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Bio-economic efficiency of copper alloy mesh technology in offshore cage systems for sustainable aquaculture

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In the present study, innovative and environment friendly copper alloy mesh material was used in an offshore cage system to compare with traditional nylon nets, in a one-year grow-out cycle of European seabass (*Dicentrarchuslabrax*). Based on combined indicators such as growth performance, feed utilization with bio-economic assessment of initial investment costs, it was observed that copper alloy mesh performed higher productivity indices and economic benefits compared to those in the antifouling coated traditional nylon net pens. Results showed that copper alloy mesh is a promising alternative material that could be used in offshore cage aquaculture with an improved economic return.

[Keywords: Fish cage systems, copper alloy mesh, nylon net cage, sustainable aquaculture, antifouling paint, economic evaluation]

Introduction

The intensive aquaculture industry in Europe is in a rapid growth during the last ten years, expending from a production of 1,573,192 tons in 2005 up to 2,531,412 tons in 2014[1]. According to the statistics of Food and Agriculture Organization of the United Nations, world aquaculture production provides almost the half of marine originated food for human consumption[2]. The significant increase of the world population with a daily births rate of around 15000 reached around 7.4 billion today[3], and over the next 34 years it is expected to amount around 9.6 billion[4]. Depending on the human population increase, there is a need for food supply, which is a challenge the food industry faces. Suitable marine sites available around Europe, are important potancial areas for the aquaculture industry to meet the increasing demand for protein for human consumption.

The reduction of biofouling on nets might overall benefit in terms of better fish growth induced by increased feeding rate, reduced fish stress and lower labor costs from net cleanings and changes[5]. Antimicrobial caractheristics of copper alloys in health care applications are reported earlier[6]. Nowadays, copper alloy is available as a wire mesh materials that can be weaved into a cage net and replace polymer nettings. However, little information is available about environmental effects and performance of copper alloy mesh in marine aquaculture systems. There are only few studies focused on the effects of copper alloy mesh compared to traditional nylon nets are restricted to British Columbia[7, 8], Hawaii[9], Chile[10, 11, 12], the USA[13], Turkey[5, 14], and to Greece[15]. Copper alloy mesh has been reported as biofouling-free material for fish cages, and is capable to improve fish health due to a clean and more sanitary environment[5]. The use of copper alloy mesh instead of traditional nylon nets in Atlantic salmon cages, have been reported to result in improved economic benefits[10] as well as reduced environmental impacts[12]. Additionally, biofouling resistant copper alloy mesh can reduce the drag forces and improve durability of the cages in highly exposed offshore sea conditions[16].

Copper alloy mesh seems to be a promising alternative material for providing solutions to meet the problems that fish farmers challenge in high-energy offshore conditions. However, shifting to an innovative new material from copper-painted nylon nettingsis another challenge and there is little information available[10]on their economic benefits compared to the traditional nylon nets which are commonly used in the marine aquaculture industry.

Copper alloy meshes hold the promise of increased profitability with a reduction of maintenance costs and environmental concerns, based on reduced biofouling in marine cage systems. Hence, the aim of the present study was to investigate benefits of adopting copper alloy mesh as a new technology in marine aquaculture systems in terms of productivity and positive economic impacts versus traditional nylon nets with anti-fouling coating.

Materials and Methods

The experiment was conducted in the Strait of Canakkale (formerly, *the Dardanelles*) off the coast of Guzelyali town (Canakkale-Turkey; 40°03’42” N - 26°20’36” E, 40°03’51” N - 26°20’45” E, 40°03’45” N - 26°20’55” E, 40°03’36” N - 26°20’48” E). Experimental location is an exposed sea site that experiences three to five meter-high waves. There is a two-way direction water flow along the strait; the water flow from Marmara Sea to the Aegean forces a surface current in one direction and an undercurrent in the opposite direction.

Two surface gravity type octagonal shaped HDPE (high density polyethylene) fish cages were designed with a volume of 150 m^3 each. The net enclosures were 5 meter in depth with a diameter of 6 meters wide (Figure 1). Experimental cages were deployed into a 2 x 2 bay grid system, which was submerged to 4 meters from surface. The entire mooring system was set to the 4 m submerged collectors lifted with surface buoys of 750 L volume and tentioned with 12 anchor lines of 100 m fitted to the bottom with 500 kg deathweight anchors (Figure 2). One octagonal HDPE frame with galvanized steel brackets was fitted with copper alloy mesh, while the other cage frame with the same shape and material was fitted with a traditional nylon net that was coated with a commercial antifouling paint prior to deployment.

