdf.

Gibbs, M.T. (2004). Interactions between bivalve shellfish farms and fishery resources. *Aquaculture*, 240 (1-4), 267-296.

Government of Kenya Report (2007). Government of Kenya: State of the Inland systems report: Towards an Integrated Management of the Kenya's Inland Resources. Pp108.

Haycock, N.E., Burt, T.P., Goulding, W.T., & Pinay, G. (1996). Introduction. In: Buffer Zones: their processes and potential in water protection. Haycock NE, Burt TP, Goulding WT, Pinay G, editors. Harpenden, UK: Quest Environmental.

Hajkowicz, S. (2006). Multi-attributed environmental index construction. *Ecol. Econ.*, 57(1), 122–139.

Huber-Pestalozzi G. (1938). Allgermeiner Teil. Blaualgen. Bacterien. Pilze. Das Phytoplankton des Süsswasser, 1. Teil (ed. Huber-Pestalozzi), pp. 1-6 + 1-342. Schwizerbart'sche-Verlagsbuchhandllung, Stuttgart.

ICES (2005). European Union Legal Framework - Report of the Working Group on Environmental Interaction of Mariculture, 11-15 April, Ottawa, Canada. ICES WGEIM Report 2005.

Inglis, G.J., Hayden, B.J., & Ross, A.H. (2000). An overview of factors affecting the carrying capacity of coastal embayments for mussel culture. NIWA Client Report CHC00/69, Christchurch, New Zealand.

IUCN (2012). International Union for Conservation of Nature: Guidelines for Application of IUCN Red List Criteria at Regional and National Levels: Version 4.0. Gland, Switzerland and Cambridge, UK: IUCN. Iii +41pp.

Kundu, R., Aura, C.M., Nyamweya, C., Agembe, S., Sitoki, L., Lung'ayia, H.B.O., Ongore, C., Ogari Z., & Werimo, K. (2017). Changes in pollution indicators in Lake Victoria, Kenya and their implications for lake and catchment management. *Lakes Reserv. Res. Manage*., 22, 199-214.

Liu, R.Z., & Borthwick, A.G. (2011). Measurement and assessment of carrying capacity of the environment in Ningbo, China. *J. Environ. Manag.,* 92 (8), 2047-2053.

Lung'ayia, H., Sitoki, L., & Kenyanya, M. (2001). The nutrient enrichment of Lake Victoria (Kenyan waters). *Hydrobiologia*, 458, 75-82.

Masese, F.O., Omukoto, J.O., & Nyakeya, K. (2013). Biomonitoring as a prerequisite for sustainable water resources: a review of current status, opportunities and challenges to scaling up in East Africa. *Ecohydrology & Hydrobiology,* 13(3), 173-191.

Masese, F.O., Achieng', A.O., Raburu, P.O., Lawrence, T., Ives, J.T., Nyamweya, C., & Kaunda-Arara, B. (2020). Distribution patterns and diversity of riverine fishes of the Lake Victoria Basin, Kenya. *International Review of Hydrobiology,* https://doi.org/10.1002/iroh.202002039.

McKindsey, C.W., Thetmeyer, H., Landry, T., & Silvert, W. (2006). Review of recent carrying capacity models for bivalve culture and recommendations for research and management. *Aquaculture,* 261 (2), 451-462.

Mora, C., Chittaro, P.M., Sale, P.F., Kritzer, J., & Ludsin, S.A. (2003). Patterns and processes in reef fish diversity. *Nature,* 421, 933–936.

Mora, C., Tittensor, D.P., & Myers, R.A. (2008). The completeness of taxonomic inventories for describing the global diversity and distribution of marine fishes. *Proc. Roy. Soc. B*, 275, 149-155.

Munguti J.M., Kim J., & Ogello O.E. (2014). An Overview of Kenyan Aquaculture: Current Status, Challenges, and Opportunities for Future Development. *Fisheries and Aquatic Science*, 17(1), 1-11.

Musa, S., Aura, C.M., & Kundu R. (2014). Wild-Caught fish versus aquaculture fish products: A fish marketing concept for aquaculture quality improvement, A case study of Nyanza Region, Kenya. *Int. J. Sc. Rsch.*, 3, 2319-7064.

Musinguzi, L., Lugya, J., Rwezawula, P., Kamya, A., Nuwahereza, C., Halafo, J., Kamondo, S., Njaya, F., Aura, M.C., Shoko, A.P., Osinde, R., Natugonza, N., & Ogutu-Ohwayo, R. (2019). The extent of cage aquaculture, adherence to best practices and reflections for sustainable aquaculture on African inland waters. *Journal of Great Lakes Research*, https://doi:10.1016/j.jglr.2019.09.011.

