

# AQUATIC RESEARCH



Aquatic Research 1(1), 38-49 (2018) • DOI: 10.3153/AR18005

Original Article/Full Paper

## CONSTRUCTION, ASSEMBLY AND SYSTEM DEPLOYMENT OF A FISH CAGE WITH COPPER ALLOY MESH PEN: CHALLENGING WORK LOAD AND ESTIMATION OF MAN-POWER

Murat Yiğit<sup>1</sup> , Michael Osienski<sup>2</sup> , Judson DeCew<sup>3</sup> , Barbaros Çelikkol<sup>2,3</sup> ,  
Osman S. Kesbiç<sup>4</sup> , Mustafa Karga<sup>5</sup> , Ümit Acar<sup>6</sup> , Evrim Kurtay<sup>7</sup> , Barış Özalp<sup>1</sup> ,  
Musa Bulut<sup>1</sup> , Ümüt Yiğit<sup>1</sup> , Nic Taylor<sup>8</sup> , Robert L. Dwyer<sup>9</sup> 

### Cite this article as:

Yiğit, M., Osienski, M., DeCew, J., Çelikkol, B., Kesbiç, O.S., Karga, M., Acar, Ü., Kurtay, E., Özalp, B., Bulut, M., Yiğit, Ü., Taylor, N., Dwyer, R.L. (2018). Construction, Assembly and System Deployment of a Fish Cage with Copper Alloy Mesh Pen: Challenging Work Load and Estimation of Man-power. Aquatic Research, 1(1), 38-49. DOI: 10.3153/AR18005

### ABSTRACT

In the present study, a 150 cubic m net pen was designed as part of a collaborative research effort between the International Copper Association (ICA-USA), the University of New Hampshire (UNH-USA) and Canakkale Onsekiz Mart University (COMU-Turkey) in August 2011. The fish cage was developed to support the creation of a small scale demonstration farm, located in the Strait of Canakkale, off the coast of Guzelyali town in Turkey. The surface gravity-type, octagonal shaped fish cage was designed to have a diameter of 6 m and a copper alloy mesh chamber depth of 5 m. The present study details the cage construction and system deployment of one fish cage utilized a chain link mesh net chamber with a copper alloy developed by Wieland-Werke in Germany, with reference to work load challenge and estimation of man-power necessary for the partial and total work efforts. As a conclusion, one cage equipped with copper-alloy mesh pen was brought to a final shape with the net chamber assembled and attached to the cage frame in 3 days and 90 man-hours. The HDPE (high density polyethylene) cage frame was assembled by an outside company, therefore detail of the main cage frame is not discussed in this paper.

**Keywords:** A Copper alloy mesh, Cage construction, System deployment, Work load and pan-power, Cage aquaculture, Çanakkale Strait (Dardanelles)

- <sup>1</sup> Canakkale Onsekiz Mart University, Faculty of Marine Science and Technology, Departments of Aquaculture and Marine Technology Engineering, Canakkale, Turkey
- <sup>2</sup> University of New Hampshire, Department of Mechanical Engineering, Durham, NY-USA
- <sup>3</sup> University of New Hampshire, Institute of Ocean Engineering, Durham, NY-USA
- <sup>4</sup> Kastamonu University, Faculty of Veterinary, Kastamonu, Turkey
- <sup>5</sup> Kastamonu University, Vocational School of Inebolu, Kastamonu, Turkey
- <sup>6</sup> Canakkale Onsekiz Mart University, Bayramic Vocational School, Canakkale, Turkey
- <sup>7</sup> Ege University, Faculty of Fisheries, Department of Aquaculture, Izmir-Turkey
- <sup>8</sup> University of Plymouth, School of Marine Science and Engineering, Plymouth, UK
- <sup>9</sup> International Copper Association, Ltd., P.O. Box 536, Woods Hole, MA 02543, USA

