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Restocking of small water bodies for a post Covid recovery and growth of fisheries and aquaculture production: Socioeconomic implications

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ABSTRACT

Restocking of fish in Small Water Bodies (SWBs) is one of the technologies that can be used to enhance fish-food production for post Covid recovery and growth in food security, and national development. The current study aimed at assessing the socioeconomic impact and stock performance of restocked Nile tilapia fingerlings in SWBs in 15 counties in the Western and Central regions where the Aquaculture Business Development Programme (ABDP) is implemented. The study employed both primary and secondary data from socioeconomics, environmental characteristics and fisheries and aquaculture aspects. There was no restocked dam with a low ($<$1.66) socioeconomic impact, indicating the potential for restocking. The majority (n = 27; 79%) of the restocked SWBs had a moderate (1.66–2.33) impact, owing to the inherent constraints of adoptability by the local community. Twenty one percent (n = 7; 21%) of the SWBs had a high (2.34–3.00) impact and with better environmental conditions. The average condition factor (K) of tilapia in restocked SWBs was 1.24 ± 0.53 SD, suggesting excellent fish growth condition. Notably, restocking the SWBs could benefit riparian fishing communities by improving their livelihoods and providing food and nutritional security. Given the limited exploitation of fish in most SWBs in the developing countries, additional community awareness and capacity building interventions are needed to enhance optimal use of SWBs in post Covid era.

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Introduction

In several countries around the world, inland fisheries and aquaculture sectors are important for poverty alleviation, food security, gender empowerment, cultural services, ecosystem function and biodiversity. However, they are facing declining trends in fisheries production [6]. For example, in Kenya, the sector supports approximately 1.2 million people directly and indirectly, working as fishers, traders, processors, suppliers, and merchants of fishing accessories, employees, and their dependents with the inland capture fisheries contributing about 69% of Kenya's total fish production [28].

Globally, the inland fishery is currently facing a slew of internal and external challenges, including increased fishing pressure, invasive species, biodiversity loss, environmental degradation, ownership issues, ecological changes, climate change, insufficient information, and disjointed policies [31,52,53]. The decrease in the inland wild catches were further impacted by flooding in the first half of 2020, and the Covid-19 pandemic due to curfew hours and restrictions of movements. Notwithstanding, fishery resources are limited, thus, if conventional management approaches based on science, co-management, and diplomacy are not followed, and fishing pressure is not controlled, it will continue to rise until either the fishery or the stock collapses [6]. The African decline in fisheries and aquaculture production is being addressed using emerging technologies and innovations such as cage culture [12,50], improved climate smart methods and investment in other production systems such as Small Water Bodies (SWBs) [13].

Small Water Bodies (SWBs) are amongst the least-studied parts of the water environment in most developing countries, and they are largely excluded from fisheries management planning [25,28]. For example, even though Kenya has over 1000 dams, the majority of those are stocked with fish, water bodies that are monitored with measurable data captured by national statistics only include Jipe, Tana, and Turkwel [15,28]. Since most governments and private sectors now view fisheries and aquaculture as key drivers of the blue economy for sustainability and food security, SWBs are being used more effectively to improve food and nutrition security in rural and peri-urban areas [13]. However, it is critical that promoting sustainable fisheries development does not impact on the environment and considers all sectors and resource users involved in the inclusion of SWBs [24].

Although most developing countries, including Africa, have numerous dams and small reservoirs, there is the potential to increase fisheries and aquaculture production at the local level, using SWBs to bridge the national fish consumption deficit of 10 kg person^{-1} year-1 [27]. Because of their small size and the fact that they are either state-owned or communal property, these SWBs resources could be easily managed by local governments or dependant communities to increase fisheries productivity [19]. With the observed decrease in fisheries contribution to most Gross Domestic Products (GDPs) due to declines in capture fisheries [28], using SWBs (dams, pans, and reservoirs) for fisheries production could significantly increase productivity and fisheries yield, thereby reducing food insecurity and malnutrition [26]. In Kenya, for example, lower fish consumption per capita has been identified as a major contributor to the high prevalence of malnutrition in most rural areas [56]. In the debate over fish production, fisheries cultivation and restocking has the potential to bridge the fish supply gap and increase national fish consumption per capita [13,27,49].

