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Toward integration of sea cucumber and cockles with culture of shrimps in earthen ponds in Kenya

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Abstract

This study presents the first trial application of an integrated multi-trophic aquaculture (IMTA) system in pond culture in Kenya using a combination of locally available species. Sea cucumber, *Holothuria scabra*, and cockles, *Anadara antiquata* were obtained from the wild for culture trials with Indian white shrimp, *Penaeus indicus* in an IMTA for comparison with monoculture of shrimps in intertidal earthen ponds. The monoculture treatment (T1) ponds were stocked with *P. indicus* juveniles at a stocking density of (5 ind/m^2; 12.9 g/m^2) while the IMTA treatment (T2) combination had *H. scabra*, *P. Indicus*, and *A. antiquata* stocked at (1.2 ind/m^2; 105.78 g/m^2, 5 ind/m^2; 12.9 g/m^2 and 3.5 ind/m^2; 142.48 g/m^2) respectively. During the culture period, the harvest weight gain (mean ± *SE*) for shrimps in T1 was 13.17 ± 0.75 g while the organisms in T2 combination a weight gain of 13.19 ± 0.57 g for shrimps, 175.03 ± 27.84 g for sea cucumber, and 44 ± 0.97 g for cockles. Economic analysis revealed increase in net income in T2 with a cost benefit ratio of 1.77 higher than T1. The findings of this study provide a basis for integration of *H. scabra* and *A. antiquata* into Kenya's coastal mariculture through application of pond IMTA technology.

KEYWORDS
Anadara antiquata, aquaculture, *Holothuria scabra*, *Peanaeus indicus*, pond

1 | INTRODUCTION

The exploitation of sea cucumber and cockles in capture fisheries has raised worldwide conservation concerns. The heavy exploitation of these species has been related to high prices they fetch in the international market and increasing demand. Although these organisms are cultured in other parts of the world, available culture techniques have not been introduced in Kenya. We report here preliminary results of culture trials of these organisms in existing culture facilities using integrated multi-trophic aquaculture (IMTA) culture technology for income diversification, increase in production and improvement of livelihoods of the farmers depending on marine aquaculture enterprises. The study was designed to evaluate the potential of introducing organisms feeding at different trophic levels to the pond culture system. The IMTA set up made used deposit feeding sea cucumbers and filter feeding cockles as extractive organisms while marine shrimp formed the fed component of the system.

The trial used the sandfish, *Holothuria scabra* Jaeger, the most commercially valuable sea cucumber species commonly found in tropical and sub-tropical countries (Conand & Muthiga, 2007). Wild stock depletion and increased demand for the species triggered interest to develop culture techniques for *H. scabra* aimed at increasing the numbers, reducing fishing pressure from the wild while providing alternative sources of income in different countries across the globe (Kumara & Dissanayake, 2017). Some countries like Vietnam, Madagascar, Tanzania, and the Philippines initiated restocking and sea ranching (Eriksson, de la Torre-Castro, Purcell, & Olsson, 2014; Kunzmann, Beltran-Gutierrez, Fabiani, Namukose, & Msuya, 2018; Purcell, Hair, & Mills, 2012; Senff, Blanc, Slater, & Kunzmann, 2020; Watanabe, Sumbing, & Lebata-Ramos, 2014).

Increasing demand for seafood products and search for alternative livelihoods for the coastal communities led to promotion of integrated aquaculture (Chang et al., 2020; Chopin, Cooper, Reid, Cross, & Moore, 2012; Troell, 2009) and subsequently focus shifted to modern integrated aquaculture approaches such as IMTA. The IMTA approach is widely used in developed countries like Japan, China, and South Korea where sea cucumber, *Apostichopus japonicus* has shown great potential for integration with other organisms (Chopin et al., 2001, 2008; Neori et al., 2007; Zamora, Yua, Carton, & Slater, 2018). As a culture system, IMTA has been defined as the farming in proximity of aquaculture species of different trophic levels and with complementary ecosystem functions (Chopin et al., 2001; Neori et al., 2004). The main advantages of the approach allows one species uneaten feed, nutrients and wastes to be recaptured and converted into fertilizer, feed, and energy for the co-cultured organisms and to take advantage of the synergistic interactions between the cultured species (Chopin et al., 2001; Neori et al., 2004). Alexander, Freeman, and Potts (2016) and Sara et al. (2021) recognized IMTA for increased long-term sustainability and profitability per cultivation unit and not per species in isolation as is carried out in monoculture. Adoption of novel culture technologies like the IMTA offers opportunities for increased production and economic gains as compared to existing monoculture practices being conducted in most pond systems. In the present trial, cockles *Anadara antiquata*, an edible bivalve species that feeds through filter feedings and scavenging for organic detritus in the sediment, were introduced to utilize the waste from the co-cultured organisms. It is noteworthy that successful integrations of sea cucumber with shrimps (Purcell, Patrois, & Fraisse, 2006), and sea cucumber with mollusks (Slater & Carton, 2007) have been previously reported.

Although integrated culture in earthen ponds is widely practiced in Kenya, there has so far been no any research effort on IMTA to assess the potential and economic viability in coastal mariculture systems. Aquaculture production and species diversification in Kenya has been promoted thorough adoption of integrated aquaculture where output from one farming system is used as in input for another subsystem (Ngugi, Bowman, & Omolo, 2007). Integrated aquaculture is majorly practiced in freshwater paddies and ponds for the production of fish–rice, fish–livestock, and fish–vegetable combinations (Ngugi et al., 2007). In the marine aquaculture sector, milkfish–shrimp, milkfish–mullet combinations under pond polyculture systems have been tried in the intertidal areas (Mirera, 2011) where results were promising. Aquaculture production estimates in Kenya are over 100 Mt/year of finfish, shellfish, and seaweeds all produced at a small-scale level with more than 90% of the farms being managed by organized community groups (Munguti, Obiero, Orina, Musa, & Mwaluma, 2017). The main contributing factors for this are; overfishing of local populations of the culture species, limited farming space, and pollution from aquaculture. The aim of the present study was therefore to assess the potential of integration of sea cucumber with marine shrimps and cockles raised in tidal earthen ponds by investigating the effects on growth, survival, water quality, and economic performance. The trials will recruit sea cucumber and cockles as culture species in Kenya's coastal mariculture thereby diversify species and income streams for small-scale earthen pond shrimp farms.

