

# Cyprus' Offshore Aquaculture Mooring Systems: Current Status and Future Development

V. Vassiliou, M. Menicou, M. Charalambides, J. DeCew and I. Tsukrov

**Abstract**—Cyprus' offshore aquaculture industry has promising prospects taking into account that Cyprus is an island. Its production trend is increasing overtaking bigger countries such as Greece and Italy. However, current mooring systems seem to be under-performing acting as obstacles for its future development. Furthermore, shallow coastal waters scarcity due to competing industries dictates future development to come by moving further from shore exposing fish farms and subsequently mooring systems to harsher environmental loadings. It is, therefore, of paramount importance to design mooring systems based on engineering and scientific principles and leave behind the present "trial and error" methods. This paper presents the current state of Cyprus' offshore aquaculture industry and focuses of its mooring designs by proposing a new methodology for designing more reliable systems, hence ensuring its future.

**Keywords**—Environmental loadings, mooring systems design, numerical modeling, offshore aquaculture

## I. INTRODUCTION

OFFSHORE aquaculture economic activity was introduced in Cyprus over the past twenty years. Cyprus' government policy, initiated in 2007, aimed to promote this economic activity and reach the annual production level of 10000tn over the next seven years from 2500tn, in 2008.

The Cyprus Department of Fisheries and Marine Research (DFMR) latest report indicate that in 2010 the total aquaculture production rose to 4077tns compared to 3390tns in 2009, a more than 20% increase corresponding to just above 20mil Euros [1]. Similarly, the 2009 Fisheries and Aquaculture Statistics report from the Food and Agriculture Organization of the United Nations (FAO) shows that Cyprus has the second largest increasing trend behind Turkey, in a 10 year period starting from 2000 and ending in 2009, overtaking significantly larger Mediterranean countries such as Greece and Italy [2], as depicted in Fig. 1.

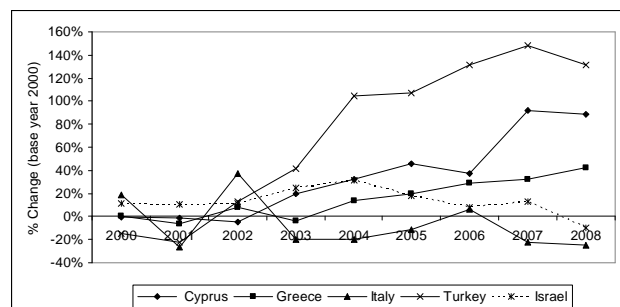


Fig. 1 Aquaculture production of marine fish

Nevertheless, as the second quarter of 2012 is closing in the target of 10000tn by 2013 seems to be unachievable. Scarce available coast lines and competing tourist economic activity that prohibit materialisation of this policy are some of reasons but other more practical ones are also to be blamed. In particular, in recent years one in three offshore aquaculture companies in Cyprus suffered severe losses and ceased operations due to environmental conditions. This accident rate is excessively high when compared to Northern European offshore aquaculture industry. In fact, taking into account that Cyprus is located in an isolated "protected" area of the Mediterranean Sea which wears out any major environmental phenomena, such high failure rates signify that current mooring systems seem to be underperforming. This coupled with the fact that offshore aquaculture economic activity needs to be developed further away from coast in order to tackle the problems of competing industries, further highlights the need for more robust and reliable mooring designs.

Consequently, this paper examines the current state of Cypriot aquaculture installations and their engineering aspect and proposes a more scientific structured approach for the development of more reliable mooring scenarios.

## II. OVERVIEW OF CYPRUS OFFSHORE AQUACULTURE

Based on the 2010 report, in Cyprus there are seven licensed companies that operate offshore aquaculture fish farms. Their main product portfolio consists of sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*) although on a commercial basis blue fin tuna (*Thunnus thynnus*) is also cultured and in much smaller quantities the species sharp snout bream (*Puntazzo puntazzo*), red porgy (*Pagrus pagrus*), pandora (*Pagellus erythrinus*), and rabbit fish (*Siganus rivulatus*) are also cultured [3].

V. Vassiliou, M. Menicou and M. Chalambides are with Frederick Research Center, 1303 Nicosia, Cyprus (e-mails: eng.vv@fit.ac.cy; eng.mm@fit.ac.cy; bus.chm@fit.ac.cy).

