

FINAL REPORT

Blue Growth Initiative through Farming of Silver Pompano (*Trachinotus blochii*) and Rabbitfish (*Siganus sutor*) for Food Security and Improved Livelihood in East Africa (BLUEGRASI)

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Abstract

This research aimed at breeding and producing seeds for silver pompano (*Trachinotus blochii*) and rabbitfish (*Siganus sutor*), examined their growth performance, survival and feed utilization under formulated feeds and cultured at various stocking densities and culture systems. The study also evaluated their farming cost compared to other cultured species and their impact on community livelihoods. Rabbitfish brooders and juveniles and silver pompano brooders were collected for breeding purposes. The silver pompano brooders were injected with gonadotropin-releasing hormone. The silver pompano were fed with five experimental diets containing 5% and 10% effective microorganisms (EM) and 5% and 10% of both EM and shrimp meal and randomly stocked in hapas at one (PSD1), two (PSD2), three (PSD3) and four (PSD4) individuals/m³. Both trials were conducted for eight weeks. Twenty rabbitfish per hapa were fed on four feeds in which fishmeal was replaced by black soldier fly larvae (BSFL) at 0, 50 and 75% with a control. The rabbitfish fingerlings were stocked at 1.5 (SSD1.5), 2.5 (SSD2.5) and 3 (SSD3) individuals/m² for ponds and 12 (SSD12) and 24 (SSD24) individuals/m³ for cages and fed at 5% for 112 days for cages and between 108 and 144 for ponds, respectively. A site hydrodynamics study was also conducted. A total of 323 respondents including fish farmers, fish traders, fishers and others were interviewed to understand their income, fish price and preference. We also assessed the economics of producing rabbitfish in ponds and cages. A socio-economic and livelihoods study involving milkfish and Nile tilapia farmers was conducted by using a semi-structured questionnaire. Results indicated that the rabbitfish brooders in the first experiment were infected by ectoparasites, whereas in the second experiment, they were immature to breed. Similarly, no eggs were produced for silver pompano because brooders were immature. Feeding did not affect final body weight (FBW), daily weight gain (DWG), feed conversion ratio (FCR) and survival rate of silver pompano ($P > 0.05$). The silver pompano juveniles reared at PSD1 attained a significantly higher FBW, DWG and survival rate, and better FCR than other stocking densities ($P < 0.05$). The results for rabbitfish feeding trial are currently under review in a journal and thus cannot be shared. The rabbitfish reared in the pond at SSD2.5 attained significantly higher FBW, DWG and survival rate, than other stocking densities ($P < 0.05$). However, the rabbitfish cultured at SSD1.5 and SSD3 had a statistically comparable survival rate ($P > 0.05$). The rabbitfish reared in cages at SSD24 attained significantly higher FBW, DWG and survival rate, than those cultured at SSD12 ($P < 0.05$). The results on site hydrodynamics indicated that, the water currents speed ranged from 0.344 m/s to 1.113 m/s, wave heights ranged from 0.35 m to 2.7 m. Fish traders earned a higher monthly income compared to other occupations, while the hospitality industry earned the least monthly income. Rabbitfish and silver pompano attracted a higher price/kg (25-35%) compared to milkfish and Nile tilapia grown in seawater. All value chain actors indicated a higher preference for rabbitfish compared to milkfish, silver pompano and Nile tilapia grown in seawater. The ponds generated relatively higher benefit than cages. Nile tilapia farmers earned a higher monthly income compared to milkfish farmers. Both farmers farm fish to obtain income, employment and food. Findings show that, any of the feeds tested may be used for rearing silver pompano under similar study conditions, while inappropriate stocking density may impose negative effects on feed utilization and growth both for silver pompano and rabbitfish. Fish traders

earn more money while rabbitfish is a preferred fish. Nile tilapia farming is profitable compared to milkfish, while both provide income, employment and food security.

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List of symbols/acronyms

ANOVA	Analysis of Variance
AWAC	Acoustic Wave and Current profiler
BLUEGRASI	Blue Growth Initiative through Farming of Silver Pompano and Rabbitfish
EM	Effective Microorganisms
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
HDPE	High-density polyethylene
IMS	Institute of Marine Sciences
JICA	Japan International Cooperation Agency
KMFRI	Kenya Marine and Fisheries Research Institute
KMFSED	Kenya Marine Fisheries Socio-Economic Development
KMKM	Kikosi Maalum cha Kuzuia Magendo
KTC	Kwetu Training Centre
MASMA	Marine Science for Management
NEPAD	New Partnership for Africa's Development
RAS	Recirculating Aquaculture System
RGoZ	Revolutionary Government of Zanzibar
SPSS	Statistical Package for Social Science
TAFIRI	Tanzania Fisheries Research Institute
UDSM	University of Dar es Salaam
URT	United Republic of Tanzania
WIOMSA	Western Indian Ocean Marine Science Association

1. Introduction

The East African countries rely heavily on land-based agriculture to feed a growing population and drive the economy. In Tanzania and Kenya, land-based agriculture contributes more than 30% of Gross Domestic Product (GDP) (Jayne *et al.*, 2019). However, agriculture faces challenges including shrinking farmlands, declining fertility and dependency on rain that is not only scarce but quite unpredictable due to climate change (Khan & Akhtar, 2015). Thus, there is a need to look beyond land-based resources to ensure sustainable food security, employment and income generation for the coastal community. Blue Ocean Resources such as mariculture have the potential to contribute to food security, income and employment, hence contributing to GDP. Indeed, the African countries have already recognized this potential by formulating several policies such as African Union's Agenda 2063; New Partnership for Africa's Development, NEPAD; Policy Framework and Reform Strategy; Sustainable Blue Economy Conference, Nairobi, November 2018 to utilize successfully the valuable resources in the Oceans. However, Blue resources are currently minimally exploited in East Africa (Faulkner *et al.*, 2021).

