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RESEARCH PAPER

Effects of Off-Coast Bluefin Tuna Fattening on Water Quality in the Eastern Mediterranean Sea

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Abstract

Bluefin tuna farming in the Mediterranean has been expanding since the mid-1990s. Expansion of tuna farming has been accompanied by widespread concerns about its impacts on the marine environment. The aim of the present study was to investigate impacts of a capture-based tuna farm located in the Gerence Bay on the water column and sediment.

With this aim, temperature, salinity, pH, dissolved oxygen, chlorophyll *a* and nutrients in the water column and organic carbon variables in the sediment were measured on a seasonal basis from 2011 to 2012. Samplings were made at the two reference stations and five stations around the cages. It was found that nutrient concentrations in the water column at the cage stations increased more than those of the reference stations but these differences were not statistically significant. Similarly, physico-chemical parameters and chlorophyll *a* in water column and organic carbon in sediment did not show detectable impact of tuna fattening. This was probably caused by strong currents present in the area, location of the cages away from the coast, hence high water depth and controllable feeding. It is believed that conducting monitoring studies is necessary to maintain sustainability of tuna fattening and determine the related potential impacts.

Keywords: Aquaculture, bluefin tuna, organic carbon, Mediterranean Sea, nutrients, off-coast farming.

Doğu Akdeniz'de Kıyı Ötesi Mavi Yüzgeçli Orkinos Besiciliğinin Su Kalitesine Etkileri

Özet

Akdeniz'de mavi yüzgeçli orkinos yetiştiriciliği 1990'ların ortalarından başlayarak gelişmiştir. Orkinos yetiştiriciliğinin yaygınlaşmasını izleyen süreçte, faaliyetin deniz ortamına etkileri ile ilgili önemli kaygılar oluşmuştur. Bu çalışmanın amacı, Gerence Körfezi'nde avcılığa bağlı kurulmuş olan bir orkinos çiftliğinin su kolonu ve sedimente olan etkilerinin araştırılmasıdır. Bu amaç doğrultusunda, su kolonunda sıcaklık, tuzluluk, pH, çözünmüş oksijen, klorofil a ve besleyici tuzlar ile sedimentte organik karbon değişkenleri 2011 ile 2012 yılları arasında mevsimsel olarak ölçülmüştür. Örneklemeler 2 referans istasyonu ve kafeslerin etrafındaki 5 istasyonda gerçekleştirilmiştir. Kafes istasyonlarında su kolonundaki nütrient konsantrayonlarının referans istasyonlarından daha fazla artış gösterdiği fakat bu artışların istatistiksel olarak önemli olmadığı saptanmıştır. Benzer şekilde, su kolonundaki fiziko-kimyasal değişkenler ve klorofil a ile sedimentte organik karbon değerleri de orkinos besiciliğinin etkilerinin önemli seviyelerde olmadığını göstermiştir. Bu durumun çalışma bölgesinde mevcut olan güçlü akıntılar, kafeslerin kıyıdan uzak yerleşimi dolayısıyla derinliklerin fazla olması ve beslemenin kontrollü yapılmasından kaynaklandığı söylenebilir. Orkinos besiciliğinin sürdürülebilirliğini sağlamak ve potansiyel etkilerini belirleyebilmek için izleme çalışmalarının devam ettirilmesinin gerekli olduğu düşünülmektedir.

Anahtar Kelimeler: Akuakültür, orkinos, organik karbon, Akdeniz, nütrientler, kıyı ötesi yetiştircilik.

Introduction

Rearing Atlantic bluefin tuna (*Thunnus thynnus* Linnaeus, 1758) in the Mediterranean has been expanding since the mid-1990's. Bluefin tuna is one of the most demanding and expensive tuna species in the market. Its fishery is regulated by the International Commission for the Conservation of Atlantic Tunas (ICCAT). The main growers of tuna in the Mediterranean are Italy, Malta, Spain, Croatia and Turkey. Other farms are located in Cyprus, Tunisia and Greece. Currently 54 firms are authorized to run bluefin tuna farming around the Mediterranean Sea. Tuna farming in Turkey has been started in 2002 and developed rapidly since then (Aksu, Kaymakçı-Başaran and Egemen. 2010). Although total output capacity of the present 6 farms is assumed to be 6140 tons a year in Turkey today while nominal annual catch was 535 tons in 2012 (ICCAT, 2014).

Thunnus thynnus is considered a capture-based aquacultural species as farming activity entirely depends on stocking of wild caught fish. Wild tunas are caught by purse-seines, swum into towing cages and dragged slowly, usually at 1-1.5 knots where they are fed and kept for 4-8 months, which is called “fattening” (Ottolenghi, 2008). During fattening period tuna are fed mainly with small pelagic species including sardines, herring, mackerel and squid (Basaran and Özden. 2004). Food conversion ratios (FCR) are very high ranging from 15 to 30 (Aguado-Giménez and García-García. 2005; Vita and Marin. 2007).

