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Trophic Status and Development of Aquaculture Management Areas (AMAs) For the two Major Reservoirs: Tono and Vea, in the Upper East Region of Ghana

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Abstract

Background: The development of aquaculture management areas (AMAs) is opined as one of the strategies to ensure sustainable aquaculture. AMAs allows collaborative management of individual fish farms in a coordinated manner within a demarked space, where water resources and aquaculture impacts are shared in an environmentally harmonised way. This study seeks to evaluate the trophic status and develop potential AMAs for the Tono and Vea reservoirs in the Upper East Region of Ghana.

Materials and Methods: Reservoir water depth, transparency, chlorophyll-a, nitrate-nitrogen, nitrite-nitrogen, ammonium-nitrogen and phosphorus concentrations was monitored for 15 months (February 2015-April 2016). The trophic status of the water was estimated from the concentrations of the water quality parameters after laboratory analysis. The composite values obtained were integrated into a tropic level index (TLI) equation and values compared to standard nutrient enrichment categories. The AMAs were demarcated from suitable zones within the reservoirs based on percentage allocation of the reservoirs' aquaculture carrying capacity and other factors peculiar to each reservoir.

Results: The trophic level index (TLI) showed that the Tono reservoir is super trophic (TLI: 5.23) indicating very high nutrient enrichment category, whiles the Vea Reservoir is eutrophic (TLI: 4.32) indicating high nutrient enrichment. Three potential AMAs were generated for the Tono reservoir and five AMAs for Vea reservoir, with allowable daily feed loading of 388.48 and 35.40 kg, respectively. These AMAs can produce a maximum of 107.91 and 9.83 metric tonnes of fish per production cycle in a year in Tono and Vea reservoirs, respectively.

Conclusion: The high trophic status in both reservoirs could be bio-manipulated by culturing filter-feeding planktivorous fish such as Nile tilapia. AMAs identified should be backed with policies and strategies for implementation of maximum fish production on quota basis, coupled with regular water quality monitoring programmes and continuous stakeholder engagement and participation.

Keywords: Aquaculture management area; Reservoir; Trophic status; Sustainable aquaculture; Upper East Region

Introduction

Reservoirs are often considered as artificial lakes created by the impoundment of rivers or streams, primarily for water storage, irrigation, flood control and domestic use as well as supporting capture fisheries. Generally, most reservoirs have high productivity shortly after inundation [1]. Recently, the use of reservoirs and other lentic water bodies (lakes, dugouts). for culture-based fisheries or aquaculture development is increasingly being promoted [2-9]. These studies have highlighted the potential adverse environmental impacts of aquaculture development on reservoir water quality. Most of these studies, however, did not emphasize the importance of aquaculture management areas (AMAs) for sustainable fish production in reservoirs.

Eutrophication is one of the challenges of aquaculture development, particularly with cage culture in most lentic water bodies. Thus, the trophic status in terms of primary productivity or the trophic relations between organisms are often investigated. In the aquatic environment, water bodies are distinguished as oligotrophic, mesotrophic, eutrophic, and dystrophic according to their nutrient status. The nutrient status of a water body is commonly used as an index of the general health of the aquatic ecosystem - especially, those systems that have been severely altered as result of anthropogenic activities such as water pollution and other physical disturbances [10]. Development of aquaculture management areas (AMAs) in shallow reservoirs could threaten the aquatic ecosystems and the livelihoods of riparian communities that depend on it, if the trophic status are not known.