To cope with the development policies by African countries on Blue Economy, several Eastern African countries have developed specific strategies for the exploitation of the ocean potential. East African coastal communities have traditionally relied on wild harvested fish as the principal source of protein and income. However, currently wild fish catches from both fresh and marine waters stand at 426,555 MT for Tanzania with a deficit of 100,000 MT (URT, 2023) and 163,702 MT for Kenya with a deficit of 150,000 MT (Republic of Kenya, 2022). Therefore, capture fisheries cannot feed the fast-growing human population currently at 61 million in Tanzania (URT, 2022) and 47.7 million in Kenya (Kenya National Bureau of Statistics, 2019) coupled with fast economic growth (7% in Tanzania and 6% in Kenya) and changing feeding patterns from red to white meat. Furthermore, wild fish species are overfished, the fishery is characterized by destructive fishing methods and is unsustainable due to climate-related effects. All these call for alternative sources of food and income. One of them is Blue Growth such as mariculture, which, is expected to provide local coastal communities with improved food security, increased income and employment opportunities.

Mariculture development in East Africa has previously targeted a few species including milkfish, seaweeds, mud crabs, artemia and prawns (Requintina *et al.*, 2006). A recent initiative is focused on the culture of marine tilapia, sea cucumber, silver pompano and rabbitfish (URT, 2023). However, their culture depends on poor quality seeds collected from the wild and an inadequate and poor-quality feeds (Peart *et al.*, 2021). To curb these challenges, mariculture experts from Tanzania and Kenya, undertook a detailed analysis of the potential species, for addressing food security and improving livelihoods. The experts identified silver pompano and rabbitfish as commonly caught species, which are acceptable in the local market. The species are relatively easy to breed in captivity and production technology already developed elsewhere, pending adoption in Tanzania and Kenya marine hatcheries that are at different stages of construction. A multi-disciplinary team of experts with experience in mariculture in the region partnered to implement the project called BLUEGRASI. The project outcome will improve livelihoods through farming of high value marine fish, which is in line with Vision

2025/2030 in Tanzania and Kenya, respectively and Agenda 2063 and Sustainable Development Goals.

2. Objectives

2.1 General Objectives

To increase fish production through silver pompano and rabbitfish farming in Tanzania and Kenya marine waters.

2.2 Specific Objectives

- i. To breed and produce seeds for silver pompano and rabbitfish under hatchery conditions.
- ii. To examine growth performance of silver pompano and rabbitfish fed on different feeds and stocked at different densities and culture systems.
- iii. Evaluate the cost of farming silver pompano and rabbitfish in comparison to other cultured species and the impact on community livelihoods.

3. Methodology

3.1 Collection of brooders and fingerlings for experiments

Rabbitfish brooders and juveniles were collected from Kibokoni village, Kilifi creek, Kilifi County whereas the rabbitfish seed for feeding and stocking density experiments were collected by fishers using seine nets from the wild within Shimoni Vanga sea scape in Kenya and acclimatized for two weeks before the experiments.

Forty brooders of silver pompano for breeding and producing seeds were collected using seine nets from Marumbi by fishers in Zanzibar. The collected brooders were transported in aerated tanks to Korea Zanzibar Friendship Mariculture Centre located at Beit El Ras, Zanzibar. Silver pompano for feeding and stocking density experiments were collected from the wild at Nungwi village, Northern Region in Unguja Island (5.72°S and 39.30°E) and acclimatized for two weeks before the experiments in Zanzibar.

3.2 Study areas

The experiments for breeding and growth performance, feed utilization and survival rate of silver pompano fed on various feeds were carried out at Korea Zanzibar Friendship Mariculture Centre located at Beit Al Ras, Zanzibar. The trial on growth performance, feed utilization and survival rate of silver pompano reared at different stocking densities was conducted at Makoba Bay, Mafufuni Village, Zanzibar (5° 57' 8" S and 39° 11' 35" E).

The growth performance, feed utilization and survival rate of rabbitfish reared at different stocking densities was conducted at Kibokoni village and Kwetu Training Centre (KTC) in Kilifi County, and Kijiweni village in Kwale County in Kenya.

Socio-economic survey on income, fish price and preference was conducted in three coastal counties (Mombasa, Kilifi and Kwale) in Kenya. The survey on socio-economics, livelihoods contribution and challenges of milkfish pond culture was conducted along the Tanzanian coastline, spanning from Mtwara to the Coast region, on mainland Tanzania, as well as Pemba Island in Zanzibar. For Nile tilapia cage farming, the survey was conducted in the Tanzanian part of Lake Victoria.