2 | MATERIALS AND METHODS

2.1 | Study area

This study was conducted at Umoja self- help group mariculture ponds (Figure 1) in Kilifi creek, Kibokoni, a coastal village about 10 km West of Kilifi town, Kenya. The site of the project is located along the Kilifi Creek at Longitude 039° 50′ 32″E and Latitude 03° 36′ 12″S.

2.2 | Pond preparation

The experiment was carried out over a period of 135 days from July 20, 2020 to December 3, 2020. Six, 120 m^2, or 0.012 ha (1 ha = 10,000 m^2) earthen ponds each with a depth on 1 m were drained completely and renovated by raising and compacting the dykes. Before starting the experiment, the ponds were left to sundry for a period of 1 week for eradication of all unwanted fishes. Lime ($CaCO_3$) was applied to all the ponds at the rate of 300 g/m^2. The IMTA trial was compared with traditional conventional shrimp monoculture system practiced in the farms. To create a muddy sandy substrate in IMTA treatment, a 2 cm layer of sand was applied on the pond bottom of IMTA treatment ponds to allow the sandfish to burry effectively. There were no any physical barriers installed in the IMTA ponds to allow for ease of interaction among the organisms. Ponds were then filled with water from a nearby channel during high tide. All the ponds were then fertilized with urea (3 g/m^2) and diammonium phosphate (2 g/m^2). After fertilization, the ponds were left for 10 days to allow for growth of natural food organisms in the water column. The water level was topped up and maintained at a depth of 1 m, the ponds were subsequently stocked a day after topping up the water.

2.3 | Experimental design

The experiment had complete randomized design with two treatments which were executed in triplicate and assigned randomly between six ponds. Two culture systems were tested which formed the two treatments namely IMTA treatment and marine shrimp monoculture treatment. Before the experiment, acclimatization of wild collected specimen of sea cucumber, cockles, and shrimp seeds was carried out in a separate nursery pond to test adaptability into the culture environment. The first treatment marine shrimp monoculture acted as the control experiment with *P. indicus* as the study organism. The second treatment IMTA consisted of three different candidate organisms stocked in replicate ponds at different densities shown below. Of the candidate species in the IMTA treatment, *P. indicus* was the fed species whereas *A. antiquata*, and *H. scabra* were the extractive organisms in the system.

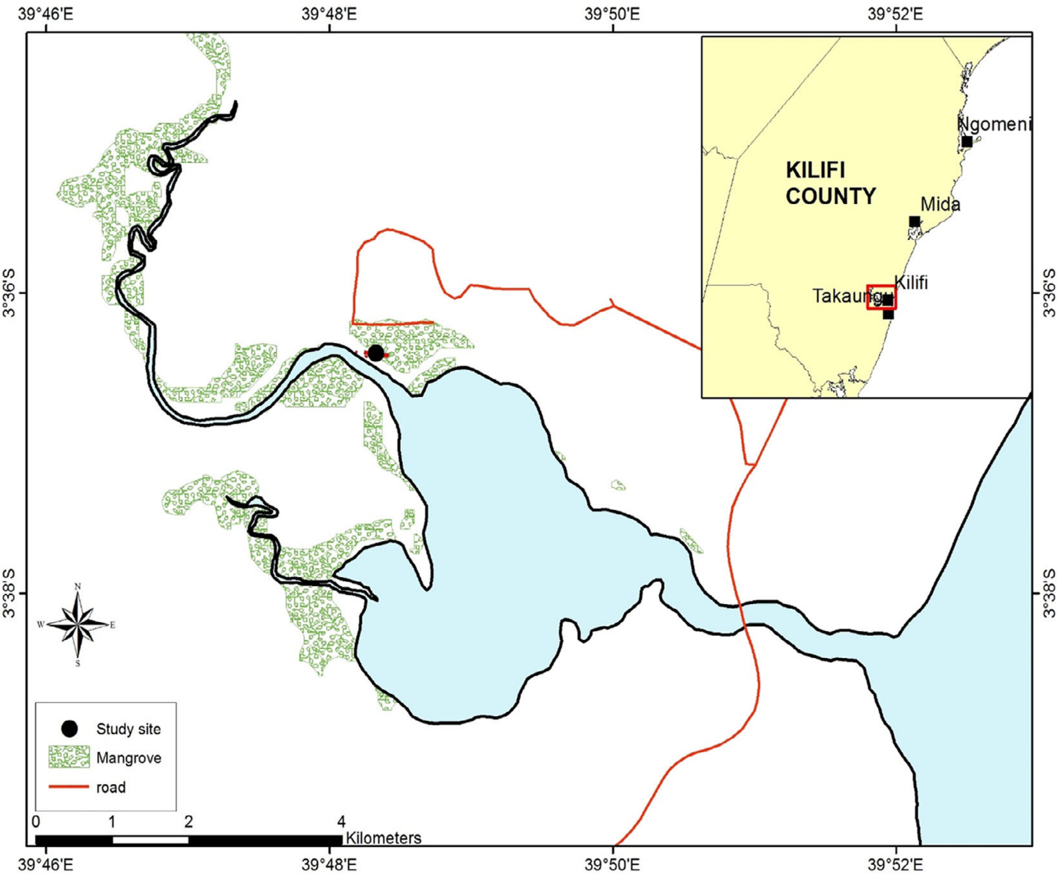

FIGURE 1 Site location for Umoja self-help group mariculture ponds in Kibokoni, Kilifi County, Kenya

2.4 | Stocking and pond management

Juveniles of *P. indicus* (2.05 ± 0.02 g) procured from a nearby community nursery pond were stocked in the six ponds of both Treatment 1 and 2 at a density of 5 inds./m^{-2} (Zaki, Nour, Abdel-Rahim, & Srour, 2004). In the IMTA treatment, wild sourced and acclimatized specimen of *H. scabra* and *A. antiquata* weighing (88.15 ± 0.05 g) and (40.71 ± 0.02 g) respectively were stocked at a density of 1.2 inds./m $^{-2}$ for *H. scabra* and 3.5 inds./m^{-2} for *A. antiquata* according to Table 1. The selection of these species and densities was according to Beltran-Gutierrez et al. (2014), Namukose, Msuya, Sebastian, Slater, and Kunzmann (2016) and Troell et al. (2011). A low cost locally formulated and prepared pellet feed containing 40% protein formulated from (soya bean meal, fishmeal, wheat pollard, rice bran, seaweed powder, and cassava binder) was used. The daily feeding rate was 5% body weight per day for the first 2 months of the experiment, it was changed gradually to 3% body weight per day during the last 2 months of the culture period with an assumption of 85% survival of the stock in each pond based on unavoidable mortality during sampling and undetected predation that might have occurred. The feed was evenly distributed over the pond surface twice daily at 9:00 a.m. and 3:00 p.m. To keep the alkalinity levels within the optimal range, calcium carbonate was applied monthly at a rate of 300 g/m^2. Natural productivity was be enhanced by DAP and UREA fertilizer application at 2 g/m^2 and 3 g/m^2, respectively, biweekly. Pond water level was be maintained at 1 m depth during high spring tide after compensating for evaporation and seepage.