Aquaculture management areas (AMAs) can be aquaculture parks, clusters or any aquaculture area within a zone where farms share a common water body or water source and where farms may benefit from a common management system aimed at minimizing environmental, social and fish health risks [1]. AMAs can also be beneficial for groups of small farmers seeking joint access to feed, seed and technical support services. Other important considerations in the designation of AMAs are the provision of access to markets and very importantly, conflict resolution with other users of common resources. AMAs require an

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administrative structure and a management system that includes setting limits to the maximum production per area according to carrying capacity, distance among the farms, and density of fish within farms. Such a system should include monitoring and remedial action plans for environmental quality, fish health, and other relevant parameters. The creation of AMAs could be a significant step forward for sustainable growth in aquaculture in regions where the farms are already operating and having difficulty with diseases and/or negative environmental impacts. AMAs also offer an opportunity for collective certification of products under an ecosystem perspective. Thus, an aquaculture zone could be an area where aquaculture is formally allowed after appropriate participatory process to design the zone and its use, taking into consideration the economic, social and environmental objectives and related risks. AMAs provide aquaculture opportunities in a coordinated manner under an aquaculture management area plan. The study could provide individual fish farmers, Fisheries Officers, aquaculture stakeholders and policy makers, a sustainable approach for allocation of individual fish farms in a given demarcated area. It can also be important for collective certification of fish and fish products.

Previous studies in most reservoirs and dugouts including Tono and Vea reservoirs in Upper East Region, Ghana [2-6] indicates that, the trophic status of these reservoirs and dugouts had not been explicitly studied to warrant zonation and implementation of AMAs for cage fish farming. The objective of this study was to determine the trophic status of the Tono and Vea reservoirs and explore potential aquaculture management areas in these two reservoirs for cage culture to enhance sustainable aquaculture.

Materials and Methods

Study area

The Tono and Vea reservoirs are the two major reservoirs of ecological and socio-economic importance in the Upper East Region, Ghana, West Africa. The Tono reservoir is located at 10°53'39" north and 1°9'57" west whiles Vea reservoir is $10^{0}52'0"$ north and $0^{0}51'0"$ west (Figure 1). Tono and Vea reservoirs were created by impoundment of the Sissile and Yarigatanga rivers, respectively. These reservoirs are public water resource managed by the Irrigation Company of Upper Regions (ICOUR), a governmental agency. The reservoirs had previously been studied for cage culture and suitable zones for cage placement [11] (Figure 1).

Water sampling and quality assurance

The Tono and Vea Reservoirs were zoned into three sections based on the direction of water flow for sampling purposes, namely; Upstream (us), midstream (ms) and down streams (ds) zones. Water samples were collected monthly from February 2015 to April 2016 using linear stratified sampling technique with three replicates from each zone or strata. That is, a total of nine sampling stations in each reservoir.

In-situ measurement of water temperature (TEM) and pH using the Hanna HI 83141 portable water meter, water depth (WD) measured with a metric tape and transparency (TRA) in terms of Secchi disc depth (SDD). Water samples for nutrient analysis were collected into 1000 ml high density polyethylene (HDPE) bottles, which were prewashed with dilute hydrochloric acid (10%) and re-washed three times on-site with the reservoir water before sampling. Water samples were collected at mid-depth (0.5-1.5 m). The nutrients that were analysed were phosphate-phosphorus (PO_4^{2-}), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), and ammonium-nitrogen (NH_4-N). For hydro-biological analysis, chlorophyll-a (CHL-a) samples were collected into 500 ml bottles covered with black plastic sheets and stored in the dark in a cool ice box to prevent deterioration of chlorophyll pigments in sunlight.

All water samples were stored in cool box (insulation boxes) at 4°C to minimize temperature effects on samples during transportation for laboratory analysis. All samples were transported (<24 hours) to CSIR-Water Research Institute's Laboratory in Tamale for analysis.

Laboratory analysis

Standard protocols for water stabilization, storage and water quality analysis were followed according to standard analytical methods for examination of water and waste-water [7,8]. Water quality samples consisting of nutrients for laboratory analysis were done using 50 ml of the sample with appropriate reagents through titration and colour indicator methods. The analytical methods used are summarized in Table 1. Samples were kept in a refrigerator at 4°C until analysis were completed (approximately in 3 days).

Primary productivity in the form of algal chlorophyll (chlorophyll-a) was determined using spectrophotometric method (Table 1), Water samples were filtered into a 50 ml centrifuge tube and then 10 ml was taken after aqueous acetone (90%) extraction in the laboratory. The supernatant was poured into a 1 cm cuvette. The spectrophotometer was zeroed with 90% acetone and readings taken at 663 nm, 645 nm, 630 nm extinctions. Final chlorophyll-a values were calculated using a given equation [8].