3.3 Study design, execution and data collection techniques

3.3.1 Breeding and producing seeds for silver pompano and rabbitfish under hatchery conditions

The collected brooders and juveniles intended for breeding were transported to the hatchery at the Kenya Marine and Fisheries Research Institute (KMFRI), where they were acclimatized in 1000 L tanks for 20 days while fed *ad libitum* with a seaweed-formulated diet containing 35% crude protein. Two breeding experiments were conducted for rabbitfish. In the first experiment, 100 rabbitfish brooders were reared in flow through system and recirculating aquaculture system (RAS) and fed at 3% body weight. The rabbitfish with an average weight of 95.26 ± 3.48 g were stocked at 25 fish/1000 L. During the second experiment, 20 rabbitfish juveniles with an average weight of 7.43 g per 1000 L tank were also cultured at KMFRI by using a RAS and flow through system. The fish were fed twice daily by using a seaweed-formulated feed at 3% body weight for 90 days.

At the rearing site, the collected brooders were disinfected by using 100 ppm formalin for 20 minutes. The fish were acclimatized in the tanks under a photoperiod of 20 hours light and 4 hours dark for five months while fed on squids and trash fish before spawning trials. The silver pompano brooders weighed 700 g to 1200 g. After acclimatization, the brooders were checked for readiness to spawn by using a biopsy technique (cannulation) (Gopakumar *et al.*, 2012). The brooders were dorsal-muscularly injected with two doses of 500 IU/kg body weight gonadotropin-releasing hormone (GnRH) at an interval of 24 hours.

3.3.2 Assessing growth performance, feed utilization and survival rate of silver pompano and rabbitfish fed on various feeds and reared at different stocking densities and culture systems

A total of five experimental diets containing 5% and 10% effective microorganisms (EM) (EM5 and EM10) and 5% and 10% of both EM and shrimp meal (SH), SHEM5 and SHEM10) were formulated (Supplementary Information Table 1). These diets were hand-fed three times daily to nine silver pompano per hapa in two replicates for eight weeks. At the end of the experiment, survival rate, final body weight (FBW), daily weight gain (DWG) and feed conversion ratio (FCR) were determined (Hamed *et al.*, 2017).

A total of four feeds in which fishmeal was replaced by black soldier fly larvae (BSFL) at 0, 50 and 75% hereafter BSFL0, BSFL50 and BSFL75, respectively with a commercial feed as a control were used for rearing rabbitfish. Twenty fish/m³ were stocked into hapas in four replicates and fed to the four experiments at 5% body weight for 90 days.

The acclimatized silver pompano were randomly stocked in hapas at four stocking densities of one (PSD1), two (PSD2), three (PSD3) and four (PSD4) individuals/m⁻². The fish in each hapa were fed with a formulated feed (Supplementary Table 2) twice a day initially at 10% followed by 8%, 5%, and 3% average body weight per day. At the end of the experiment, the survival rate, FBW, DWG and FCR were determined (Hamed *et al.*, 2017).

The rabbitfish fingerlings were stocked at 1.5 (SSD1.5) and 3 (SSD3) individuals/m² for Kibokoni ponds and 2.5 (SSD2.5) individuals/m² for KTC ponds,

while the cages at Kijiweni were stocked with 12 (SSD12) and 24 (SSD24) individuals/m³ all in duplicate. The fish were hand-fed twice daily with a 25% crude protein diet at a feeding rate of 5% average body weight per day for 112 days for cages and between 108 and 144 for ponds.

A study was conducted by KMFRI in collaborations with the fishers to understand the site hydrodynamics at Kibokoni, Kilifi Creek, Dabaso, Mida Creek – Kilifi County, Kijiweni and Tsunza Kwale County in Kenya. The sites included sheltered and relatively open waters. The hydrodynamics characteristics of the cage sites were determined by using an Acoustic Wave and Current profiler (AWAC, Model WAV 7499, Nortek, Qingdao, China). The AWAC equipment was deployed at the maximum depth at the different study sites to measure tidal variation (m), waves (m), temperature (°C), current speed (m/s) and direction (degrees) for 4 to 19 days. Seasonal variability was captured between North East, and South East Monsoons.

3.3.3 The cost of farming silver pompano and rabbitfish in comparison to other cultured species and impact on community livelihoods

A total of 323 respondents including fish farmers (5.8%), fish trade (47.1%), fishers (31.8%) and other (15.2%) were interviewed by using semi-structured questionnaire in Kwale, Kilifi and Mombasa counties, Kenya. The aim was to understand the income among the fish practitioners, the price of fish species sold including silver pompano and rabbitfish and consumer preferences for the marketed fishes.

The study assessed the economics of producing rabbitfish cultured at different stocking densities in wooden cages and intertidal earthen ponds. Intertidal ponds were stocked at densities of 3 fish/m², while cages were stocked at 40 fish per/m³ over a culture period of six months. Fish were fed using innovative macro-algae-based feeds. Costs were defined in terms of fixed and variable costs. Harvested fish were sold at the prevailing market price. Cost benefit was evaluated according to Shoko *et al.* (2019).