Mwamburi, J. (2016). Spatial variations in sedimentary organic matter in surficial lake sediments of Nyanza Gulf (Lake Victoria Kenya) after invasion of water hyacinth. *Lakes and Reservoirs: Research and Management*, 21, 94-113.

Mwebaza-Ndawula, L. (1994). Changes in relative abundance of zooplankton in northern Lake Victoria, East Africa. *Hydrobiologia*, 272, 259-264.

Newell, R.I.E. (2004). Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs: a review. *J. Shellfish Res*., 23 (1), 51–61.

Njiru, J.M., Aura, M.C., & Okechi, J.K. (2019). Cage fish culture in Lake Victoria: A boon or a disaster in waiting? *Fish Manag Ecol*., 26, 426–434.

Nowrouzi, S., & Valavi, H. (2011). Effects of environmental factors on phytoplankton abundance and diversity in Kaftar Lake. *Journal of Fisheries and Aquatic Sciences*, 6 (2), 130-140.

Nunes, J.P., Ferreira, J.G., Gazeau, F., Lencart-Silva, J., Zhang, X.L., Zhu, M.Y., & Fang, J.G. (2003). A model for sustainable management of shellfish polyculture in coastal bays. *Aquaculture*, 219 (1-4), 257-277.

Ochieng, N. (2017). Effect of fish farming on household food security in Western Kenya. African *Journal of Food, Agriculture, Nutrition and Development,* 17, 11657-11672. 10.18697/ajfand.77.15965.

Ogello, E.O., & Munguti J.M. (2016). Aquaculture: a promising solution for food insecurity, poverty and malnutrition in Kenya. *African Journal of Food Agriculture, Nutrition and Development*, 16 (4), 11332-11351.

Peters, C.J., Wilkins, J.L., & Fick, G.W. (2007). Testing a complete-diet model for estimating the land resource requirements of food consumption and agricultural carrying capacity: the New York State example. *Renew. Agric. Food Syst*., 22 (02), 145-153.

Raillard, O., & Ménesguen, A. (1994). An ecosystem box model for estimating the carrying capacity of a macrotidal shellfish system. *Mar. Ecol. Prog. Ser.*, 115, 117–130.

Read, P., & Fernandes, T.F. (2003). Management of environmental impacts of marine aquaculture in Europe. *Aquaculture*, 226 (1-4), 139-163.

Requier, F., Andersson, G. K., Oddi, F.J., & Garibaldi, L.A. (2020). Citizen science in developing countries: how to improve volunteer participation. *Frontiers in Ecology and the Environment*, 18(2), 101-108.

Sedgwick, P. (2015). Multistage sampling. *BMJ* (online), 351, h4155. 10.1136/bmj.h4155

Shitote, Z., Wakhungu, J., & China, S.S. (2013). Challenges Facing Fish Farming Development in Western Kenya. *Greener Journal of Agricultural Sciences*, 3, 305-311. 10.15580/GJAS.2013.3.012213403.

Smucker, N.J., & Detenbeck, N.E. (2014). Meta-analysis of lost ecosystem attributes in urban streams and the effectiveness of out-of channel management practices. *Restor. Ecol*., 22,741-748.

Souchu, P., Vaquer, A., Collos, Y., Landrein, S., Deslous-Paoli, J.M., & Bibent, B. (2001). Influence of shellfish farming activities on the biogeochemical composition of the water column in Thau lagoon. *Mar. Ecol., Prog. Ser*., 218, 141-152.

Stiftung, F.E. (2012). Regional Disparities and Marginalisation in Kenya. Elite PrePress Ltd, Kenya. ISBN No: 9966-957-68-5. Accessed on 16/03/2021 at: https://library.fes.de/pdf-files/bueros/kenia/09859.pdf.

Stephenson, P.J., Ntiamoa-Baidu, Y., & Simaika, J.P. (2020). The Use of Traditional and Modern Tools for Monitoring Wetlands Biodiversity in Africa: Challenges and Opportunities. *Front. Environ. Sci*., 8, 61. doi: 10.3389/fenvs.2020.00061.

Tavernini, S., Nizzoli, D., Rosseti, G., & Viaroli, S. (2009). Trophic state and seasonal dynamics of phytoplankton communities in two sand-pit lakes at different successional stages. *Journal of Limnology*, 68 (2), 217–228.

