Open sea cage culture of cobia: a catalyst for the blue economy along Indian coasts

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The escalating global demand for fish protein necessitates the expansion of aquaculture from land to sea, facilitated by floating sea cages. In this study, the National Institute of Ocean Technology (NIOT), Chennai, Tamil nadu conducted a pilot-scale culture of hatchery-reared cobia seeds (*Rachycentron canadum*) in HDPE collar floating cages (9 m diameter with a cultivable volume of 320 m^3). These cages were strategically deployed at Olaikuda (Gulf of Mannar, Tamil Nadu) and Thuplipalem (Andhra Pradesh), representing semi-protected (SP) and open sea (OS) environments respectively. The evaluation focused on growth performance, with cobia seeds stocked in cages at an initial biomass of 150 g/m^3 (SP) and 154 g/m^3 (OS), featuring an initial average weight of 32.49 ± 1.77 g and a total length of 15.6 ± 0.91 cm during stocking. In SP site, cobia exhibited significant growth, reaching an average weight of 3830 g in 270 days, with a specific growth rate (SGR) of 1.76% with a survival rate of 77%. In contrast, despite the longer culture period of 322 days at the OS site, lower average weight of 2550 g with an SGR of 1.35% with survival rate 62% at SP. Physicochemical and biological parameters at both sites remained within optimal ranges. Notably, the OS site experienced higher wave heights (ranging from 0.56 to 2.28 m); potentially impacting feeding patterns, high energy expenditure due to the exposed weather conditions resulted into reduced growth rate compared to the sheltered bay. This study aims to elucidate the comparative suitability of environmental settings and its economic feasibility for open sea cage farming.

Keywords: Blue economy, cobia, growth rate, mariculture, sea cages, wave height.

Introduction

GLOBALLY, marine cage-based fish farming has experienced significant development in recent years and represents a potential source of fish protein[1]. In comparison, India's cage culture is still in its early stages, despite having an advantageous tropical climate, a long coastline stretching 8118 km, 12 nautical miles of territorial waters, and approximately 4 million marine fishermen residing in 3432 fishing villages across 66 coastal districts in 9 coastal states and 4 union territories. The country also features 6 major and 40 minor fishing harbours along with 1537 marine fish landing centres[2].

Despite the high protein content in fish, global fish production remains around 140 million tonnes (mt), which is relatively lower than the world's cereal production of 2686 mt (ref. 3). India's total fish production was reported to be 14.73 million metric tonnes (MMT) for the year 2020–21, with capture fishery contributing 3.48 MMT and culture fishery contributing approximately 11.25 MMT (Indian Fisheries Annual Report 2021–22). As capture fisheries have reached their maximum sustainable level, there is a pressing need to expand culture fishery, specifically through open sea-cage farming, as land-based aquaculture production often leads to multiple conflicts. Open sea-cage farming offers stable water quality and comparatively fewer conflicts in the offshore environment. Furthermore, land-based culture typically produces an average of 0.5 kg/m^3 (5000 kg/ha), while open sea-cage farming allows up to 100 kg/m^3 production through intensified culture operations, such as those involving *Hippoglossus hippoglossus*[4]. Offshore cage farming facilitates high-density seed stocking compared to land-based culture, employing simpler operations and harvesting methods with multi-trophic level usage[1].

Cobia (*Rachycentron canadum*) stands out as one of the essential candidates, demonstrating superior growth rate combined with consistent demand in both domestic and international markets[5–7]. Various environmental settings, particularly wave height, influence the growth of cultured fish. Hence, site selection considerations for fostering the growth of the blue economy through cage culture should also consider the environmental parameters to reap the maximum benefits.

The process of identifying a suitable location requires a diverse range of data, encompassing environmental factors, socio-economic considerations, legal aspects and planning-related information[8]. Successful finfish cultivation

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necessitates stable environmental conditions to optimize growth and ensure survival. Considering these crucial factors, two distinct environmental settings were chosen for the present study at Olaikuda (Gulf of Mannar, Tamil Nadu), representing a semi-protected (SP) environment, and Thuplipalem (Andhra Pradesh), representing an open sea (OS) environment. This study aims to assess the influence of water quality and environmental parameters such as wave height on the growth of cultured fish. The economic feasibility of fish cultivation in an offshore environment is explored by considering factors such as rough weather conditions, distance from the landing site and accessibility to other critical facilities. These considerations are discussed considering the cost of production, a key parameter crucial for ensuring the profitability of fish farming.