A total of 63 milkfish and 50 Nile tilapia farmers were visited and interviewed on socio-economics and livelihoods contribution using a semi-structured questionnaire. The milkfish and Nile tilapia farmers were also asked to provide the challenges they face during the production process. Partial enterprise budget analysis was used to determine the relative profitability of milkfish pond farming and Nile tilapia cage culture. The profitability analysis adopted a market farm gate price of TZS 8,000.00 per kg converted into USD 3.43 per kg for Nile tilapia and TZS 4,385.00 per kg converted into USD 1.88 per kg for milkfish (USD 1 = TZS 2,335).

3.3.4 Statistical analysis

The data were tested for normality and homogeneity of variances by using Shapiro-Wilk and Levene's tests, respectively. Inferential analysis was performed by using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test. The growth rate and survival rate for rabbitfish cultured in cages at two stocking densities, and breeding purposes for RAS and flow through systems were tested by using two sample *t*-test. Results with $P \leq 0.05$ were considered statistically significant. All the statistical analyses were conducted using the SPSS software version 20. Quantitative results are presented as mean $\pm$ standard error of the mean (SEM).

4. Results

4.1 Breeding and producing seeds for silver pompano and rabbitfish under hatchery conditions

The reared rabbitfish brooders increased from 95.26 ± 3.48 g to 113.89 ± 4.01 g with a DWG of 0.53 ± 0.06 g/day within eight weeks of rearing. Despite the faster growth, fish were infected with ectoparasites that caused mortality of the brooders after the 10th week. The rabbitfish brooders reared in the flow through system had significantly higher survival rate than those cultured in the RAS ($P < 0.05$) during the first experiment (Table 1). Fish in the RAS exhibited high parasite preference than those in the flow through system. During the phase two, the rabbitfish juveniles reared in the flow through system had significantly higher FBW, specific growth rate (SGR) and survival rate than those cultured in the RAS ($P < 0.05$) during the first experiment (Table 1).

Table 1. The growth performance and survival rate of rabbitfish during the two experimental phases

Phase	Parameter	Culture system	
		Recirculating aquaculture system	Flow through system
One	Survival rate (%)	8.1 ± 4.6^a	38.4 ± 1.10^b
Two	FBW (g)	21.79 ± 0.74^a	31.04 ± 0.56^b
	SGR (% day ⁻¹)	1.45 ± 0.14^a	2.09 ± 0.04^b
	Survival rate (%)	$21.1\% \pm 4.2^a$	$48.4\% \pm 1.19^b$
	FCR	3.77 ± 0.12^a	2.26 ± 0.09^b

The results on phase one based on eight weeks of rearing, phase two base on six weeks of rearing

The silver pompano used did not fully mature thus no eggs were produced during the study period.

4.2 The growth performance, feed utilization and survival rate of silver pompano and rabbitfish fed on various feeds and reared at different stocking densities

The results on silver pompano indicated statistically comparable FBW, DWG, FCR and survival rate among the fish fed on the various dietary treatments ($P > 0.05$; Table 2). The silver pompano juveniles reared at PSD1 attained significantly higher FBW, DWG and survival rate, and better FCR than those cultured at PSD2, PSD3 and PSD4 ($P < 0.05$; Table 2).

Table 2. The effects of dietary treatments on growth performance and nutrient utilization and survival rate of *T. blochii*

Feed parameters	Control	EM5	EM10	SHEM5	SHEM10
FBW (g)	48.51 ± 16.05	57.00 ± 28.97	50.02 ± 8.16	60.15 ± 30.79	46.8 ± 21.92
DWG (g/day)	0.52 ± 0.145	0.66 ± 0.31	0.56 ± 0.36	0.71 ± 0.32	0.53 ± 0.21
FCR	3.33 ± 0.16	2.59 ± 0.27	2.82 ± 0.27	2.5 ± 0.02	2.68 ± 0.03
Survival rate (%)	94.45 ± 5.56	88.89 ± 0.00	88.89 ± 0.00	100 ± 0.00	94.45 ± 5.56
Stocking density	PSD1	PSD2	PSD3	PSD4	

FBW (g)	467.22 ± 3.35 ^a	261.99 ± 2.72 ^b	176.2 ± 2.54 ^{b,c}	120.61 ± 1.97 ^c
DWG (g/day)	1.94 ± 0.01 ^a	1.08 ± 0.04 ^{b,c}	0.72 ± 0.09 ^b	0.49 ± 0.06 ^c
FCR	2.09 ± 0.13 ^a	3.86 ± 0.48 ^b	4.48 ± 0.21 ^{b,c}	5.07 ± 0.37 ^c
Survival rate (%)	92.59 ± 3.70 ^a	81.48 ± 1.85 ^b	72.84 ± 1.23 ^{b,c,d}	70.34 ± 1.85 ^d

PSD = pompano stocking density, EM = effective microorganisms and SHEM = shrimp and effective microorganisms. Values are the mean ± SD for triplicates. Values in the same row with different superscripts are significant different at $P > 0.05$.