**Submitted:** 15.12.2017

**Accepted:** 29.01.2018

**Published online:** 31.01.2018

**Correspondence:** Murat Yiğit

**E-mail:** [muratvigit@comu.edu.tr](mailto:muratvigit@comu.edu.tr)

©Copyright 2018 by ScientificWebJournals

Available online at

<http://aquatres.scientificwebjournals.com>

## Introduction

The rapid expansion of the aquaculture industry showed an increase of one million tons of production over the last ten years, reaching around 2.5 million tons of harvest from European waters and about 73.8 million tons from around the world in 2014 (FAO, 2016). The continuous increase of production and expansion of marine aquaculture facilities to exposed offshore areas has brought new challenges to finfish farmers to address problems such as biofouling, predation, or fish escapes in high-energy sea conditions. Besides, environment friendly production with proper management and environment friendly approach is the key towards the sustainability of the aquaculture industry. One of the main problems in cage farming is biofouling on nylon fish nets. Biofouling, the attachment and growth of seaweed or other marine organisms causes reduction of water flow through the mesh, while decreasing oxygen levels inside the pens (Braithwaite and McEvoy, 2005; Lader et al., 2008; Nys and Guenther, 2009; Berillis et al., 2017). The drag resistance of the nets and flotation, waste removal from the cage environment, or fish welfare can also be reduced by the development of biofouling on fish nets (Braithwaite and McEvoy 2005; Braithwaite et al. 2007; Nys and Guenther 2009; Fitridge et al. 2012; Bloecher et al. 2013; Klebert et al. 2013). Therefore, frequent change of nylon fish nettings or in-situ cleaning is necessary in cage farms to keep the system secure and promote proper fish growth. Alternatively, antifouling coatings such as copper-based paintings on fish nets are also used against biofouling (Nys and Guenther 2009; Fitridge et al. 2012), which significantly increase the operational costs (Solberg et al., 2002; Braithwaite et al., 2007). However, continuous leaching of copper from the fish nets into the water environment has been reported over a short time, usually six to eight months (Braithwaite et al., 2007; Bloecher et al., 2013; Castritsi-Catharios et al., 2015), causing toxic effects on non-target marine life due to accumulation of the active ingredients from the paints in the water as well as in the sediments under the fish cages (Katranitsas et al., 2003, Nys and Guenther, 2009; Burrige et al., 2010).

Besides the mechanical, economic or environmental advantages of copper alloy mesh compared to the traditional nylon nettings (Chambers et al., 2012; Aufrecht et al., 2013; Drach, 2013; González et al., 2013; Ayer et al., 2016; Efsthathiou et al., 2016; Kalantzi et al., 2016; Yigit et al., 2016; Buyukates et al., 2017; Yigit et al., 2017, 2018), and the higher structural stability of the copper alloy nets exposed to high energy water conditions assuring volumetric integrity in the cage environment and preventing deformation on

the structure (Berillis et al., 2017), the construction and assembly of the new technology mesh pens and moreover forming the material into a fish cage is a new challenge still remaining as a question to be answered and an issue that might interest fish cage producers and net manufacturers. Moving cage aquaculture to more exposed sites has brought cage farmers to re-consider materials and equipment for cost effective production with higher economic benefits and production of healthier fish. However, not only the cost of the materials but also construction, assembly or deployment work of new technologies is a new challenge for fish farmers that still remains as a question to be answered. Therefore in the present study, the construction, assembly and the formation of the material into a cage pen shape along with the deployment of copper alloy mesh cage in the mooring grid system has been evaluated with reference to work load in terms of time and length of the work, i.e. days and man-hours.