Materials and methods

The location of Olaikuda and the OS at Thuplipalem along the southeast coast of India, were chosen for comparative assessment of the growth of *R. canadum* (Figure 1). The Olaikuda sandy substratum site is in a shallow, semi-protected bay with depth approximating ~7 m. This relatively tranquil location is characterized by clear water and

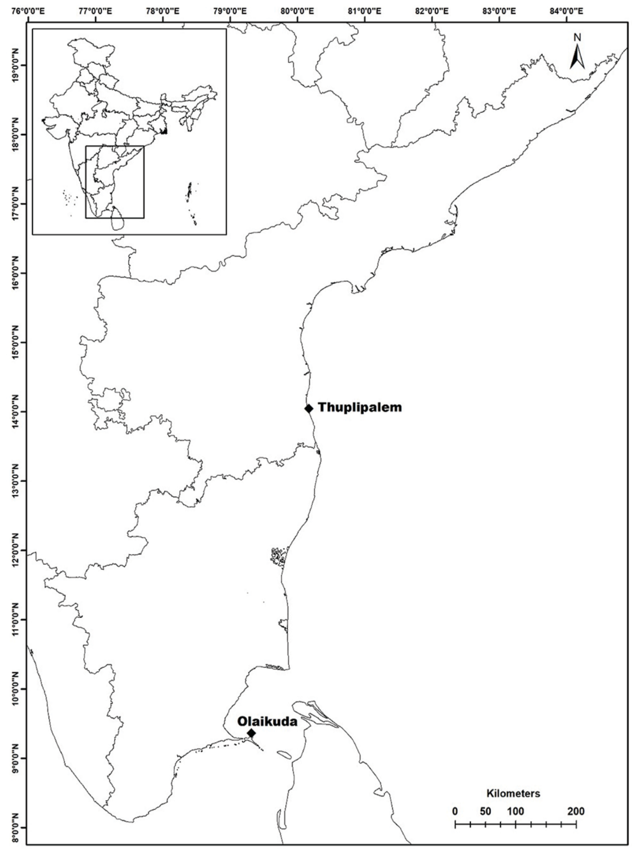

Figure 1. Map showing the study area at Olaikuda, Tamil Nadu and Thuplipalem, Andhra Pradesh, India.

a favourable coastal environment, making it conducive for the sea-cage culture of marine finfish.

The OS environment at Thuplipalem, a sandy substratum off Nellore, Andhra Pradesh, is ~14 m deep and often encounters high waves. HDPE collar floating cages (9 m in diameter with a cultivable volume of 320 m^3) were deployed using a multipoint mooring system at both sites[9].

Regular monitoring and recording of water quality parameters such as salinity, temperature, pH and dissolved oxygen (DO) were done with a pre-calibrated water quality probe (YSI model 563A, Ohio, USA) at both sites. The nutrients, namely nitrite, nitrate, inorganic phosphate (IP), silicate, total nitrogen (TN), ammonia and total phosphorus (TP) were measured in seawater samples following the standard protocol[10]. The significant wave height (SWH) data were obtained from the automatic recording wave rider buoys installed and maintained by the Indian National Centre for Ocean Information Services, Ministry of Earth Sciences, Government of India.

