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Environmental Characteristics in a Fish Farm with Copper Alloy Cage System in the Dardanelles

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Authors' Contribution
SU and YB performed the experimental work and wrote the article. MY, MB and RKG were involved in cage system coordination and data recording and evaluation. MB did the field work. CB helped in data evaluation. MY and BC helped in paper writing.

Key words
Environmental variables, Copper cage system, Aquaculture, Dardanelles

ABSTRACT

This study was conducted in a copper alloy cage fish farm to observe the environmental properties of the marine system. Water quality parameters such as temperature, salinity, pH and dissolved oxygen, total suspended solids, chlorophyll-a and inorganic nutrients such as NO_2+NO_3, NH_4, PO4 and SiO_2 were observed between May 2014 and September 2014 in the study area. The observed results were compared with acceptable limits pronounced in international organizations such as EPA and FAO, and national organizations such as WPCR and RTMAF as well as the previous studies conducted in the region. According to the results, a decrease in dissolved oxygen and pH was observed at the farm while increases in inorganic nutrients except for ammonia were recorded. TSS values showed significant positive correlation with TP, indicating that TSS was supported by fecal pellets or unused fish feed in the cage system. MDS analysis results showed that TSS, chlorophyll-a and TP were similar throughout the sampling period. The study showed that copper alloy cage system did not have any negative impact on the marine system, compared with the limits provided by FAO, EPA, WPCR and RTMAF as well as with previously conducted studies in the region.

INTRODUCTION

Fish farming in cage systems is one of the most commonly used methods to fill the gap in Mediterranean aquaculture in recent years, with the rapid growth of seabream and seabass culture in off-shore facilities. While contributing to the economy through aquaculture, it is necessary to control the factors that may affect the ecological structure of the region. In fact, meeting the optimum water quality criteria required by fish in aquaculture is one of the most important factors in order to produce fish in the desired stock and reach the table size in a healthy way. However, the most important issue is the robustness of the mesh cages, regardless of the materials used. Therefore, preventive measures have to be taken against any risk of damages to the cage system due to wave, wind or any other reason and the system should be resistant to strong weather conditions. In order to cope with such negative factors and to provide optimum water quality criteria, different methods have been applied in cage farming in recent years. One of these methods is the use of copper alloy cages instead of traditional nylon nets known to cause organic material accumulation.

Earlier investigations on copper alloy mesh reported that these net materials with its stay-clean feature may provide a more favorable and non-stressful environment for fish. Furthermore, despite the higher initial investment costs, it was reported that copper alloy mesh could be economically beneficial in long term (Yigit *et al*., 2013; Grass *et al*., 2011; Berillis *et al*., 2017; Yigit *et al*., 2017). Besides, Tsukrov *et al*. (2011) reported that copper alloy nets are more resistant to high currents and storms. In an earlier study it was revealed that on an annual basis, high concentrations of Cu was release into the surrounding marine environment right after deployment of the system and throughout the first 3-4 months, but the release of Cu from the mesh seemed to be stabilized 9-10 months after installation (Kalantzi *et al*., 2016).

The expected yield in cage cultivation depends on many factors such as temperature, salinity, pH and dissolved oxygen concentrations as well as inorganic nutrients present in the environment, flow rate, feeding

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management and stock densities, or a combination of all these factors, which might be species-specific. Kalantzi *et al.* (2016) reported that bioaccumulation of Cu in fish mussel tissues followed the same trend with the Cu release progress from the mesh during the first 9 months of cage installation which decreased to similar values in mussel tissues from the nylon net cage after one year of cage deployment. Further, the authors reported that fish did not seem to be affected by the net type, and similarly the sediments also did not seem to be affected during the 1-year of experiment.

Table I. The accaptable limits for water quality variables and inorganic nutrients for aquaculture and fish farming in national and international organisations.

Variable	RTMAF[1]	WPCR[2]	FAO[3]	EPA[4]
Temperature (℃)	20 - 25	n.a.	Species specific	n.a.
Salinity (‰)	5 - 44	n.a.	n.a.	n.a.
pH	7.5 - 8.5	6.0 - 9.0	6.5 - 7.5	5.5 - 8.5
O_2 (% - mg L^{-1})	4 - 8	>90	70 - 100	30 - 60
TSS (mg L^{-1})	2	30	25 - 100	n.a.
NO_2 (mg L^{-1})	0.02	n.a.	0 - 0.5	0.01 - 0.05
NO_3 (mg L^{-1})	0.1 - 1	n.a.	100 - 200	50
NH_4 (mg L^{-1})	0.2 - 0.3	n.a.	0 - 2.5	0.04 - 1
PO_4 (mg L^{-1})	n.a	n.a.	1 - 20	0.5 - 0.7
TP (mg L^{-1})	n.a.	n.a.	n.a.	n.a
SiO_2 (mg L^{-1})	2 - 5	n.a.	n.a.	n.a.