TABLE 1 Results of statistical analysis for the two treatments and data (Mean ± *SEM*) for initial and final weights and lengths calculated on pooled data of individual *Penaeus indicus*, *Holothuria scabra*, and *Anadara antiquata* (NWG, DGR, SGR, Survival, AFCR, and Yield) are mean values (±*SEM*) of three replicate ponds

Growth and yield variables	T1 Monoculture of *P. indicus*	T2 IMTA of *H. scabra*	*A. antiquata*	*P. indicus*
Stocking density (Ind/m^2)	5	1.2	3.5	5
n	600	144	420	600
Individual stocking weight (g)	2.58 ± 0.46	88.15 ± 5.92	40.71 ± 0.41	2.58 ± 0.46
Individual harvest weight (g)	15.76 ± 2.29	263.18 ± 31.53	84.92 ± 1.24	15.76 ± 0.53
Individual stocking length (cm)	6.4 ± 0.6	10.5 ± 0.1	6.5 ± 0.03	6.4 ± 0.6
Individual harvest length (cm)	13.11 ± 0.69	21.74 ± 0.79	9.33 ± 0.12	13.09 ± 0.67
AFCR (fed component)	0.88 ± 0.13			0.97 ± 0.24
Individual net weight gain (g)	13.17 ± 0.75	175.03 ± 27.84	44 ± 0.97	13.19 ± 0.57
Daily growth rate (g day^{-1})	0.96 ± 0.03	1.29 ± 0.21	0.32 ± 0.01	0.96 ± 0.01
Specific growth rate (% day^{-1})	1.99 ± 0.02	4.1 ± 0.09	3.25 ± 0.01	1.99 ± 0.02
Survival (% day^{-1})	72.8 ± 1.54	56.32 ± 7.53	74.12 ± 7.08	80.1 ± 5.9
Production (kg/treatment 135 day^{-1})	20.57 ± 2.25	66.46 ± 4.24	97.51 ± 3.25	22.84 ± 2.21

Note: Data are mean ± SE for 135 days study period.

2.5 | Growth and yield estimations

Growth calculations involved computation of mean length (cm) and weight (g) for marine shrimps in monoculture treatment and also for sea cucumbers, cockles, and marine shrimps for the IMTA treatment. Sampling for growth was carried out after every 20 days subsequent to the next high tide followed by adjustment of feeding rates based on calculated pond biomass. Weights of 30% of the total number of the organisms in the different treatments were measured individually using a digital electronic balance, Aslor model, having 0.01 g precision. The total length of the organisms was determined using a measuring board. Graphical plots of mean weights against time were used to visualize growth. At the end of the experiment, shrimps were first partially harvested using a drag net. The ponds were then drained off while capturing the sea cucumbers and cockles in Treatment 2 and the remaining stock of shrimps in both treatments. Performance of the organisms in both treatments were evaluated in terms of final Average Body Weight (ABW, g), Net Weight Gain (NWG, g), Daily Weight Gain (DWG, g day^{-1}), Specific Growth Rate (SGR, % day^{-1}), Daily Growth Rate (DGR, g), Apparent feed conversion ratio (AFCR), Survival, and Yield kg ha^{-1} calculations were executed as shown in Table 2.

Mean ± *SEM* for initial and final weights were calculated based on pooled data of individual organism of the three replicate ponds $N = 600$ for marine shrimps in both T1 and T2. Under T2, cockles had $N = 420$ per pond while sea cucumbers had $N = 145$.

2.6 | Water quality analysis

Physicochemical variables to establish the water quality profile of the treatment ponds were taken after every 3 weeks, on a day before the tidewater exchange. Water samples were collected using a horizontal water sampler (Boyd & Tucker, 1992) from three sampling points in each pond for both IMTA and monoculture treatments and from the creek channels that brought in water to the ponds. Salinity, pH, dissolved oxygen, water temperature, conductivity, and total dissolved solids (TDS) were measured in situ using a multi-variable meter kit Hanna instruments

TABLE 2 Information on calculations

Variable	Calculation
SGR	(ln final weight–ln initial weight)/rearing days*100
NWG	Mean final weight–mean initial weight
DWG	Mean final weight–mean initial weight/culture days
DGR	Mean final weight–mean initial weight/culture days
AFCR (Shrimp only)	Feed applied (dry weight)/live weight gain
Net yield	Total biomass at harvest–total biomass at stocking
Survival (%)	Final number harvested/initial number stocked*100

model. Light penetration as a measure of water transparency from each sampling station was determined using a white Secchi disk. Water samples for chemical analysis to determine nitrite–nitrogen (NO_2–N), total ammonium nitrogen (TAN), nitrate–nitrogen (NO_3–N), and phosphate–phosphorous (PO_4–P) were ice-chilled and taken to KMFRI Mombasa center laboratory for preservation in preparation for analysis. Before nutrient analysis, water samples were filtered through microfiber glass filter paper (Whatman GF/C) using a vacuum pressure air pump. The samples were then subjected to an auto analyzer of model, Seal-quatro A33 for analysis using the Continuous Flow Analysis technique. All analyses were carried out according to standard methods described in American Public Health Association (APHA), American Water Works Association (AWWZ), and Water pollution Control Federation (WPCF) (2005).