Juvenile cobia seeds at 90 days post-hatch (dph), with weights ranging from 29.8 to 34.3 g and a mean weight of 32.49 ± 1.77 g, were acquired from the Rajiv Gandhi Centre for Aquaculture Hatchery, Pozhiyur, Kerala. Three thousand seeds were transported by road using circular HDPE tanks (capacity 1000 litre) at a density of 1 seed/litre, following standard protocols[11]. The fish seeds were transported from the shore in 1000 litre tanks placed in a catamaran (mechanized traditional boat) filled with source water. The fish seeds were then stocked in floating, 2 m diameter nursery cages, deployed inside 9 m diameter circular cages, using 3 mm mesh size nets (volume 4 m^3) at a stocking density of 63 individuals/m^3. The fish were fed twice a day (7 am and 4 pm) with nursery feed (crumble size 2 mm with 48% protein composed of fish and krill meal) at 10% of the total biomass and grown for 30 days. After 30 days of culture (DOC), the fish reached an average weight of 200 g and 197 g at Olaikuda and Thuplipalem respectively. Subsequently, they were released into grow-out cages with knotless poly alanine nets (mesh size 8 mm), featuring a culture volume of 320 m^3. The initial stocking density was 521 g/m^3 at Olaikuda and 594 g/m^3 at Thuplipalem.

The fish in the grow-out cages were provided with floating pellet feed ranging in sizes from 4, 6, 8, 10 to 12 mm, containing 42% protein composed of fish and krill meal. The feeding rate commenced at 6–8% of the total biomass during the nursery phase. To facilitate effective pellet distribution, the feed pellets were gradually released in the direction of the waves, allowing ample time for them to move away from the release point. This ensured sufficient time for the fish to consume the pellets, while minimizing the escape of unconsumed pellets from the cage.

However, during the initial growth phase in the OS (Thuplipalem), a considerable number of floating pellets escaped from the cages due to high wave action, resulting in increasing feed expenses. To mitigate feed loss, smooth tarpaulin sheets (80 cm height) were stitched inside the cage net at the water level. Throughout the pre-grow-out and grow-out phases, the fish were fed to satiation, typically starting at around 6% of the total biomass during pre-grow-out and progressively reducing to 3% by the end of the culture.

To maintain optimal conditions, the nets were periodically cleaned from fouling algae and organisms to reduce drag and ensure consistent water flow through the cages. Regular SCUBA diving was conducted at both sites to monitor the condition of the fish and the nets.

The growth pattern was recorded every 30th day by documenting the length and weight of the fish. Body weight was measured using an electronic digital balance (± 0.1 g) and length using a fish measuring board. No mortality was recorded during sampling and live fish were released back into the cages after measurements. The length–weight relationship was calculated as

$$W = aL^b,$$

where W is the weight of the fish (g), L the total length of the fish (cm), a the intercept and b is the slope of the regression line and graphs were prepared using Microsoft Excel. If $b = 3$, then growth is isometric, $b > 3$ indicates positive allometric growth, while $b < 3$ indicates negative allometric growth[12,13]. Table 1 gives the details.

Triplicate samples were analysed with quality control techniques, including thorough standardization. The spatial variations of physico-chemical parameters were tested using one-way ANOVA. Factor analysis (FA) was performed using 13 environmental and growth parameters[14], and the strong (>0.75), moderate (0.75–0.50) and weak (0.50–0.30) factor loadings were classified according to the standard protocol[15]. To establish sample adequacy, the Kaiser–Meyer–Olkin (KMO) criterion was used. To reduce the impact of discrepancies in measurement units and variance, all parameters were normalized using a Z-scale transformation (mean = 0; variance = 1), which rendered the data dimensionless for FA. A correlation matrix was applied for 10 environmental and growth parameters considering its importance in aquaculture. SPSS software (version 18.0) was used for the analyses.

Table 1. Summary of growth parameters used to express results of growth rates of cobia

Parameters (unit)	Equation
Absolute growth (g)	$AG = W_2 - W_1$
Absolute growth rate (g/day)	$AGR = (W_2 - W_1)/(t_2 - t_1)$
Relative growth	$RG = (W_2 - W_1)/W_1$
Relative growth rate	$RGR = (W_2 - W_1)/W_1(t_2 - t_1)$
Instantaneous growth rate (g/day)	$IGR = (\ln W_2 - \ln W_1)/(t_2 - t_1)$
Specific growth rate (%/day)	$SGR = 100 * (\ln W_2 - \ln W_1)/(t_2 - t_1)$
Length–weight relationship	$W = \alpha L^b$

W_1, Initial wet weight of fish at stocking; W_2, Final wet weight of fish; t_1, Age at stocking; t_2, Age at the time of harvest; L_t, Total length at age t; α and b are constants; α, Rate of decline in growth rate with age; A_0/α is expected to be a constant.