[1]Republic of Turkey Ministry of Agriculture and Forestry (Limit values for farming sea bream); [2]Water Pollution Control Regulation of Republic of Turkey (Acceptable limits for aquaculture); [3]Food and Agriculture Organization of the United Nations (Acceptable limits for aquaculture); [4]Environmental Protection Agency (Acceptable limits for aquaculture).

Sea bream was grown in the experimental copper alloy mesh cage system, and the proposed water quality limit values proposed by various international organizations are given in Table I. Water quality characteristics in the area are widely studied and well established previously (Türkoğlu *et al.*, 2004; Koçum, 2005; Aydın *et al.*, 2010; Ateş *et al.*, 2014), but the number of studies on the potential impact of cage farming with copper alloy mesh on water quality criteria is quite scarce with the only one report of Buyukates *et al.* (2017) in the Dardanelles. Therefore, the aim of this study was (1) to investigate the possible effects of copper alloy cages on marine systems, (2) to compare the water quality values obtained in the sea bream cage system with the marine water quality criteria of Environmental Protection Agency (EPA), the Food and Agriculture Organization of the United Nations (FAO), Water Pollution Control Regulation of Republic of Turkey (WPCR) and Republic of Turkey Ministry of Agriculture and Forestry (RTMAF), and (3) to determine the similarity with the results obtained from the previous studies in the region if any.

MATERIALS AND METHODS

Experimental location

An offshore cage farm located in the northern part of the Aegean Sea was used in this study. The average depth of the farm location was 45 m, with a gentle slope of sea bottom from 40 to 50 m. The cage system was deployed 1.15 km (0.6 nautical miles) off the coast of a small town (Guzelyali) in the Strait of Canakkale (formerly known as Dardanelles) (Fig. 1), and the study site was far from terrestrial inputs. Operational period in the farm site lasted 150 days from May to September 2014. An antimicrobial wrought copper-zinc brass alloy with the ASTM designation of C44500 was produced into a cage net material, which contained Cu (70–73%), Zn (29.18–25.57%), Sn (0.80–1.20%), P (0.02–0.10%), Pb (0.07%), and Fe (0.06%) according to the analyses presented by the German Copper Institute (https://www.kupferinstitut.de/en/arbeitsmittel/kupferschluessel.html).

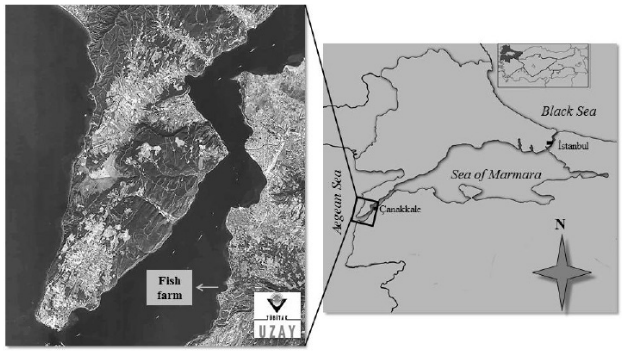

Fig. 1. Location of the fish farm with copper alloy cage system in Dardanelles

Water quality analyses

Seawater quality parameters were measured in the cage farm site over a 5 months period between 01 May and 30 September 2014 during the operational period. A multi-probe water quality analyzer (YSI 600 XL MPS) was used for the *in situ* measurement of water quality parameters such as temperature, salinity, dissolved oxygen (DO), and pH. After sea water sampling using a 5 L water sampler for the nutrients, samples were filtered through 47 mm GF/F filters in the laboratory by gentle vacuum and then frozen for further analysis. Spectrophotometric analysis of nitrite+nitrate (NO_2+NO_3), and ammonia (NH_4), soluble reactive phosphorus (PO_4), total phosphorus (TP) and silicate (SiO_2) were conducted according to Strickland and Parsons (1972). Gravimetric determinations of total suspended solids (TSS) were performed according to Clesceri *et al*. (1998). Measurement of chlorophyll-*a* (chl-*a*) concentration was performed spectrophotmetrically after 90% acetone extraction according to APHA (1995). All water quality parameters were determined in triplicate.