2.7 | Economic analysis

An economic analysis was carried out based on the developed IMTA system in comparison to the shrimp monoculture system. The economic performance of the treatments and their comparison were analyzed with estimation of total income, net income, and Cost Benefit Ratio (CBR) as shown below and according to Biswas et al. (2012).

$$\text{Net income} = \text{Total income} - \text{total expenditure}$$

$$\text{CBR was determined as CBR} = \text{Total income}/\text{total expenditure}$$

Expenditure composed of costs of inputs including the cost the different seeds (*P. indicus*, *A. antiquata*, and *H. scabra*), feeds administered, labor, fertilizers, lime, netting material, and other operational costs like purchase of tools for pond maintenance, payment for security hire and pond attendant. The cost of production was estimated based on local market value price in the current U.S. Dollar equivalence (1USD = 110 Kenya currency). Produced crop of shrimps was sold at the local market outlet and in hotel while the sea cucumbers were sold to a local dealer for export. Total return from the crop produced was estimated by price of organisms sold. Gross margin was estimated by subtracting the total production cost from the total return. The costing did not include the initial investments but rather the routine farm operations. The outcome of the economic analysis was used to determine the viability of both systems.

2.8 | Data analysis

Growth variables: Daily Growth Rate (DGR), Food Conversion Ratio (FCR), Specific Growth Rate (SGR), yield, survival, and economic performance were analyzed by an independent *t* test for equality of means and one–way

ANOVA followed by Tukey HSD test for comparison and to infer growth between test organisms in IMTA and monoculture treatments. Water quality data was analyzed by repeated measures ANOVA with treatment as the main factor and time as a sub factor.

Comparisons of the different treatments IMTA against monoculture was analyzed by calculating the mean values of different growth variables and expressing the results in table and graphical formats. Statistical analyses were carried out using Excel version 2013 and SPSS statistical software IBM version 22. Data are presented as mean (±*SE*). Results were considered significant at ($p < .05$).

3 | RESULTS

3.1 | Growth, survival, and yield variables in monoculture and IMTA treatment

Growth of *P. indicus* was almost similar in both Treatments 1 and 2 at a final body weight of 15.76 ± 2.29 and 15.76 ± 0.53 respectively and with no significant differences ($p > .05$).

Harvesting from both culture systems took place after a period of 135 days and the growth of the experimental organisms was determined. As the ponds could not be drained completely survival and production was determined from 98% of the animals harvested and their mean body weight. The organisms in both treatments were healthy with no any disease occurrence during the experimental period, apart from an occurrence during the initial phase of the experiment where a few sea cucumbers in one of the ponds were observed to have open wounds which was attributed to presence of a mud crab predator in the pond. The growth performance and survival data recorded during the experimental period and calculations carried out at the end of the experiment are presented in Table 1. Among the organisms cultured in the IMTA treatment *H. scabra* attained the highest final average body weight (ABW) of 263.18 ± 54.63 g followed by *A. antiquata* at 84.92 ± 2.16 g. NWG, DWG, and SGR did not show any difference for *P. indicus* in both treatments. Growth trends for the experimental organisms in T1 and T2 were as presented in (Figures 2 and 3).The highest survival was recorded among *P. indicus* with T2 at 80.1% and T1 at 72.8%. *H. scabra* recorded the lowest survival of 56.32%, which was significantly different from the other organisms at ($p < .05$). In this study, AFCR for both treatments was insignificant at ($p > 0.206$) with T1 recording a lower value of 0.88 and T2, a value of 0.97. A production of 20.67 kg of *P. indicus* was obtained in T1, which was not significantly different ($p < .559$) from 22.84 kg obtained in T2. Among the IMTA combination of organisms, production was highest among the *H. scabra* and *A. antiquata* at 66.46 kg and 97.51 kg respectively during the 135 days culture period.

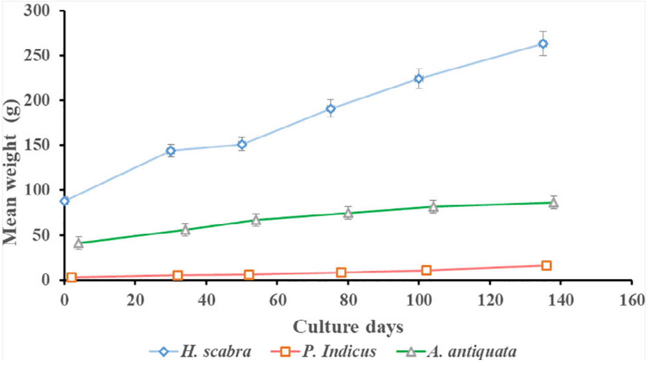

FIGURE 2 Mean weight of *Penaeus indicus*, *Holothuria scabra*, *Anadara antiquata* in IMTA ponds during the experimental period. Values are means (±*SEM*) of pooled data of three replicates in each pond per sampling date at a 20-day interval

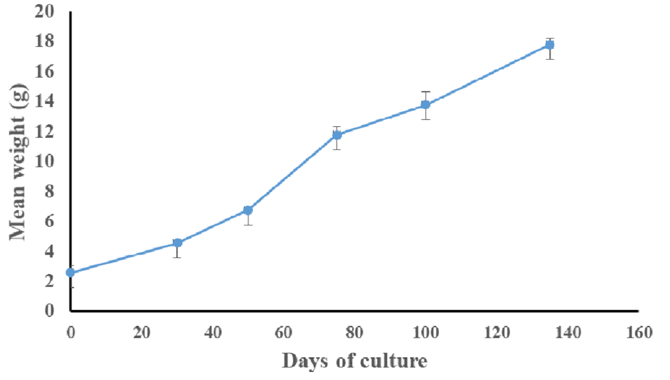

FIGURE 3 Mean weight of *Penaeus indicus* in monoculture ponds. Values are means (±*SEM*) of pooled data of individual shrimps in three replicates ponds

3.2 | Water quality

Physico-chemical variables of the culture water in experimental ponds are as presented in Table 3. All the nutrient variables had significant differences between IMTA and monoculture treatments ($p < .05$). However, temperature, pH, salinity, transparency, and dissolved oxygen did not show marked variations in water quality between the treatments during the culture period. Among the monitored variables, temperature in the ponds varied between 25.6 and 34.5°C and salinity ranged from 35 ppt to 43 ppt for both Treatment 1 and Treatment 2 during the experimental period. Mean values of inorganic nitrogenous (NO_2–N, NO_3–N and TAN) and phosphate-phosphorous (PO_4–P) concentrations were significantly lower ($p < .05$) in T2 as compared to T1.