The results of rabbitfish on feeding are currently under review at Aquaculture Research and thus cannot be shared [Okemwa, D., Ngugi C., Mirera, D.O. (2024). Effects of replacing dietary fishmeal with black soldier fly larvae meal on rabbitfish (*Siganus sutor*) reared in brackish water intertidal earthen ponds (Under review Aquaculture Research)]. The rabbitfish reared in pond at SSD2.5 attained significantly higher FBW, DWG and survival rate, than other stocking densities ($P < 0.05$). However, the rabbitfish cultured at SSD1.5 and SSD3 had statistically comparable survival rate ($P > 0.05$; Table 3). The rabbitfish reared in cages at SSD24 attained significantly higher FBW, DWG and survival rate, than those cultured at SSD12 ($P < 0.05$).

Table 3. Growth performance and survival rate of rabbitfish (*Siganus sutor*) reared at different stocking densities in ponds and cages

Culture system	Pond			Cage	
Stocking density	SSD1.5	SSD2.5	SSD3	SSD12	SSD24
FBW (g)	41.83 ± 3.76 ^a	73.45 ± 2.53 ^b	58.32 ± 2.21 ^c	57.70 ± 8.26 ^a	78.76 ± 10.39 ^b
DWG (g/day)	0.21 ± 0.08 ^a	1.12 ± 0.73 ^b	0.27 ± 0.02 ^a	0.15 ± 0.08 ^a	0.29 ± 0.03 ^b
Survival rate (%)	43.24 ± 4.36 ^a	78.68 ± 2.43 ^b	73.50 ± 3.41 ^b	62.84 ± 2.30 ^a	72.63 ± 4.62 ^b

SSD = *Siganus sutor* stocking density

The results on site hydrodynamics indicated that, the water currents in relatively open areas at Kijiweni had a maximum speed ranging from 0.83 m/s to 0.8690 m/s. Water current speed across the channel (V) was relatively lower than current along the channel (U). Flood (incoming) current dominated the site that led to an inverse correlation of the V-Velocity vs U-Velocity. The wave heights ranged from 0.35 m to 0.36 m.

The sites at mangrove creeks such as Kibokoni – Kilifi creek and Tsunza had maximum water current speed of 1.113 m/s and 0.89 m/s, respectively. The maximum wave height at Kibokoni and Tsunza was 2.7 m and 1.3 m, respectively. Water movement along the mangrove creek bay at Dabaso was relatively slow with a maximum current speed (V) of 0.344 m/s and maximum current speed (U) across the bay of 0.24 m/s. There was an inverse relationship between V-Velocity and U-Velocity. The maximum wave height (Hs) at Dabaso was 1.61 m.

4.3 The cost of farming silver pompano and rabbitfish in comparison to other cultured species and impact on community livelihoods

Fish traders earned more monthly income compared to other occupations, while hospitality industry provided the least monthly income. Rabbitfish and silver pompano attracted higher price/kg (25-35%) compared to milkfish and Nile tilapia grown in seawater (Fig. 1).

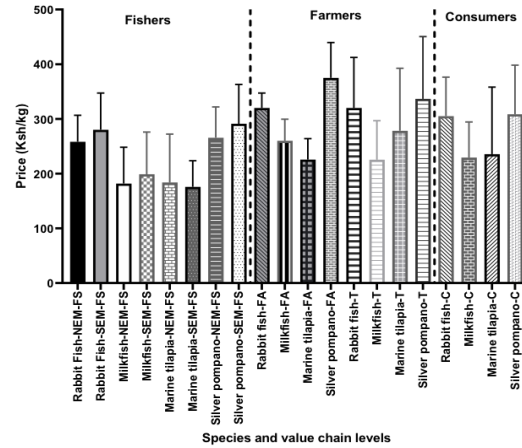


Figure 1. Price variations per kg in Ksh (1 USD = 120 Ksh) reported by fishers, farmers, traders and consumers

All value chain actors indicated higher preference for rabbitfish compared to milkfish, silver pompano and Nile tilapia grown in seawater (Fig. 2).

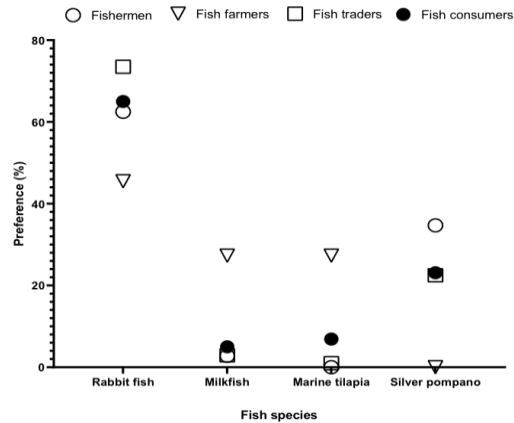


Figure 2. Preference of different fish species by value chain actors in Kilifi, Mombasa and Kwale

Both ponds and cages provided loss during the first production cycle. The ponds generated relatively higher benefit during the second cycle of production to the last one.

Table 4. Cost benefit analysis of rearing rabbitfish in earthen ponds and cages

Culture system	Y1, cycle 1	Y1, cycle 2	Y2, cycle 1	Y2, cycle 2
Pond (800 m ²)	(-2765)	2765	2765	2765

Cage (50 m ³)	(-4904)	368	368	368
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Note: 1 USD = 125 Kenya shillings (KSH).