J. DeCew and I. Tsukrov are with the Department of Mechanical Engineering at the University of New Hampshire, Durham, NH 03824, US (e-mails: Jud.Decew@unh.edu; Igor.Tsukrov@unh.edu)

This work is based on a sponsored research project funded by the Cyprus' Research Promotion Foundation and the European Commission's Structural Funds with the protocol number TEXNOLOGIA/MHXAN/0308(BIE)/02.

The main location of the majority installations of the aquaculture companies is at the east side of the Akrotiri Peninsula in between the Akrotiri and the Vasiliko bay at the southern part of Cyprus, as shown in Fig. 1. On average the installations are located at a distance of 1 to 4 km from the shore, at water depths ranging from 18 - 70 meters and with a distance of about 2 km between each other [3]. Almost a decade ago there were also offshore aquaculture installations at the southwest part of Cyprus, offshore the city of Paphos. However, after a high intensity storm the majority of the aquaculture cages were destroyed due to failure of their mooring lines that left them ungoverned at the mercy of the rough sea waves.

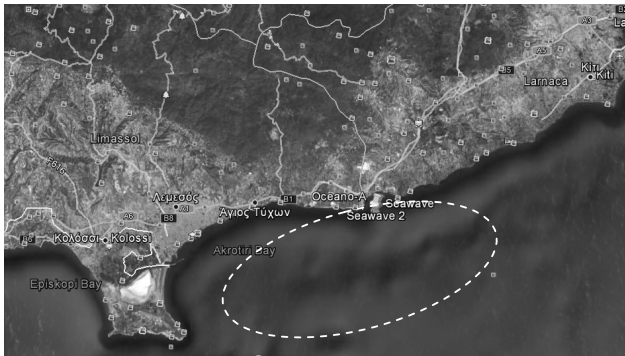


Fig. 2 Akrotiri Peninsula and location of offshore installations

Almost all Cypriot fish farms utilize surface grid arrays as their mooring system. Surface grid arrays are the predominant mooring system in the aquaculture industry worldwide and are part of a group of five different types, the rest being (a) submerged grid array; (b) single point moorings; (c) tension leg platforms; (e) multipoint anchor arrays. Surface grid arrays consist of a series of anchor legs supported by floats, interconnected by lines, shackles and connection plates. They mostly utilized with plastic gravity-type net pens. The mooring grid is located at depths of approximately five meters below surface and is held up off the bottom with cylindrical or spherical floating elements on each anchor leg. The anchor legs are made up of chain and rope and extend down to the bottom beneath the floats and the grid to plow embedment or dead-weight anchors [5].

### III. CURRENT MOORING DESIGN AND ENGINEERING

The current mooring design of the majority of the Cypriot offshore aquaculture fish farms is based on the “trial and error” method for deploying surface grid arrays. The mooring design is typically based on the type of mooring system to be deployed and engineering principles only contribution are on the issue of basic anchoring tension calculations and anchors positioning. The various parameters existing at the area of deployment are not considered except for the case of sea basin’s depth. Overall, a “do-it-yourself” mentality governs the deployment of fish farms coupled with practical knowledge of experienced divers which usual leads to over sizing system

components and connections. Apart from the cage’s parts which are purchased by dedicated companies, the type, dimensions, material, physical properties etc for the rest of the mooring parts’ are selected on a ‘trial and error’ basis and bought from the local hardware stores.

In particular, a typical fish farm’s anchoring is implemented either with 10 to 12 tones cement blocks and/or anchors; the floating cages are of approximately 20m diameter created with double high density polyethylene (HDPE) tubes of 250mm diameter passed through brackets of an inverse Greek gamma shape on which net pens and net pen tension weights of 20 to 50Kg are connected that provide a restoring force to help resist net deformation and volume loss in waves and currents; the connecting elements are shackles, mooring lines of 3-strand rope or 8-plait with a 45mm or 40mm diameter, stud-link chains of approximately 30m length and iron rope rings; finally, the floating devices utilized are plastic, foam-filled cone-shaped floating buoys of 1000L [4]. The following Fig. 3 gives a bird’s eye-view of a typical cage arrangement, as well as the orientation of the offshore aquaculture farm towards the predominant wind, while Fig. 4 gives a graphical side view of the whole system and its components.