3.3 | Economic comparisons

The economic analysis was performed to evaluate the net income and cost benefit ratio between the shrimp monoculture ponds and the IMTA ponds. The analysis showed that net income and cost benefit ratio was higher in IMTA ponds as shown in Table 4. There was 58 and 15% increase in net income and CBR respectively in the IMTA than the monoculture treatment. This was as a result of increased production and higher selling price of the harvested organisms which was contributed by higher growth in IMTA system. The species in the IMTA set-up were also allowed to interact without any negative effect, which saved on the cost of construction of barriers in the culture systems. The monoculture treatment did not break even and had a value of USD (300.63) while the net income achieved from the IMTA treatment was USD 514.63. Net income and CBR varied differently in IMTA treatment and in the monoculture treatments. The calculated CBR was 1.77 and 0.27 from the IMTA and monoculture treatment respectively. This was as a result of increased production that attracted good prices.

4 | DISCUSSION

This study is the first to report on pond-integrated culture of *H. scabra* with *P. indicus* and *A. antiquata*. The approach employed is viable with a number of potential benefits to farmers which includes (a) improved water quality in terms of nutrient concentrations; (b) improved yield and income through production of sea cucumbers and cockles that benefit from the nutrients generated in the culture system; and (c) decreased dependence on external inputs such as feeds and nutrients from fertilizer applications.

TABLE 3 Physico-chemical characteristics of experimental pond water collected from marine shrimp monoculture (T1) and IMTA (T2) ponds

Water quality variables	Means Tukey test					
	Treatments		Sampling time			
Variable	1	2	August 10, 2020	September 1, 2020	September 22, 2020	October 13, 2020
Dissolved oxygen (mg L^{-1})	3.69 ± 0.39	3.65 ± 0.39	3.5 ± 0.35	3.2 ± 0.24	3.9 ± 0.34	3.96 ± 0.33
Temperature (°C)	30.78 ± 0.41	30.5 ± 0.41	27.15 ± 0.34^{c}	30.67 ± 0.06^{b}	32.54 ± 0.52^{a}	32.2 ± 0.54
Transparency	32.08 ± 0.14^{a}	30.17 ± 0.14^{b}	30.88 ± 0.23	31.16 ± 0.085	31.3 ± 0.25	31.17 ± 0.05
Salinity (ppt)	38.58 ± 0.51	38.3 ± 0.51	36.6 ± 0.14^{b}	41.35 ± 0.81^{a}	38.72 ± 0.41	37.04 ± 0.51
pH	8.37 ± 0.08	8.32 ± 0.08	8.36 ± 0.16	8.74 ± 0.25	7.72 ± 0.074^{a}	8.56 ± 0.13
Phosphate–phosphorous (mg L^{-1})	0.103 ± 0.007^{a}	0.06 ± 0.007^{b}	0.083 ± 0.004	0.085 ± 0.06	0.078 ± 0.004^{c}	0.08 ± 0.007
Nitrate–nitrogen (mg L^{-1})	0.062 ± 0.003^{a}	0.023 ± 0.003^{b}	0.048 ± 0.004	0.038 ± 0.005	0.04 ± 0.003	0.044 ± 0.004
Ammonia–nitrogen (mg L^{-1})	0.061 ± 0.004^{a}	0.029 ± 0.004^{b}	0.042 ± 0.002	0.052 ± 0.006	0.041 ± 0.004	0.044 ± 0.003
Nitrite–nitrogen (mg L^{-1})	0.05 ± 0.008	0.03 ± 0.008	0.03 ± 0.005	0.045 ± 0.01	0.041 ± 0.008	0.043 ± 0.004

Note: The mean values followed by different superscripts in each factor indicate significant difference at ($p < .05$).

TABLE 4 Comparison of economic returns in monoculture (T1) versus IMTA (T2) systems. Values for total income, net income, and cost benefit ratio represent means of three replicates

Items		T1 Expenditure USD	Income items	USD items	T2 Expenditure	USD	Income items	USD
Stocking biomass	*Penaeus indicus*	1800 × 0.05 = 82	20.6 × 5.45 =	112.36	1800 × 0.05 =	82	22.8 × 5.45	124.26
	Holothuria scabra	–	–	–	435 × 0.36 =	157	46.48 × 18.18	845
	Anadara antiquata	–	–	–	1260 × 0.09 =	113	80 × 2.72	217.6
Labor		181.82				181.82		
Lime		38.63				38.63		
Fertilizer		31.81				22.72		
Feeds		33.45				29.81		
Others		45.45				45.45		
Total expenditure (TE)		413.16	Total income (TI)	112.36	Total expenditure (TE)	670.43	Total income (TI)	1186.86
Net income		TI–TE		−300.8				516.43
Cost Benefit Ratio (CBR)		TI/TE		0.27195				1.7703

Note: Calculation for 0.012 ha pond and 135 days culture period in U.S. Dollar (1USD = 110 Kenya currency).

4.1 | Improved growth and yield through integration

A comparative performance analysis between IMTA and monoculture made in this study portrayed the feasibility of farming shrimps, bivalves and sandfish together in low fed brackish ecosystem. The IMTA model performed better in terms of production, economic returns, environmental health, and ecological benefits as compared to the monoculture system, an outcome that concurs with recent studies by Tang (2017) and Chang et al. (2020).

In this study, shrimps in the IMTA treatment showed slightly higher production estimates 22.84 kg as compared to the monoculture treatment 20.61 kg which could have been attributed to efficient nutrient utilization where nutrient waste, fecal waste and uneaten feeds were extracted from the system by the extractive organisms such as algae, filter feeders and deposit feeders (Samocha, Fricker, Ali, Shpigel, & Neori, 2015). Growth performance of Indian white shrimp in this study gave similar results of an average final body weight of 15.76 g and a SGR of 1.99% both TI and T2 trials, an indication that the conditions for growth and species combinations were optimum for both treatments which also enhanced the recorded good survival rates of 72.8 and 80% for T1 and T2 respectively. There was no any potential effect on lack of extra sand in monoculture ponds. Sea cucumbers in the IMTA treatment grew bigger and faster at a SGR of 4.1% and a net weight gain of 175 g in 135 days of culture exhibiting a growth of 38 g/month which could have been contributed by *H. scabra* intrinsic high growth potential and presence of rich organic feed in the pond bottom mainly from uneaten feed and fecal waste of the fed species in the system. This is comparable to studies by Agudo (2012) and Purcell (2004) which showed that growth of sandfish in earthen ponds was 20–72 g month^{-1}. Shelley (1985) estimated that in the natural *H. scabra* can grow at 14 g/month. In this study survival of sea cucumbers was 56.3%, which was the lowest as compared to the other co-cultured organisms. This could have been attributed to predation from mud crabs that are commonly found at the experimental site of this study. Several studies have shown that survival of *H. Scabra* is normally high 50–85% in ponds (Agudo, 2012; Duy, 2012; Gamboa, Aurelio, Ganad, Concepcion, & Abreo, 2012) as compared to the open sea pens where there has been variation in survivorship averaging at 48% (Robinson & Pascal, 2012).