Expansion of tuna farming in the Mediterranean has been accompanied by widespread concerns about impacts of the industry on the environment (Moraitis *et al*. 2013), the most important of which is unconsumed feeds and metabolic wastes due to fattening activity (Vezzuli *et al.* 2008). Fishing effort on wild tuna juveniles and pelagic fish stocks used for feed supply are other environmental issues (ICES, 2002). While studies on environmental effects of tuna farming are quite limited (Vita *et al*. 2004; Aguado-Gimenez *et al*. 2006; Vita and Marin. 2007; Vezzulli *et al*. 2008; Aksu, Kaymakçı-Başaran and Egemen. 2010), they gradually tend to increase (Vizzini and Mazzola. 2012; Moraitis *et al.* 2013; Mangion *et al.* 2014).

Impacts of tuna rearing on marine environment are expected to be greater than those of other farming activities such as processes for sea bass and sea bream in terms of high biomass rear and feed conversion ratios, nevertheless almost all the studies show that they are negligible and limited to the cage area (Vita and Marin. 2007; Vezzulli *et al*. 2008; Aksu, Kaymakçı-Başaran and Egemen. 2010). In addition, environmental effects of fish farming at floating cages varies with farm management, feed type, stocking density and the hydrography of the site (Wu, 1995), another reason for which is that the capture-based aquaculture of tuna is not a continuous process and lasts only four to eight months. After fattening has been processed, the sea may regenerate itself.

Mediterranean mariculture has been moved from small land-based operations to large farms scattered along the coastline and more recently to off shore in order to cope with outcomes of increased production (Grigorakis, 2011). Offshore farming is thought to be advantageous for both the fish farms and the environment considering higher water quality based on exposure of offshore locations to currents, waves and winds, which is therefore regarded as a means to overcome the problems caused by coastal fish farming (Vezzulli *et al*. 2008). Covering large marine areas, tuna farms are generally constructed off-coasts. Although there is no consensus on the term “offshore”, Holmer (2010) defines terms of ‘coastal’, ‘off coast’ and ‘offshore’ farming considering distance from the shore, depth, exposure to offshore impacts and wave height. Off-coast farming is known to take place in depths between 10 and 50m, especially at sheltered areas which are visible coastwise. Accordingly, the studied farm could be called an ‘off-coast’ farm.

Considering continues expansion of new off-coast farms around the Mediterranean it is necessary to recognize environmental impacts of this new sector so as to facilitate sustainable development of tuna fattening. However, studies dealing with the impacts of capture-based tuna on water quality operated at off-coast conditions are lacking at the present time. The aim of this study was therefore to observe likely effects of a capture-based tuna farm on water quality operated at an off-coast location in the Eastern Mediterranean.

Materials and Methods

Study Area

The study was conducted in Gerence Bay, SE Aegean Sea with an area of approximately 42000 m^2 and connected to the surrounding sea through a strait (Figure 1a). When the study was performed, the farm had two 66 m and two 50 m cages where 460 ton tuna was stocked. In order that tuna should be fattened, fishes were used such as sardine, herring, anchovy, mackerel and menhaden-type species. Feeding was performed under the inspection of scuba divers to finally decrease potential negative impacts of feed wastes.

Sampling and Analytical Methods

In order to find out impacts of tuna farming, water and sediment samplings were seasonally made at the two reference stations, the one being 200 m (R200) and the other 1km (R1000) west to 5 stations (cage stations; C1, C2, C3, C4 and C5) and related cages over the area (Figure 1b) on 1 July 2011, 4 October 2011, 23 March 2012 and 30 May 2012. Coordinates and depths of the stations are presented in table 1.

During the study, surface, mid and bottom water samplings were taken seasonally with a Nansen bottle from each station. Temperature and salinity were measured by SCT meter (YSI 30), pH by pH meter (YSI pH100), dissolved oxygen by oxygen meter (YSI 55) and transparency by Secchi disc. The water samples were taken to the lab via cold-chain. Variations of nitrite-nitrogen, nitrate-nitrogen, ammonium-nitrogen and phosphate-phosphorus in the water column were colorometrically measured using spectrophotometer (Parsons *et al*. 1984).

Seawater was filtered through GF/C filter paper to determine chlorophyll *a* and left to acetone extraction for 20 hours and measured absorbance of the samples using spectrophotometer (Strickland and Parsons, 1972; Parsons *et al*. 1984).

Sediment samplings were taken by Van-veen grab at each station. Organic carbon level in every sediment sample was measured using dichromate oxidation method according to modified Walkley-Black titration (Gaudette *et al*. 1974).