Restocking of SWBs has emerged as one of the most used enhancement techniques due to increased pressure on global inland and marine fisheries to increase production [66]. SWBs can thus promote community fisheries and aquaculture initiatives to increase fish production and availability in rural areas with proper management and husbandry [30]. Furthermore, the Mekong River Commission [47] has shown how SWBs can serve as focal points for rural and peri-urban multi-uses such as irrigation, hydropower generation, and fisheries. They demonstrate how SWBs can be used for rural irrigation to promote the production of other food sources as a dietary supplement. As a result, SWBs appear to be a neglected "hotspot" for rural fisheries production, necessitating effective management strategies [16,40]. Such SWB management strategies are an initiative that is in line with the Sustainable Development Goals (SDGs), particularly SDG 1 - no poverty; SDG 2 - zero hunger; SDG 3 - good health and well-being; SDG 13 - climate action; and SDG 14 - life below water ([33]; Kenya [51]). The strategies also contribute to Africa's Agenda 2063 on rural food production and other national pillars focusing on food and nutrition security [27,36]. Despite their economic importance and ability to contribute to food and nutritional security, SWBs are not adequately recognized at the national level and thus are not adequately reflected in national economic data [40].

Fish restocking in lakes and SWBs is one of the oldest management strategies, but it has sparked controversy because it has disrupted native fish ecosystems, contributed to the loss of wild strains, and, in many cases, reduced genetic diversity [62]. Nonetheless, restocking can play an important role in SWBs supplementing capture fisheries management when done correctly. Restocking juveniles can supplement those produced naturally, increasing fish numbers and fisheries yields if spawning habitat is scarce or of poor quality [63]. Because reproduction in the water is impossible, certain fish populations in SWBs rely entirely on restocking [10]. Tilapia introductions have been amongst the most successful in SWBs fishery development worldwide. Several tilapia species have been introduced successfully into reservoirs in Africa, Asia, and South America [46,57,58,63]. Their implementation typically results in massive increases in fishery productivity in SWBs that retain lacustrine conditions with long water retention durations [10]. Restocking takes place in the nursery zones of various African dams and SWBs [38]. Because predators are eliminated, and fishing is prohibited in nursery areas, tilapia populations can grow in a predator-free environment [23].

However, in some cases, introductions have caused more harm than good [42]; thus, numerous preventative measures have been advocated [18]. Before beginning stocking or introduction programs, several issues should be thoroughly investigated (Cowx, 1999) [21]. Other management strategies could achieve fishery goals at a lower cost, with longer-term benefits, or with fewer changes to the existing biological community. The size and number of fish that must be stocked influence whether the endeavour is cost-effective and long-term [10]. If stocking must be continued indefinitely, other enhancing strategies may be more cost-effective in the long run [1]. Negative effects on the environment and biota should be adequately considered, and attempts should be abandoned if negative consequences are predicted (Cowx, 1999) [21]. This necessitates a thorough understanding of the biology and ecology of the species under consideration for introduction and careful consideration of the species' or related species' previous histories of introduction (FAO, 2010) [26].

As commercial fisheries become more difficult and less economically viable, the world is increasingly relying on aquaculture to supply fish for human consumption [20]. Stock enhancement, a closely related activity in which large numbers of fish are reared and then released, is a common practice aimed at increasing the number of fish in rivers and along coasts [64]. Aquaculture and stock enhancement practices raise some welfare and conservation concerns for the fish raised in captivity and for the local populations and habitats influenced by fish-rearing activities (FAO, 2010) [26].

Restocking of aquatic systems aim to replenish depleted fish stocks [3]. It could allow for the reduction of frozen fish imports and the restoration and protection of endangered species [29]. However, the promotion of restocking raises many questions about the species and strains to use and the arrangements to make for the long-term management of aquatic resources [3]. For example, restocking must be preceded by constructing artificial spawning grounds, which should not be undertaken without a thorough assessment of land-use factors, catchment environmental degradation, and the possibility of alien species invasion [10]. Ecological imbalances, changes in community structure, and loss of genetic integrity are potential risks bound to restocking [3]. Likewise, restocking fish outside of their native geographic ranges for fishery enhancement or other management purposes has frequently resulted in hybridization between native and introduced species [2].

There are various emerging efforts by fisheries managers to develop appropriate and viable methodologies for the inland lakes' sustainable management through restocking and introductions [48]. This demonstrates the socioeconomic value of restocking for communal benefits. Several studies have determined the carrying capacity of aquatic systems and yield and proposed various restocking mechanisms such as the use of native endemic fish species that require little or no supplementary feeding to boost production (e.g., [13,37,43,45,60]). However, there is limited information on the socioeconomic impact to the community after restocking has been undertaken. The present study fills this gap by looking into the socioeconomic implications of restocking SWBs to expand fisheries and aquaculture production in this post Covid era.