Bivalves have been used in IMTA systems based on their ability to directly capture organic particulates from the culture site and also nutrient extraction from the system (Chopin, 2013a, 2013b). In this study, cockles, *A. antiquata*, which are bivalves were used as filter feeders from the system. They also served as potential benefits for sustainable food production as shown by Yip, Knowler, Haider, and Trenholm (2017). The growth performance exhibited by the cockles was satisfactory with a net weight gain of 44 g, a SGR of 3.25% and a survival rate of 74.1%. Population studies by Mzighani (2005) showed that *A. antiquata* in the natural environment exhibits an isometric growth with a minimum shell length of 5 cm and a maximum of 72 cm and a corresponding whole live weight of 5–60 g. Differences in size composition happens to be a function of fishing pressure and environmental factors. In the current study, the bivalve was found to be feasible in the co-culture IMTA pond system with the Indian white shrimp *P. indicus* through improving water quality and increasing production in shrimps and sea cucumbers integration.

4.2 | Water quality status within integrated culture systems

The recorded physico-chemical variables were within the required optimum range for shrimp culture in brackish environment (Chakraborti, Sundaray, & Ghoshal, 2002). The tidal water exchange, initial application of lime and monthly fertilizer application resulted to the optimal water quality in the culture systems. The inorganic nutrient variable of water improved in the IMTA system in comparison to the monoculture with more effective removal of both inorganic nitrogenous and phosphate-phosphorous concentrations from the culture water. In the IMTA treatment Inorganic nutrient removal might have been facilitated by algal biomass, presence of cockles and sea cucumbers as extractive organisms which might have also enabled uptake of particulate organic matter through filter feeding and consumption of organic matter from the pond bottom as demonstrated by Chang et al. (2020). Studies have shown that water quality variables like temperature, dissolved oxygen, and salinity are capable of influencing growth of cultured organisms (Tsuzuki, Cavalli, & Bianchini, 2000). However, in this study, there were no significant variations in in situ water quality variables between the two treatments an indication that the different results achieved in organism weight gain and production could be attributed to variations in species combinations. In both systems, natural growth of microscopic aquatic plants provided a possible mechanism for extraction of inorganic nutrients from the culture water (Cunha et al., 2019). In the IMTA system, cockles were used in extraction of the suspended particulate matter in the system through filter feeding (Shpigel, Neori, Popper, & Gordin, 1993). The effective role of bioremediation was played by the sea cucumbers, which fed on organic matter deposited on the pond bottom which further improved nutrient recirculation through bioturbation (Purcell, 2004).

4.3 | Economic performance

The total economic benefit and yield of a fish production system depends on the choice of fish or crop selected (Wang, Li, Dong, Wang, & Tian, 1999). In this study, a marine shrimp monoculture was compared with an IMTA model using marine shrimps, cockles, and sea cucumber. Results of economic analysis portray viability of the IMTA system. The main reasons being use of lower densities of the integrated organisms which in the long run reduces the associated inputs in form of feeds and fertilizers. This is in addition to the benefits associated with IMTA where non-fed organisms depend on energy being generated from wastes and uneaten feeds coming from the system. The tradition with farmers at the experimental site has been stocking at higher densities of 8 inds./m^{-2} in monoculture farms which is much higher than densities of 5 inds./m^2 used in this study which was mainly to accommodate the other integrated species.

The current state of capture fisheries resources shows that most of them have stagnated or are on the verge of collapse because of overfishing (FAO, 2018). On the other hand, the global population is on the increase which poses a challenge to food security (FAO, 2020). Therefore, aquaculture being a fast growing animal production sector in the world could offer possible solutions through production of affordable protein using viable technological innovations. The performance demonstrated in this study is attractive to fishermen and farmers within the coastal rural communities as an opportunity of improving their socio economic welfare.

5 | CONCLUSIONS

Pond integration is an improved system compared to the usual monoculture shrimp production. In the present study, higher profitability was reached by integration and cultivation of extractive species, which assimilated excess nutrients maintaining a balance in the system. Therefore, the findings of this study exhibited that IMTA involving marine shrimps as fed species with cockles and sea cucumbers as extractive organisms is appropriate toward sustainable development of mariculture in earthen ponds as a low intensive culture system that can be adopted by the coastal farmers in the region. Further research on longer culture period and using different species combinations of commercial value need to be explored to assess suitability for culture and application in IMTA systems.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

AUTHOR CONTRIBUTION

Authors made substantive contribution to the reported work.

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REFERENCES

Agudo, N. S. (2012). Pond grow-out trials for sandfish (*Holothuria scabra*) in New Caledonia. In C. A. Hair, T. D. Pickering, & D. J. Mills (Eds.), *Asia-Pacific Tropical Sea Cucumber Aquaculture. ACIAR Proceedings* (Vol. 136, pp. 104–112). Canberra: Australian Centre for International Agricultural Research.

Alexander, K. A., Freeman, S., & Potts, T. (2016). Navigating uncertain waters: European public perceptions of integrated multi trophic aquaculture (IMTA). *Environmental Science & Policy*, *61*, 230–237. https://doi.org/10.1016/j.envsci.2016.04.020

APHA, AWWA, WPCF. (2005). *Standard methods for the examination of water and wastewater* (21st ed.). Washington, D.C.: APHA-AWWA-WEF.

Beltran-Gutierrez, M., Ferse, S. C. A., Kunzmann, A., Stead, S. M., Msuya, F. E., Hoffmeister, T. S., & Slater, M. J. (2014). Co-culture of sea cucumber *Holothuria scabra* and red seaweed *Kappaphycus striatum*. *Aquaculture Research*, *2014*, 1–11. https://doi.org/10.1111/are.12615

Biswas, G., Ananda Raja, R., De, D., Sundaray, J. K., Ghoshal, T. K., Anand, S., … Ponniah, A. G. (2012). Evaluation of productions and economic returns from two brackish water polyculture systems in tide-fed ponds. *Journal of Applied Ichthyology*, *28*(1), 116–122. https://doi.org/10.1111/j.1439-0426.2011.01909.x

Boyd, C. E., & Tucker, C. S. (1992). *Water quality and pond soil analysis for aquaculture* (p. 183). Alabama Agric. Exp Station, Auburn University: Auburn, AL.