## Materials and Methods

### *Calculation of Man-hours*

Man hour calculation, an important data for production profitability management in the industry was calculated to provide information for strategic decision makers using the following formulae according to Ingram (2018):

$$\text{Man hour} = \text{LN} \times \text{WH} \times \text{WD}$$

where, LN= number of labor, WH= working hours, WD= total length of the operation in days (working days)

### *Site Conditions and Materials Used*

An offshore gravity type HDPE (high density polyethylene) cage, with a volume of 150 m<sup>3</sup>, was designed to deploy into a 4m-submerged grid system moored with anchors to a depth of 45 m in the Strait of Canakkale (formerly the Dardanelles) (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), 0.6 nautical miles off the coast of Dardanos town area (40°03'42"N - 26°20'36"E). The surface gravity-type 150 m<sup>3</sup> volume net pen was designed as part of a collaborative research effort between the International Copper Association (ICA-USA), the University of New Hampshire (UNH-USA) and Canakkale Onsekiz Mart University (COMU-Turkey) in August 2011. The octagonal shaped floating fish cage was designed to have a diameter of 6 m and a copper alloy mesh chamber depth of 5 m. The copper-alloy wire was antimicrobial wrought copper-zinc brass alloy with the ASTM designation of C44500 was formed into a mesh of 3.0 cm for the fish pen. The results of the analyses

of the copper-alloy material given by the German Copper Institute are presented in Table 1.

**Table 1.** Analyses of copper-alloy material of the mesh used for the CAM pen (means  $\pm$  SD)

Contents	Min (%)	Max (%)	mean $\pm$ SD (%)
<b>Cu</b>	70.00	73.00	71.50 $\pm$ 2.12
<b>Zn</b>	29.18	25.57	27.38 $\pm$ 2.55
<b>Sn</b>	0.80	1.20	1.00 $\pm$ 0.28
<b>P</b>	0.02	0.10	0.06 $\pm$ 0.06
<b>Pb</b>	N/A	0.07	0.07
<b>Fe</b>	N/A	0.06	0.06

An antimicrobial wrought copper-zinc brass alloy with the ASTM designation of C44500, data from German Copper Institute:

<https://www.kupferinstitut.de/en/arbeitsmittel/kupferschluessel.html>

N/A: not available

### *Copper alloy mesh Pen Construction*

Assembly of materials and construction of copper-alloy mesh pen was conducted at the facilities of Port of Canakkale (Kepez-Turkey). The net panel mesh fabricated by Wieland-Werke was unpacked and laid out. The net chamber bottom panel was first assembled. A 6 m length of the 2.5 m wide mesh was positioned near the cage frame. Then two 6 m sections of the 1.75 m wide mesh was positioned on each side forming a 6 m by 6 m square (Figure 1).



**Figure 1.** Two lengths of 1.75 m mesh were positioned on both sides of the 2.5 m mesh to form the bottom net panel

The edges of the three net sections were then outlined with straight wire (Figure 2). Afterwards, the net panels were secured together with helix coils. Special care was taken to insure the coil went around both straight wires and associated fence knuckles (Figure 3).



**Figure 2.** Straight wire was used to outline all edges of the mesh



**Figure 3.** Helix coils were utilized to attach the two parts together

The corners of the square bottom panel were then removed to create the necessary octagonal shape. In order to do this, the outer edges of the octagonal bottom panel were first outlined with straight wire. Thereafter, using the wire as a guide, the mesh was cut (Figure 4). After removing the excess material, the exposed ends of the cut wire were knuckled over the outline wire. As a next step, the side panels were organized for assembly. Each side panel consisted of two

sections of 2.5 m length mesh. Therefore, sixteen mesh sections were cut from the remaining rolls of material. Two sections that form a side panel were then laid out radially from the bottom net panel. Note that the side panels were oriented so that the salvaged edge of the side panel was “horizontal” in the deployed configuration. The top and bottom edges of the mesh panels were outlined with straight wire. The lower portion of the side panels were then attached to the bottom panel using helix coils, similar to the method utilized in the bottom panel assembly (Figure 5, 6).