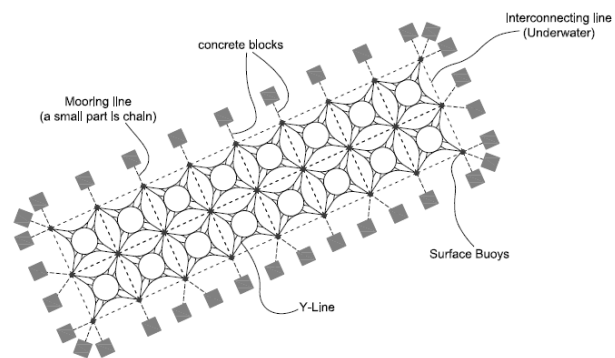


Fig. 3 Bird's eye view of aquaculture array

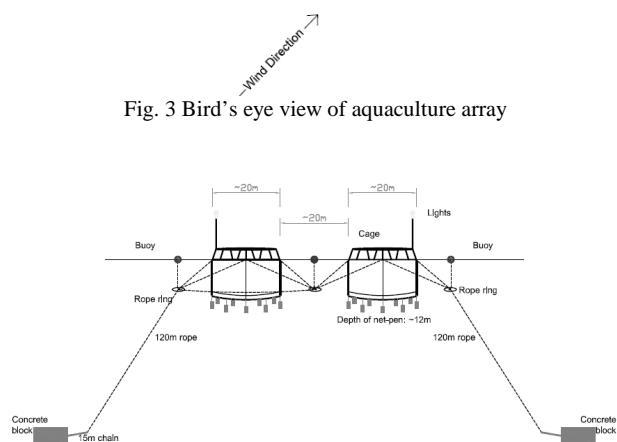


Fig. 4 Side-view of mooring system

This method is not characterized as reliable and robust enough as expressed through the partial failure rates and especially in the case of complete failure of Sagro Aquaculture fish farm near Paphos International airport. In December 2001 and after a high storm event mooring lines were broken and the grid arrays were left unanchored. In the aftermath of the destruction undersized mooring line's diameter and inconsistent maintenance practices were blamed [6].

#### IV. PROPOSED METHODOLOGY

To overcome the issues of underperforming mooring system and for the future development of the Cyprus offshore aquaculture a robust engineering approach is proposed. The approach is of a bottom-up, evidence-based character such as in any classic engineering problem, far superior than the "trial and error" techniques currently employed by fish farmers.

In brief, the proposed engineering methodology consists of (a) understanding the environmental conditions at the area of investigation; (b) design and analysis of the mooring system using numerical or physical models; (c) field monitoring procedures; and finally (d) validation of the models with in-situ data.

Starting with the environment conditions, it is a fact that although the design of mooring systems can easily be grouped and analyzed, based on their similarities, as described in Section II, the environmental conditions and their understanding are essentially unique and location specific. In fact the primary forcing mechanism on aquaculture installations are waves and currents hence it is of paramount importance to quantify the level of exposure as this is characterized by the current velocity (velocity profiles of tidal, wind and pressure driven currents) and wave height (prevailing wave spectra, and 25 or 50 year significant wave height and period). Accurate identification of operational (daily) and extreme (storm events) environmental load cases for design purposes will help develop more accurate numerical models thus extract more reliable results. Current profiles are typically measured with Doppler instruments whereas the local wave climate can be either measured with deployed instrumentation or estimated from meteorological stations' wind data, weather buoys and other sources.

Following environmental loading recording, numerical models are developed that provide insight into system dynamics, mooring tensions, and possible system resonance. Scaled physical modeling were crossed out since they require significant infrastructure such as wave tanks and flumes and are also far more time consuming. The numerical technique chosen is that of finite element analysis procedures.

Validation of the models with in-situ data and field monitoring procedures, have an iterative nature and are the last stages of the methodology

#### V. RESEARCH PROJECT AND RESULTS

This effort is expressed through a funded research project that has the acronym "Mooring" and it is currently ongoing.

Three different participant organizations are engaged within the project's seven work packages, two of which are academic institutions which are lead by Frederick Research Centre in Cyprus accompanied by University of New Hampshire in the US and supported by a leading Cypriot aquaculture SME, Seawave Fisheries Ltd.

The Mooring research project aims at the development of a structured approach for mooring systems design appropriate for the Cyprus region. For this reason a numerical model of a candidate mooring system representative of a Cyprus fish farm was constructed in the University of New Hampshire's Aqua-FE software package. The software uses the finite element analysis approach most recently described by [7]. Aqua-FE can simulate waves and currents on marine structures such as fish cages and moorings and output selected component motion and tension values.