Data Analyses

Kolmogorov-Smirnov test and Levene statistical analyses were conducted for normal distribution convenience test of parameters and homogeneity test of variances, respectively. Significance test of the groups whose variances were found homogeneous was performed by Tukey test following ANOVA and Mann Whithney-U test following Kruskal-Wallis performed for groups whose variances were not homogenous to find out variations between the stations and between the seasons (Ergün, 1995; Sümbüloğlu and Sümbüloğlu. 2000). In addition, Principal component analysis (PCA) was applied to

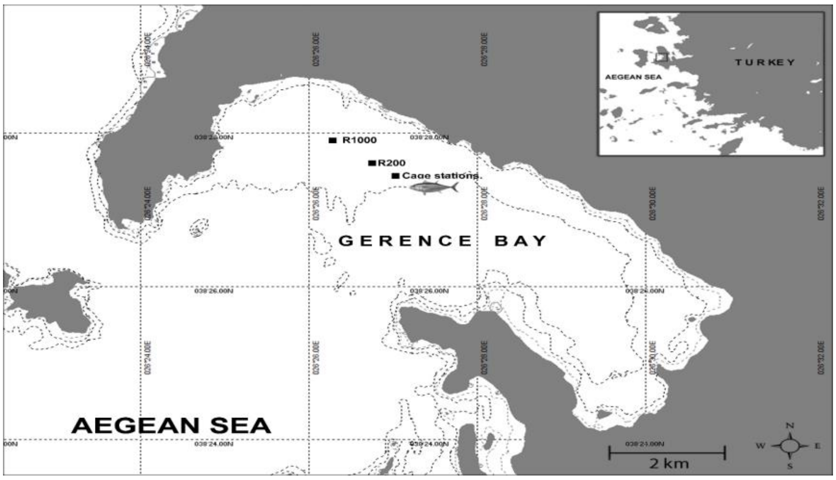

Figure 1a. Sampling stations in the study area.

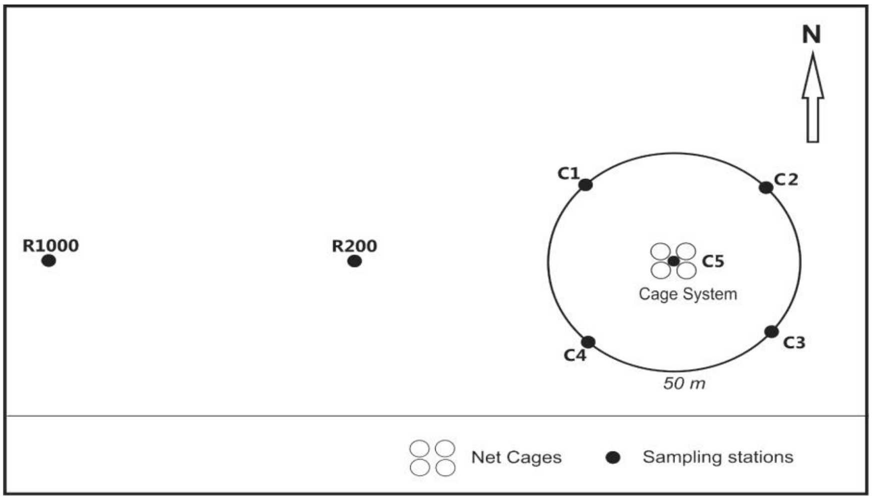

Figure 1b. Placement of the sampling stations (not drawn to scale).

Table 1. Coordinates and depths of the studied stations

Stations	Coordinates	Depths (m)
C1	38°27'20.3" N; 26°27'12.7" E	53
C2	38°27'22.3" N; 26°27'22.3" E	50
C3	38°27'11.9" N; 26°27'33.4" E	58
C4	38°27'10.8" N; 26°27'13.2" E	57
C5	38°27'18.0" N; 26°27'18.5" E	52
R200	38°27'25.1" N; 26°27'4.70" E	51
R1000	38°27'34.5" N; 26°27'45.9" E	48

evaluate to the temporal and spatial characteristics of water quality (Simeonov *et al*. 2003). PCA allows associations between variables, reducing the dimension of the data matrix. PCA was performed on normalized data using the factor procedure. All statistical analyses were done using the SPSS 16.0 software.

Results

Temperature

The samplings made in the Gerence Bay determined the lowest temperature as 14.7 °C in March 2012, at R1000 in the mid depth and the highest temperature as 23.9 °C in July on the surface water at C2 (Table 2). Means and standard error values for temperature were calculated as 19.61±0.33 °C in the Gerence Bay all the year round.

Salinity

The seasonal samples there showed the lowest salinity to be 35.0 ppt on surface water at C2 and C3 and mid water at C5 in May 2012 and the highest salinity 37.8 ppt in July 2011 at C3 in the mid water. Means and standard error values for salinity were found to be 36.34±0.07 ppt in the Gerence Bay all the year round.

pH

The lowest and highest pH's were measured as 7.68 and 8.28 in July 2011 at C4 on the surface and in March 2012 at R1000 in the mid waters, respectively. Means and standard error values for pH were found to be 8.06±0.02 in the Gerence Bay in 2011-2012.

Secchi Disc

The lowest and highest Secchi values were determined to be 6.05 m and 16.15 m at C3 and C2 stations in May 2012 and July 2011, respectively.