**Figure 4.** The corners of the bottom net panel were removed to form an octagon



**Figure 5.** The side panels were laid out radially from bottom panel to ease assembly.



**Figure 6.** Copper alloy chain link mesh panel laid out near the cage frame

Working synchronously, the lower rim was prepared for attachment. The lower rim composed of eight lengths of straight 5cm diameter copper alloy pipe and eight respective 45 degree elbows. Each of the straight 4 pipes was inserted into a respective elbow. To secure these together, a hole was drilled through both components and secured with a loop of straight wire (Figure 7). The sides of the net were finished by attached the top and bottom portions of the net via helix coils (Figure 8). Once attachment of the bottom and top portions of the side panels were completed using helix coils, each completed side panel was folded, one at a time, into the center of the cage (Figure 9). As each panel was folded in, adjacent panels were connected together along “its vertical edge” via two lengths of wire. This step was repeated for 7 of the 8 sides. The remaining one side was finished the following day, hence the work load for the side number 8 was included in the calculations of the other day.

As the next step, the bottom rim pipe sections were fitted to the net chamber. The final lengths of the pipe had to be altered (cut) due to the elbows having a larger bending curvature than expected. The pipes were then drilled and connected together (Figure 10). The lower rim was then attached to the net chamber with double loops that encompassed the net pipe and both outline wires of the panels. The double loops were placed approximately every 20cm along the length of the pipes (Figure 11).



**Figure 7.** Each straight pipe length was first attached to a 45 degree elbow



**Figure 9.** The side panels were folded to the inside of the cage to allow adjacent panels to be secured together.



**Figure 8.** The bottom and top portions of the side panels were attached via helix coils.



**Figure 10.** Double loop ties were placed every 20cm on the bottom net rim



**Figure 11.** Double loop ties were placed every 20cm on the bottom net rim

The final side panel seam was secured using the same method as discussed previously. At this stage, the entire net chamber was formed. To prepare for attaching the net to the upper rim, the top portion of each net panel was aligned to rest on top of the remaining net. This was accomplished by folding the net on top of itself (Figure 12). Similar to the previous system, the HDPE insulators were not made to specification. Therefore, certain sections were taped to insure that the copper alloy material would not come in contact with the steel brackets (Figure 13).



**Figure 12.** Side panels were folded to align the top edge of the net for attachment of the top rim



**Figure 13.** Insulating tape covering exposed metal to prevent galvanic corrosion.

The top pipe assembly was then lifted approximately one m off the ground with a crane, allowing the top edge of the net chamber to be secured. The net chamber was then attached using double loop ties every 20 cm around the entire pipe (Figure 14). Once the net was attached, the system was raised for a visual inspection. It was found that additional wire mending was required at the intersections of the seam in the side panels (Figure 15). To reinforce this area, lengths of straight wire were fed through the mesh and tied off.



**Figure 14.** The net chamber being attached to the top pipe assembly



**Figure 15.** Seams between the side panels required additional wire support.

The final system can be seen in Figure 16. After the inspection was completed, the cage was prepared for deployment. Bridle lines were placed under the cage and the system lowered and close-coupled for deployment Figure 17.



**Figure 16.** The completed fish cage with copper-alloy mesh being raised for inspection.



**Figure 17.** Bridle lines placed under the cage for lowering the system

Once the copper-alloy mesh pen construction was completed, the close-coupled cage was lifted off the pier by the

main deployment crane and lowered into the water (Figure 18). The cage was towed from the pier out to the mooring grid site. This was done by a single tow line attached to a towing vessel (Figure 19).



**Figure 18.** The cage being deployed into the water



**Figure 19.** The cage was towed to the mooring site via a single line

Once the cage was transported to the site, the cage was secured into the mooring grid (Figure 20). An additional HDPE surface support boat was needed to help guide the cage and the crew (Figure 21). Each cage line was wrapped and tied to the floatation pipes on the cage in a figure eight fashion (Figure 22).