Estimation of Trophic status

The trophic status of the Tono and Vea reservoirs were determined from the trophic level index (TLI). Concentration of total phosphorus (PO_4^{2}–P), total nitrogen (nitrate-nitrogen, nitrite-nitrogen, and ammonium-nitrogen), transparency (SDD) and chlorophyll-a levels were combined to construct the TLI for both reservoirs. Estimation were based on these four trophic state indicator variables (Equations 1-4) and computed into the final TLI (Equation 5), as indicated below. These formulae were derived from the equations recommended by Lim and Webster [10]. The TLI values obtained were compared with trophic level thresholds accordingly [10]. Thus, the higher the TLI value, the worse the water quality.

$TL_{nitrogen} = -3.61+3.01 \log (N_{total})$ Equation (1)

$TL_{phosphorus} = 0.218+2.92 \log (P_{total})$ Equation (2)

$TL_{transparency} = 5.10+2.27 \log (1/\text{Secchi disc depth} - 1/40)$ Equation (3)

$TL_{chlorophyll-a} = 2.22+2.54 \log (\text{chl-a})$ Equation (4)

$TLI = (TL_{nitrogen} + TL_{phosphorus} + TL_{transparency} + TL_{chlorophyll-a})/4$ Equation (5)

Where,

TL: Trophic Level, $N_{total:}$ Total Nitrogen, P_{total}: Total Phosphorus

Development of aquaculture management areas (AMAs)

Areas suitable for aquaculture obtained from previous studies [12] were demarcated into clusters or zones called aquaculture management areas (AMAs) based on several factors. The factors considered during the demarcation for the development of AMAs in the Tono and Vea reservoirs were trophic status, aquaculture carrying capacity, feed conversion rate (FCR), stocking density, expected bulk fish weight (fish yield) and average weight of fish for the two reservoirs (Figure 2). Ecologically sensitive areas for wildlife or aquatic birds were avoided. Site or zones for social good such as areas near water abstraction

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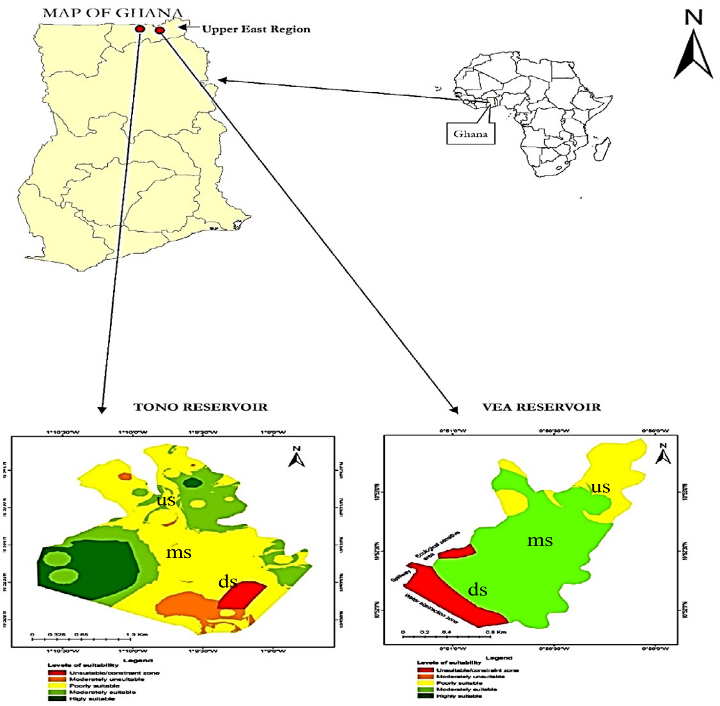

Figure 1: Tono and Vea reservoirs showing suitable aquaculture zones (in green colour) for development of aquaculture management areas.