Results and discussion

The physical parameters such as sea surface current (SSC) and total suspended solids (TSS) were in the optimal range[16,17] (Table 2). The mean water temperature was 28.40° ± 0.71°C and 28.44° ± 1.67°C at Olaikuda and Thuplipalem respectively. There was no significant difference ($P > 0.05$) in the maximum temperature, though the lowest temperature of 25.3°C was recorded in Olaikuda. Salinity was higher at Olaikuda (34.40 ± 0.21 PSU) compared to Thuplipalem (28.81 ± 3.851 PSU). Overall, the DO level was slightly higher at Thuplipalem (4.65 ± 0.60 mg/l) compared to Olaikuda (4.29 ± 0.93 mg/l), and was comparable with the coastal environment on the east coast[18]. The nutrients (ammonia: 0.20 ± 0.12 and 0.29 ± 0.31 μM, nitrite: 0.51–0.27 μM and 0.10 ± 0.06 μM, nitrate: 3.93–12.40 and 0.61 ± 0.46 μM) at both locations were comparable to previous studies in Palk Bay[18,19] and Thuplipalem[20]. Nitrates were comparatively high at Olaikuda, but the mean nutrient concentrations at both sites were within the optimal levels suggested for fish farms[16]. Despite the spatial distance between both stations, there was no statistical significance ($P > 0.05$) in nutrient concentration, except for nitrite ($F = 15.09$, $P < 0.001$) and nitrate ($F = 80.08$, $P < 0.001$).

Information about the waves will help in the identification of suitable locations, and the design of cage and mooring systems. Waves along the west coast of India are high during the monsoon season with significant wave heights reaching up to 6 m (ref. 21). During other months, wave heights are normally less than 1.5 m (ref. 22). Wave action was comparatively high (0.56–2.28 m) at Thuplipalem, while it ranged from 0.30 to 0.70 m at Olaikuda (Figure 2). The difference in wave height was significant ($F = 101.29$, $P < 0.001$), which may be one of the factors contributing to the limited fish growth at Thuplipalem.

Factor analysis on water temperature, pH, salinity, DO, TSS, nitrite, nitrate, ammonia, length, wave, number of fish, individual fish weight and total weight explained 84.41% of the total variance for the first factor. Reduction in the dimensionality of the original dataset was achieved through FA[23]. Factor 1 (VF1) explains 33.10% of the total variance and indicates a moderate positive loading of nitrite (0.72) and DO (0.56), and a strong positive loading of individual fish length (0.89), individual weight (0.92) and total weight (0.95) (Figure 3). Factor 2 (VF2) explains 23.92% of the total variance and positive loadings of salinity (0.59) and nitrate (0.88), and negative loadings of TSS (–0.54) and wave (–0.86). This indicates that the higher waves and high TSS would impact the growth of fish negatively. Thus, waves are one of the limiting environmental factors in the growth of fish in floating cages.

Stocking and fish growth

The nursery rearing in small cages deployed inside the grow-out cages resulted in high survivability reaching

Table 2. Summary of water quality parameters at Olaikuda and Thuplipalem

Parameters	Olaikuda (SP) Mean	Olaikuda (SP) Range	Thuplipalem (OS) Mean	Thuplipalem (OS) Range
WT (°C)	28.40 ± 0.71	25.30–30.50	28.44 ± 1.67	26.01–30.65
pH	8.18 ± 0.07	8.00–8.27	8.20 ± 0.09	8.07–8.38
Salinity (PSU)	33.00 ± 0.21	33.00–34.00	32.00 ± 0.851	33.60–33.86
DO (mg/l)	4.59 ± 0.93	3.98–5.96	4.65 ± 0.60	3.87–5.88
TSS (mg/l)	20.58 ± 10.03	8.32–38.16	19.01 ± 6.01	9.07–30.18
Nitrite (μM)	0.51 ± 0.27	0.11–0.91	0.10 ± 0.06	0.02–0.21
Nitrate (μM)	3.93 ± 2.55	3.11–12.40	0.61 ± 0.46	0.17–1.92
Ammonia (μM)	0.20 ± 0.12	0.02–0.37	0.29 ± 0.31	0.08–1.06
Chlorophyll-*a* (mg/m^3)	1.45 ± 0.45	1.40–2.0	1.38 ± 0.50	1.50–2.0