**Figure 20.** Securing the cage into the mooring grid



**Figure 21.** HDPE support boat used to guide the cage and the crew



**Figure 22.** Fully deployed cage at the farm site

## Results and Discussion

The fact that nylon nettings in the marine environment are subject to biofouling is one of the most important operational challenges cage aquaculture. Biofouling can prevent rational water flow-through in the nets and affect the water quality in the pens due to lower water circulation and less oxygen concentrations degrading the culture environment (Braithwaite et al., 2007; Fitridge et al., 2012; Ayer et al., 2016). Biofouling is reported to contribute to direct and indirect impacts on fish health and growth performance because of restriction of water exchange, increased risks of diseases, as well as deformation on the cage structure (Fitridge et al., 2012). In a cage environment with extreme biofouling, high levels of mortalities have been recorded due to anoxia (Fitridge et al., 2012). These can cause negative effects on fish health and growth performance, that may result in lower feed utilization and higher feed conversion ratio. Under these circumstances fish producers use more and more chemicals and chemo-therapeutants to improve fish health and meet the target growth rates due to fluctuating market pressure. Hence, periodic removal and cleaning of the nets, the use of antifouling paints in order to protect the nettings, in-situ cleaning of the nets by divers are the common maintenance practices that the fish farmers have to undertake regularly for the prevention of detrimental effects of biofouling (Braithwaite et al., 2007; Fitridge et al., 2012; Ayer et al., 2016). Being subject to mechanical fatigue or tearing especially due to vertical tidal movements and also subject to attacks by marine predators from outside of the cage environment (Jackson et al., 2015) are serious risks for cage farmers using nylon nettings, since rips in net-pens lead

to fish escapes, which will not only cause to economic losses for the farmer, but also damage wild fish species through genetic contamination, and by transferring parasites and diseases to fish wild populations. Additionally, the added weight of biofouling increases the risk of tearing on the nylon nets when cage is under heavy tidal actions due to vertical forces in the waves (Jackson et al., 2015). The higher mechanical strength of the copper alloy fish net pens prevents the loss of fish through escapes (Dwyer and Stillman, 2009; Drach, 2013). Also Chambers et al. (2012) reported that the strength of copper netting also deters predators such as seals and sharks.

Overall, the construction and assembly of copper alloy mesh cages which are considered as new technology for cage farms, is a crucial importance to secure fish hauling chambers for a safe and ecological production. The ability to understand forming the copper alloy mesh panels into a fish pen shape, on-land construction and assembly of the material, sea water deployment of the finalized cage system with copper alloy mesh is a critical information to the aquaculture farming community. The approach presented in this paper showed that by considering the work load and pan-power measurements on the net chamber work, a good approximation of the system construction could be made.

In the present study, one offshore-type cage equipped with copper-alloy mesh pen was brought to a final shape with the net chamber assembled and attached to the cage frame and deployed in to a mooring grid in 3 days and 90 man-hours. Since the HDPE cage frame used in this study was assembled by an outside company, the detail of the main cage frame has not been discussed in this paper.

During inspection of the final system, it was noted that the helical wire used for merging the two side panels together may be a weak point in the structure. In case of a failure of the helical wire line, it could result in a catastrophic failure for the entire system. Hence, additional vertical straight wires (2 per side) connecting the bottom net rim to the upper rim has been installed as a backup after inspection in order to secure the system for high energy sea conditions.

Additionally, it is important to note that having side panels consisting of 2 sections of mesh increased the time and complexity of assembling the net chamber. The straight and helical wire restricted the netting from compressing laterally. Even though, no significant problems were encountered with the methodology applied during the field work in this study, it is advisable to manufacture the side panels in one piece instead of 2 separate sections, which had to be connected by using a helical wire during installation. In general,

reducing the number of individual sections on the structure might reduce failure risks of the system in high energy sea conditions, as well as operational costs and labor-force for inspection and modification in case of possible failure issues during fish production in the sea environment.

