Climate Resilient Mariculture Technologies for Food and Nutritional Security

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Abstract

In India, marine fish production is achieved through capture fisheries and mariculture- culturing of finfish, shellfish, seaweed, etc., in the sea. Increasing protein demand has to be met through increased marine fish production. As marine capture fisheries is in a stagnating phase, the additional fish production has to be achieved through mariculture. Technologies like cage farming and seaweed farming are being promoted by the Indian Council of Agricultural Research (ICAR)-Central Marine Fisheries Research Institute (CMFRI) for more than a decade. These interventions assisted in enhancing the marine fish production and income of the fishers. One of the anticipated issues while expanding sea cage farming is the increased organic and inorganic load in the water and consequent disease problems. In this context, the concept of bio-mitigation along with increased biomass production can be adopted by integrating different groups of commercially important aquatic species that are having varied feeding habits. This concept is known as Integrated Multi-Trophic Aquaculture (IMTA). The environmental and economic stability and social acceptability is ensured through IMTA. The ICAR-CMFRI has successfully demonstrated IMTA under participatory mode with a fishermen group by integrating seaweed *Kappaphycus alvarezii* with cage farming of Cobia (*Rachycentron canadum*). Through demonstration, the total seaweed produced under IMTA was 2.2 times higher than the control. Similarly, the cobia yield was 1.3 times higher than the control. Additionally, the total amount of carbon sequestered into farmed seaweed was 2.2

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times higher than the control. At present in adoption stage, the total seaweed produced under IMTA was 3.1 times higher than the control. Integration of seaweed with cobia cages favorably generates additional revenue and is efficient in reducing both organic and inorganic matter from unutilized feed and excreta and thereby ensuring ecological balances. It is also one of the significant mitigating measures on the adverse impact of climate change and earns carbon credit to our country.

Keywords

Food and nutritional security · Resilient mariculture · *Kappaphycus alvarezii* · Cage farming · Cobia (*Rachycentron canadum*) · Integrated Multi-Trophic Aquaculture (IMTA)

4.1 Introduction

Aquaculture growth involves the expansion of cultivated areas worldwide, and density of aquaculture is determined by installations and species cultured with greater use of formulated feed resources. Poor and irregular management results in negative impacts on the environment and on the society. Increased environmental sustainability, economic stability through improved output, lower costs, species diversification with societal acceptability, risk reduction, and job creation are the prerequisites for "Engineered Aquaculture." The efficient use of nutrient resources, as well as the opportunity of diverse products and benefits while reducing impacts, and therefore integrated aquaculture, becomes a very important practical way to implement ecosystem approach to aquaculture (EAA) (FAO 2008). Farming of multiple species will effectively utilize the resources and bio-mitigate the production waste. This will increase the resilience of the operation with reduced risks which are the integral part of EAA.

Integration of fish and vegetation has been adopted for centuries. In the 1970s, John Ryther reignited interest in Integrated Multi-trophic Aquaculture (IMTA) in which advantages of synergistic interactions among species and the environment is appraised. He is considered as the grandfather of modern IMTA, his seminal work "integrated waste-recycling marine polyculture systems," for combining polyculture, integrated mariculture or aquaculture, ecologically engineered aquaculture, and ecological aquaculture. Later in 2004, Jack Taylor combined integrated aquaculture and multi-trophic aquaculture into the term integrated multi-trophic aquaculture. Integrated aquaculture not only provides food products but also many benefits to the ecosystem (Fang et al. 2018).

IMTA can be "applied to open-water or land-based systems, marine or freshwater systems, and temperate or tropical systems" (Chopin 2013a, b). Choices in the design of the IMTA systems can vary on different climatic, environmental, biological, physical, chemical, economic, historical, societal, and political governance conditions, prevailing in the parts of the world where they operate (Chopin 2013a, b). Culture organisms must be chosen from different trophic levels by factoring in (a) "their complementary functions in the ecosystem" and (b) "economic potential of the culture organisms." Usually, fed species such as finfish or shrimp are cultivated with extractive species, such as seaweeds and aquatic plants that recapture inorganic dissolved nutrients, and shellfish and other invertebrates that recapture organic particulate nutrients for their growth (Chopin 2006). There is tremendous opportunity to use marine macro algae as bio-filters, and to process them and produce products with commercial value. However, only a few countries are doing IMTA on a commercial scale, and globally most of the seaweed culture is taken up as open water monoculture, for example, in Asia, South America, South Africa, and East Africa.