Initial stocking rate of European seabass (*D. labrax*) in the experimental cages were 1.47 kg/m^3. Prior to the start of the growth experiment, fish were sampled and bulk weight, which was repeated at the end of the study. Experimental fish with an initial mean weight of 110±6.0 g were fed a commercial diet (42% CP, 24% CL, 21.8 kJ/g diet gross energy, 19.3 mg/kJ P:E ratio) twice a day throughout the study. However, the experimental site experiences around 10-12 storms in a year and feeding was interspaced for 6-8 days during each of the heavy sea conditions. Hence, the number of actual feeding days was 252 days, despite the feeding trial continued for 360 days in total. During the course of the study, seawater temperature was measured periodically and recorded.

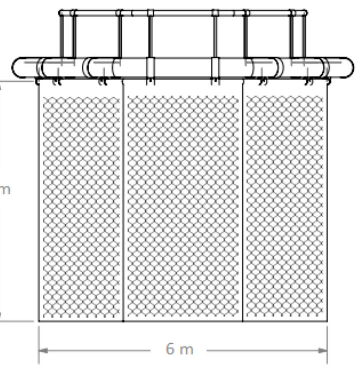

Figure 1. Cage design used in the experiment

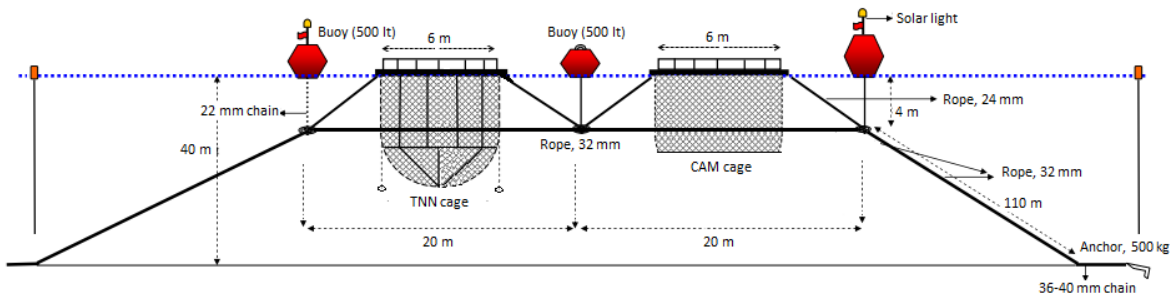

Figure 2. Design of mooring and grid system used in the study

For the feed conversion ratio (FCR), two formulae were used, i.e., the "biological FCR" and the "economical FCR", where the former indicates the feed potential without the consideration of mortalities and other fish losses, whereas the economical FCR however takes these conditions into account. Hence, in order to count the weight loss attributed to mortalities, the economic FCR was also considered for the evaluation of feed utilization. All formulae used in the calculation of growth performance and feed utilization are given below Table 1.

Table 1. Growth performance and feed utilization of European seabass reared in offshore copper alloy mesh (CAM) and traditional nylon net (TNN) cages for a period of 12 month

Cage Type	CAM	TNN
Initial wet weight (mean, g)	110.0±6.0	110.0±7.0
Final wet weight (mean, g)	385.5±54.4	309.6±35.7
Individual weight gain (g)	275.5	199.6
Relative growth rate (RGR, %)	250.5	181.5
Survival rate (%)	88.0	85.0
Specific growth rate (SGR, %/day)	0.384	0.287
Initial biomass (kg/m^3)	1.47	1.47
Final biomass (kg/m^3)	4.52	3.51
Initial total biomass (kg)	220	220
Final total biomass at harvest (kg)	678.5	526.3
Total biomass gain (kg)	458.5	306.3
Daily biomass increase (kg/day)	1.27	0.85
Percent biomass increase (%)	208.4	139.2
Total feed consumption (kg)	687.7	582.0
Biological FCR (FCR_{bio})	1.50	1.90
Economical FCR (FCR_{eco})	1.42	1.72

Survival rate (%) = (number of fish recovered / number of fish stocked) x 100

Relative growth rate (RGR, % increase in weight) = [(final wet weight – initial wet weight) / initial wet weight] x 100

Specific growth rate (SGR, % growth per day) = [(ln(final wet weight) – ln(initial wet weight)) / (number of culture days)] x 100

Total biomass gain = (final biomass – initial biomass)