Trobajo, R., Clavero, E., Chepurnov, V.A., Sabbe, K., Mann, D.G., Ishihara, S., & Cox, E.J. (2009). Morphological, genetic and mating diversity within the widespread bioindicator *Nitzschia palea* (Bacillariophyceae). *Phycologia*, 48, 443–459.

USEPA (1998). Lake and reservoir bioassessment and biocriteria technical guidance document. U.S. Environmental Protection Agency, Washington, D.C. 841-B-98-007.

Wang, Y., Liu, Y., Li, Y., & Li, T. (2016). The spatio-temporal patterns of urban–rural development transformation in China since 1990. *Habitat Int*., 53, 178-187.

Tables

Table 1. Key tools used in the socio-economic analysis in the SWBs survey in the determination of carrying capacity for fisheries production.

Tool/method	Aim
1. Semi-structured questionnaire	To generate socio-demographic information and perceptions on fisheries development indicators
2. Participant observation and transect walks	To verify socio-economics activities and existing resources in the community, establish a rapport with community members and to debrief stakeholders on current research activities
3. Composite Indices	To provide weighted aggregated scores for the indicators for establishing the general community perceptions
4. Spider Web Analysis	To describe the variations in socio-economic indicators across the study sample

Table 2. Water quality parameters for the sampled SWBs for both western and central regions of Kenya.

Parameter	Western		Central	
	Mean ± SE	**Range**	**Mean ± SE**	**Range**
Temperature (°C)	24.57 ± 0.36	19.7 - 30.2	22.91 ± 0.4	20.30 - 26.4
Dissolved Oxygen (mg L^{-1})	5.13 ± 0.35	1.07 - 9.71	6.82 ± 0.22	4.81 - 8.23
Ammonium (µg L^{-1})	76.17 ± 11.96	1.56 - 251.56	54.75 ± 9.89	10.94 - 175.31
pH	7.40 ± 0.10	5.64 - 8.46	8.22 ± 0.11	7.08 - 9.08
Secchi Depth (m)	0.32 ± 0.05	0 - 1.5	0.55 ± 0.08	0.2 - 1.1
Total nitrogen (µg L^{-1})	425.86 ± 45.39	86.53 - 1103.37	521.44 ± 97.91	234.95 - 1487.05
Total phosphorus (µg L^{-1})	96.48 ± 10.98	14.71 - 310.4	102.65 ± 39.97	1.86 - 657.57
Chlorophyll-a (µg L^{-1})	52.04 ± 6.75	5.63 - 310.4	31.21 ± 4.71	1.80 - 85.05
Total coliforms/100mL (cfu)	2547.37 ± 463.59	300 - 10,000	975.51 ± 379.05	6 - 12,000
Faecal coliforms/100mL (cfu)	457.89 ± 103.54	0 - 3000	254.62 ± 100.91	0 - 3000
Depth (m)	2.14 ± 0.18	1.0 - 6.0	3.9 ± 0.61	1 - 18.1

Table 3. Fish relative abundance (%) during the survey on SWBs in western and central regions of Kenya. Empty spaces indicates absence during sampling period.

No.	Species	Central (%)	Western (%)
1	*Barbus* spp.	0.11	
2	*Barbus appleurogramma*	0.66	
3	*Barbus paludinosus*	5.01	
4	*Barbus paludiusus*	0.11	
5	*Cambarus sp.*	2.62	
6	*Clarias gariepinus*	1.96	3.70
7	*Cyrinus carpio*	0.33	
8	*Coptodon zilli*	3.27	
9	*Gambusia* sp	0.65	
10	*Haplochromis* sp	2.51	26.36
11	*Labeo gregorii*	0.76	
12	*Labeo victorianus*	1.63	0.22
13	*Micropterus salmoides*	0.54	
14	*Oreochromis esculentus*	0.11	
15	*Oreochromis leucosticus*	0.11	24.62
16	*Oreochromis niloticus*	48.91	33.55
17	*Oreochromis variabilis*	2.83	
18	*Tilapia mosambicus*	5.77	
19	*Tilapia rendalii*	11.76	
20	*Tilapia variabilis*	9.80	
21	*Unidentified tilapia*	0.22	
22	*Enteromius jacksonii*		0.65
23	*Enteromius kerstenii*		1.31
24	*Enteromius neumayeri*		0.22
25	*Enteromius paludinosus*		8.50
26	*Oreochromis zilli*		0.22%
27	*Protopterus aethiopicus*		0.22%
28	*Labeobarbus altianalis*		0.22%

Table 4 a). Estimated and classified carrying capacities (mt) of small water bodies (SWBs) using water depth, Socio-economics Index (SI), Trophic Status Index (TSI) for western Kenya.