Inorganic extractive components of IMTA farmed/being experimented in India are seaweeds such as *Kappaphycus alvarezii* and *Gracilaria edulis*. The culture of these organisms that are low in the food chain and that extract their nourishment from the sea involves relatively low input. The organic extractive components are the oysters and mussel. During recent years, fish-farming in floating cages has also been introduced in the open waters. It is then realized that the recycling of waste nutrients by seaweed and filter-feeding shellfish is the most likely way to economically improve mariculture sustainability.

4.2 CMFRI Technology – Sea Cage Farming of Cobia

In recent years, the availability of high value fish from sea is declining mainly due to over-exploitation of stocks. However, the demand for marine fish is increasing year after year, as it is an important source of protein, fatty acids, and it provides essential nutrients to the poorer sections of the society. Hence, the additional requirement of sea fish has to be met only by farming in seas, namely, mariculture. The Mandapam Regional Centre of "Central Marine Fisheries Research Institute" (CMFRI) is currently developing advanced technologies for the "seed production" and "farming of high value marine finfishes." One such technology is sea cage farming of cobia *Rachycentron canadum*.

The Mandapam Regional Centre of ICAR-CMFRI through intensive research on cobia has developed innovative technologies for (a) breeding, (b) seed production, and (c) cage farming of cobia. The technologies enable the fishermen to earn additional income and livelihood. Further, cobia farming can be undertaken on a small scale. Research findings as reported by Johnson et al. 2019 reveals that (a) cobia is a suitable species for sea cage farming and that (b) cobia quickly grows to attain a weight of 2–3 kg in about 6 months and 4–8 kg in about a year. Cobia is a popular table fish due to its high quality of meat. In India, cobia is sold as whole or as steaks in the domestic market. It has a very good demand in states like Kerala, Tamil Nadu, Maharashtra, West Bengal, Karnataka, and Goa. The present production level is not enough to meet the domestic demand. As the culture practice of the cobia is picking up momentum, it will also have export potential in the future. As a result of the initiation taken by the CMFRI–Mandapam, cage farming of cobia is being adopted by more than 100 groups in the coastal districts of Tamil Nadu with the support of central and state government agencies.

4.3 Integrated Multi-trophic Aquaculture

One of the anticipated issues while expanding sea cage farming is the increased organic and inorganic load in the water and consequent disease problems. In this context, the idea of bio-mitigation along with increased biomass production can be achieved by integrating different groups of commercially important aquatic species that have varied feeding habits. The ICAR-CMFRI has successfully conducted a demonstration of IMTA under participatory mode with a fishermen group at Munaikadu (Palk Bay), Ramanathapuram district, Tamil Nadu, India, by integrating seaweed *Kappaphycus alvarezii* with cage farming of Cobia (*Rachycentron canadum*). Since seaweed farming is being widely adopted on the coast of Tamil Nadu, integration of seaweed with cage farming of cobia was initially attempted (Figs. 4.1 and 4.2).

4.3.1 *Kappaphycus alvarezii* Farming

Kappaphycus alvarezii is a red alga, which is widely used as phycocolloids (carrageenan), food, fodder, and bio-fertilizer. *Kappaphycus alvarezii* farming methods include but are not limited to floating bamboo raft method, tube net method, and monoculture technique. Nevertheless, on the Tamil Nadu coast, India the floating bamboo raft method is widely adopted. Further, this method is ideal for coastal waters with moderate wave action and depth as well. The mainframe of the floating bamboo raft is 12 × 12 feet. As regards its construction, 4 bamboos (4 feet each) are

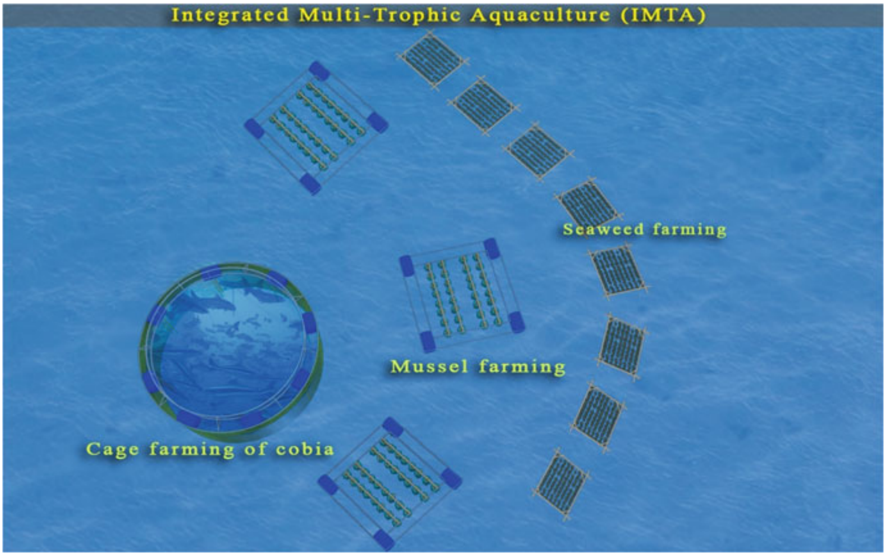

Fig. 4.1 IMTA (Schematic aerial view)