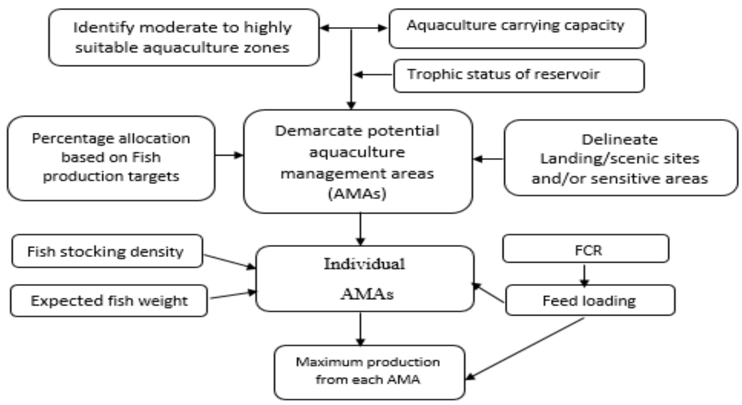

Figure 2: Conceptual model for development of aquaculture management areas (AMAs) at Tono and Vea reservoirs.

points and navigation routes were demarcated to avoid social conflicts. Allocation of existing and potential fish landing sites were inferred from key informants: fishers operating on the reservoir more than 5 years, fishery officers from Fisheries Commission, managers of the reservoir from the Irrigation Company of Upper Regions and riparian community members. Based on these factors, AMAs were generated within the suitable zones in the reservoirs (Figure 2).

The number of fish to stock was calculated from the simple equation: Ns = Wc/W

Where; Ns is the number of fish to stock per m^3 of cage,

Wc is the expected total fish weight per cubic meter of cage at harvest,

Parameters	Method
PO_4^{2-}- P	Stannous chloride method
NO_3-N	Hydrazine reduction method
NO_2-N	Diazotization method
NH_4-N	Direct nesslerization
Chl-a	Spectrometry by acetone extraction

Table 1: Summary of analytical methods used for water quality determination of samples from Tono and Vea reservoirs (February 2015 – April 2016).

W is the desired mean fish weight at harvest.

Expected total (bulk) weight was proposed as 150 kg per cubic meter based on the low volume High Density (LVHD) cage culture Technology adopted for this study [13]. The LVHD cages have higher productivity and better water exchange efficiency (>50%) compared to conventional cages with bigger volume [13]. Also, LVHD cage culture could be more suitable for shallow reservoirs like Tono and Vea. The expected average weight was set at 250 g based on cage culture feasibility studies conducted in Vea reservoir [3] and observed fish market demands of the area.

Expected cage volume (Cv) per AMA was estimated from the equation: $Cv = \% A \times CC$,

Where, % A is the percentage area allocation, CC is aquaculture carrying capacity of the reservoir.

Under the assumption of 180 days' culture period (Cp) to produce 150 kg m^{-3} of fish, feed conversion rate of 1.5, Ns = 600 individual fish (fingerlings), initial stocking weight of fish: 5 g,

Thus, $600 \times 5 = 3000$ g $\equiv$ 3 kg of fish, Actual weight gained (Wg):150-3 = 147 kg,

Feed requirement/m (Fr): (Wg/FCR)/Cp, [(147/1.5)/180 = 0.54 kg m^{-3}]

Therefore, feed loading as allowable feed (Fl) per day in each AMA was estimated from the equation: $Fl = Cv \times Fr$

The maximum production (Mp) of fish per AMA was estimated from equation: $Mp = Wc \times Cv$, where, Wc is expected weight per cubic metre (m^3) and Cv is the expected cage volume.

Data analysis for water quality variables to obtain mean values, ranges, standard error, and summation were performed in Microsoft excel (Version 2013). The outputs were presented in tables and figures. Suitable zones generated, demarcated and identified as potential AMAs were further verified by ground-truthing and multi-stakeholder confirmation.

Results

Trophic status of reservoirs

Four water quality variables; transparency, total phosphorus, total nitrogen and chlorophyll-a representing the physical, chemical and biological components in relation to trophic status of reservoirs and lakes were identified and computed as inputs for trophic level index (TLI) estimation (Table 2) [14-17].