a) Western Region							
County	**SWB**	**Size (ha)**	**Depth (m)**	**SI**	**TSI**	**Carrying capacity (mt)**	**Remarks**
Busia	Buhuyi	5	2	0.47	0.58	8.12	Low
	Changara	0.84	4	0.51	0.65	3.34	Low
	Munana	10	3	0.51	0.54	24.79	Low
	Namalenga	8.5	2.5	0.56	0.6	21.4	Low
	Namonye	5	2	0.41	0.54	6.642	Low
Homabay	Kobodo	2.5	2	0.41	0.54	3.32	Low
	Konyango	7	1.5	0.55	0.64	11.09	Low
	Yao Kosiga	8	6	0.48	0.68	47.00	Medium
	Kouma	1.8	5	0.38	0.5	5.13	Low
	Oseno	20	2	0.54	0.58	37.58	Medium
	Pap Orage	1	1.5	0.52	0.66	1.54	Low
	Ramula	3	1.5	0.56	0.6	4.54	Low
	Yongo	8	1.5	0.5	0.58	10.44	Low
Kakamega	Mumonyonzo	1.5	1	0.5	0.67	1.51	Low
	X-Rasa	2	1.5	0.49	0.60	2.65	Low
	Lugulu	1.4	3	0.45	0.62	3.52	Low
	Lumino	7	1	0.48	0.62	6.25	Low
	Musembe	6	3	0.53	0.59	16.89	Low
Kisii	Ibeno	2	1	0.47	0.73	2.06	Low

a) **Western Region**							
County	**SWB**	**Size (ha)**	**Depth (m)**	**SI**	**TSI**	**Carrying capacity (mt)**	**Remarks**
Kisumu	Buoye	0.8	1.5	0.44	0.59	0.93	Low
	Hejope	0.5	2	0.6	0.66	1.19	Low
	Huma	1	1	0.48	0.53	0.76	Low
	Kere	0.26	1.5	0.48	0.61	0.34	Low
Migori	Konyona	0.25	2	0.43	0.66	0.43	Low
	Gwitembe	1	1.5	0.49	0.57	1.26	Low
	Karamu	18	2	0.63	0.58	39.46	Medium
	Mahena	1	2	0.47	0.65	1.83	Low
	Silanga Mubachi	11	2	0.49	0.61	19.73	Low
	Nyamome	8	3.5	0.51	0.60	25.70	Low
	Olasi	20	2	0.53	0.66	41.98	Medium
	Siabai	3	1	0.49	0.62	2.73	Low
	Silanga	6	2	0.49	0.51	8.99	Low
Siaya	Mauna	15	2	0.54	0.51	24.79	Low
	Nyadong	2	1	0.45	0.56	1.51	Low
	Nyagoko	8.6	1.5	0.46	0.68	12.11	Low
	Ochot	11	2.5	0.48	0.48	19.01	Low
	Uranga	11	3	0.51	0.52	26.25	Low

Table 4 b). Estimated and classified carrying capacities (mt) of small water bodies (SWBs) using water depth, Socio-economics Index (SI), Trophic Status Index (TSI) for central Kenya.

b) Central Region

County	SWB	Size (ha)	Depth (m)	SI	TSI	Carrying capacity (mt)	Remarks
Embu	Gitaru	290	9.1	0.55	0.54	2351.35	High
	Ithatha	3.3	1.6	0.47	0.54	4.02	Low
	Kamburu	1125	15.1	0.54	0.55	15135.90	High
	Kindaruma	1000	3.5	0.51	0.45	2409.75	High
	Masinga	12000	5.7	0.52	0.48	51217.9	High
Kajiado	Enkaroni	5	3	0.44	0.63	12.474	Low
	Iyarat	3	3.5	0.4	0.66	8.316	Low
	Kiserian	41.8	18.1	0.48	0.48	522.95	High
	Olmirrui	0.1	3	0.45	0.58	0.25	Low
	Olokii	10	2.5	0.47	0.66	23.27	Low
Kiambu	Kimunyu	0.27	3	0.51	0.52	0.64	Low
	Rungiri	3	6.5	0.51	0.49	14.62	Low
	Tigoni	10.19	2.5	0.4	0.64	19.56	Low
	Twiga	3	6.2	0.48	0.47	12.57	Low
Kirinyaga	Ahiti Ndomba	2	4.4	0.48	0.43	5.45	Low
	Kangai	0.53	2.4	0.55	0.52	1.09	Low
	Karura	10	1.7	0.52	0.52	13.79	Low
	Njuki-ini	2	4.3	0.52	0.51	6.84	Low
	Thiba	0.75	1.5	0.61	0.65	1.34	Low
Machakos	Katangi	5	4.1	0.47	0.55	15.90	Low
	Kwale	10	3.5	0.47	0.65	32.08	Medium
	Muthetheni	10	3.2	0.51	0.57	27.91	Low