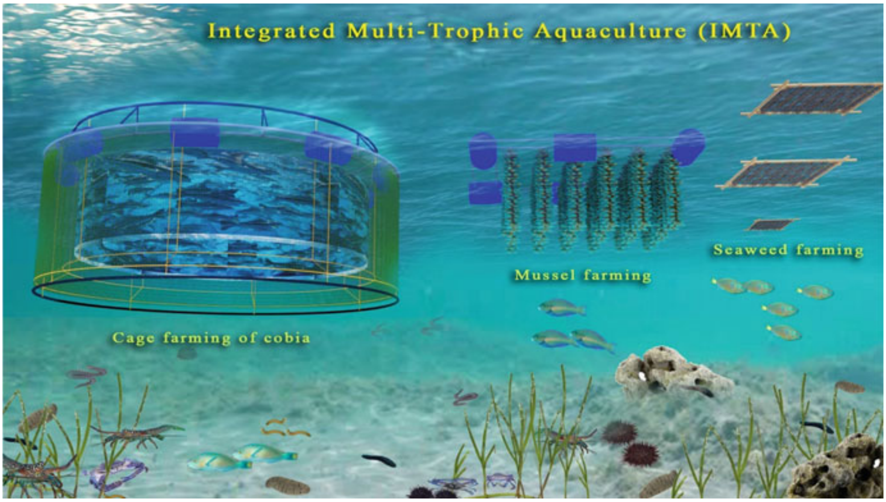

Fig. 4.2 IMTA (Schematic cross-sectional view)

Plate 4.1 Seaweed fragments are tied on the rope

fastened diagonally in the four corners of the mainframe (Plates 4.1 and 4.2). Approximately 20 polypropylene-twisted ropes along with seed materials are tied in the raft. Along the length of rope, about 150–200 grams of seaweed fragments are tied at a spacing of 15 cm in such a way that about 20 seaweed fragments are tied in a single rope. As regards the total seed requirement, it is about 60–80 kg/raft. In order to avoid grazing, a fish net with a dimension of 4 m × 4 m size is tied to the bottom of the raft (Johnson and Gopakumar 2011; Johnson et al. 2017). The crop duration is about 45 days. Annually, a gross revenue of ₹1,50,000 is being earned by a family in *Kappaphycus* farming.

Plate 4.2 Bamboo raft method – *Kappaphycus* farming

Plate 4.3 Cage farming of cobia

4.3.2 Demonstration of IMTA

A total of 16 bamboo rafts (12 × 12 feet) with 60–80 kg of seaweed per raft were integrated along with one of the cobia cages for a span of 4 cycles of seaweed farming (covering 180–210 days of cobia farming). The rafts were placed 15 feet away from the cage in a semi-circular manner, so as to enable the seaweed to absorb the dissolved inorganic nutrient wastes arising from the cage and that moves along the water current from the cage.

A GI cage of 6 m diameter and 3.5 m depth with 750–1000 cobia fingerlings was integrated with the above seaweed raft system. The fingerlings of cobia were fed @ 5% total biomass of fish with chopped low-value fishes (sardine, lesser sardine, rainbow sardine, etc.) twice a day. Net cages were changed based on the subjective assessment of fouling of the net in order to have sufficient water exchange. The crop period for cobia is 6–7 months (Plates 4.3, 4.4 and 4.5). As a control, a separate set of rafts of the same number were grown in a different location without any integration with the cobia farming cages.

Plate 4.4 Seaweed rafts

Plate 4.5 Seaweed rafts (16 Nos.) integrated with cobia cage

4.3.2.1 Economic Benefits Through Increased Seaweed Production Under IMTA

One complete cycle of seaweed extends for an average of 45 days. In one raft of 12 × 12 feet, the average yield without integration was 150 kg per raft, whereas in the raft integrated with a cobia rearing cage the average yield was 260 kg. The seaweed rafts were brought near the shore for harvesting. After retaining 60–80 kg as seed material for the next crop, the remaining material was sun dried near the shore for 3 days and sold in dried form. The average dry weight of the harvested seaweed is only 10% of the wet weight. Within 2 or 3 days from harvest, the rafts were seeded once again and integrated to the cobia rearing cage. Four cycles of seaweed farming were performed in a row for a period of 6–7 months.