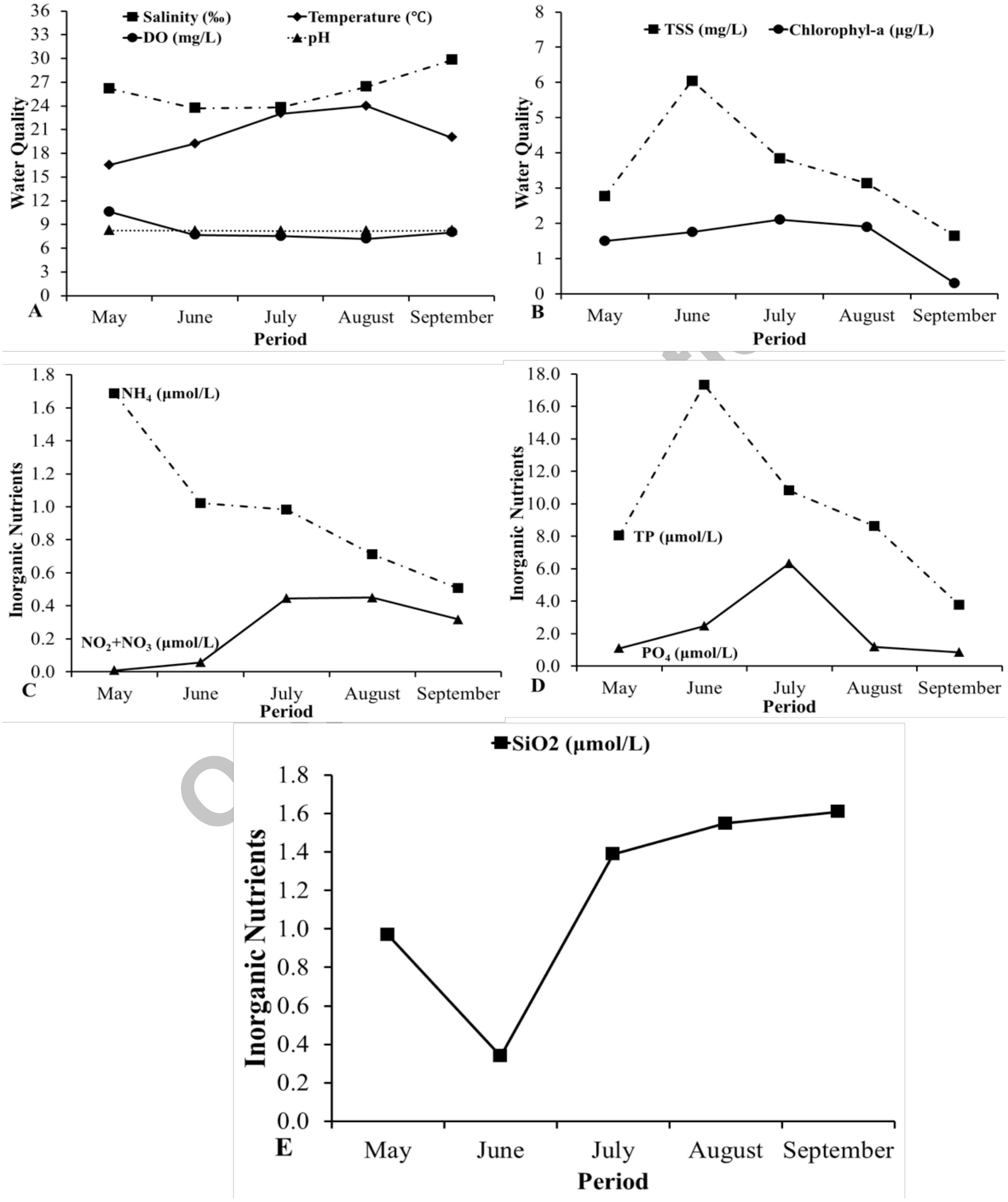

Fig. 2. Temporal variations of water quality parameters (A), TSS and Chlorophyll-a (B), NH4 and NO_2 + NO_3 (C), TP and PO_4 (D) and SiO_2 (E) at the copper alloy mesh pen site between 01 May and 30 September 2014.

RESULTS

In order to determine the possible effects of the cage system with copper alloy nettings on the water quality in the Dardanelles, the water quality criteria were monitored over a period of 5 months. The results were compared with values provided by international organizations such as EPA and FAO, as well as the limit values given by national organizations such as WPCR and RTMAF, and other studies previously conducted in the region.