Man hour calculation is important especially for production profitability management in the industry and calculating man hours may give important information for strategic decision makers. For example if the construction, assembly and deployment of one cage system is performed in two weeks with 15 labor working for 7 hours a day and 6 days a week, the man-hour would result as;

$$15 \text{ labor} \times 7 \text{ hours} \times 6 \text{ days} \times 2 \text{ weeks} = 1,260 \text{ man hour}$$

Assuming that the expected benefit from this one cage is 20,000 USD, the man-hour productivity would results as;

$$20,000 / 1,260 = 15.87 \text{ USD}$$

Based on these calculations, for each hour work in the field for the construction and deployment of one cage, each labor contributes 15.87 USD value of work to the building of the system. In this scenario, if a labor were given a payment of 16 USD per hour work effort for example, the benefit from one cage would not be profitable as a result, because each labor contributed less than 16 USD per hour to the total income from one cage (Ingram, 2018).

In the present study, work load and labor human man power in terms of man-hours were not converted into economic indices such as labor costs or man hour productivity, since the cost of labor force may differ among regions and countries, as the correct labor costs may include governmental, state or local fees and social secure taxes, medical care taxes, workers compensation insurance or other fees etc. (Ingram, 2018). Furthermore, it is required to consider different hourly rates for each professional category in order to calculate the total labor cost of a work. It means that for example in construction and assembly or the deployment of the system into the mooring grid, the cost for a junior labor will not be the same as for a senior technician or an experienced seaman. These costs will also differ according to category as well as country or region. Therefore, the evaluation of construction, assembly and system deployment of the new cage net technology applied in the present study has been focused on work load in terms of time and length of work, i.e. days and man-hours in the present study. These outputs obtained in the present study are important for decision makers and system managers to make possible strategic re-

sponses and take necessary measures in operational arrangements or changes to ensure profitability of the work program in order to provide economic benefits for the company.

During the first day of the field work in the present study, the man-hour was recorded as of 35, which covered the duties of unpacking the fabricated panel mesh, positioning the net panels, outlining edges with straight wire, securing panels with helix coils, cutting panels according to the designed octagonal shape, and assembling the net chamber bottom panel, preparing side panels, cutting mesh sections, lay out of sections for forming the side panels, outlining the top and bottom edges of the mesh panels with straight wire, attachment of lower portion of the side panels to the bottom panel using helix coils, preparation of the lower rim for mesh pen attachment, securing the straight pipes by inserting into a respective elbow and drilling in order to secure both components with straight wire.

The second day of the field work which also needed a man-hour of 35, comprised the finishing the sides of the net by attaching the top and bottom portions of the net via helix coils, folding each of the completed side panel, connecting adjacent panels together via wire for all sides of panels, fitting the bottom rim pipe sections to the net chamber, drilling the pipes and connecting, attachment of the lower rim to the net chamber with double loops.

For the third day of the field work, a man-hour effort of 20 was obtained, which covered the challenging work of securing the final side panel seams, forming the entire net chamber, preparing the attachment of the net to the upper main rim, taping certain sections to insure no contact of copper alloy material with steel brackets, lifting the top pipe assembly with a crane in order to allow securing the top edge of the net chamber and attaching the net chamber to the upper main rim using double loop ties, raising up the system with a crane for visual inspection, reinforcing the system where necessary using straight wire, preparing the cage for seawater deployment, lowering the system by bridle lines, lifting up and lowering the complete system into the water from the pier, towing the cage from the pier out to the mooring grid site by a towing vessel, securing the cage into the mooring grid with the support of an HDPE work boat, wrapping each cage line around the main floatation pipe and securing the entire system in the mooring grid system.

## Conclusion

As a conclusion, the total man hour was found as 90 man-hours with 5 labors working 6 hours a day for 3 days in total

for the field operation of construction, assembly and seawater deployment of one cage with an innovative copper alloy mesh pen into the mooring grid system in a secure way. The findings in the present study may be used by decision makers and production managers for strategic responses, necessary measures in operational arrangements to ensure profitability of the work during construction of copper alloy mesh pens.