Materials and methods

Study area and sites sampled

The study was undertaken in the counties where the Aquaculture Business Development Programme (ABDP) is being implemented in Western and Central regions of Kenya. The counties included were Homa Bay, Migori, Kakamega, Kisii, Kisumu, Siaya, Busia, Kirinyaga, Nyeri, Meru, Tharaka Nithi, Embu, Kiambu, Machakos and Kajiado (Fig. 1). The SWBs which were considered for this survey were those that were restocked under the ABDP, and the first priority was given to those SWBs that had initially been assessed in the study on carrying capacity assessment of SWBs for Aquaculture Production [13,14] as well as others that had also been identified and restocked albeit without the initial baseline assessment.

Under this restocking programme, out of the 47 SWBs that were each stocked with tilapia fingerlings in May 2021, baseline information had been collected from 22 SWBs while 25 of them lacked the baseline information from the initial survey, also referred to as baseline (BL). Thirty-four (34) restocked SWBs were sampled in April 2022 in the endline survey (EL) and which was arrived at by considering the constrained period allocated and the vastness of the sites. Firstly, at least 2 SWBs per county which had baseline information were considered. In case of absence of baseline information, a dam per sub county and eventually, per ward (as administrative unit) was prioritised to still end up with 2 or 3 SWBs sampled per county. This was aimed at ensuring full representation of the ABDP counties.

Approach for socioeconomic impact development of restocked SWBs

Fig. 2 represents a schematic diagram linking the selected socioeconomic indicators of restocked SWBs in relation to the indicators of ecology and fish growth performance. The approach involved the use of physico-chemical characteristics of SWBs, restocked SWB's socioeconomic characteristics, and fish morphometric parameters.

Physico-chemical and ecology of restocked SWBs

Physico-chemical electronic sensor-based probes were used to take measurements at every sampling site. Data was immediately captured on field data sheets as well as the online Kobo Collect system for onward transmission and archiving. The main physical and chemical parameters measured using standard methods [4] were: water column depth (m), temperature (°C), dissolved oxygen (DO, mg L^{-1}), conductivity (μS cm^{-1}), pH, salinity (ppt), oxidation-reduction potential (ORP) and total dissolved solids (TDS, mg L^{-1}). Water transparency was measured using a standard Secchi disk (20 cm Ø).

Water sampling for laboratory analysis was conducted at three pre-selected sites and sampled; two at the littoral areas and one at the centre. The samples were then composited to make one sample. The water samples for soluble nutrient fractions were filtered and stored in polyethylene bottles under refrigeration at about 4 °C for further laboratory analyses.