Environmental characteristics of culture sites of Olaikuda and Thuplipalem

Parameters	Olaikuda (SP)	Thuplipalem (OS)
Distance from shore (km)	1.2	4.0
Depth (m)	7	14
Substratum type	Coralline sand	Sandy
SSC (cm/s)	60–120	60–120
SHW (m)	0.30–0.70	0.88–1.33

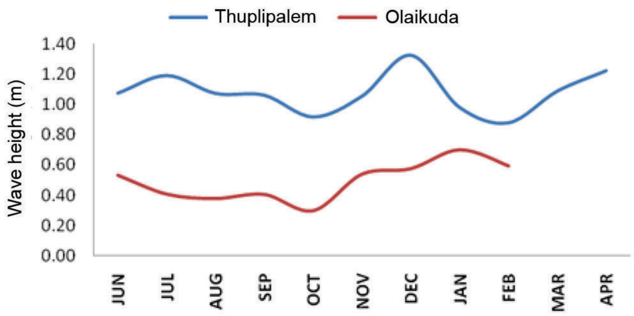

Figure 2. Variation of average wave height at both the sites during 2016 and 2017 (data is given till the culture period at both the sites).

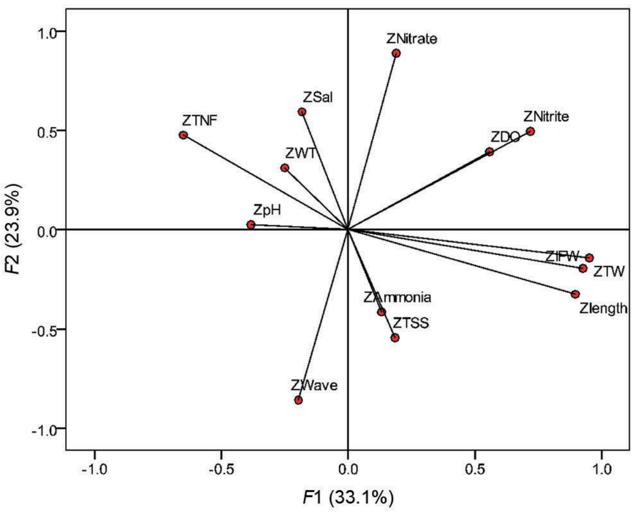

Figure 3. Factor loading *F*1 and *F*2 for environmental and growth parameters.

97.66% at Olaikuda and 99% at Thuplipalem. These rates are comparable to earlier studies[24]. In the present case, cobia showed better growth in Olaikuda (SP) compared to Thuplipalem (OS), though the culture started with a similar mean individual fingerling weight of 32.49 ± 1.77 g. In 270 days better growth (mean weight of 3828 ± 330 g) was noticed at the SP site. Even after 322 days, the growth was 2545 ± 314 g at the OS site. Again, though the initial stocking density was similar at both the sites (154 g/m^3 at the SP site and 150 g/m^3 at the OS site), density at the time of harvest was 13,816 g/m^3 at the SP site and 7396 g/m^3 at the OS site. Better biomass (Table 3) and better economic gains (Table 4) were achieved at the SP site due to comparatively better survival (77%) than at the OS site (62%). Similarly, specific growth rate (SGR) was 1.76% at the SP site compared to 1.35% at the OS site.

The length–weight relationship for cobia at SP and OS sites was 2.85 and 3.16 respectively, indicating negative allometric growth at the OS site. This may be attributed to the rough weather prevailing there. Conversely, positive isometric growth was observed at the SP site likely due to calm environmental conditions[13]. Although the growth rates of cobia in this study are lower than those reported (6 kg in 12 months) in Mexico[5,25], they are similar to the growth rates of approximately 2–4 kg/yr in floating cages, 2–3 kg/yr in pond conditions and 400 g/yr in tank conditions[25]. In this case study, a mean weight of 3828 ± 330 g was achieved in 270 days with a higher stocking density of 13.816 kg/m^3, which is comparable to other similar observations[24,25].