## Acknowledgement

The authors would like to acknowledge the financial support of International Copper Association for the development of the demonstration farm in Canakkale-Turkey. We would also like to acknowledge the authorities of the Port of Canakkale (Kepez) for logistic support with port facilities, crane, forklift and vessels during construction and deployment of the system. Further, many thanks to Mr. Hal Stillman (Global Initiative Leader for Technology Development and Transfer at International Copper Association, ICA-USA) and to Mr. Langley Gace (President of InnoSea Systems, Inc. USA, former Aquaculture Applications Development Manager at ICA) for their valuable inputs, technical advices and support throughout the study.

## References

- Aufrecht, J., Grohbauer, A., Hofmann, U., Drach, A., Tsukrov, I, et al. (2013) Corrosion, antifouling properties, fatigue and wear of copper alloys for seawater applications. Copper 2013 International Conference, Santiago, Chile.
- Ayer, N., Martin, S., Dwyer, R.L., Gace, L., Laurin, L. (2016). Environmental performance of copper alloy Net-pens: Life cycle assessment of Atlantic salmon grow-out in copperalloy and nylon net pens. *Aquaculture*, 453, 93-103.
- Berillis P., Mente E. and Kormas K.A. (2017). The Use of Copper Alloy in Aquaculture Fish Net Pens: Mechanical, Economic and Environmental Advantages. *Journal of FisheriesSciences.com*, 11(4), 1-3.
- Bloecher N., Olsen Y., Guenther J. (2013). Variability of Biofouling Bommunities on Fish Cage Nets: A 1-year Field Study at a Norwegian Salmon Farm. *Aquaculture*, 416-417, 302-309.

- Braithwaite R.A., M.C.C. Carrascosa, McEvoy L.A. (2007). Biofouling of Salmon Cage Netting and the Efficacy of a Typical Copper-Based Antifoulant. *Aquaculture*, 262, 219-226.
- Braithwaite, R.A., McEvoy, L.A. (2005). Marine bio-fouling on fish farms and its remediation. *Advance in Marine Biololgy* 47, 215-252.
- Burridge L., Weis J.S., Cabello F., Pizarro J., Bostick K. (2010). Chemical Use in Salmon Aquaculture: A Review of Current Practices and Possible Environmental Effects. *Aquaculture*, 306, 7-23.
- Buyukates Y., Celikkol B., Yigit M., DeCew J., Bulut M. (2017). Environmental Monitoring Around an Off-shore Fish Farm with Copper Alloy Mesh Pens in the Northern Aegean Sea. *American Journal of Environmental Protection*, 6, 50-61.
- Castritsi-Catharios J., Neofitou N., Vorloou A.A. (2015). Comparison of Heavy Metal Concentrations in Fish Samples From Three Fish Farms (Eastern Mediterranean) Utilizing Antifouling Paints. *Toxicological and Environmental Chemistry*, 97, 116-123.
- Chambers, M., Bunker, J., Watson III, W.H., Howell III, W.H. (2012). Comparative growth and survival of juvenile Atlantic Cod (*Gadus morhua*) cultured in copper and nylon net pens. *Journal of Aquaculture Research and Development* 3, 137-142.
- Drach, A. (2013). Utilization of Copper Alloys for Marine Applications. Doctoral dissertation, University of New Hampshire.
- Dwyer, R.L., Stillman, H. (2009). Environmental Performance of Copper Alloy Mesh in Marine Fish Farming: The Case for Using Solid Copper Alloy Mesh. *EcoSea Innovation in Aquaculture, International Copper Association* pp: 18.
- Efstathiou, P.A., Kouskouni, E., Karlovasiti, V., Manolidou, Z., Efstathiou, A.P. (2016). Use of copper alloy cage in floating fish culture for the farming of Mediterranean marine fish. 2nd International Congress on Applied Ichthyology & Aquatic Environment 10-12 November 2016, Messolonghi, Greece.
- FAO, 2016. FAO Statistical Query Results, Fisheries and Aquaculture Information and Statistics Branch - 05/12/2016  
[http://www.fao.org/figis/servlet/SQServlet?file=/work/FIGIS/prod/webapps/figis/temp/hqp\\_585971118044155575.xml&outtype=html](http://www.fao.org/figis/servlet/SQServlet?file=/work/FIGIS/prod/webapps/figis/temp/hqp_585971118044155575.xml&outtype=html)
- Fitridge, I., Dempster, T., Guenther, J., de Nys, R., (2012). The impact and control of biofouling in marine aquaculture: a review. *Biofouling Journal of Bioadhesion Biofilm Research*, 28(7), 649-669.
- Gonzalez, E.P., Hurtado, C.F., Gace, L., Augsburger, A., (2013). Economic impacts of adopting copper alloy mesh in trout aquaculture: Chilean example. *Aquaculture Economics & Management*, 17(1), 71-86.
- Ingram D., (2018). How to estimate man-hour productivity in construction. Cited 12.01.2018. <http://smallbusiness.chron.com/estimate-manhour-productivity-construction-80878.html>
- Jackson, D., Drumm, A., McEvoy, S., Jensen, O., Mendiola, D., Gabina, G., Borg, J.A., Papageorgiou, N., Karakassis, Y., Black, K.D. (2015). A pan-European valuation of the extent, causes and cost of escape events from sea cage fish farming. *Aquaculture*, 436, 21-26.
- Kalantzi, I., Zeri, C., Catsiki, V.A., Tsangaris, C., Strogyloudi, E, et al. (2016). Assessment of the use of copper alloy aquaculture nets: Potential impacts on the marine environment and on the farmed fish. *Aquaculture*, 465, 209-222.
- Katranitsas A., Castritsi-Catharios J., Persoone G. (2003). The Effects of a Copper-based Antifouling Paint on Mortality and Enzymatic Activity of a Non-Target Marine Organism. *Marine Pollution Bulletin*, 46, 1491-1494.
- Klebert, P., Lader, P., Gansel, L., Oppedal, F. (2013). Hydrodynamic interactions on net panel and aquaculture fish cages: a review. *Ocean Engineering*, 58, 260-274.
- Lader, P., Dempster, T., Fredheim, A., Jensen, O. (2008). Current induced net deformations in full-scale cages for Atlantic salmon (*Salmo salar*). *Aquaculture Engineering*, 38, 52-65.