Chakraborti, R. K., Sundaray, J. K., & Ghoshal, T. K. (2002). Production of *Penaeus monodon* in the tide fed ponds of Sunderbans. *Indian Journal of Fisheries*, *49*, 419–426.

Chang, Z., Neori, A., He, Y., Li, J., Qiao, L., Pretson, S. I., … Li, J. (2020). Development and current state of seawater shrimp farming with emphasis on integrated multitrophic pond aquaculture farms, in China—a review. *Reviews in Aquaculture*, *12*, 1–15. https://doi.org/10.1111/raq.12457

Chopin, T. (2013a). Integrated multi-trophic aquaculture—Ancient, adaptable concept focuses on ecological integration. *Global Aquaculture Advocate*, *16*(2), 16–19. https://doi.org/10.1007/978-1-4614-5797-8_173

Chopin, T. (2013b). Aquaculture, Integrated Multi-trophic Aquaculture (IMTA). http://www.springerreference.com/index/chapterdbid/226358 © Springer-Verlag Berlin Heidelberg 2013.

Chopin, T., Buschmann, A. H., Halling, C., Troell, M., Kautsky, N., Neori, A., … Neefus, C. (2001). Integrating seaweeds into marine aquaculture systems: A key towards sustainability. *Journal of Phycology*, *37*, 975–986. https://doi.org/10.1046/j.1529-8817.2001.01137.x

Chopin, T., Cooper, J. A., Reid, G., Cross, S., & Moore, C. (2012). Open water integrated multi trophic aquaculture: Environmental biomitigation and economic diversification of fed aquaculture by extractive aquaculture. *Reviews in Aquaculture*, *4*, 209–220. https://doi.org/10.1111/j.1753-5131.2012.01074

Chopin, T., Robinson, S. M. C., Troell, M., Neori, A., Buschmann, A. H., & Fang, J. (2008). Multitrophic integration for sustainable marine aquaculture. In S. E. Jørgensen & B. D. Fath (Eds.), *The encyclopedia of ecology* (pp. 2463–2475). Oxford: Elsevier. https://doi.org/10.1016/b978-008045405-4.00065-3

C. Conand, & N. A. Muthiga (Eds.). (2007). Commercial sea cucumbers: a review for the Western Indian Ocean. WIOMSA Book Series No. 5. 66pp. https://doi.org/10.1201/9780203869543-c86

Cunha, M. E., Quental-Ferreira, H., Parejo, A., Gamito, S., Ribeiro, L., Moreira, M., … Pousao-Ferreira, P. (2019). Understanding the individual role of fish, oyster, phytoplankton and macroalgae in the ecology of integrated production in earthen ponds. *Aquaculture*, *512*(2019), 734297. https://doi.org/10.1016/j.aquaculture.2019.734297

Duy, N. D. Q. (2012). Large-scale sandfish production from pond culture in Vietnam. In C. A. Hair, T. D. Pickering, & D. J. Mills (Eds.), *Asia–Pacific Tropical Sea cucumber aquaculture. ACIAR proceedings* (Vol. 136, pp. 34–39). Canberra: Australian Centre for International Agricultural Research.

Eriksson, H., de la Torre-Castro, M., Purcell, S., & Olsson, P. (2014). Lessons for resource conservation from two contrasting small fisheries. *Ambio*, *44*, 204–213. https://doi.org/10.1007/s13280-014-0552-5

FAO. (2018). The State of World Fisheries and Aquaculture (2018)—Meeting the sustainable development goals. Rome. Licence: CC BY-NC-SA 3.0 IGO.

FAO. (2020). *The state of world fisheries and aquaculture (2020). Sustainability in Action*. Rome, Italy: Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/ca9229en

Gamboa, R. U., Aurelio, R. A., Ganad, D. A., Concepcion, L. B., & Abreo, N. A. S. (2012). Small- scale hatcheries and simple technologies for sandfish (*Holothuria scabra*) production. In C. A. Hair, T. D. Pickering, & D. J. Mills (Eds.), *Asia–Pacific Tropical Sea Cucumber Aquaculture. ACIAR Proceedings* (Vol. 136, pp. 63–74). Canberra: Australian Centre for International Agricultural Research.

Kumara, A., & Dissanayake, C. (2017). Preliminary study on broodstock rearing, induced breeding and grow-out culture of the sea cucumber *Holothuria scabra* in Sri Lanka. *Aquaculture Research*, *48*, 1058–1069. https://doi.org/10.1111/are.12948

Kunzmann, A., Beltran-Gutierrez, M., Fabiani, G., Namukose, M., & Msuya, F. E. (2018). Integrated seaweed—Sea cucumber farming in Tanzania. *WIO Journal of Marine Sciences*, *17*(2), 35–50. https://doi.org/10.4314/wiojms.v17i2.4

Mirera, D. O. (2011). Experimental polyculture of milkfish (*Chanos chanos*) and mullet (*Mugil cephalus*) using earthen ponds in Kenya. *Western Indian Ocean Journal of Marine Science*, *10*(1), 59–71.

Munguti, J. M., Obiero, K. O., Orina, P. S., Musa, S., Mwaluma, J., Mirera, D. O., … Njiru, J. M. (Eds.). (2017). *State of aquaculture in Kenya*. Nairobi, Kenya: Laxpress Services.

Mzighani, S. (2005). Fecundity and population structure of cockles, *Anadara antiquata* L. 1758 (Bivalvia: Arcidae) from a Sandy/Muddy Beach near Dar es salaam, Tanzania. *Western Indian Ocean Journal of Marine Sciences*, *4*, 77–84.

Namukose, M., Msuya, F. E., Sebastian, C. A., Slater, M. J., & Kunzmann, A. (2016). Growth performance of the sea cucumber *Holothuria scabra* and the seaweed *Eucheuma denticulatum*: Integrated mariculture and effects on sediment organic characteristics. *Aquaculture Environmental Interaction*, *8*, 179–189.