Though the cages were deployed at two sites with different environmental conditions, the water quality parameters were within the optimal range for cage culture. Hence, a similar management strategy was implemented at both locations. During the culture period, the influence of wave height and associated turbulence was comparatively higher at the OS site (Thuplipalem) than that at the SP site (Olaikuda). This affected the growth rate of fish and considerably increased the operational cost, resulting in the reduction of

Table 3. Summary of growth parameters of cobia at the culture sites in Olaikuda and Thuplipalem

Parameters	Olaikuda (SP)	Thuplipalem (OS)
Initial age at stocking (dph)	90	90
Age at harvest (dph)	360	412
Grow out duration (days)	270	322
Average initial size (g)	33	32
Initial stocking density (g/m^3)	150	154
Average final size (g)	3,828	2,545
Final density (g/m^3)	13,816	7,396
Absolute growth (g)	3,795	2,513
Absolute growth rate (g/day)	14.05	7.80
Instantaneous growth rate (g/day)	0.0176	0.0135
Specific growth rate (%)	1.76	1.35

Table 4. Summary of culture economics obtained from Olaikuda and Thuplipalem

Particulars	Olaikuda	Thuplipalem
Capital investment (9 M ϕ cage components and deployment)	820,000	820,000
Depreciation cost (12.5% of capital cost)	102,500	102,500
Total biomass	4,144	2,366
Gross income @ Rs 325/kg of fish	1,346,800	768,950
Total operation cost (seed, feed, boat, labour and storehouse)	869,760	576,390
Income (gross income – operational cost)	477,040	192,560
Income after deduction of depreciation cost	374,540	90,060
Bank interest @ 9% of capital cost	73,800	73,800
Net profit (deduction of bank interest)	300,740	16,260

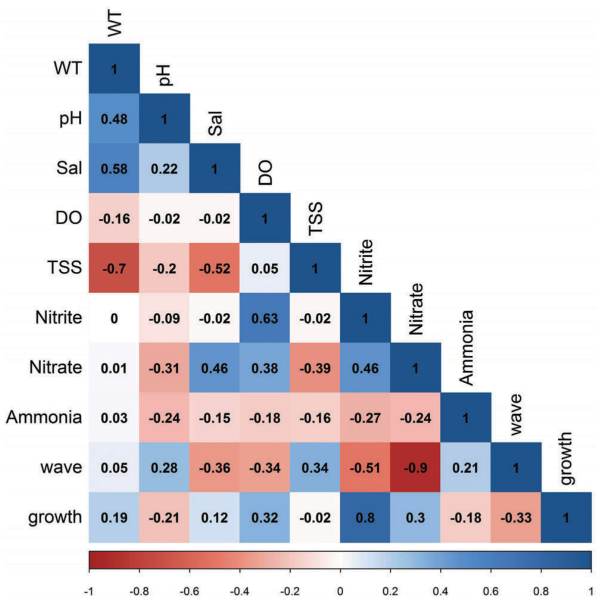

Figure 4. Correlation matrix heat map showing the values of Pearson correlation coefficient for selected parameters (positive values in blue and negative radius in red). They range from –1 to 1, where –1 indicates a perfect negative linear relationship between the variables, 1 indicates a perfect positive linear relationship between the variables, and 0 indicates no relationship between the variables.

net profit from 36% at Olaikuda to 26% at Thuplipalem (ratio between operational cost and gross income). Pearson's correlation suggested that fish growth was positively correlated with nitrite ($r = 0.8$) and negatively correlated with wave height ($r = -0.33$) (Figure 4).

The OS at Thuplipalem is highly exposed to both the southwest (SW) and northeast (NE) monsoons compared to Olaikuda situated in Palk Bay. SWH was 1.32 m at the OS site and 0.30 m at the SP site. Although the SW monsoonal winds are stronger in the Gulf of Mannar and Palk Bay, the impact of waves during the SW monsoon is less[26]. During the NE monsoon, the OS site experiences frequent cyclonic events, resulting in turbulent water conditions[27]. The SP site is shallower than the OS site, facilitating better assemblage of fishes around the cage culture site for protection and feed availability[28].