Results from the water quality and nutrient loading (total nitrogen and total phosphorus) indicated that the Tono and Vea reservoirs were ultra-micro and oligo trophic, respectively (Tables 3 and 4). The combined effects of four trophic indicators showed that Tono reservoir has a trophic level index (TLI) of 5.23, which indicates that the reservoir had very high nutrient enrichment, and thus super trophic (Table 3). Similarly, the Vea reservoir with the trophic level index (TLI) of 4.32, indicates that the reservoir was high in nutrient and thus eutrophic (Table 4). But the primary productivity in terms of chlorophyll-a indicated meso-trophic and ultra-micro trophic status for the Tono and Vea reservoirs, respectively (Tables 3 and 4).

Development of potential Aquaculture Management Areas (AMAs)

Suitable zones identified from previous studies [11] were inferred and further delineated. The re-mapping produced sub-zones or clusters called aquaculture management areas (AMAs) that can be managed under a given management option which is socially acceptable to all stakeholders. Having considered various social-infrastructural factors (delineation of sites for water abstraction, navigation route, fishing areas and fish landing sites), three potential AMAs for the Tono reservoir and five potential AMAs for Vea reservoir were generated in the suitable zones within the reservoirs (Figures 3 and 4). From these areas, different sizes of AMAs would have varying degrees of fish production potential based on the aquaculture carrying capacity.

Allocation of production targets based on the aquaculture carrying capacity and trophic status indicates that the amount of fish feed loading that could be allowed within each AMAs should be different (Tables 5 and 6). Although, the Vea reservoir had more AMAs, the maximum fish

Parameters	Tono reservoir		Vea reservoir	
	Mean (SE)	Range	Mean (SE)	Range
SSD (m)	0.5507 (0.0546)	0.35-1	0.4256 (0.027)	0.2-0.56
Chl-a (mg m^{-3})	1.3653 (0.0434)	1.21-1.74	0.0606 (0.003)	0.079-0.5
PO_4^{2-} (mg m^{-3})	101.7 (12.9)	33-191	51.8 (12.6)	1-110
NH_4-N (mg m^{-3})	3174 (643.5)	250-7830	786.7 (15.2)	730-890
NO_3^{2}-N (mg m^{-3})	2990.33 (966.8)	12-11130	2486.1 (803.5)	160-9110
NO_2-N (mg m^{-3})	256.33 (83.2)	8-1050	32.8 (3.8)	9-50
T. Nitrogen (mg m^{-3})	6420.66 (1693.5)	270-20010	3305.6 (822.5)	899-10050
SE: Standard Error, Mean values were used in estimation of TLI, T: Total, SSD: Secchi Disc Depth, Chl-a: Chlorophyll-a				

Table 2: Descriptive statistics of water quality variables for trophic level index (TLI) estimation in Tono and Vea reservoirs (February 2015 – April 2016).

Trophic state	Nutrient E.C.	TLI	Chl-a (mg m^{-3})	SDD (m)	T. phosphorus (mg m^{-3})	T. nitrogen (mg m^{-3})
Ultra-micro trophic	Practically pure	0.0-1.0	<0.33	>25	<1.8	<34 (7.85)
Micro trophic	Very low	1.0-2.0	0.33-0.82	25-15	1.8-4.1	34-73
Oligo trophic	low	2.0-3.0	0.82-2.0	15-7	4.1-9.0 (4.81)	73-157
Meso trophic	Medium	3.0-4.0	2-5 (2.56)	7.0-2.8 (5.68)	9.0-20	157-337
Eutrophic	High	4.0-5.0	5.0-12.0	2.8-1.1	20-43	337-725
Super trophic	Very high	5.0-6.0 (5.23)	12-31	1.1-0.4	43-96	725-1558
Hyper trophic	Saturated	>6.0	>31	<0.4	>96	>1558
E.C: Enrichment Category; TLI: Trophic Level Index; Chl-a: Chlorophyll-a; SDD: Secchi Disk Depth; T.: Total						

Table 3: Estimated trophic state (values in bold parenthesis) and corresponding quantitative parameters of the trophic level index for Tono reservoir.