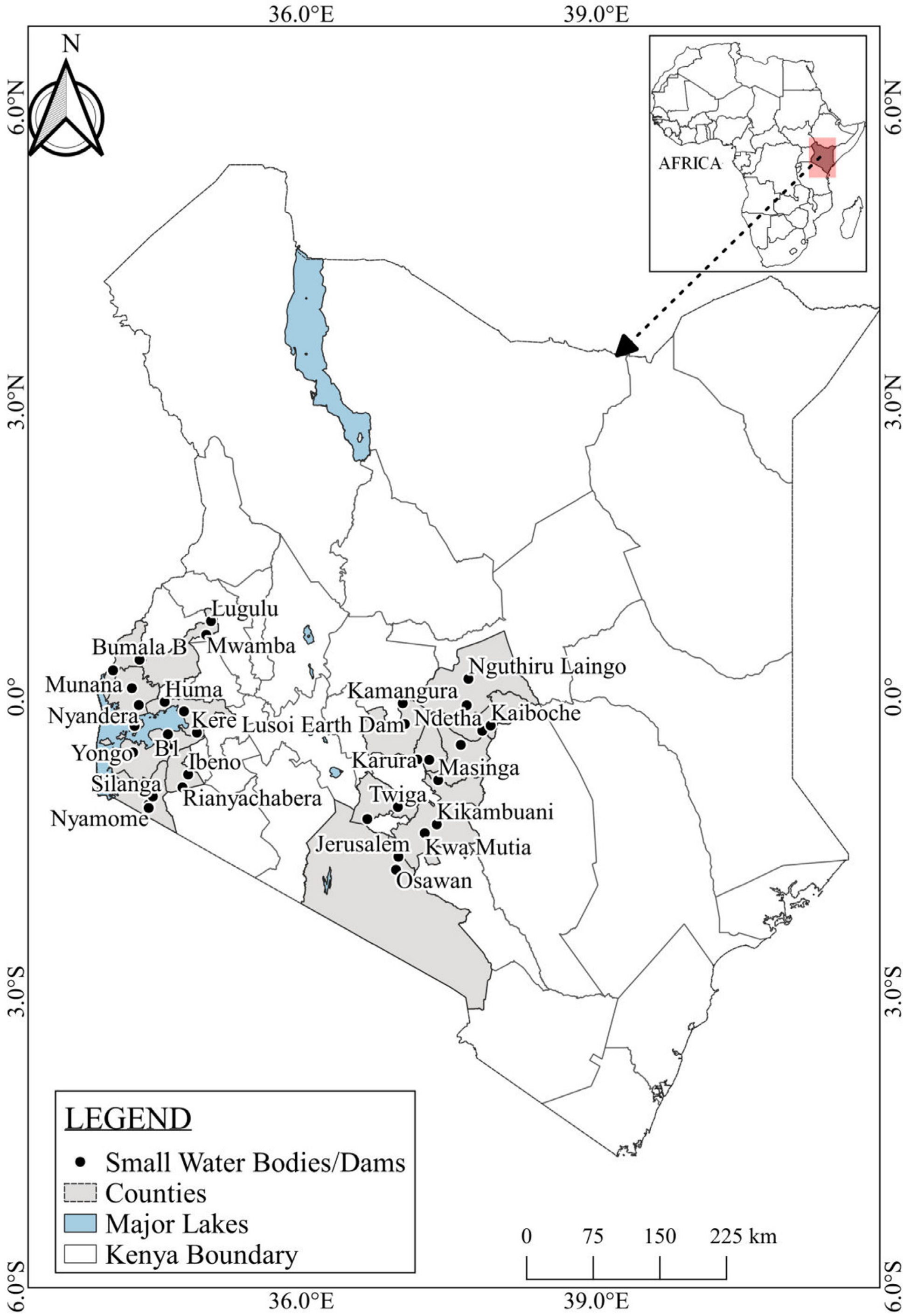

Fig. 1. Map of Kenya showing the 34 sampled SWBs for the endline survey (EL) activity in both Central and Western regions.

Samples for TN and TP were refrigerated without filtration. Samples for Chlorophyll-a were filtered using GF/C filters, securely wrapped in aluminium foil before refrigeration at about 4 °C and then later transported to the laboratory for further analysis [4].

Levels of nitrogen (ammonium-NH_4^+-N; nitrite-NO_2^--N; nitrate-NO_3^-- N; total nitrogen-TN), phosphorus (soluble reactive phosphorus-SRP; total phosphorus-TP), silicate species, chlorophyll-*a*, and total suspended solids (TSS) concentrations were analysed for all the study sites using standard methods described in APHA [5].