Apparently, fish cultured in the OS site have encountered comparatively higher roughness and turbulent conditions than those at the SP site. In the wild, fishermen experience lower fish catch during rough sea states due to altered physical conditions of water affecting feeding patterns and other associated responses[29]. Although wild fish tend to swim away to calmer waters during rough sea conditions to reduce their energy requirement for balancing their position[30,31], in the cages they cannot move to calm waters, thereby facing the roughness of the sea to survive in a captive condition.

Generally, cobia feeds on benthic crabs, shrimps and other crustaceans, as well as other fishes and squids[32]. During rough sea conditions, floating feed pellets easily escape from the cages due to high waves, and the fish also struggle to reach the floating pellets. Often, their efforts to catch feed pellets fail in rough sea states[12,33]. During such disturbances, fish primarily use pelvic fins to stabilize their position and maintain an upright and stable posture, which may consume more energy than normal[34,35]. The energy expenditure of fish, quantified by the number of movements for swimming against turbulent water flow, indicates that they spend maximum energy while performing feeding motions to capture prey[36]. The respiration rate increases 3- to 22-fold while swimming against altered water flow and spending more energy[34,36].

Wild cobia prefers to inhabit at reef structures, shipwrecks and man-made objects in the waters[37] and it grows from 1.5 to 6.5 kg in one year[38]. However, fish cultured in OS floating cages do not have a similar habitat of wild cobia. They change their physical conditions according to sunlight, turbidity, increased wave height and turbulence. Fish cultured in the OS site must have faced comparatively rougher and more turbulent seas than those at the SP site. Also, the chances of non-feeding or lesser feeding during rough conditions in the OS site might have impacted the growth of fish. Among the environmental parameters, wave height appears to be an important factor that influences growth.

Economic viability

The economic viability of aquaculture, or any business, depends on the calculation of the difference between the cost of production and the cost of sales. The stability of the market value of cobia is a pivotal factor influencing the profitability of its farming. Input costs, including capital (culture system), seed (young fishes), feed, manpower, and considerations such as proximity to allied facilities like cold storage for feed, along with distance from the landing site to the cage site significantly impact overall costs. A detailed analysis conducted during the open sea-cage culture demonstration between the sites explicitly revealed that the cost of production at Thuplipalem, an OS site, amounted to Rs 243/kg. In contrast, the cost of cobia production at Olaikuda, a SP bay, was Rs 209/kg, resulting in profit margins of Rs 82/kg and Rs 116/kg respectively (excluding capital investment).

When factoring in depreciation on capital and interest on investment, the net profit works out to Rs 6.87/kg for Thuplipalem and Rs 72/kg for the Olaikuda site. However, it is crucial to note that the profit margin will experience considerable variation when the scale of operation is expanded to a commercial scale system of 100-plus tonnes.

Conclusion

The critical significance of selecting an appropriate site for sea-cage farming cannot be overstated, as it directly influences the growth and survival of fish during the culture period, consequently impacting the overall sustainability of the farming venture. The present study underscores this importance, revealing that cobia cultivated in the SP site (Olaikuda) exhibited superior growth and survival rates compared to that in the OS site (Thuplipalem), where more turbulent environmental conditions prevailed. Moreover, the operational costs associated with maintaining a culture cage in OS conditions are notably high, attributed to factors such as longer travel, increased manpower requirements, and higher watch and ward expenses, particularly when the scale of operation is below 100 tonnes of productivity. Recognizing the predominant exposure of Indian coastal waters to OS conditions, there is a pressing need for technological advancements in the development of robust cages equipped with automated feeding systems. Such innovations are crucial to ensure not only higher productivity, but also better economic returns from offshore mariculture, addressing the challenges posed by the distinct characteristics of OS environments.

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ACKNOWLEDGEMENT. We thank the Director, National Institute of Ocean Technology, Chennai for his guidance and the Ministry of Earth Sciences, Government of India, for providing support to carry out this study.

doi: 10.18520/cs/v126/i2/222-228