Trophic state	Nutrient E.C.	TLI	Chl-a (mg m^{-3})	SDD (m)	T. phosphorus (mg m^{-3})	T. nitrogen (mg m^{-3})
Ultra-micro trophic	Practically pure	0.0-1.0	<0.33 (-0.87)	>25	<1.8	<34 (6.98)
Micro trophic	Very low	1.0-2.0	0.33-0.82	25-15	1.8-4.1	34-73
Oligo trophic	low	2.0-3.0	0.82-2.0	15-7	4.1-9.0 (5.22)	73-157
Meso trophic	Medium	3.0-4.0	2-5	7.0-2.8 (5.93)	9.0-20.0	157-337
Eutrophic	High	4.0-5.0 (4.32)	5.0-12.0	2.8-1.1	20-43	337-725
Super trophic	Very high	5.0-6.0	12-31	1.1-0.4	43-96	725-1558
Hyper trophic	Saturated	>6.0	>31	<0.4	>96	>1558

E.C: Enrichment Category; TLI: Trophic Level Index; Chl-a: Chlorophyll-a; SDD: Secchi Disk Depth; T.: Total

Table 4: Estimated trophic state (values in bold parenthesis) and corresponding quantitative parameters of the trophic level index for Vea reservoir.

Tono	% Allocation*	Projected cage vl.m^{-3}	Feed load/d/kg	Max. pdtn. (kg)
AMA 1	0.3	215.82	116.54	32373.00
AMA 2	0.65	467.61	252.51	70141.50
AMA 3	0.05	35.97	19.42	5395.50
Total		719.4	388.48	107,910.00

*65%, 30% and 5% of production target allocation within suitable zones from suitable zones.
vl.: volume, FCR: 1.5, Develop with 1 km between cluster and 10m between cages as buffer zone as recommended by the Ghana National Aquaculture Code of Practice and guidelines, and Fishery Regulation Act.2010, (L.I. 1968).

Table 5: Aquaculture management areas and production plan for Tono reservoir.

Variables	% allocation*	Projected cage vl.m^{-3}	Feed load/d/kg	Max. pdtn. (kg)
AMA 1	0.04	2.622	1.42	393.30
AMA 2	0.06	3.933	2.12	589.95
AMA 3	0.5	32.775	17.70	4916.25
AMA 4	0.3	19.665	10.62	2949.75
AMA 5	0.1	6.555	3.54	983.25
Total		65.55	35.40	9,832.50

*4%, 6%, 50%, 30% and 10% of production target allocation within suitable zones.
vl.: volume, FCR: 1.5, Develop with 1 km between clusters and 10m between cages as buffer zone as recommended by the Ghana National Aquaculture Code of Practice and guidelines, and Fishery Regulation Act. 2010, (L.I. 1968).

Table 6: Aquaculture management areas and production plan developed for Vea reservoir.

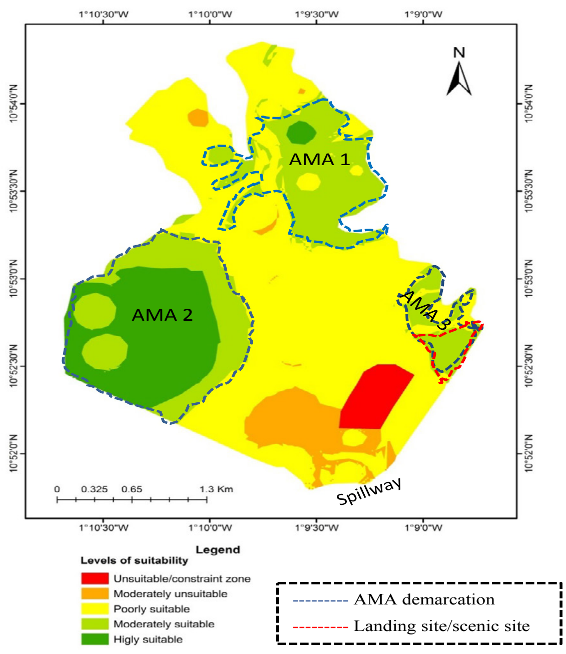

Figure 3: Aquaculture management area map generated for aquaculture development in Tono reservoir.