The total dried seaweed production of the integrated rafts after 4 cycles was 1,280 kg, while that of non-integrated rafts was only 576 kg. An additional yield of 704 kg of seaweed was achieved through integration with cobia cage farming (Table 4.1). Also there was an increased number (average 90–100) of newly

Table 4.1 Comparison of cost and returns of seaweed cultivation by IMTA (16 rafts/1 cage/4 cycles) and non-IMTA

Particulars	IMTA	Non-IMTA	Difference
Dried seaweed production (for 4 cycles, 16 rafts)	1,280 kg	576 kg	704 kg
Price of dried seaweed (Rupees per kg)	37.50	37.50	–
Gross Revenue (Rupees)	48,000	21,600	26,400
Total Costs (Rupees) (16 rafts × Rs. 1000 per raft)	16,000	16,000	–
Net income (Rupees) (Gross Revenue – Total Cost)	**32,000**	**5600**	**26,400**
Profit margin (%) {(Net income/Revenue) × 100}	**67**	**26**	**41**

Plate 4.6 Comparison of seaweed yield both non-integrated (with cobia cage) (L) and integrated farming (R)

Plate 4.7 More numbers of newly emerged apical portion/tips from integrated rafts

emerged apical portion/tips in a bunch of harvested seaweed from the rafts integrated with the cobia cages, due to effective organic waste mitigation. However, the same was less (average 30–40 numbers) from the rafts that were not integrated. The bunches having more numbers of newly emerged apical portion/tips, when used for replanting, are ready for harvest within 40 days, whereas the seaweed with less numbers of newly emerged apical portion/tips, if used as seed, are ready for harvest only after 54 days (Plates 4.6 and 4.7). There was an additional revenue generation/additional net income of ₹26,400 with an increased profit margin of 41% through the integration of seaweed rafts to cobia cages with same operational cost for the rafts.

Table 4.2 Comparison of economics of sea cage farming of cobia with and without IMTA (for one cage and one crop of 6 months duration)

S. No.	Particulars	IMTA (Rupees)	Non-IMTA (Rupees)	Difference
750 cobia seeds were stocked in a 6 m diameter and 3.5 m depth GI cage				
1	Fixed cost (one cage)	61,600	61,600	0
2	Total operating cost	1,30,000	1,30,000	0
3	Total cost of production (6 months)	1,91,600	1,91,600	0
4	**Yield of farmed fish (in kg) (in 6 months average wt. 2.2 kg)**	**1220**	**960**	**260 kg**
5	**Gross revenue in Rupees (@₹290 per kg)**	**3,53,800**	**2,78,400**	**75,400**
6	Net income (Rupees)	1,62,200	86,800	75,400
7	Net operating income (income over operating cost) in Rupees	2,23,800	1,48,400	75,400
8	Farm gate price (Rupees)	290.00	290.00	0
9	Capital productivity (operating ratio) (Total operating costs/Gross revenue)	0.37	0.47	–
10	Cost of production in Rupees per kilogram (Total cost of production/Yield of farmed fish)	157	199	42

Plate 4.8 View of harvested cage farmed cobia fishes from the integrated cages

4.3.2.2 Economic Benefit Through Increased Cobia Production Under IMTA

The integration of cobia cage with seaweed rafts generated favorable returns for the farmers with respect to the finfish production. In a 6-month production cycle of cage farming of cobia under IMTA (along with 4 cycles for the integrated seaweed), an average yield of 1,220 kg was achieved whereas in the non-integrated cobia cage the yield was only 960 kg. The gross revenue generated from the cobia yield (with an average weight of 2.2 kg/fish and at the rate of ₹290/kg) was ₹3,53,800 for the integrated cages and ₹2,78,400 for the non-integrated cages. Hence, an additional

Plate 4.9 Harvested seaweed from integrated (with cobia cage) farming

net operating income of ₹75,400 was realized from the integrated cage (Table 4.2; Plates 4.8 and 4.9).

The decrease in operating ratio from ₹0.47 to ₹0.37 and cost of production per kilogram from ₹199 to ₹157 for non-integrated and integrated cages, respectively, increased the profit percentage.

The sequestration of the organic waste by seaweeds acts as a fertilizer for itself, and also decreases the organic load in the natural water body and helps the fish to save and minimize its energy expenditure toward warding off environmental stress, thus helping it to have a better growth rate over its counterpart cultured in a non-integrated manner.