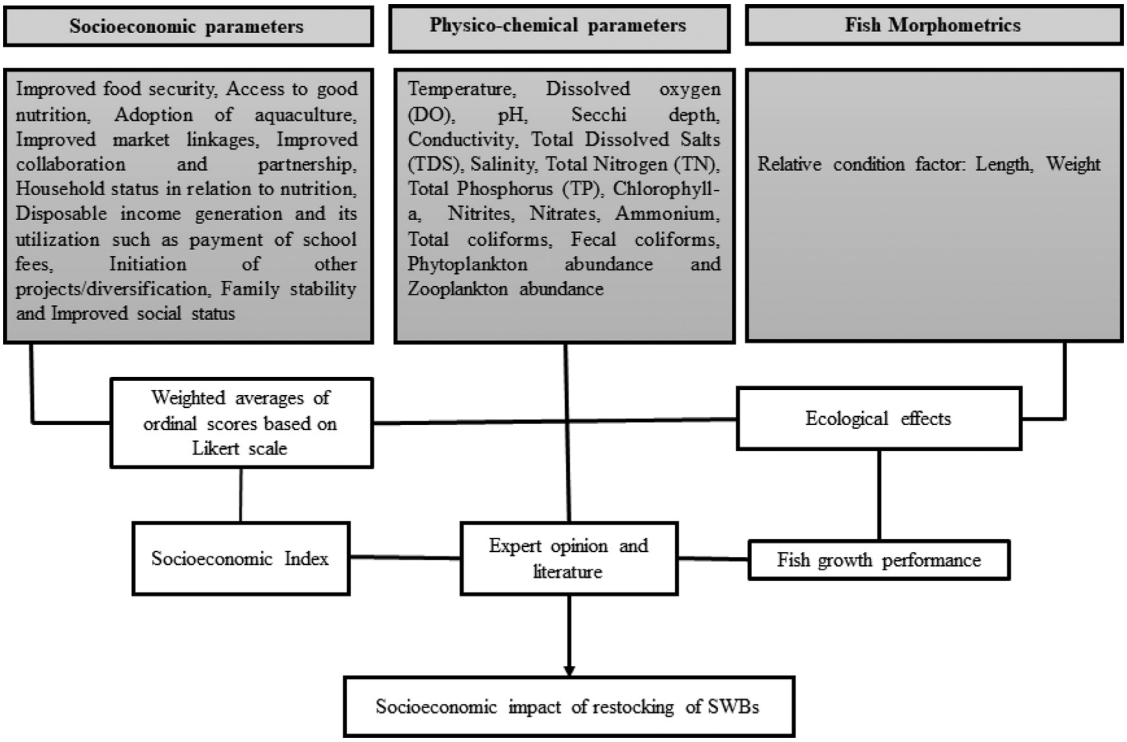

Fig. 2. Schematic representation towards the determination of socioeconomic impact of restocking SWBs using socioeconomic indicators associated with restocked SWBs, ecological factors affecting characteristics of Small Water Bodies (SWBs) and restocked fish growth performance in central and western Kenya.

Samples for phytoplankton were taken using a horizontal 2.2 L Van Dorn sampler from sub-surface to a 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 microscopy analysis. Phytoplankton cells were identified to species level, as much as possible, and counted using a Zeiss Axiovert 35 inverted microscope. The taxa were identified using the methods described by Huber–Pestalozzi [35].

Zooplankton samples were collected using a Nansen type plankton net of 60 μm mesh size and 30 cm aperture diameter. The net was lowered as close to the bottom as possible without disturbance and a vertical haul taken. Where this was not possible, a known volume of dam water was filtered. Samples were preserved in 5% formaldehyde solution. In the laboratory, samples were made to a known volume and sub samples of known volume taken and placed in a counting chamber using methods suggested by Korovchinsky [41]. Estimates of abundance of zooplankton were made from counts of sub samples under a Leica dissecting microscope (x25) considering the sample, sub-sample and water volume filtered.

Fish morphometrics from restocked SWBs

Fish samples were collected using a beach seine net 50 m long with a depth of 3 m and a stretched mesh size of 1 inch provided with a towing manila rope of 100 m reduced to 50 m due to the size of the SWBs. The net was mounted on a portable inflatable rubber dingy. The ropes were operated by at least 8 member teams boosted by the hired local community members. Catches were weighed to a range of 0.01 kg to 0.1 kg depending on their size. All the fish samples collected were sorted out according to families and identified to species level as described by Witte and Van Densen [67], although the target species was *Oreochromis niloticus* stocked earlier. The total length (TL mm), the standard length (SL mm), the total weight (g) were measured using a digital weighing scale. The fish sex, and where possible, the maturity status was determined as described by Bagenal [17].

Fish growth performance was estimated by determining the length-weight relationship, described by the equation W = aLb; where, W is the total body weight (g) and L is the total length (cm). Whereas a and b are the coefficients of the functional regression between W and L [9]. The condition factor (K) was determined to understand the health condition of fish by using the formula: K = 100 W/L3; where K = condition factor, W = weight (g) and L = Length (cm) [9].

Socioeconomic impact of restocked SWBs

Observations on the general environmental conditions of the SWB's catchment including land use patterns, substrate types, basin vegetation cover, and the climatic elements that may affect the benefits to be derived from the restocked dams were recorded immediately on arrival. A socio-economics status index (SES) that incorporated ten socio-economic dimensions related to fish restocking were: food security, access to good nutrition, adoption of aquaculture, improved market linkages, improved collaboration and partnership, household status in relation to nutrition, disposable income generation and its utilization such as payment of school fee, initiation of other projects / diversification, family stability and improved social status and were calculated as a measure of impact of the intervention.

The SES score was derived from weighted averages of the specific ordinal scores subject to the Likert scale ratings (3 = High; 2 = Moderate; 1 = Low). In this case, each response was assigned a weight from 1, 2, and 3, respectively. The 3-point scale was summed to obtain Total Weighted Score (TWS) for each factor while the Weighted Average Score (WAS) was computed by dividing TWS with a total number of responses. In order to determine the Likert scale rank for each factor, Eq. (1) was used [65].

$$\mathbf{WAS} = \frac{\mathbf{TWS}\ [(3\mathbf{xH}) + (2\mathbf{xM}) + (1\mathbf{xL})]}{\mathbf{Total\ number\ of\ respondents}} \tag{1}$$

where, WAS = Weighted Average Score; TWS = Total Weighted Score; H = High; M = Moderate; and L= Low.