Dissolved Oxygen

The seasonal sampling in the area where the tuna farm is located found the lowest and highest dissolved oxygen concentrations to be 6.40 mg L^{-1} and 8.30 mg L^{-1} in the mid water at C3 and R1000 in October 2011 and March 2012, respectively (Table 2). Means and standard error values of dissolved oxygen were measured as 7.28±0.06 for the year concerned.

Nutrients

Nitrite-Nitrogen

The seasonal sampling found the lowest and highest nitrite-nitrogen to be 0.05 µM and 1.41 µM in the mid and bottom waters at C1 in July 2011 and May 2012, respectively. Table 3 presents seasonal minimum, maximum, average and standard values of nitrite-nitrogen measured at all the stations in Gerence Bay. Figure 2 illustrates annual means and standard errors.

Nitrate-Nitrogen

The lowest and highest nitrate-nitrogen concentrations were found to be 0.01 µM and 1.04 µM on surface and bottom waters at C1 and R200 in October 2011 and March 2012, respectively.

Table 3 presents seasonal minimum, maximum, average and standard values of nitrate-nitrogen measured at all the stations in Gerence Bay with Figure 2 illustrating annual means and standard errors.

Ammonium-Nitrogen

The minimum and maximum seasonal measurements of ammonium-nitrogen concentrations were found to be 0.06 µM and 2.78 µM on surface

Table 2. Minimum, maximum, average and standard error values of physico-chemical parameters

Stations		Temperature (˚C)	pH	DO (mg L^{-1})	Salinity (ppt)
C1	Range	14.8-23.3	7.79-8.21	6.65-8.12	35.1-36.9
	Mean ± SE	19.56±0.92	8.01±0.05	7.31±0.13	36.31±0.21
C2	Range	14.9-23.9	7.74-8.22	6.48-8.06	35.0-37.0
	Mean ± SE	19.73±0.96	8.05±0.05	7.15±0.15	36.22±0.20
C3	Range	14.8-22.5	7.86-8.24	6.40-8.23	35.0-37.8
	Mean ± SE	19.58-0.91	8.07±0.04	7.26±0.19	36.36±0.22
C4	Range	14.9-23.5	7.68-8.25	6.44-8.18	35.6-37.0
	Mean ± SE	19.61±0.95	8.06±0.05	7.23±0.17	36.36±0.15
C5	Range	15.1-22.7	7.85-8.24	6.56-8.01	35.0-37.0
	Mean ± SE	19.57±0.89	8.08±0.04	7.39±0.15	36.4±0.19
Ref 200	Range	15.1-22.6	7.83-8.25	6.50-8.17	35.2-37.1
	Mean ± SE	19.39±0.86	8.06±0.05	7.25±0.15	36.34±0.18
Ref 1000	Range	14.7-22.7	7.8-8.28	6.48-8.30	35.5-37.2
	Mean ± SE	19.86±0.88	8.07±0.05	7.36±0.16	36.38±0.17
All stations	Range	14.7-23.9	7.68-8.28	6.40-8.30	35.0-37.8
	Mean ± SE	19.61±0.33	8.06±0.02	7.28±0.06	36.34±0.07

Table 3. Minimum, maximum, average and standard values of nutrients

Periods		NO_2-N (µM)	NO_3-N (µM)	NH_4-N (µM)	PO_4-P (µM)
July 2011	Range	0.05-0.42	nd-0.24	nd-2.78	nd-6.74
	Mean ± SE	0.20±0.03	0.03±0.01	1.03±0.13	2.55±0.44
October 2011	Range	nd-1.18	0.01-0.61	0.06-0.97	0.92-6.74
	Mean ± SE	0.24±0.06	0.28±0.03	0.37±0.05	2.68±0.31
March 2012	Range	nd-0.48	nd-1.04	0.45-1.39	0.31-1.84
	Mean ± SE	0.20±0.03	0.45±0.05	0.69±0.05	0.54±0.08
May 2012	Range	nd-1.41	0.01-0.22	0.21-0.97	nd-6,43
	Mean ± SE	0.53±0.08	0.05±0.00	0.54±0.05	0.80±0.41