As part the research project are also work-packages that (a) perform a state-of-the-art review of alternative mooring scenarios available and their respective merits and (b) perform a cost-benefit analysis regarding those and their respective merits under Cyprus' offshore environment operating requirements.

The preliminary assembled Aqua-FE mooring model developed, described a typical Cyprus fish farm consisting of a surface grid array securing 18 fish cages as depicted in Fig. 5. The 40 meter long grid lines are suspended 5 meters below the surface by thirty float and chain assemblies, each having a 1000 liter float and 14 mm diameter chain. Twenty-six anchor legs, consisting of 110 meters of 45 mm nylon line, 27 meters of 42 mm diameter chain and a 12 tone deadweight anchor secure the mooring to the seafloor. Note that in the numerical simulations, the anchor positions were fixed.

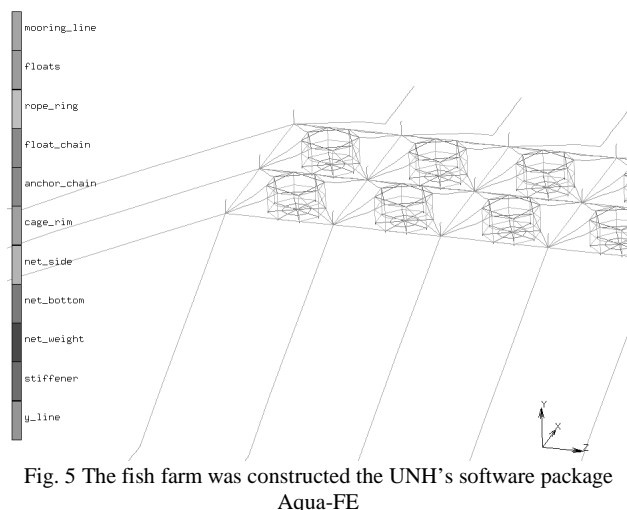


Fig. 5 The fish farm was constructed the UNH's software package Aqua-FE

Each grid bay contains a 20 meter diameter gravity-type fish cage. The cages consist of floating superstructure of 2 high density polyethylene (HDPE) pipes, 25 brackets, and a handrail. The buoyant rim supports a 10 meter deep net chamber and 16 concrete weights.

For this analysis, the net had a twine diameter of 1.8 mm and a mesh spacing of 8 mm. This high solidity (34.8%) grow-out net is typically used during initial fish stocking / grow-out and represents a worst case design condition due to the increased drag of the net. The net chamber typically dominates the drag of fish cages, as documented by [8]. The entire cage and mooring system model was constructed using 1659 nodes and 2522 elements.

The development of the current profile of the area of investigation is achieved through the purchase and deployment of RDP600 instrument from AANDERAA Data Instruments. RDP600 is a medium range, 600kHz self-recording Doppler current profiler that can be configured to deal with several profiles simultaneously for optimum flexibility [9], as shown in Fig. 6.

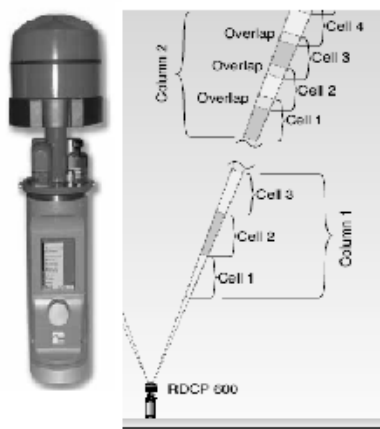


Fig. 6 RDCP600 Doppler current profiler

In contrast, historical wave data for the extraction of the load conditions were not available. For this reason records of the wind speed and direction will be used to predict the wave conditions. The methodology to develop the wave environmental load cases was as follows. Wind speed and direction data were purchased from local meteorological stations near the coast of Cyprus. The wind data were then processed to determine the relationship between the wind speeds, direction, duration and fetch. Average and maximum values were then utilized to generate a spectrum based, for example, on the Pierson-Moskowitz approach described in [10]. Note that this approach is only one of the possible approaches, and its usage has to be validated. Using wind speeds corrected to 19.5 meters above the water surface, the spectral energy of the sea,  $S$ , significant wave height,  $H_{mo}$ , and dominant wave frequency,  $f_p$ , can be calculated using the following Eq. (1)-(3).

$$S(f) = \frac{ag^2}{(2\pi)^4 f^5} e^{-0.74 \left( \frac{g}{2\pi U f} \right)^4} \quad (1)$$

$$f_p = \frac{0.87g}{2\pi U} \quad (2)$$

$$H_{mo} = \frac{0.21U^2}{g} \quad (3)$$

Where  $\alpha$  is a shaping factor,  $g$  is gravity,  $f$  is the wave frequency, and  $U$  is the wind speed.