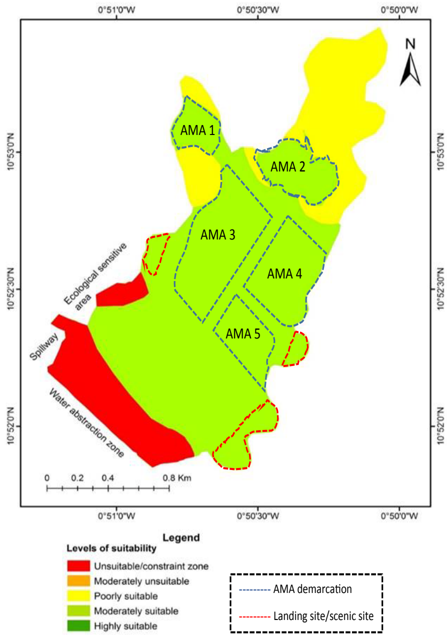

Figure 4: Aquaculture management area map generated for aquaculture development in Vea reservoir.

production from its AMAs was 9, 835 kg compared to 107, 910 kg for Tono reservoir (Tables 5 and 6). The results indicated that, reservoirs with more social-infrastructural consideration could have less AMAs which leads to lower potential for fish production apart from the size of the reservoir being a limiting factor.

Discussion

Trophic status and aquaculture management areas

The trophic status of a water body is determined by the integration of several ecological change indicators to obtain trophic indices. Variation in methods of estimation of trophic status for lakes and reservoirs makes it difficult for objective comparison. This is because fish productivity in reservoirs is considered to be dependent on morphometric, edaphic and climatic factors with emphasis on nutrient availability and primary productivity; thus, oligotrophy is seen as trophic status that needs to be corrected [18].

Carlson's trophic state index (TSI), TRIX index, trophic diatom indices, benthic trophic state index, oligochaete trophic index, trophic level index (TLI) are commonly used for trophic state indices. The latter index, TLI is seen as more robust and reliable as it involves more nutrients that affects eutrophication. The TLI integrates the important limiting nutrients in water, namely phosphorus and nitrogen (nitrite-nitrogen, nitrate-nitrogen, ammonium-nitrogen), in addition to those that are conventionally used (transparency: Secchi disc depth and chlorophyll-a) for assessment of eutrophication status in lakes and reservoirs, with other sophisticated ones conducted using various water quality models [14]. Other studies suggest the use of nitrite-nitrogen based TSI as nitrites are easily converted to nitrate through nitrification, decreases the fluorescence and affects photosynthesis; thus analogous to Carlson's index [12].

The higher the number of indicators used for the estimation of trophic index, the better [17]. Thus, this could have enhanced the efficiency of the trophic level index (TLI) obtained for both reservoirs as four major indictors were used: transparency (SDD), chlorophyll-a, total phosphates, and total nitrogen as TLI; compared to less indictors used in the Carlson trophic state (TSI). The estimated trophic levels of chlorophyll-a and transparency (SDD) in the Tono reservoir indicated that the reservoir was meso-trophic. However, further analysis involving the nutrients indicate Tono reservoir was super eutrophic (TLI: 5.23) and thus, very high in nutrient enrichment. This study showed that the use of the TLI could provide a more comprehensive way of assessing the physical, chemical and biological status of reservoirs and lakes.