The Sociometric Scale interval was calculated using Eq. (2) [65] and the overall socio-metric scale was segmented as: ≤2.34 High <3.00; ≤1.67 Moderate <2.33; ≤1.00 Low <1.66. The choice of the variables for the index construction was based on empirical studies on aquaculture [2].

$$\mathrm{SMS} = \frac{\mathrm{Max} - \mathrm{Min}}{\mathrm{N}} \tag{2}$$

Data analyses and interpretation

All the data was entered in Microsoft Excel spreadsheet and eventually analysed using R statistical software version 3.6.0 [59]. The physico-chemical and plankton data was compared using the non-parametric Kruskal–Wallis one-way ANOVA to examine the uncertainty of values and variations through pair-wise comparisons. Significance difference was assessed at $p < 0.05$.

Physico-chemical, fish growth performance and SES for each dam was tabulated and comparisons on baseline (BL, baseline information) and endline (EL, after restocking) surveys with reference values deduced inform of remarks and related to the socioeconomic impact performance of each SWB. Thereafter, conclusions and recommendations were drawn from the importance, weaknesses and gaps based on the socioeconomic performance of each SWB. The information was shared with policy makers at community level, county, and national level in order to develop mitigation measures as per the recommendations for each SWB.

Results and discussion

Physico-chemical parameters

Physico-chemical parameters in both central and western restocked small water bodies were within tolerable ranges for fish growth (Table 1). During the EL survey, pH levels was neutral with an average of 7.8 ± 0.3 and with a similar value during the BL survey; that were within the recommended range of 6 – 9 [61]. The TSS (average value of 136.41 ± 11.40), total coliforms (average value of 35×10^3 ind L^{-1}), *E. coli* (22.0×10^3 ind L^{-1}), ORP (within the range of 300–500 mV, [34]), salinity (< 0.02 ppt and within range), nitrites (within range of 0.75–5 mg L^{-1}), nitrates (0–40 mg L^{-1}) [61], and ammonium (within range of 0.06 ppm at pH 9 and temperature of 25 °C to 160 ppm at pH 6 and temperature of 5 °C, L-Shafey, 1998) were within limits of optimum concentrations for fish growth and survival.

Other notable physico-chemical parameters recorded were within range for fish growth and they included SRP (within range of < 15 µg L^{-1}), Hadness (< 150 mg L^{-1}), TP (within range of 10–15 µg L^{-1}), and TN (within range of < 75 µg L^{-1}) [61]. The primary and secondary productivity of the EL survey consisting of Chlorophyll-a (>7.5 and <40 µg L^{-1} for Lake Victoria, [7,11,39]), phytoplankton abundance (> 300 ind L^{-1}) and zooplankton abundance (> 100 ind L^{-1}), respectively, showed good ecological health and SWBs production which could support fish restocking and farming [39]. Table 1 shows other vital physico-chemical parameters that were recorded in restocked SWBs. Although the data for each parameter is missing in some expeditions, the available data showed consistency towards providing variable conditions for supporting the growth and survival of restocked tilapia fish in terms of temperature (20–31 °C for fish adapted to higher temperatures, < 20 °C for fish adapted to low temperatures, Mires 1995) [68], DO (≥ 3 mgL^{-1}, [61]) and conductivity (< 200 µScm^{-1}, [8]).

Restocked fish condition factor (K)

The condition factor (K) for specimens sampled in all the SWBs was approximately > 1.00 (Fig. 3) with an average value of 1.24 ± 0.53 SD, suggesting that the fish were in excellent growth condition. The condition factor is a parameter that depicts the well-being of a fish and reflects the current feeding conditions of the fish [22]. Therefore, it can be used

Table 1
Means (± < 1.0 values) of physico-chemical variables for baseline (BL) and endline (EL, after restocking) surveys conducted in 15 counties in central and western counties of Kenya under the Aquaculture Business Development Programme (ABDP). – (dash) = no data available.