For the purposes of the initial investigation regular waves, having a height of 2 meters and period of 8 seconds, and a co-linear, constant with depth, 0.4 m/s current, were applied to the system as shown in Fig. 7.

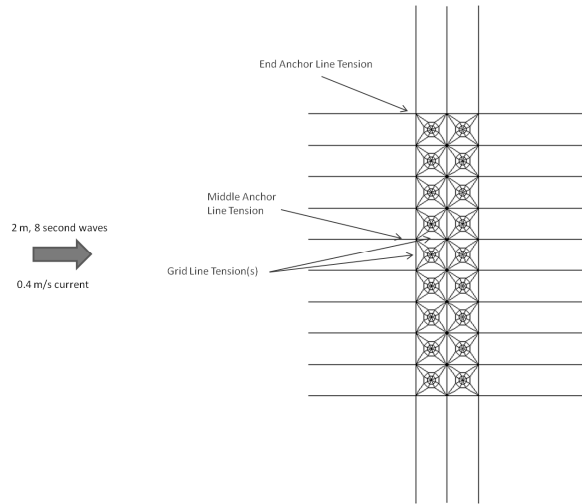


Fig. 7 Surface grid array arrangement and current and wave parameters

The model was run for 180 seconds, allowing the system to enter a cyclic steady state response. The deformed geometry of the system can be seen in Fig. 8.



Fig. 8 The deformed geometry of the fish cage mooring system

The results of the analysis showed that anchor and grid lines have maximum tensions of 47 kN and 37 kN, respectively, as shown in Fig. 9 and Fig. 10. These values are significantly lower than the minimum breaking load of the line (306 kN) [11].

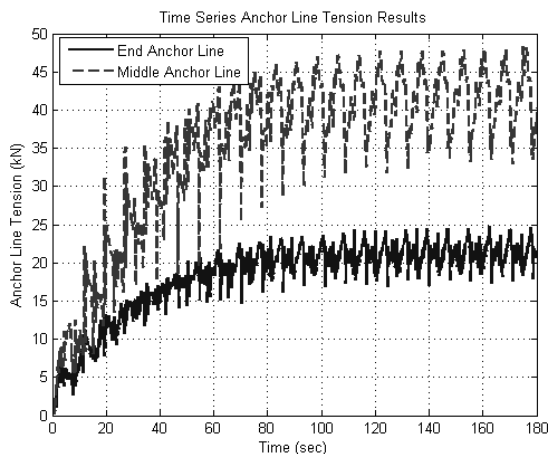


Fig. 9 The time series anchor tensions

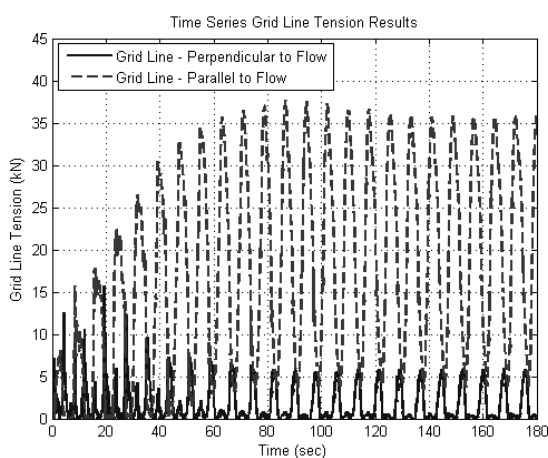


Fig. 10 The time series grid line tensions

However, it is important to note that this analysis is preliminary. The wave characteristics and current profile were estimated and might not represent the actual extreme loading conditions at the site. In addition, the system was oriented perpendicular to the loading, which is only one of the possible arrangements in the field. A more thorough investigation will be performed on various scenarios once all parameters are recorded and categorized.

## VI. CONCLUSIONS AND FUTURE RESEARCH

Within this paper the current state of the Cyprus' offshore aquaculture was presented. The main focus was on the current mooring designs and engineering as these have proven to be a major drawback by constantly underperforming.