nd: non detected

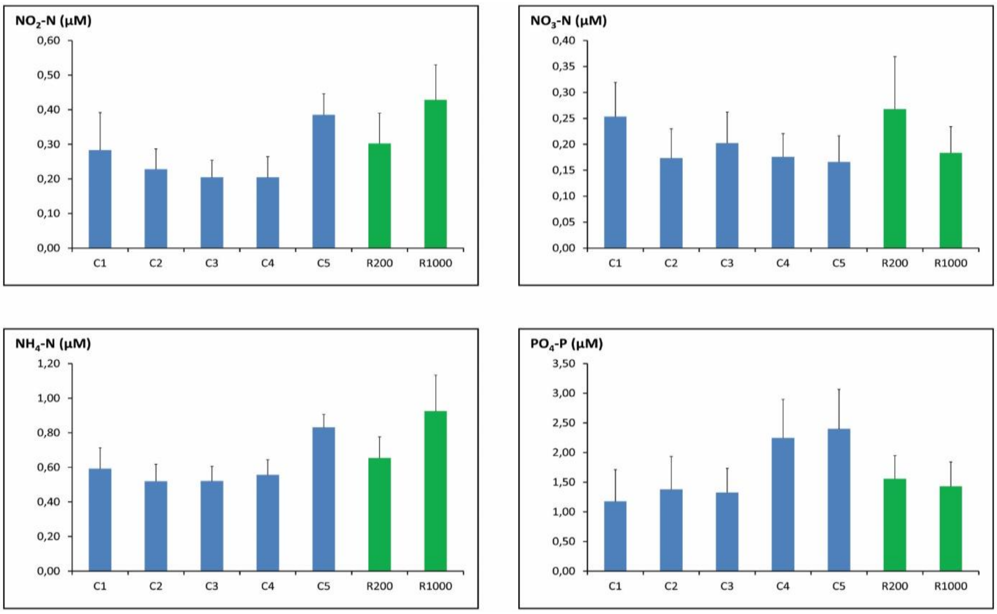

Figure 2. Variation of annual nutrients (mean and standard error values)

and mid waters at C1 and R1000 in October 2011 and July 2011, respectively. Table 3 presents seasonal minimum, maximum, average and standard values of ammonium-nitrogen measured at all the stations in Gerence Bay.

Phosphate-Phosphorus

The minimum seasonal measurements of phosphate-phosphorus concentrations were found to be 0.31 µM at most of the stations in various depths in March 2012. The maximum measurement of phosphate-phosphorus concentration was found to be 6.74 µM on the bottom water at C1 in July 2011 and in the mid water at C2 in October 2011. Table 3 shows seasonal minimum, maximum, average and standard values of phosphate-phosphorus measured at all the stations in Gerence Bay.

Statistical analyses did not present significant differences for all nutrient elements between cage and reference stations ($P>0.05$), only with important seasonal variations ($P<0.05$).

Chlrophyll a

The lowest and highest chlorophyll *a* values were found to be 0.38 µM and 5.67 µM on bottom waters at C1 and C2 in May 2012 and October 2011, respectively. Significant statistical differences were not observed for chlorophyll *a* between cage and reference stations ($P>0.05$).

Organic Carbon in Sediment

Organic carbon values ranged from 0.38 to 1.84 % at cage stations and 0.19 to 1.0 % at reference stations in sediment samples (Figure 3). The lowest and highest values were determined as 0.19 % and 1.84 % at R1000 and C5 stations in October 2011, respectively. Significant statistical differences were not observed for organic carbon between cage and reference stations (P>0.05).

Principal Component Analysis

Three PC's were found to account for 77 % of the variance in the whole data set.

The first PC, accounting for 32 % of total variance was correlated with pH, DO and phosphate. Excessive phosphate caused by fattening activities in the first PC enables organic matter to increase (phytoplankton blooming, feeding processes etc.). Decreases of DO values can be observed due to the presence and degradation of the organic matter in the medium. The second PC, accounting for 28 % of total variance was correlated with nitrite, nitrate and ammonium. The nutrient type component could be interpreted as representing influences of tuna rearing (aquacultural effects). Chlorophyll *a* accounted for the greatest loading for PC3, which explains 17 % of the total variance (Table 4).

Discussion

Effects of tuna fattening on the marine environment is expected to be greater than that of farming of other fishes such as sea-bass and sea-bream because of its bigger biomass and the high feed conversion ratio (Aguado-Gimenez and Garcia-Garcia. 2005; Vezzulli *et al.* 2008). Nevertheless, effects of marine aquaculture vary based on the farm management, feed type, stocking density, and hydrodynamic conditions in the area concerned (Wu, 1995; Vita and Marin. 2007).

Values of temperature in the water column varying based on air temperature were found to be similar to each other except in March. The lowest values were normally observed in the winter sampling. Salinity and pH values varied seasonally with the highest in July 2011 and the highest in March 2012, respectively. The study found Secchi disk depth to have changed between 6.05 and 16.15 m with the lowest and highest in spring months and July when the primary productions were maximum and minimum, respectively. Aksu (2009) reported in the study conducted in Izmir Bay that Secchi disc value ranged from 3.15 to 9.45 m at the cage stations in fish farms in closed coves around it.