Region	County	Dam	Temperature (°C)		DO (mg L^{-1})		Conductivity (µS cm^{-1})	
			BL	EL	BL	EL	BL	EL
Central	Embu	Ithatha	23.7	25.45	4.81	4.18	_	667.66
		Masinga	25.80	28.58	5.7	5.65	_	668.86
	Machakos	Kikambuani	_	22.9	_	5.85	_	630.06
		Kwa mutia	_	24.13	_	6.52	_	631.35
	Kiambu	Twiga	22.40	24.58	7	5.54	_	635.74
		Ringiri quarry	20.80	24.07	7.6	7.82	_	1.37
	Kajiado	Jerusalem	_	21.95	_	3.53	_	679.53
		Endiro	_	24	_	9.6	_	675.1
	Kirinyaga	Makoka Kangai	20.9	_	6.7	66.1	_	_
		Karura	24.4	_	6.4		_	_
	Nyeri	Lusoi Earth Dam	_	21.7	_	_	_	386.4
		Kamangura-Mikomboni	_	20		_	_	291.3
	Meru	Nguthuro-Laingo	22.3	24.3	7.2	_	_	386.5
		Kiambogo	_	27.2	_	_	_	386.4
	Tharaka Nithi	Ndetha	29.40	_	5.2	_	_	_
		Tharaka-Kaiboche	_	_	_	_	_	_
Western	Busia	Munana	24.6	26.4	3.81	6.325	_	380
		Bumala B	_	26.55	_	5.875	_	99.85
	Homabay	B1	_	29.2	_	4.45	_	144.1
		Pap Orange	22.40	26.2	2.2	5.94	_	144.7
		Yongo	25.50	25.2	2.66	6.78	_	438.7
	Kakamega	Lugulu	22.7	23.65	7.26	5.605	_	332.1
		Mwamba	_	23.15	_	3.53	_	145
	Kisii	Ibeno	28.00	25.6	_	7.46	_	36.4
		Rianyachabera		23.8	_	6.2	_	69.4
	Kisumu	Buoye	24.70	26	552	6.7	_	195
		Huma	24.10	22.1	7.64	5.83	_	148.6
		Kere	24.1	22.1	7.64	5.83	_	148.6
	Migori	Nyagesese	_	27	_	6.04	_	90.9
		Nyamome	_	26	_	7.28	_	196.2
		Silanga	_	26.4	_	6.24	_	25.1
	Siaya	Nyandera	_	28.75	_	3.99	_	389.6
		Adhiri	_	24.10	_	3.11	_	97.3
		Uranga	24.50	25.05	2.59	5.59	_	194

to determine whether the fish are utilizing their feeding source [32,44]. The condition factor of > 1.00 indicated that the restocked fish were well fed and in healthy condition.

Socioeconomic impact of restocked SWBs

The current EL study recorded no restocked SWB with low socio-economic index indicative of the potential of restocking of SWBs for future investment in such systems to supplement capture fisheries and aquaculture (Table 2). Hitherto, majority (n = 27; 79%) of the restocked SWBs had moderate impact that may have been attributed to the inception limitations of such an activity in natural environments. Several authors have observed the lack of quick adoption of such projects by the intended local communities due to culture, differences in the main economic activity and low level of cohesiveness [11,54,55]. One of the main constraints encountered in a moderately scored SWB was the inaccessibility by the local community to harvest the restocked fish since restocking due to management restrictions or lack of fishing gear. Other notable reason was some of the community's focus on the dominant agricultural socioeconomic activity, and where restocked tilapia received little attention. However, those with high impact (n = 7; 21%) had favourable socio-economic and environmental conditions and were able to access the restocked fish to add to their food nutritional value and as a source of income for their households.