Neori, A., Chopin, T., Troell, M., Buschmann, A. H., Kraemer, G. P., Halling, C., … Yarish, C. (2004). Integrated aquaculture: Rationale, evolution, and state of the art emphasizing on seaweed bio filtration in modern mariculture. *Aquaculture*, *231*, 361–391. https://doi.org/10.1016/j.aquaculture.2003.11.015

Neori, A., Troell, M., Chopin, T., Yarish, C., Critchley, A., & Buschmann, A. H. (2007). The need for a balanced ecosystem approach to blue revolution aquaculture. *Environmental Science and Policy for Sustainable Development*, *49*(3), 36–43. https://doi.org/10.3200/envt.49.3.36-43

Ngugi, C., Bowman, J., & Omolo, B. (2007). A new guide to fish farming in Kenya, Aquaculture CRSP Management Office, College of Agricultural Science Oregon State University, 418 Snell Hall, Corvallis, Oregon 97331–1643 USA.

Purcell, S. W. (2004). Rapid growth and bioturbation activity of the sea cucumber *Holothuria scabra* in earthen ponds. *Proceedings of Australasian Aquaculture*, *2004*, 244.

Purcell, S. W., Hair, C. A., & Mills, D. J. (2012). Sea cucumber culture, farming, and sea ranching in the tropics: Progress, problems and opportunities. *Aquaculture*, *368–369*(2012), 68–81. https://doi.org/10.1016/j.aquaculture.2012.08.053

Purcell, S. W., Patrois, J., & Fraisse, N. (2006). Experimental evaluation of co-culture of juvenile sea cucumbers, *Holothuria scabra* (Jaeger), with juvenile blue shrimp, *Litopenaeus stylirostris* (Stimpson). *Aquaculture Research*, *37*, 515–522. https://doi.org/10.1111/j.1365-2109.2006.01458

Robinson, G., & Pascal, B. (2012). Sea cucumber farming experiences in south-west Madagascar. In C. A. Hair, T. D. Pickering, & D. J. Mills (Eds.), *Asia–Pacific Tropical Sea cucumber aquaculture. ACIAR Proceedings* (Vol. 136, pp. 142–155). Canberra: Australian Centre for International Agricultural Research.

Samocha, T. M., Fricker, J., Ali, A. M., Shpigel, M., & Neori, A. (2015). Growth and nutrient uptake of the macroalga *Gracilaria tikvahiae* cultured with the shrimp *Litopenaeus vannamei* in an integrated multi-trophic aquaculture (IMTA) system. *Aquaculture*, *446*, 263–271. https://doi.org/10.1016/j.aquaculture.2015.05.008

Sara, G., Mangano, M. C., Berlino, M., Corbari, L., Lucchese, M., Milisenda, G., … Helmuth, B. (2021). The synergistic impacts of anthropogenic stressors and COVID-19 on aquaculture: A current global perspective. *Reviews in Fisheries Science and Aquaculture*, *29*(3), 1–13. https://doi.org/10.1080/23308249.2021.1876633

Senff, P., Blanc, P., Slater, M., & Kunzmann, A. (2020). Low-technology recirculating aquaculture system integrating milkfish *Chanos chanos*, sea cucumber Holothuria scabra and sea purslane *Sesuvium portulacastrum*. *Aquaculture Environmental Interactions*, *12*, 471–484. https://doi.org/10.3354/aei00377

Shelley, C. (1985). Growth of *Actinopyga echinites* and *Holothuria scabra* (Holothuroidea: Echinodermata) and their fisheries potential (as beche-de-mer) in Papua New Guinea. Proc. Fifth International Coral Reef Cong. Tahiti, 5, 297–302.

Shpigel, M., Neori, A., Popper, D. M., & Gordin, H. (1993). A proposed model for "environmentally clean" land-based culture of fish, bivalves and seaweeds. *Aquaculture*, *117*, 115–128. https://doi.org/10.1016/0044-8486(93)90128-l

Slater, M., & Carton, A. G. (2007). Survivorship and growth of the sea cucumber *Australostichopus* (Stichopus) mollis (Hutton 1872) in polyculture trials with green-lipped mussel farms. *Aquaculture*, *272*, 389–398. https://doi.org/10.1016/j.aquaculture.2007.07.230

Tang, Q. S. (2017). *Advisory research report on green development of aquaculture* (pp. 3–53). Beijing, China: Ocean Press.

Troell, M. (2009). Integrated marine and brackish water aquaculture in tropical regions: Research, implementation, and prospects. In D. Soto (Ed.), *Integrated mariculture: A global review*, (pp. 44–131). Rome: FAO.

M. Troell, T. Hecht, M. Beveridge, S. Stead, I. Bryceson, N. Kautsky, … F. Ollevier (Eds.). (2011). Mariculture in the WIO region—Challenges and prospects. WIOMSA book series no. 11. Viii + 59pp. FAO fisheries and aquaculture technical paper. No. 529. Rome, FAO. pp. 47–131.

Tsuzuki, M. Y., Cavalli, R. O., & Bianchini, A. (2000). The effects of temperature, age and acclimation to salinity on the survival of *Falfantepenaeus paulensis* postlarvae. *Journal of the World Aquaculture Society*, *31*, 459–468. https://doi.org/10.1111/j.1749-7345.2000.tb00896.x

Wang, J., Li, D., Dong, S., Wang, K., & Tian, X. (1999). Comparative studies on cultural efficiency and profits of different polycultural systems in penaeid shrimp ponds. *Journal of Fisheries of China*, *23*(1), 45–52 (in Chinese). Retrieved from. http://en.cnki.com.cn/Article_en/CJFDTOTAL-SCKX901.007.htm

Watanabe, S., Sumbing, J. G., & Lebata-Ramos, M. J. (2014). Growth pattern of the tropical sea cucumber, *Holothuria scabra*, under captivity. *JARQ*, *48*, 457–464. https://doi.org/10.6090/jarq.48.457

Yip, W., Knowler, D., Haider, W. G., & Trenholm, R. (2017). Valuing the willingness-to-pay for sustainable seafood: Integrated multitrophic versus closed containment aquaculture. *Canadian Journal of Agricultural Economics*, *65*, 93–117. https://doi.org/10.1111/cjag.12102

Zaki, M. A., Nour, A. A., Abdel-Rahim, M. M., & Srour, T. M. (2004). Effect of stocking density on survival, growth performance, feed utilization, and production of marine shrimps Penaeus Semisulcatus in earthen ponds. *Egyptian Journal of Aquatic Research*, *30(B)*, 429–442.

Zamora, L. N., Yua, X., Carton, A. G., & Slater, M. J. (2018). Role of deposit-feeding sea cucumbers in integrated multitrophic aquaculture: Progress, problems, potential, and future challenges. *Reviews in Aquaculture*, *10*, 57–74. https://doi.org/10.1111/raq.12147

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