b) Central Region

County	SWB	Size (ha)	Depth (m)	SI	TSI	Carrying capacity (mt)	Remarks
	Muoni	13	3	0.48	0.53	29.76	Low
Meru	Kaguru	1.5	1.5	0.46	0.46	1.43	Low
	Nguthuru Laingo	6.5	1.5	0.53	0.54	8.37	Low
	Nkunga	68	1.5	0.55	0.41	69.00	Medium
	Ontulili	68	1.5	0.53	0.42	68.12	Medium
Nyeri	Chinga	175	2.8	0.54	0.50	396.90	Medium
	Gaikuyu	0.59	2.2	0.54	0.43	0.90	Low
	Guara	2	2	0.54	0.58	3.76	Low
	Hohwe	3	3.6	0.47	0.40	6.09	Low
	Ichamara	2	2	0.57	0.31	2.12	Low
	Kiboya	0.85	2	0.42	0.33	0.71	Low
	Kiunyu	0.85	1	0.51	0.55	0.72	Low
	Njengu	9	3.1	0.57	0.42	20.04	Low
Tharaka Nithi	Gatonto	0.75	2	0.47	0.14	0.30	Low
	Ndetha	0.75	2	0.47	0.59	1.25	Low

Table 5. A typical tabulation of socio-ecological characteristics of each small water body (example shown is Ithatha dam in Embu County) as conclusive remarks for the potential of fisheries investment. In this case, the species recorded in this dam during the survey were Tilapia mosambicus (T. *m*), *Oreochromis niloticus* (*O. n*), *Tilapia rendalii (T. r)*, *Clarias garepinus* (*C. g*) and *Barbus* sp. The study recommends restocking at semi- intensive levels (based on SI and carrying capacity attained) of endemic *O. n* and *C. g* given that other fish species exhibited low abundances.

Parameter	**Observed value**	**Reference value**	**Remarks/interpretation**	**Carrying capacity (mt)**
Socio-economics Index (SI)	0.54	0.4 ≤ Low-scale commercial < 0.6	Recommended for low scale commercial fish farming	4.02
Trophic status index (TSI)	0.55	0.50 – 0.70 (Eutrophic)	Can support fairly high productivity	
Ammonium (µg L^{-1})	37.8	2000 µg L^{-1}	Within the recommended limit for fish growth	
Dissolved Oxygen (DO) (mg L^{-1})	8.2	5 and above mg L^{-1}	Favourable for fish growth	
Temperature (^{0}C)	23.5	20-31 for warm temperature adaptive fish < 20 for cold adaptive fish	Preferred temperature for fish growth	
pH	7.1	6-9	Best for fish growth	
TN:TP	23.8	10 - 30	No limiting nutrient. Can support diverse population of algae	
Secchi Depth (m)	0.4	0.35 – 0.5	If turbidity is from phytoplankton, the dam is in good condition.	
Fish condition factor	1.84 (*T. m*), 2.55 (*T. r*)	2.9 - 4.8	*T. m* had poor performance while *T. r* had fair performance. *O. n* and *C. g* recommended for restocking at semi-intensive levels.	
Microbial contamination indicators (Faecal Coliforms) cfu/100 ml)	160	10^3 – 10^4	1. Presence of fishing beach site with settlement. 2. Surrounded by forest trees	
Phytoplankton Shannon index H	2.98	H’ ≥ 2.5	Good availability of plankton. Both wild restocking and cage fish	

			farming involving food supplements recommended.	
Phytoplankton abundance (Ind. L^{-1})	159	300 and above	Conducive for fish farming if enhanced with supplementary feeds	

Figure Legends

Figure 1. Study sites in a) western, and b) central regions of Kenya.

Figure 2. Schematic representation towards the establishment of carrying capacities of small water bodies (SWBs) for fisheries production.

Figure 3. Possible parameters for the calculation of carrying capacity based on the potential interactions in a typical small water body ecosystem.

Figure 4. Concentrations of phytoplankton abundance (Ind. L^{-1}) in the surveyed SWBs of western and central regions of Kenya.

Figure 5. Variations in socio-economic indicators associated with SWBs in western and central regions of Kenya.