Concentrations of DO in coastal waters undergo

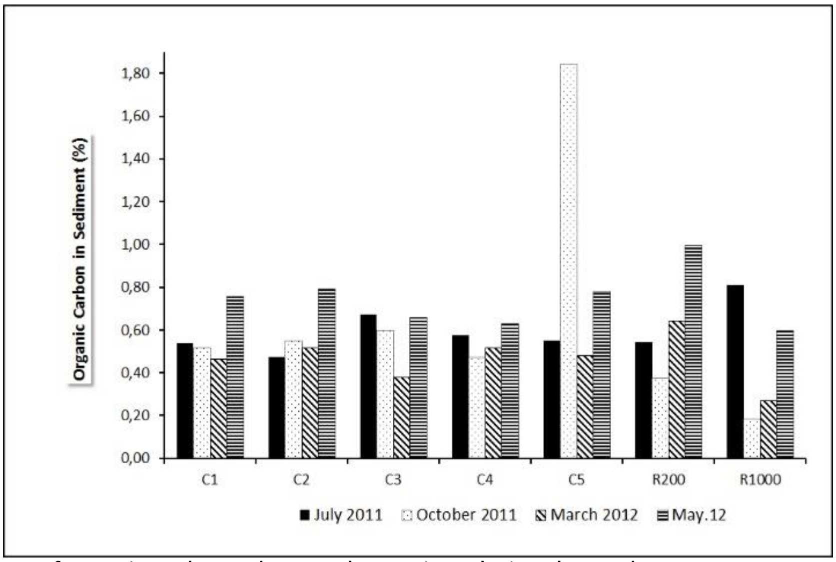

Figure 3. Variations of organic carbon values at the stations during the study.

Table 4. Loadings of experimental variables on the first three rotated principal components for the whole data set

Variable	PC1	PC2	PC3
DO	0,804	-0,332	-0,112
pH	0,735	0,525	0,362
Salinity	-0,256	-0,518	0,364
Chlorophyll *a*	0,543	0,246	-0,627
NO_2	0,363	0,517	-0,531
NO_3	0,490	0,766	0,012
NH_4	0,162	-0,778	-0,410
PO_4	-0,777	0,231	-0,468
Eigenvalue	2,55	2,23	1,34
Varience (%)	31,89	27,86	16,73

spatial and temporal change irrespective of aquacultural processes (Sangulin *et al.* 2010). Dissolved oxygen varied seasonally in the present study as well. The highest values were found at the reference stations during winter sampling whereas the lowest measurements were 6.4 mg L^{-1} at C4 station in October sampling, which is significantly higher than 5.0 mg L^{-1}, a critical value for aquatic organisms. Kaymakçı-Başaran *et al.* (2007) found DO values to range between 5.2 and 9.2 mg L^{-1} in the off-coast net cages at the fattening facility. Sangulin *et al.* (2010) reported that DO values typically varied between 7.03 and 7.62 mg L^{-1} at sea bass - sea bream and tuna farms with lowest value being 6.74 mg L^{-1} in autumn, which is consistent with those of the present study. The related authors (Aksu *et al.* 2010) in the long-term study at the same farm from 2005 through 2008 previously determined oxygen values to be 6.37 – 8.40 mg L^{-1}, which is also consistent with our present measurements (6.40-8.30 mg L^{-1}).

Concentrations of nitrite, one of nitrogen forms did not show any significant differences between the stations but indicated that seasonal variations were comparatively effective and that concentrations varied from 0.05 to 1.41 µM. Nitrite-nitrogen values measured at the same farm changed between nd-1.39, nd-2.51 and nd-1.08 µM in 2005-2006, 2006-2007 and 2007-2008, respectively (Aksu *et al.* 2010). The highest value was found at the cage station while the study determined no significant differences between the stations as in our present study. Matijevic *et al.* (2006) determined lower nitrite values (0.0-0.25 mmol m^{-3}) than those of the present study, reporting that nitrite measurements showed no significant statistical differences between the stations. Sangulin *et al.* (2010), also found lower nitrite values (0.0002-0.0068 mg L^{-1}).

Nitrate-nitrogen values at the stations ranged from 0.01 to 1.04 µM with no significantly statistical differences between them. Previous studies observed higher nitrate measurements such as 0.04-2.01 µM (Aksu *et al.* 2010). The studies performed at other tuna fattening farms showed lower nitrate values than those at the present study (Matijevic *et al.* 2006; Sangulin *et al.* 2010).

Ammonium concentrations ranged from 0.06 to 1.69 µM with no significant statistical differences between the stations. The same farm previously showed higher ammonium measurements which varied between nd-1.34 µM, 0.09-3.53 µM and nd-2.48 µM in 2005-2006, 2006-2007 and 2007-2008 (Aksu *et al.* 2010), respectively. Matijevic *et al.* (2006) reported that ammonium values ranged from 0.0 to 2.41 mmol m^{-3} without significant variations between the cage and reference stations. Sangulin *et al.* (2010) did not either find any significant differences between the cage and reference stations.

Nitrite, nitrate and ammonium concentrations were therefore found to indicate more effective in seasonal differences than those between the stations.

Phosphate-phosphorus concentrations fluctuated between 0.31 and 6.74 µM with higher annual mean phosphate values at the cage stations. In addition, there were no significant variations between the cage and reference stations and phosphate measurements were higher than those in the previous studies (Aksu *et al.* 2010). Matijevic *et al.* (2006) reported lower phosphate values (0.028-1.42 mmol m^{-3}). Matijevic *et al.* (2006) and Aksu *et al.* (2010) likewise found no significant differences between the cage and reference stations.