Majority (41%) of milkfish farmers earn a monthly income of only between USD 42.83 and USD 128.48, while 33% gain an amount of USD < 42.83. Only a few milkfish farmers (2%) each make either between USD 299.79 and 385.44 or USD > 385.44. (56%). In contrast, most surveyed Nile tilapia farmers earn a monthly income of USD < 428.27, while 22% gain between USD 428.27 and USD 856.53. A few Nile tilapia farmers (8%) and (6%) make between USD 856.53 and USD 1,284.80, and USD 1,284.80 and USD 1713.06, while 8% generate up to USD > 2,141.33 per month.

Most milkfish pond farmers sold their fish in retail (58%), wholesale (40%) and on-farm (31%), while 9% sold through middlemen and 7% to hotels and restaurants. Majority of Nile tilapia cage farmers sold their fish through middlemen (98%) and on-farm (65%) while the rest sold through retailers (31%), wholesale (29%) and to hotels and restaurants (22%). Both milkfish pond farmers (90%) and Nile tilapia cage (100%) used phone-calls and short messages as the most important means of accessing market information.

Milkfish pond farming accrued a negative net return of USD -6,905, an income above variable cost of USD -4,063.32 and a break-even yield of 4,135 kg. Nile tilapia cage farming had a net return of USD 5,207, an income above variable cost of USD 9,6712, a break-even yield of 12,627 kg and break-even price above total cost of USD 3.06 per kg.

Majority of milkfish pond farmers are engaged in the activity for food (89%), income (83%), gaining knowledge and skills (21%), employment (13%), specialization (11%) and prestige (10%). Nile tilapia cage farmers are engaged in the activity for gaining knowledge and skills (94%), income (82%), employment (62%) and food (40%).

Both milkfish and Nile tilapia farmers were faced by inadequate feeds, funds and technical support. Inadequate seeds, theft, and the presence of predators were reported challenges specifically for milkfish pond farming. Explicitly, Nile tilapia cage farming was affected by low production, poor marketing information, inadequate working tools, poor storage facilities and poor transportation facilities.

5. Analysis and Discussion of the Results

5.1 Breeding and producing seeds for silver pompano and rabbitfish under hatchery conditions

Fish in the RAS exhibited high ectoparasites prevalence than those in the flow through system was due to continuous utilization of the same water for rearing (Jørgensen *et al.*, 2009). This also implies the RAS treatment system possibly was inefficiency in removing the parasites from the recirculated water. The ectoparasites attacked and caused harm to the gills and partly eyes and skin of the fish, leading to their death.

The rabbitfish brooders reared in the flow through system had higher growth performance and survival rate than those cultured in the RAS. Better growth performance of the juvenile rabbitfish habitat in flow through system is attributed to its resemblance to the ocean currents with calm water (Vergés *et al.*, 2014). The low survival rate was low in the RAS was associated to the ectoparasites that hade more prevalence for such a system than flow through water system. The silver pompano used could not produce eggs

because the brooders were immature weighing less than 1 kg, with only two males weighing 1.2 kg each. Usually, silver pompano mature after reaching 1 kg to 1.5 kg (Gopakumar *et al.*, 2012).

5.2 The growth performance, feed utilization and survival of silver pompano and rabbitfish fed on various feeds and reared at different stocking densities and culture systems

The study indicated comparable growth performance, feed utilization and survival rate of silver pompano fed on various feeds, similar to the findings by Hamed *et al.* (2017). This could be due to the beneficial effects of EM and shrimp meal on improving growth performance, feed utilization and survival rate of various species such as Nile tilapia (Opiyo *et al.*, 2019; Abdel-Aziz *et al.*, 2021) due to its ability to reduce stress (Lara-Flores *et al.*, 2003). Accordingly, any of the feeds tested can be used for rearing silver pompano under similar study conditions.

The silver pompano reared at PSD1 attained higher FBW, DWG and survival rate, and better FCR compared to those cultured at other stocking densities, similar to the report by Chavez *et al.* (2011) and Ezhilmathi *et al.* (2022). The increased growth performance at low stocking density is related to enhanced feed utilization efficiency. In this study, the silver pompano reared at a low stocking density of one individual m⁻² had better feed utilization efficiency than other tested densities, which led to improved growth performance. The reduced survival rate of silver pompano at relatively higher stocking densities of PSD3 and PSD4 is due to physiological stress caused by increasing stocking density (Ezhilmathi *et al.*, 2022). High stocking density is a common stressor in cultured fish species (Liu *et al.*, 2019). These findings suggest that, inappropriate stocking density may impose negative effects on feed utilization of juvenile silver pompano.

The rabbitfish reared in pond at SSD2.5 attained significantly higher growth performance and survival rate. This is contrary to El-Sayed (2002), who showed that survival rate was low at high stocking density, indicating that stocking density had an influence on growth performance and survival rate. High stocking density can be a source of stress affecting fish welfare and growth rate (Baldwin, 2011). The low survival rate in fish stocked in ponds at low stocking density was caused by high water temperature and salinity, which reached 35 °C and 60 ppt, respectively during the hot season of the year between February and April. The rabbitfish reared in cages at SSD24 attained significantly higher FBW, DWG and survival rate, than those cultured at SSD12. Similarly, seabass also grew faster at high stocking densities (Jørgensen *et al.*, 1993; Papoutsoglou *et al.*, 1998). These results imply that, stocking density influences growth and survival rate of rabbitfish in ponds and cages. Farming of rabbitfish in cage can be enhanced to optimum stocking density as the relatively high stocking density used to improve growth and survival rate of fish.