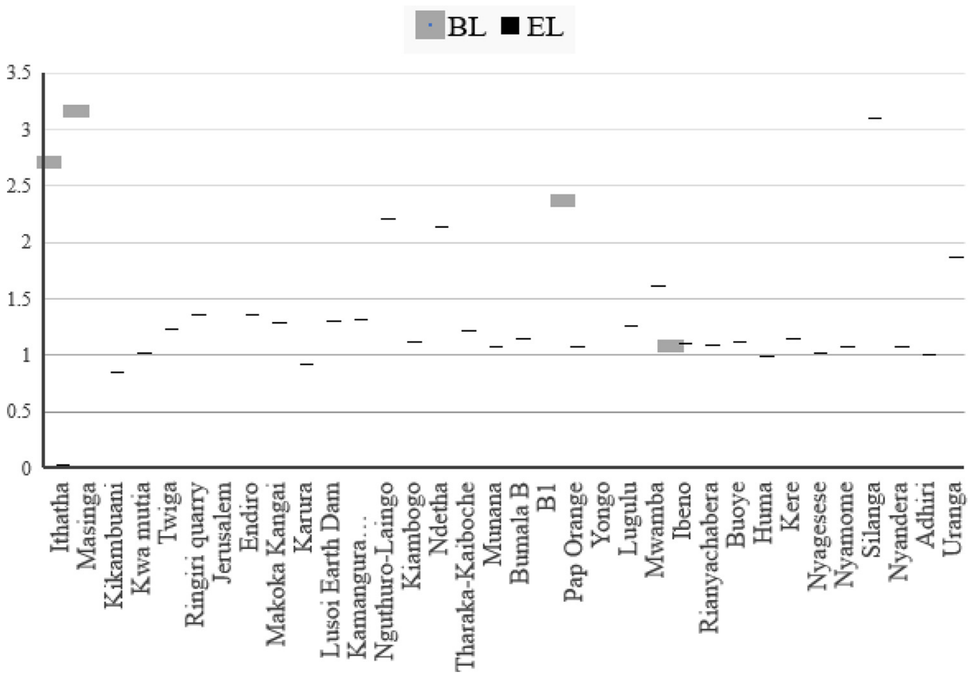

Fig. 3. Condition factor of baseline (BL) and endline (EL) surveys for 34 SWBs in 15 counties under the Aquaculture Business Development Programme (ABDP) in central and western counties of Kenya. Data for BL was only available for 4 SWBs, the remaining 30 SWBs had only EL data.

Table 2
The socioeconomic impact of restocked SWBs during the endline survey (EL) under the Aquaculture Business Development Programme (ABDP) in 15 counties of central and western regions of Kenya. Reference value: ≤2.34 High <3.00; ≤1.67 Moderate <2.33; ≤1.00 Low <1.66.

Region	County	Dam	Observed value	Impact
Central	Embu	Ithatha	2.28	Moderate
		Masinga	2.37	High
	Machakos	Kikambuani	2.28	Moderate
		Kwa mutia	2.05	Moderate
	Kiambu	Twiga	2.73	High
		Ringiri quarry	2.33	Moderate
	Kajiado	Jerusalem	2.50	High
		Oswan	2.27	Moderate
	Kirinyaga	Makoka Kangai	2.88	High
		Karura	2.28	Moderate
	Nyeri	Lusoi Earth Dam	2.48	High
		Kamangura-Mikomboni	2.18	Moderate
	Meru	Nguthuro-Laingo	2.33	Moderate
		Kiambogo	2.23	Moderate
	Tharaka	Ndetha	2.30	Moderate
	Nithi	Tharaka-Kaiboche	2.13	Moderate
Western	Busia	Munana	2.12	Moderate
		Bumala B	2.28	Moderate
	Homabay	B1	2.24	Moderate
		Pap Orange	2.28	Moderate
		Yongo	2.17	Moderate
	Kakamega	Lugulu	2.33	Moderate
		Mwamba	2.16	Moderate
	Kisii	Ibeno	2.12	Moderate
		Rianyachabera	2.20	Moderate
	Kisumu	Buoye	2.12	Moderate
		Huma	2.10	Moderate
		Kere	1.88	Moderate
	Migori	Nyagesese	1.86	Moderate
		Nyamome	2.33	Moderate
		Silanga	2.08	Moderate
	Siaya	Nyandera	2.50	High
		Adhiri	2.58	High
		Uranga	1.92	Moderate

Conclusion and recommendations

The average condition factor (K) of tilapia in restocked SWBs was 1.24 ± 0.53 SD, suggesting that the fish were in excellent growth condition. Water conditions also revealed that the studied SWBs had good primary and secondary productivity necessitating the need to invest in such systems through fish restocking. Additionally, most dams registered moderate to high socioeconomic impact on riparian communities. These findings indicate that restocking the SWBs with tilapia was beneficial to the riparian communities, since the species rapidly established itself. Given the limited exploitation of fish in some SWBs, additional community awareness and capacity building interventions are needed to realize the enormous potential identified during the survey. Riparian communities will benefit from improved livelihoods as well as food and nutrition security. Overall, it is recommended that additional SWBs restocking with tilapia will broaden the geographic scope and community coverage of aquaculture business enterprises. The suggested actions include the following:

- i Provision of fishing equipment (crafts and gear) to SWB communities in order to encourage them to explore fishing as a form of income diversification.
- ii SWB fencing to prevent encroachment and possible pollution from dispersed sources.
- iii Desilting and reengineering SWB structures and nearby ecosystems to reduce sediment and pollutant loading; and
- iv Future restocking to be undertaken after considering environmental and social characteristics of each SWB and its locality.

Data availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Declaration of Competing Interest

The authors have no conflict of interest.

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