The water quality parameters (temperature, salinity, dissolved oxygen and pH) measured in 5 m depth from the surface at the farm site during the course of the five months period are presented in Figure 2A. Water temperature varied between 16.5 and 24.0 °C and photoperiod followed the natural course during this period of the year (01 May - 30 September 2014). Salinity was recorded in the range between 23.7 and 29.8 ‰. A slight change was recorded for DO levels in seawater from 7.2 to 10.6 mg L^{-1}, while the levels of pH wer*et al*most stable ranging between 8.2 and 8.25. The results for chl-*a* and TSSs are shown in Figure 2B. As an indicator of primary production, the chl-*a* ranged between 0.301 and 2.104 µg L^{-1}, while the TSS ranged from 1.65 to 6.05 mg L^{-1} at 2 m depth from surface during the course of the 5 months period.

The findings for inorganic nutrient levels are given in Figure 2C-E. The values for NH_4 and NO_2+NO_3 ranged from 0.51 to 1.69 µmol L^{-1}, and 0.009 to 0.450 µmol L^{-1}, respectively. The PO_4 varried among the sampling periods with the lowest value in September and the highest in July, ranging from 0.86 to 6.34 µmol L^{-1}. The TP values, ranging between 3.76 and 17.33 µmol L^{-1} also showed the lowest value in September and a peak in June. The SiO_2 varried between 0.34 and 1.61 µmol L^{-1} throughout the 5 months period.

DISCUSSION

The physicochemical values and inorganic nutrient concentrations obtained in the study were examined in 5 months period and no extreme deviations were detected. The lowest temperature value was recorded in May and the highest in August. The highest salinity values were measured in September showing the effects of the Aegean Sea current and the lowest salinity values were measured in June and July resembling the influence of the Black Sea current. pH values were found to correspond with the standard pH values of a marine environment (Kocataş, 1993). In addition, the temperature, salinity and pH values did not exceed the limit values presented by EPA, FAO, WPCR and RTMAF, and were found similar with previous studies in the region (Türkoğlu *et al*., 2004; Koçum, 2005; Odabaşı and Buyukates, 2009; Aydın *et al*., 2010; Ateş *et al*., 2014). One of the most important factors in fish production is the concentration of dissolved oxygen (DO), dependent to temperature and salinity. It is known that a decrease in DO concentrations may cause a decrease in the resistance of fish to parasites and diseases, even if no lethal effects. Fish may refuse feeding under low DO concentrations (< 2 mg L^{-1}), which may adversely affect eating habits in return as well (Buttner *et al*., 1993). The DO values measured in the present study ranged from 7.2 to 10.6 mg L^{-1}, where the highest value was observed in May when the water temperature was the lowest, while the lowest value was observed in August when the water

Table II. Pearson correlations between water quality parameters and inorganic nutrients in the study area.

Variable	Significant Level	NO_2+NO_3	NH_4	PO_4	TP	SiO_2	TSS	Chl-a
Temperature	r	0.931*	-0.663	0.414	-0.022	0.555	0.005	0.37
	p value	0.022	0.222	0.489	0.972	0.331	0.993	0.54
Salinity	r	0.145	-0.421	-0.667	-0.877	0.611	-0.857	-0.889*
	p value	0.816	0.481	0.21	0.051	0.274	0.063	0.043
pH	r	-0.73	0.332	-0.773	-0.336	-0.225	-0.349	-0.687
	p value	0.161	0.585	0.125	0.58	0.717	0.564	0.20
DO	r	-0.717	0.83	-343	-0.232	-0.234	-0.282	-0.181
	p value	0.172	0.082	0.572	0.707	0.704	0.645	0.77
TSS	r	-0.323	0.196	0.386	0.998**	-0.824	1	0.628
	p value	0.596	0.752	0.521	0	0.086		0.256
Chl-*a*	r	0.113	0.373	0.576	0.657	-0.30	0.628	1
	p value	0.857	0.537	0.31	0.229	0.624	0.256	

temperature increased. The DO values varied in the range of FAO, WPCR, and RTMAF reports during the course of the study (Table I). In addition, the DO values in the present study were similar to earlier reports from the same region (Türkoğlu *et al*., 2004; Buyukates and Inanmaz, 2010; Ateş *et al*., 2014).

The amount of TSS has a significant effect on visibility, and can directly influence plankton growth, as an indirect effect on fish production. High levels of TSS concentrations are one of the important factors that should be controlled in fish farming as it may cause clogging of the gill filaments and off-flavor in fish (Buttner *et al*., 1993). The TSS values obtained in this study were significantly lower than the values given by FAO and did not exceed the limits provided by WPCR for marine systems which is 30 mg L^{-1}. On the other hand, TSS values exceeded the limit value of 2 mg L^{-1} reported by RTMAF (Table I). The possible reason for this could be attributed to the over-feeding during that period. As a matter of fact, NH_4, PO_4 and TP concentrations were*t al*so higher in the summer season compared to the other months, which can be an indication of over feeding as well. In addition, no significant correlation was found between the TSS and the chl-*a*, which revealed that TSS was not controlled by primary production, but was significantly affected by TP concentration due to the significant correlation between these two variables (Table II). Thus, TSS was most probably under the influence of fecal waste or uneaten feed particles scattered from the cages. Additionally, the TSS and chl-*a* values obtained in the present study also overlapped with the values in previous studies conducted in the region (Türkoğlu *et al*., 2004; Odabaşı and Buyukates, 2009; Buyukates and Inanmaz, 2010).