The results on site hydrodynamics at Kibokoni – Kilifi creek indicated a current/velocity (U) of 1.113 m/s, which could be associated to the steep topography of the creek (Turner, 2000). Water current rates of 0.1 to 1.0 m/s are acceptable for cage placement and position (Lake Victoria Fisheries Organization, 2018). Sites characterized with U velocities of 1.0 to 1.5 m/s and more than 1.5 m/s are described as highly and extremely exposed, respectively (Faltinsen & Shen, 2018). The water current speed was

above 1 m/s at Kibokoni – Kilifi creek. This site should be used for cage installation with a caution because of the likelihood of very large forces on the cage structure and mooring system that may lead to breakage or shifting of cages or cage deformations (Holmer, 2010; Moe *et al.*, 2010) with a possibility of losing up to 80% of volume available to hold fish in gravity cages (Aarsnes *et al.*, 1990). Current speeds of 0.13 to 0.35 m/s were observed to reduce the cage volume by 20 to 40 % causing the cage bottom being pushed upwards.

5.3 The cost of farming silver pompano and rabbitfish in comparison to other cultured species and impact on community livelihoods

Fish traders earned more monthly income than other occupations because they possess storage facilities thereby sell to different categories of customers, including high income markets when fish supply is low, thus earning high income. They also diversify income sources beyond fish trading (Degen *et al.*, 2010). Rabbitfish and silver pompano attracted higher price compared to other species. This is probably due to their easy to prepare, availability, less bony, palatability and high preference in the market (Trondsen *et al.*, 2004). All value chain actors indicated higher preference for rabbitfish compared to other species in the market, similar to results reported in Karuga and Abila (2007). This is attributed to fish consumption levels and frequency (Pieniak *et al.*, 2011), and good quality, easy to prepare, availability, less bony, affordability and palatability (Trondsen *et al.*, 2004). The ponds generated relatively higher benefit than cages during the second cycle of production to the last one. This is because the cages were small for experimental purposes and stocked at low densities, thus the yield was low, ultimately resulting in less profit.

Majority of Nile tilapia farmers earned a higher monthly income compared to most milkfish farmers. The lower monthly income obtained for milkfish is due to its low price in the market. Both Nile tilapia and milkfish farmers accessed market information through mobile phones and messages, which is a common means of accessing market in low-income communities (Burrell & Oreglia, 2015) and marketing (Aura *et al.*, 2019). Nile tilapia farmers were making a net profit as compared to milkfish farmers who were not due to income and price of the respective fish species. Nile tilapia fish fetches a higher market price compared to low-priced milkfish. Both milkfish and Nile tilapia farmers practice farming in order to obtain income, employment, food and gain knowledge and skills. However, Nile tilapia cage farmers emphasize on income generation while milkfish pond farmers strengthen more on obtaining food, which ultimately caused the negative profit.

Both milkfish and Nile tilapia farmers indicated consuming fish because of easy availability and delicious taste. Indeed, the two species studied herein have been indicated to contribute to food security for small-scale fish farmers in other countries (Obiero *et al.*, 2019; Shadrack *et al.*, 2021; Munguti *et al.*, 2022). Therefore, the current concerted efforts to develop aquaculture in Kenya and Tanzania should be enhanced in order to increase fish supply and improve livelihoods through blue economy. Milkfish

and Nile tilapia farmers are facing the similar challenges. Interestingly, theft and inadequate seeds were only reported by milkfish pond farmers attributed to the current lower production, which does not motivate farmers to provide adequate security to their farms. The inadequate seeds are contributed by unavailability of operational hatcheries in the region.

6. Outputs, Outcomes and impacts of the project

Three published papers in international journals

- i. Mirera D. O., Salim A., Josyline Kendi¹, 2023. Hydrodynamics of nearshore coastal waters: Implications for marine cage farming in Kenya. *WIO Journal of Marine Science* 22(2)2023 25-41
- ii. Mirera, D. O., Magondu, E.W., Esther, W., W. and Wainaina, M. W., Muli B., Okemwa, D., Angulu, R., Heba, I. and Moyoni H. Fish preference at different value chain levels and implications for management of mariculture. *Marine Policy* 157 (2023) 105845
- iii. Shalli, M.S., Mmochi, A.J., Rubekie, A.P., Yona, G.K., Shoko, A.P., Limbu, S.M., Mwita, C.J., Lamtane, H.A., Hamed, S.S., Jiddawi, N.S., Mapenzi, L.L., 2024. The contribution of milkfish (*Chanos chanos*) pond farming to socio-economics and coastal community livelihoods for a sustainable blue economy in Tanzania. *Aquaculture International*, <https://doi.org/10.1007/s10499-024-01408-4>.