Chlorophyll *a* is a measure of photosynthetic phytoplankton biomass, changing based on solar ray and nutrients. The study showed that chlorophyll *a* fluctuated from 0.38 to 5.67 µg L^{-1}. Considering annual chlorophyll *a* values, the highest mean was observed as 2.52 µg L^{-1} at C2 in the process of the study, for which no significant statistical variations were found between the stations. Pitta *et al.* (1999) measured highest chlorophyll *a* concentration as 3.5 µg L^{-1} at the cage station in Ithaki farm. There are no environmental quality standard values for chlorophyll *a* around the Mediterranean coasts while chlorophyll *a* is a standard value as 10 µg L^{-1} for North European waters to avoid eutrophication (Pitta *et al.* 1999) which was higher than 5.67 µg L^{-1} by the present study.

One of the most important impacts of aquaculture on marine environment is that feeds not consumed by fish and their faeces have been accumulated below the cages on the sediment whose organic carbon concentrations is one of the remarkable variables in determining its quality (Karakassis *et al.* 2000; Hydland *et al.* 2005). Organic carbon concentrations in the sediment in the present study ranged from 0.19 to 1.84 %. Statistical tests found negligible differences between the seasons and between the stations. On the other hand, the cage stations showed higher values than the reference stations. Annual means of the cage and reference stations were 0.64 % and 0.55 %, respectively. Aksu *et al.* (2010) reported organic carbon values ranging from 0.25 to 0.97% at the same farm. Such low values can be based on the fact that depths are high and current systems strong in the area. Lampadariou *et al.* (2005) reported that total organic carbon in the sediment at 7 different farms varied between 0.3 and 17.0 %. Sangulin *et al.* (2010) reported that carbon values ranged from 0.53 to 2.58 % at the farm where they performed their research on tuna. In that study, the cage stations found higher measurements than the reference stations did, which was attributed to local water currents causing smaller particles (faecal pellets) to be distributed over a wider area and large waste (excess feed) to sink directly just below cages.

In conclusion, nutrients in the water column and organic carbon concentrations of the sediments at the cage stations increased more than those of the reference stations but did not lead to any eutrophication risks due to the fact that the cages were away from the coast and in deep water column with strong currents and feeding was conducted under control.

It is of great use to periodically perform the follow-ups in order to maintain sustainability of tuna fish fattening process in off-coast net cages and determine the related potential negative impacts.

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References

Aguado-Gimenez, F. and Garcia-Garcia, B. 2005. Changes in some morphometric relationships in Atlantic bluefin tuna (*Thunnus thynnus thynnus* Linnaeus, 1758) as a result of fattening process. Aquaculture, 249 (1-4): 303-309. doi:10.1016/j.aquaculture.2005.04.064

Aguado-Gimenez, F., Garcia-Garcia, B., Hernandes-Lorente, M.D., Cerezo-Valverde, J. 2006. Gross metabolic waste output estimates using a nutritional approach in Atlantic bluefin tuna (*Thunnus thynnus*) under intensive fattening conditions in western Mediterranean Sea. Aquaculture Research, 37: 1254-1258. doi:10.1111/j.1365-2109.2006.01541.x

Aksu, M. 2009. Investigation of the Impacts of some fish farms on marine environment in the Izmir Bay (İzmir Körfezi'ndeki Bazı Balık Çiftliklerinin Sucul Çevreye Etkilerinin Araştırılması). E.U. Journal of Fisheries & Aquatic Sciences, 26 (4): 271–279.

Aksu, M., Kaymakçı-Başaran, A. and Egemen, Ö. 2010. Long-term monitoring of the impact of a capture-based bluefin tuna aquaculture on water column nutrient levels in the Eastern Aegean Sea, Turkey. Environmental Monitoring and Assessment, 171(1-4): 681-688. doi: 10.1007/s10661-010-1313-y

Başaran, F. and Özden, O. 2004. The investigation of the rearing of bluefin tuna (*Thunnus thynnus* Linnaeus, 1758) on culture conditions. E.U. Journal of Fisheries & Aquatic Sciences, 21(3-4): 343-348.

Ergün, M. 1995. Bilimsel araştırmalarda Bilgisayarla İstatistik Uygulamaları, SPSS for Windows. Ocak Yayınları Eğitim Dizisi:2, Ankara, 292 pp.

Gaudette, H.E., Flight, W.R., Toner, L. Folger, W. 1974. An inexpensive titration method for the determination of organic carbon in recent sediments. Journal of Sedimentary Petrology, 44: 249-253. doi: 10.1306/74D729D7-2B21-11D7-8648000102C1865D

Grigorakis, K. and Rigos, G. 2011. Aquaculture effects on environmental and public welfare - the case of Mediterranean mariculture. Chemosphere, 85(6):899-919. doi:10.1016/j.chemosphere.2011.07.015

Holmer, M. 2010. Environmental issues of fish farming in offshore waters: perspectives, concerns and research needs. Aquaculture Environment Interactions, 1: 57−70. doi: 10.3354/aei00007

Hyland, J., Balthis. L., Karakassis, I., Magni, P., Petrov, A., Shine, J., Vestergaard, O. and Warwick, R. 2005. Organic carbon content of sediments as an indicator of stress in marine benthos. Marine Ecology Progress Series, 295: 91-103. doi:10.3354/meps295091

ICCAT, 2014. ICCAT Record of BFT Farming Facilities. http://www.iccat.int/en/ffb.asp (accessed December 19, 2014).