Observed ecological changes (trophic levels) that may occur within a given aquatic habitat helps in futuristic management options that should be deployed. Eutrophication could be minimized through nutrient control, bio-manipulation, regulations, public awareness, environmental education and changes in social and cultural perspectives of lakes and reservoirs [16]. In this study, the Tono and Vea reservoirs have varying degrees of eutrophication (from very high to high) which could be bio-manipulated for cage culture by using filter-feeding planktivorous fish such as tilapia. With compensatory high dissolved oxygen concentration (>5 mg l^{-1}) as observed in Tono and Vea reservoirs, cage culture of tilapia in these trophic waters could be beneficial for fish growth, with or without intensive fish feeding. However, the threshold for added enrichment from fish feed vary with the prevailing trophic state of the environment [15]. Thus, the estimated amount of feed loading into each reservoir could be minimized based on the estimated threshold for each AMA using supplementary feeding regimes. Therefore, extruded or floating pelletized feeds are preferred since such feeds could stay longer on the water surface for it to be consumed by the fish. This promotes better fish growth as well as minimizing rapid sinking of feed that could pollute the water. The fish culture process may cause changes in the water quality through nutrient loading from fish faeces and ammonia released into the water from fish respiration (cultural eutrophication). However, a threshold for each AMA in a given reservoir could safeguard the reservoir from further pollution from cage culture as well as allow the utilization of eutrophic reservoirs for sustainable production of fish. AMAs development processes must factor in such effects into its estimation as indicative in this study. As a result, for sustainable aquaculture development, some studies [10] suggest an allocation of <1% of the carrying capacity within a suitable area as an AMA. Studies conducted on Brazilian reservoir showed that percentage allocation for three aquaculture parks in the Itaipu reservoir were 0.46%, 0.48%, 0.09% for sustainable aquaculture promotion [10] similar to those obtained in this study for AMA allocation (<1%) for Vea and Tono reservoirs in Ghana.

This study provides an integrated approach to the delineation of AMAs in inland water bodies such as reservoirs, lakes and lagoons. Thus, it is worth noting that some potential AMAs in Vea reservoir (AMAs 1 and 2) may be too small for commercial production (<500 kg per production). However, such smaller AMAs could be allocated to small holder fish farmers. These smaller AMAs could be easy to manage and monitor, in terms of water quality changes, input and output effects on reservoirs. Good water quality depends on effective control and management of the threat of cultural eutrophication [16-18]. Existing fisher-folks operating in the reservoirs could be trained to own and manage these AMAs to maintain good water quality, mitigate water-user conflicts, and enhance livelihoods and food security for the riparian communities. This study also provides some evidence (aquaculture stakeholders' inclusion approach) to minimize and avoid social objection towards cage culture development in the Tono and Vea reservoirs. Most of the reservoir areas where landing sites exist were avoided, route or fishing grounds for canoes navigation were maintained, and additional areas were created along the AMAs to avoid water-user conflicts associated with cage culture.

Conclusion

Aquaculture management areas (AMAs) in the Tono and Vea reservoirs could contribute approximately 117.74 metric tonnes of Nile tilapia per year. Fish production could be doubled, if a six-month production cycle is adopted per year. The three AMAs in Tono and five AMAs in Vea reservoir could be exploited to support inland aquaculture development policies of the Ghana Government. This study had shown that with the application of trophic status, carrying capacity estimation coupled with fish production factors, AMAs could be identified and developed for sustainable cage culture on reservoirs in northern Ghana. Consequently, capture fisheries could be integrated with culture-based fisheries in reservoirs in a sustainable way. Therefore, AMAs for the Tono and Vea reservoirs should be promoted as a pragmatic cage culture management approach for sustainable aquaculture production in these reservoirs. It is further recommended that, pilot cage production of fish in designated AMA should be jointly monitored for futuristic decision making by aquaculture research scientists, regulators, and interested small-scale fish farmers in Tono and Vea reservoirs.

There is the need for further studies involving biosecurity consideration within the potential AMAs for Tono and Vea reservoirs, which was not explicitly considered for this study. Pilot fish production within potential AMAs in Tono and Vea reservoirs could be implemented to serve as a baseline to monitor nutrient loading effects on the current trophic status of the reservoirs based on the maximum production targets postulated in this study. From this premise, the up-scaling of the AMA approach to other shallow reservoirs (<10 m depth) could help boost fish production in reservoirs as well as minimize social objection and water-user conflicts over shared water resources.

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