Percent biomass increase (%) = [(final total biomass – initial tlotal biomass) / initial total biomass] x 100

FCR_{bio} (biological feed conversion ratio = feed intake (g) / weight gain (g)

FCR_{eco} (economical feed conversion ratio = feed intake (g) / ((final weight (g) – (final fish number x initial mean weight (g)))

For the evaluation of economic profit and bio-economic efficiency, total (US$) and proportional (%) initial investment costs for a 2x2 bay grid-mooring system with two offshore fish cages with either copper alloy mesh (CAM) and traditional nylon net (TNN) were used. Operational costs applied in this study were modified using structures given by Matsunaga et al[17], Kaiser et al[18], Bezerra et al[19], Yigit et al[20], Bulut et al[21], and Yildirim et al[22], and consisted of the effective operational costs (EOC), which are basicly related to labor costs; total operational costs (TOC) derived from the EOC and other expenses such as time dependent depreciation of equipments. Total production cost (TPC) was obtained by the addition of TOC and the compensation of investment (CI) that was a value as 15% per annum on fixed investments. The operational costs comprised the expenses for labor, initial fish purchase, feed expences, gasoline, food for staff, environmental monitoring, depreciation and maintenance of the equipment.

Production parameters such as feed conversion ratio (FCR), final weight of fish, feeding cost, gross income, gross revenue and profit from fish in the two production systems (CAM and TNN) were applied for the evaluation of the bio-economic efficiency for European seabass. An averageprice of the commercial diets (1.82 US$/kg) were used based on the actual market rates and the currency was converted from Turkish Lira (TL) to US Dollars (US$) according to rates of (3.76) from XE Currency Converter[23]. The production cycle was 12-month and the market selling prices of European seabass was set to 7.50 US$/kg for the harvested fish.

Results and Discussion

For the estimation and comparison of the performance of CAM cage and TNN cage, production efficiency indicators such as survival rate, fish growth performance, weight gain, biological -and economical FCR values were used.

Survival rates in both cage systems were over 85% and showed that the culture environment, the net material in this case, did not have any affect on survival rates of fish in cage. Growth performances in both cage environments were comparable to earlier studies[24, 25, 26, 27]. The SGRs obtained in the present study for experimental fish in CAM (0.40 %/day) and TNN (0.30 %/day) cages were in agreement with the findings of Akbulut et al[24](0.50 %/day) and Baki and Kalma[26](0.40 %/day) who investigated European seabass growth in the Blacksea with lower water temperatures (average of 7.9-25 °C). Similar results in terns of SGR for seabass have been reported by Copelandet al[25] (0.47-0.53 %/day), Person-Le Ruyet et al[28] (0.45%/day), Monteroet al[29] (0.51-0.53), d'Orbcastel et al[30] (0.43-0.50 %/day), and Ganzon-Naret[27] (0.20-0.48 %/day).

Güroy et al[31]reported SGRs of 0.6-0.7 %/day in seabass of 170 g in a culture environment with water temperature of 24 °C, and the study of

Person-Le Ruyetet al[28] was conducted at a lower water temperature of 13 °C, where the SGRs were found as 0.45 %/day, however the authors[28] reported higher SGRs (1.29 %/day and 1.21 %/day) for seabass when the water temperature increased to 25 and 29 °C, respectively. Similarly, Ercan et al[32] reported that both salinity and temperature affected SGRs of seabass, and found SGRs of 0.7-0.9 %/day at water temperatures between 10-18 °C, and 1.8-2.3 %/day between 20-29 °C.

However Hossu et al[33] reported higher SGRs for European seabass in the Aegean Sea, where the average water temperature was higher (12-25 °C). The discrepancies recorded for growth data during the course of the study, could be attributed to the low water temperature in the study area when compared to the southern water temperatures in the Aegean where most of the Seabass farms in Turkey are located. Average annual seawater temperature in the Aegean Sea is in a range between 12.4-25 °C[28], whereas seawater temperature recorded in the present experimental site varied between 7.9-24.5 °C. Furthermore, the number of total days with water temperature below 18 °C was recorded as 210 (7 month). In the Aegean Sea however, water temperature below 18 °C is available for a period of 4 month at maximum[28]. Additionally, the offshore research site experiences around 10 to 12 heavy storms in a year and the feeding activity was weather dependent. Feeding activity was withheld for 6-8 days during heavy storms. As a result, the number of actual feeding days was 252, even though the feeding experiment continued for a period of 360 days in total. All these conditions might have affected the lower growth rates in the present study compared to the reports from the Aegean Sea.