Postgraduate students

- i. One PhD student is completing his thesis on determining the best management practices and cost-effective method of farming silver pompano in earthen ponds in order to improve finfish mariculture production in Tanzania.
- ii. One MSc. Student submitted a Dissertation Titled “The potential use of effective microorganisms to develop aquafeeds for sustainable fish farming”.
- iii. One MSc student constructed two cages for silver pompano farming and cost implication in comparison with tilapia farming in Lake Victoria.

Three MSc. students registered in the project to undertake different research activities

- i. Okemwa D. M. Effects of replacing dietary fish meal with black soldier fly larvae meal on rabbitfish (*Siganus sutor*) reared in brackish water intertidal earthen ponds. Thesis accepted submitted for the fulfillment of a Masters Degree in the School of Natural Resource and Environmental studies Karatina University, Karatina, Kenya.
- ii. Growth performance of rabbitfish (*Siganus sutor*) fed on a spinosum (*Euchemia denticulatum*) seaweed formulated diet (MSc research at Pwani University)- Irene Kasichana Heba. Ongoing.
- iii. The Performance of juvenile silver pompano (*Trachinotus blochii*) in net cages in the Kenyan Coast (MSc research at Pwani University)-Rose Damaris Angulu. Ongoing

One Poster presentation in the WIOMSA symposium 2022

Mirera, O. D: Assessment of growth response of rabbitfish (*Siganus sutor*) to formulated feeds in floating cages and intertidal earthen ponds (Poster presentation in 12th WIOMSA

Popular media dissemination

- i. Mirera D. 2022. Kenyan farmers and consumers choose rabbitfish: The selection of species for marine aquaculture needs to be informed by market preferences and costumer demands according to an article published recently in Marine Policy. WIOMSA News Brief 2023 Page 31.
- ii. Mirera D. O. Rabbitfish high lights from recently published papers. Marine Policy. The article publishes the results of the “BLUEGRASI” research project which was funded by WIOMSA under its Marine Science for Management programme.
- iii. Mirera, D. 2023. Research in Kenya reveals exciting potential of farming rabbitfish in affordable culture facilities. WIOMSA News Brief, 2023. Page 31, 2023.
- iv. Omar, S. 2022. Feature: More catch more cash; Kwale fishermen adopt cage farming. The Stars News Paper, 30 and 31st July, 2022 page 32.
- v. Mandano, M. 2022. Cage farming helps free the economy of Kwale village. Peoples Daily, Friday July 22nd 2022
- vi. Mirera, D. Videos on fish farming in Kenya https://youtu.be/fS_gmypK_Nw
<https://youtu.be/ncDrcPIJk0Q>
- vii. Meeting for the official opening of the BLUEGRASI project televised by Zanzibar Broadcasting corporation on 18th May 2021
- viii. Presentation at the Institute of Marine Sciences and University of Dar es Salaam Research week in March and April 2022.
- ix. Poster exhibition in commemoration of the Union between Tanganyika and Zanzibar, 2021

Number and nature of new collaborative partnerships developed by the project.

Include also spin-off activity that may have originated from the project.

- i. Presentation to Kikosi Maalum cha Kuzuia Magendo (KMKM) on fish farming in general and silver pompano in particular.
- ii. Development, installation and farming of silver pompano in cages to harvesting. Training and working with Makoba milkfish farmers to develop ponds and farm silver pompano for the PhD thesis (introduction of silver pompano farming to farmers.
- iii. The KMFRI is collaborating with Japan International Cooperation Agency (JICA) in developing High-density polyethylene (HDPE) circular cages.

Examples showing that your project is starting to achieve any changes in target groups

- i. The results from the backyard marine hatchery for rabbitfish are used in the collaborative marine hatchery development project at Shimoni, which is supported by World Bank.

- ii. The wooden marine cage technology has been adopted by communities funded by Kenya Marine Fisheries Socio-Economic Development (KMFSED) Project funded by World Bank.

Contribution to management, pilot projects and decision-making processes at national, regional or global levels. Application of the information generated for management purposes/solving problems on the ground.

Results from BLUGRASI are used to inform the review of the National Aquaculture Policy 2023 in Kenya.

7. Conclusions and Recommendations

7.1 Conclusion

Findings of the present study show that, any of the feeds tested might be used for rearing silver pompano under similar study conditions, while inappropriate stocking density may impose negative effects on feed utilization and growth. These results on rabbitfish showed that, stocking density influences growth and survival rate of fish in ponds and cages. Farming of rabbitfish in cage can be enhanced to optimum stocking density as the relatively high stocking density used improved growth and survival rate of fish. Majority of Nile tilapia farmers earn a higher monthly income compared to most milkfish farmers, while milkfish and Nile tilapia provide income, employment and food to the society. Both Nile tilapia cage and milkfish pond farming are currently constrained by mostly similar challenges.

7.2 Recommendations

Based on the findings of the present study, the following recommendations are made:

- i. Establish the economics of silver pompano production in different aquaculture systems.
- ii. Explore feasibility of farming silver pompano using different technologies such as polyculture system for future development of the industry.
- iii. Stock rabbitfish at high stocking densities for enhanced cost-benefit analysis.
- iv. Enhance the current concerted efforts to develop aquaculture in Kenya and Tanzania in order to increase fish supply and improve livelihoods.
- v. Apply a holistic approach in addressing mariculture and freshwater fish production to improve socio-economic and livelihoods.

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