4.3.2.3 Environmental Benefits

It was found that the organic waste mitigation was more efficient in the integrated system of *Kappaphycus* farming than the non-integrated system of farming. Biochemical analysis of water and sediments from the experimental rafts and cages indicated the mutual beneficial effect of seaweeds and cobia in the integrated aquaculture system. The analyses for organic matter load and water quality parameters indicated that the organic wastes from the feed waste and excreta of fish were sequestered by the integrated seaweed. This finding is in accordance with other works which reported that mussels/oysters and seaweeds can effectively remove fish wastes and increase the production when integrated with finfish (Chopin 2008; Jiang et al. 2010; Handå et al. 2012; Zhang et al. 2013).

Seaweeds absorb carbon-di-oxide (CO_2) and reduce global warming (Israel et al. 2010). Experimental studies were conducted at Munaikadu, Ramanathapuram district, Tamil Nadu, India, on "assessment of carbon sequestration potential of seaweed" (*Kappaphycus alvarezii*) and it was observed that the carbon-di-oxide sequestration rate is about 0.0187 gday^{-1} (CMFRI Annual Report, 2015–2016). It is evident from Table 4.3 that the total amount of carbon sequestered into cultivated

Table 4.3 Comparison of carbon sequestration potential of seaweed cultivation through IMTA

S. No.	Particulars	IMTA	Non-IMTA
1	Seaweed production as wet weight (for 4 cycle, 16 rafts)	12,800 kg	5760 kg
2	Average dry weight percentage of the harvested seaweed (%)	8.75	8.75
3	Average carbon content (%)	19.92	19.92
4	**Total amount of carbon sequestered (1) × (2) × (3)**	**223 kg**	**100 kg**

seaweed (*Kappaphycus alvarezii*) in the integrated and non-integrated rafts were estimated to be 223 kg and 100 kg, respectively. This finding derives support from Tang and Fang (2012) who reported that IMTA contributes toward mitigation of the effects of climate change.

4.3.2.4 Adoption experience of IMTA in Tamil Nadu

At present in adoption stage at Munaikadu, Palk Bay, Tamil Nadu, seaweed through IMTA had a better average yield of 320 kg per raft, while in the non-integrated raft the yield was 144 kg per raft. An additional yield of 176 kg of seaweed per raft (122% additional yield) was achieved through the integration with the cage farming of cobia. Additional seaweed yield in the integrated rafts are due to the effective utilization of organic and inorganic wastes by the seaweeds. In each cycle, 60 kg of seaweed was retained as seed material and the remaining was dried. The total dried seaweed production (10 % of the wet weight) from the integrated rafts after 4 cycles was 1,664 kg (26kg × 16 rafts × 4 cycles). Whereas the production from non-integrated rafts was only 538 kg (8.4kg × 16 rafts × 4 cycles). Thus an additional yield of 1,126 kg of seaweed was achieved from 4 cycles through integration with cobia cage farming. An additional net income of Rs. 56,300/- (1,126kg × Rs.50/kg of dry weight) was realized through integration of seaweed rafts with cobia cage. The total amount of carbon sequestered into the cultivated seaweed (*Kappaphycus alvarezii*) in the integrated and non-integrated rafts was estimated to be 357 kg and 161 kg, respectively. Hence there is an addition of 196 kg carbon credit through the integration of 16 seaweed rafts (4 cycles) with one cobia farming cage (one crop). Similarly through cage farming of cobia under IMTA an average yield of 2,043 kg was achieved whereas in the non-integrated cobia cage the yield was only 1,750 kg. The gross revenue generated from the cobia yield was Rs.6,74,190/- (@ Rs. 330/kg) for the integrated cages and Rs.5,77,500 for the non-integrated cages. Hence, an additional net operating income of Rs.96,690/- was realized from the integrated cage. Therefore, the adoption of IMTA by farmers has proven increased economic returns and environmental sustainability than the trails and demonstration.

4.4 Conclusion

Integration of seaweed with cobia cages favorably generates additional revenue through increased yields of both cobia and seaweed. This is evident from the increased profit percentages in either case. Fishermen in Ramanathapuram district, Tamil Nadu, India, are being benefited through this technology and they are continuously adopting this technology with their own investment. Hence, integration of seaweed along with cage farming can be promoted for bio-mitigation. IMTA increased the profits and reduced the risk of crop failure through diversification, as *natural* crop insurance. Moreover, IMTA is efficient in controlling both organic and inorganic pollution in the natural open waters and thereby ensuring ecological balances. Thus, IMTA is an eco-friendly option with benefits including sustainable income to the coastal fishermen and livelihood security. It is also one of the significant mitigating measures that enable carbon sequestration and ecological sustainability of the marine ecosystem.

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