Lupatsch et al[34] reported in a study carried out with 120 g seabass, that the feeding levels but not stocking densities affected growth rate, feed intake and feed conversion rate in seabass of 120 g.

At the end of the growth period, fish biomass in the TNN and CAM cage units increased from an initial stocking rate 1.47 kg/m^{3}to 3.51 and 4.52 kg/m^3 over a period of 12 month, respectively. The percent increase of fish weight (relative growth rate, RGR) in the CAM cage was about 30% higher compared to the TNN cage and resulted in 678.5 kg harvest of seabass from the CAM cage, which feed consumption was recorded as 687.7 kg with an FCR of 1.50 and the feeding cost amount reached a value of 1,251.6 US$. For the fish production in TNN cage, however, the harvest value rated at 526.3 kg. Feed consumption was 582 kg with an FCR of 1.90 and the feeding cost reached a rate of 1,059.2 US$.

The FCRs obtained for CAM cage (1.50) and TNN cage (1.90) in the present study were in agreement with earlier results. Lupatsch et al[34] reported FCRs between 1.3 and 1.5 in seabass with 120-140 g weight when fed to satiation at 21 °C water temperature. Copeland et al[25] found FCRs between 1.49 and 1.62 in 300 g sized seabass adults. Similarly, d'Orbcastelet al[30] reported FCRs between 1.47 and 1.65 in seabass cultured at different stocking rates. In another study[25], FCRs of 1.49-1.62 were reported for seabass with an initial weight of about 300 g. In contrast to the FCRs found in the present study, higher FCRs (1.97-2.79) for seabass with a mean weight of 5.5 g were recorded in an earlier study[27], where lower SGRs (0.20-0.28 %/day) were recorded for the fish fed 3 and 6% of biomass, respectively.

When considering mortalities or other fish losses in cage, the economic FCR (FCR_{eco}), that also counted weight losses attributed to mortalities, resulted in a reduced rate of 1.42 for the fish in CAM cage and 1.72 for those cultured in the TNN cage. Final data in the present study showed that the CAM cage obtained 17% lower FCR_{eco} than TNN cage in average (Table 1).

Eventhough no measurements were carried out to assess volumetric integrity of the experimental cage environments in the present study, we observed that the TNN pen was visibly affected by strong currents in the Strait of Canakkale, whereas the CAM cage stayed stable and saved its geometrical shape and keeping its volumetric integrity. This condition has also been recorded by divers from underwater observations. The shifting behavior and drag force affect of currents on the nylon netting could also be seen from cage surface. When the cage net was dragged due to the currents, it has been observed that fish in cage lost appetite, refusing feed intake for 1 or 3 days depending on the strength and length of the weather condition. This observation is in agreement with an earlier report where stress recovery time of European seabass was investigated by Kayaliet al[35], who recorded that fish subjected to transport and handling stress recovered from stress conditions and started active feeding after 24 hours. In the CAM cage however, no visible diffeneces could be seen during strong currents and also stormy weather conditions, which might have a positive affect on fish appetite and welfare. The better feed utilization of fish in the CAM net compared to the

TNN pen might be attributed to the changes in volumetgric integrity forced by strong currents in offshore conditions.

The gross revenue, representing the total production sales value (US$), was around 28% higher for the CAM cage production compared to the TNN. With the deduction of feeding costs from the gross revenue, the real profit in percent was calculated as 3,123.3US$/kg for the CAM unit and 2,174.2US$/kg for the TNN cage, which is in overall 30% higher then the percent profit recorded for the production in the TNN cage (Table 2).

For an offshore cage mooring system with a 2x2 bay submerged grid, the initial investment cost was estimated as 39,240 US$ for the CAM cage and 38,580 US$ for theTNN cage unit. However, a 2x2 bay grid-mooring is a design for the deployment of four cages. Hence, inorder to assess a proportional split for one cage over the total amount, these rates were devided into four, and resulted as 22,110 US$ and 15,985 US$ total initial investment costs for the CAM and TNN cages, respectively (Table 3).