Uneaten fish feeds or fish feces released from the cage to the surrounding water environment might cause acidity, and therefore pH values are expected to be compatible with NH_4 values (Tovar *et al*., 2000; Orçun and Sunlu, 2007). Excessive increase in NH_4 values may cause high pH values and can be an important stress factor for fish. NH_4 values obtained during the present study were quite low and the highest value was recorded in May. However, there was a positive correlation between the NH_4 values and pH, even though not significant (Table II). Moreover, the NH_4 values recorded in the present study were similar to the values reported earlier in the same region (Odabaşı and Buyukates, 2009; Buyukates and Inanmaz, 2010) and did not exceed the proposed limits for sea bream in the RTMAF reports and the water quality limits recommended by FAO and EPA. SiO_2 values were under 30-40 µg L^{-1} which was the optimum growth concentration for diatioms in marine systems. The values coincided both with the values of previous studies conducted in the same marine area (Odabaşı and Büyükateş, 2009; Büyükateş and Inanmaz, 2010) and did not exceed the limit values recommended by RTMAF for sea bream production (Table I). It is known that $NO_2 + NO_3$ values may increase as a result of high currents in the region besides domestic pollution (Türkoğlu *et al*., 2004). As a result of the study, $NO_2 + NO_3$ values showed significant positive correlation with temperature (Table II). An increase in $NO_2 + NO_3$ values was observed with the increase in temperature, but this increase was not at the level of the limit values of FAO, EPA, WPCR and RTMAF. On the other hand, $NO_2 + NO_3$ values were similar to those found in previous studies (Türkoğlu *et al*., 2004; Odabaşı and Buyukates, 2009; Buyukates and Inanmaz, 2010). Fazio *et al*. (2013) showed the influence of water quality on blood parameters in cultured fish. The evaluation of blood parameters representing an important tool for aquaculture systems and it can reveal important information on fish physiology and health (Fazio, 2019). MDS analysis was performed in order to find the similarity of water quality values and variations of inorganic nutrients during the study and it was observed that 4 different groups were formed as a result of the analysis. According to the analysis, 1st group consisted of salinity, SiO_2 and $NO_2 + NO_3$, 2nd group consisted of temperature and PO_4, 3rd group consisted of pH and NH_4 and DO, and the 4th group consisted of TSS, chl-*a* and TP (Fig. 3). This showed that the values of the variables in the same group were similar in their variations within the study period.

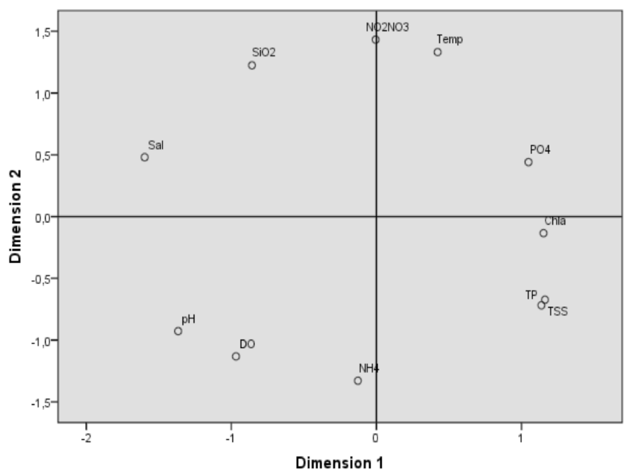

Fig. 3. MDS plot of water quality variables and inorganic nutrients in study area

CONCLUSIONS

As a result of the study, it was determined that copper alloy cages did not adversely affect the water quality in the studied marine ecosystem. Considering the physical problems and organic matter accumulation on traditional nylon mesh, potentially causing stressed environment for fish due to nuisance of net changes, and therefore reducing fish growth performance, the use of copper alloy mesh in marine aquaculture might be beneficial for environment-friendly farm operations and sustainable marine aquaculture activities with increased fish welfare or health conditions and reduced operational costs in long run.

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Statement of conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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