ICES, 2002. Report of the Working Group on Environmental Interactions of Mariculture. ICES CM 2002/F:04. Copenhagen, Denmark.

Karakassis, I., Tsapakis, M., Hatziyanni, E. Papadopolou, K-N., and Plaiti, W. 2000. Impact of cage farming of fish on the seabed in three Mediterranean coastal areas. ICES Journal of Marine Science, 57:1462-1471. doi: 10.1006/jmsc.2000.0925

Kaymakçı-Başaran, A., Aksu, M. and Egemen, Ö. 2007. Monitoring the impacts of the offshore cage fish farm on water quality located in Ildır Bay (Izmir-Aegean Sea). A.U. Journal of Agricultural Sciences, 13: 22-28.

Lampadariou, N., Karakassis, I. and Pearson, T.H. 2005. Cost/benefit analysis of a benthic monitoring programme of organic benthic enrichment using different sampling and analysis methods. Marine Pollution Bulletin, 50: 1606−1618. doi: 10.1016/j.marpolbul.2005.06.030

Mangion, M., Borgh, J.A., Thompson, R. and Schembri, P. J. 2014. Influence of tuna penning activities on soft bottom macrobenthic assemblages. Marine Pollution Bulletin, 79: 164-174. doi: 10.1016/j.marpolbul.2013.12.021

Matijevic, S., Kuspilic, G. and Baric, A. 2006. Impact of a fish farm on physical and chemical properties of sediment and water column in the middle Adriatic Sea. Fresenius Environmental Bulletin, 15: 1058-1063.

Moraitis, M., Papageorgiou, N., Dimitriou, P.D., Petreu, A. and Karakassis, I. 2013. Effects of offshore tuna farming on benthic assemblages in the Eastern Mediterranean. Aquaculture Environment Interactions, 4: 41-51. doi: 10.3354/aei00071

Ottolenghi, F. 2008. Capture-based aquaculture of bluefintuna. In: A, Lovatelli and P.F. Holthus (Eds), Capture-based aquaculture. Global overview. FAO Fisheries Tech Pap. 508, Rome: 169−182.

Parsons, T.R., Maita, Y. and Lalli, M. 1984. A

Manual of Chemical and Biological Methods for Sea Water Analysis. Pergamon Press, New York, pp 173.

Pitta, P., Karakassis, I., Tsapakis, M. and Zivanovic, S. 1999. Natural vs. mariculture induced variability in nutrients and plankton in the eastern Mediterranean. Hydrobiologia, 391: 181-194. doi: 10.1023/A:1003501832069

Sangulin, J., Babin, A. and Skrgatic, Z. 2010. Physical, chemical and biological properties of water column and sediment at the fish farms in the middle Adriatic, Zadar Country. Fresenius Environmental Bulletin, 19: 1869-1877.

Simeonov, V., Stratis, J.A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., Sofoniou, M., Kouimtzis, T. 2003. Assessment of the surface water quality in Northern Greece. Water Research, 37: 4119-4124. doi:10.1016/S0043-1354(03)00398-1.

Strickland, J.D.H. and Parsons, T.R. 1972. A practical handbook of seawater analysis. Fisheries Research Board of Canada, Ottowa, 310 pp.

Sümbüloğlu, K. and Sümbüloğlu V. 2000. Biyoistatistik, Hatiboğlu Yayınları:53, 9. Baskı, Ankara, 269 pp.

Vezzulli, L., Moreno, M., Marin, V., Pezzati, E., Bartoli, M. and Fabiano, M. 2008. Organic waste impact of capture-based Atlantic bluefin tuna aquaculture at an exposed site in the Mediterranean Sea. Estuarine, Coastal and Shelf Science, 78: 369-384. doi:10.1016/j.ecss.2008.01.002

Vita, R., Marin, A., Jimenez-Brinquis, B. Cesar, A., Marin-Guirao, L., and Borredat, M. 2004. Aquaculture of Bluefin tuna in the Mediterranean: evaluation of organic particulate wastes. Aquaculture Research, 35: 1384-1387. doi: 10.1111/j.1365-2109.2004.01155.x

Vita, R. and Marin, A. 2007. Environmental impact of capture-based bluefin tuna aquaculture on benthic communities in the western Mediterranean. Aquaculture Research, 38: 331-339. doi: 10.1111/j.1365-2109.2007.01649.x

Vizzini, S. and Mazzola, A. 2012. Tracking multiple pathways of waste from a northern bluefin tuna farm in a marine-coastal area. Marine Environmental Research, 77: 103-111. doi:10.1016/j.marenvres.2012.02.009

Wu, R.S.S. 1995. The environmental impact of marine fish culture: towards a sustainable future. Marine Pollution Bulletin, 31: 159-166. doi:10.1016/0025-326X(95)00100-2