- Nys R.D., Guenther J. (2009). The Impact and Control of Biofouling in Marine Finfish Aquaculture. In: Helio C, Yebra D (eds) *Advances in Marine Antifouling Coatings and Technologies*. Woodhead Publishing Limited, Cambridge, UK, pp 177-221. ISBN 1845693868
- Solberg, C., Saethreb, L., Julshamn, K. (2002). The effect of copper-treated net pens on farmed salmon (*Salmo salar*) and other marine organisms and sediments. *Marine Pollution Bulletin*, 45, 126-132.
- Yigit M., Celikkol B., Bulut M., DeCew J., Ozalp B., Yilmaz S., Kaya H., Kizilkaya B., Hisar O., Yildiz H., Yigit U., Sahinyilmaz M., Dwyer R.L. (2016). Monitoring of Trace Metals, Biochemical Composition and Growth of Axillary Seabream (*Pagellus acarne* Risso, 1827) in Offshore Copper Alloy Mesh Cages. *Mediterranean Marine Science*, 17(2), 396-403.
- Yigit Ü, Ergün S, Celikkol B, Bulut M, Yigit M. (2017). Bio-economic efficiency of copper alloy mesh technology in offshore cage systems for European seabass aquaculture. *Indian Journal of Geo-Marine Sciences*, 46(10), 2017-2024.
- Yigit M., Celikkol B., Yilmaz S., Bulut M., Özalp H.B., Dwyer B., Maita M., Kizilkaya B., Yiğit Ü., Ergün S., Gürses K., Büyükatdeş Y. (2018). Bioaccumulation of trace metals in Mediterranean mussels (*Mytilus galloprovincialis*) from a fish farm with copper-alloy mesh pens and potential risk assessment. *Human and Ecological Risk Assessment: An International Journal*, 24(2), 465-481.