The existing mooring design methodology was presented as well as a description of the typical fish-farm and its main components. The case of a mooring system failure was described emphasizing the weakness of the current methodology to ensure uninterrupted performance and low reliability.

To this end, a more scientific methodology is proposed and presented here. This methodology takes into account major parameters that influence an offshore mooring system which are (a) environmental conditions; (b) design and analysis using numerical models; (c) field monitoring procedures; and finally (d) validation of the models with in-situ data. A detail description of the instruments and methods utilized to extract the environmental loadings is presented accompanied by the description of an initial numerical model and presentation of the extracted simulation results. The analysis showed that the existing mooring system can withstand daily environment loads however, different variations must also be examined in addition to performance in the case of extreme storm events.

Finally, as offshore aquaculture installations are planned to be moved further away from shore, future research will be evolved around the issue of land energy dependence. Therefore, energy automation must be closely examined and different energy producing methods must be sought such as energy from Renewable Energy Sources (RES), as discussed by [12]. However, this will give rise to other technical issues such as the structural behaviour of aquaculture rings if RES generators are to be attached on them, as discussed in [13].

## ACKNOWLEDGMENT

The authors will like to express their thanks to Seawave-Fisheries Ltd and Blue Island Plc for their invaluable contribution during data elicitation. Special thanks also are paid to the MER Lab Ltd for the help in the graphic representation of the aquaculture cage.

## REFERENCES

- [1] Department of Fisheries and Marine Research, Annual Report for 2010, 2010. Available at: [http://www.moa.gov.cy/moa/dfmr/dfmr.nsf/DMLreports\\_en/DMLreport\\_s\\_en?OpenDocument&Start=1&Count=1000&Expand=1](http://www.moa.gov.cy/moa/dfmr/dfmr.nsf/DMLreports_en/DMLreport_s_en?OpenDocument&Start=1&Count=1000&Expand=1).
- [2] FAO, "Fisheries and Aquaculture Statistics, 2009" Food and Agriculture Organization of The United Nations; 2011.
- [3] Department of Fisheries and Marine Research, Aquaculture Division <http://www.moa.gov.cy/moa/dfmr/dfmr.nsf/A11/8F47ED8B84FBDB92C2256FC6003E028E?OpenDocument&highlight=%CE%B9%CF%87%CE%B8%CF%85%CE%BF%CF%84%CF%81%CE%BF%CF%86%CE%B5%CE%AF%CE%B1>.
- [4] Frederick Research Centre, "Prevailing Cyprus' mooring scenarios", unpublished report, 2011.
- [5] I. Tsukrov and J. DeCew, "State of the art review of available mooring systems for offshore aquaculture", unpublished report, 2011.
- [6] S. Agrotis, SAGRO Aquaculture Ltd, Limassol, CY, private telephone communication, June 2011.
- [7] I. Tsukrov, O. Eroshkin, D.W. Fredriksson, M.R. Swift and B. Celikkol, "Finite Element Modeling of Net Panels using Consistent Net Element," Ocean Eng., vol. 30, 2003, pp. 251–270.
- [8] J. DeCew, "Development of Engineering Tools to Analyze and Design Flexible Structures in Open Ocean Environments". Ph.D. Dissertation submitted to the University of New Hampshire in partial fulfillment of the Ocean Engineering Program. Durham, NH, 2010.
- [9] Aanderaa Data Instruments, D343, Recording Doppler Current Profiler, January 2010.
- [10] R. Sorensen, *Basic Wave Mechanics for Coastal and Ocean Engineers*, John Wiley and Sons, New York, 1993, p. 284.
- [11] J. DeCew, "Numerical Simulation to Predict Mooring System Performance, unpublished draft report 2011.

- [12] M. Menicou and V. Vassiliou, "Prospective energy needs in Mediterranean offshore aquaculture: Renewable and sustainable energy solutions," *Renew Sustain Energy Rev.*, vol. 14 (9), Dec. 2010, pp. 3084-3091.
- [13] M. Menicou, L. Papadakis and V. Vassiliou, "Towards Energy Autonomous Aquaculture: An Energy Requirement Study and a Respective Static Structural Analysis," in *Proc. 3<sup>rd</sup> MSE Conf. Renewable Energy Sources and Energy Efficiency*, Nicosia, Cyprus, 2011, pp. 459-468