Table 2. Feeding cost, gross income, gross revenue and profit from European seabass production in offshore culture systems with copper alloy mesh (CAM) and traditional nylon net (TNN) cages for a growth period of 12 month

Cage type	CAM	TNN
Initial fish cost (US$)	3.245	3.245
Total initial biomass (kg)	220	220
Total initial biomass cost (TIBC, US$)	713.87	713.87
Feed cost ($/kg)	1.82	1.82
Feed supply (kg)	687.7	582.0
Feeding cost (FC, $/kg)	1,251.6	1,059.2
Market selling price (US$ / kg)	7.50	7.50
Total biomass gain (kg)	458.48	306.32
Total production (kg)	678.5	526.3
Gross income (US$)	3,438.8	2,297.3
Gross revenue (US$)	5,088.8	3,947.3
Profit (P, $/kg)	3,123.3	2,174.2

Initial biomass cost= initial biomass (kg) x initial fish cost (US$/kg)
Feeding cost (US$/kg) = feed supply (kg) x feed cost (US$/kg)
Total biomass gain (kg) = final biomass (kg) – initial biomass (kg)
Gross income (US$) = total biomass gain (kg) x fish selling price (US$/kg)
Gross revenue(US$) = total production (kg) x fish selling price (US$/kg)
Profit(US$) = ((gross revenue –(total initial biomass cost + feeding cost)

The proportional split of total investment cost for the CAM cage was 27% higher compared to that of the TNN cage. Among the total equipment list, highest proportion consisted of the mooring system with a rate of 52.3 and 53.3 % of the initial investment for the CAM and TNN units, respectively. This was followed by the contribution of the boats and motorboats as 37.72 and 38.40 % for the CAM and TNN units, respectively. Proportional split over the initial investment for the cage+copper alloy mesh material (CAM) resulted as 55.63 %, while a rate of 32.22 % was recorded for the fish cage with naylon net material, which was almost half of the CAM unit. Considering the operational costs, the total production cost (TPC) for the TNN cage unit was around 4 % higher compared to the CAM unit, and resulted as 44,341.5US$ and 42,168.5 US$, respectively. The most expensive components contributing to the effective operational cost (EOC) were labor expenses (38.2 - 36.6%), feed expenses (20.0 - 20.2%), and food supply for staff (17.5 - 16.8%) in the CAM and TNN units, respectively (Table 4).

Table 3. Total (US$) and proportional (%) initial investment for a 2x2 bay grid-mooring system with two offshore fish cages of copper alloy mesh (CAM) and traditional nylon net (TNN).

Items	CAM		TNN	
	US$	%	US$	%
Buoy	4,050	10.32	4,050	10.50
Lightning System	810	2.06	810	2.10
Anchors	4,950	12.61	4,950	12.83
Chain	5,920	15.09	5,920	15.34
Collectors	650	1.66	650	1.69
Ropes	3,110	7.93	3,110	8.06
Connecting parts (shackle, thimble, etc.)	1,040	2.65	1,040	2.70
Total Mooring system total	*20,530*	*(52.3)*	*20,530*	*(53.3)*
Labor (for installation of mooring system)	1,650	4.20	1,650	4.28
Labor (for net chamber assemble)	660	1.68	–	–
Boats	14,800	37.72	14,800	38.36
Miscellaneous	1,600	4.08	1,600	4.15
Total for 2x2 bay grid-mooring system (4 cages)	*39,240*		*38,580*	
Proportional split (for 1 cage*)	9,810	44.37	9,645	60.34
Antifouling paint	–	–	1,190	7.44
Cages	7,200	32.56	3,500	21.90
Nets	5,100	23.07	1,650	10.32
Cage + Net	*12,300*	*(55.63)*	*5,150*	*(32.22)*
Total	22,110	100.0	15,985	100.0

Costs for project development, vehicle (forklift, truck, crain), site lease, taxes were excempt, since these were fixed values for both production systems.
* Total investment costs for a 2x2 bay grid-mooring, a design for the deployment of four cages has been devided into 4 inorder to assess a proportional split for one cage over the total amount.

It is important to consider that the proportional split of the equipments contributed to the initial investment costs is subject to change when the 2x2 bay grid systemis deployed with 4 cage units. However, in the present study, no scenario was applied, but only the current model that was applied for the comparison of the two cage units during the study were used in the calculations.

The calculated initial investment cost for the CAM cage was 27% higher then that of the TNN cage. However, at the end of the production circle, the total production sales value (US$) was 28% higher in the CAM cage then the TNN cage. This resulted also in a better profit ($/kg), and the real profit of the final harvest was obtained as 30% higher in the CAM cage compared to the TNN cage production. These findings in the present study indicate that despite the higher initial investment cost, higher gross revenue and a better profit could be reached after a one-year production of seabass in a CAM cage when compared to the TNN cage system. Considering that the main expenses such as cage construction, mooring deployment or purchase of copper alloy net material will be exempt in the second year of production, it can be assumed that a higher final profit could be reached in the second year with the condition that the same production success is reached in the following years.Similar findings have been reported for trout culture in copper alloy mesh cages[10], suggesting that the adoption of copper alloy mesh net showed positive impacts on the productive and economic aspects of trout aquaculture.

Considering that in the present study, risks and additional costs related to the use of nylon nets in cage culture, such as financial losses as a result of fish escapes from the nets, increased safety issues due to less diving activities in -and around fish cages may indicate that the values obtained in terms of economic benefits in the present study, perhaps underestimate the actual economic benefits when using CAM nets for aquaculture, which is in agreement with the report of González et al[10].

In our study, possibly the most important limitation is the small size of data analyzed as fish stocking densities in both cages were low. Additionally, different than indoor research facilities working offshore with bigger size of fish and water volume has further complications and difficulties. Hence, it might be ideal if the present study could be conducted with at least dublicate groups of cages. However, the small-size condition in the present study was a variable out of the author's control since the experiment was conducted in a small size prototype offshore cage facility that considered financial support only for two cages which consisted of one CAM net cage and one control TNN net cage. Due, we encourage further studies on CAM nets adoption in large scale fish farms with large datasets, in different environmental sites with different fish species, stocking densities and feeding strategies inorder to make a generalization of the efficient use of CAM nets in cage aquaculture.

Table 4. Operational -and production costs of European seabass in offshore copper alloy mesh (CAM) and traditional nylon net (TNN) cages for a period of 12 month

Item description	CAM		TNN	
	US$	%	US$	%
Labor	15,750	49.04	15,750	45.77
Initial fish price	713.87	2.22	713.87	2.07
Grow-out feed	1,251.7	3.90	1,059.2	3.08
Food supply (staff)	7,200	22.42	7,20	20.92
Rope line (maintenance)	500	1.56	500	1.45
Antifouling paint (for net coating)	–	–	1,190	3.46
Net maintenance	500	1.56	500	1.45
Net change labor	–	–	200	3.46
Net logistics	–	–	400	1.45
Diving (technical labor)	400	1.25	800	0.58
Diving equipment (maintenance)	300	0.93	600	1.16
Boat maintenance	4,000	12.46	4,000	2.32
Enviro-monitoring	1,500	4.67	1,500	1.74
Effective operational cost	32,115.6	100	34,413.1	100
Depreciation (D)	2,211		1,598.5	
Social charges (SC)	2,835		2,835	
General expenses(GE)	1,605.8		1,720.6	
Financial charges (FC)	1,284.6		1,376.5	
Recycling returns (from material, RM)	-1,200		-0.00	
Operational cost (Total, TOC)	38,851.9		41,943.7	
Compensation (for investment, CFI)	3,316.5		2,397.8	
Production cost (Total, TPC)	42,168.5		44,341.5	

Depreciation (D) = (initial investment cost x 10) / 100
Social charges (SC) = (total labor cost x 18) / 100
General expenses (GE)= effective operational cost x 5)/100
Financial charges (FC) = [((effective operational cost x 50) / 100) x 8] / 100
Total operationalcost (TOC)= [(EOC+D+SC+GE+FC) –RM]
Compensation for investment (CFI) = (fixed investments per annum x 15) / 100

From the results obtained in the present study, it was can be concluded that fish culture in copper allow mesh net shows positive influences in terms of economic benefits and financial return of the production as overall profit. Environmental monitoring of copper alloy has not been performed in the present study, due further research is encouraged on possible reasons and potential relation between water conditions and the improved growth performance of fish in copper alloy mesh cage systems.The CAM system with its biofouling-free nature might have possibly extended a water environment with higher oxygen level due to a better water flow through the mesh, influencing feed intake with an improved appetite as also indicated by González et al[10]. Furthermore, no signs of fish deseases were observed during the course of the production period. Survial was high in both fish cages, showing that the material of the net enclosure did not have anyinfluence on fish survialunder the conditions applied in the present study.

Conclusion

The copper alloy mesh performed to be a promising candidate for the offshore aquaculture industry since it surpassed nylon nets in terms of higher gross revenue and improved profit from fish harvest over the initial investment, total production costs and the final market selling returns under the conditions of the present research site and production cycle.

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