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# Summary

This summary serves as a comprehensive documentation of the outcomes of Deliverable 5 “Four articles in engineering or academic literature submitted”.

The list below summarizes the 6 papers that OS Aqua consortium has published and 4 submitted for publication.

1. F.E. Karathanasi, T.H. Soukissian, D.R. Hayes, ‘Wave Analysis for Offshore Aquaculture Projects: A Case Study for the Eastern Mediterranean Sea’, Climate 2022.
2. M. Polykarpou, F.E. Karathanasi, T. Soukissian, V. Loukaidi, I. Kyriakides, ‘Data-driven Tool for the Allocation of Favourable Areas for Offshore Wind Farm Development,’ 17th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), 2022.
3. M. Polykarpou, F. Karathanasi, I. Kyriakides and S. Charalambous, "A tool for the dynamic allocation of multiple marine activities," 2022 IEEE 13th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), Vancouver, BC, Canada, 2022, pp. 0082-0087, doi: 10.1109/IEMCON56893.2022.9946582.
4. Polykarpou, M.; Karathanasi, F.; Soukissian, T.; Loukaidi, V.; Kyriakides, I. A Novel Data-Driven Tool Based on Non-Linear Optimization for Offshore Wind Farm Siting. Energies 2023, 16, 2235. https://doi.org/10.3390/en16052235
5. Hadjisolomou, E.; Antoniadis, K.; Rousou, M.; Vasiliades, L.; Abu-Alhaija, R.; Herodotou, H.; Michaelides, M.; Kyriakides, I. Predicting Coastal Dissolved Inorganic Nitrogen Levels by Applying Data-Driven Modelling: The Case Study of Cyprus (Eastern Mediterranean Sea).  *4th ICED 2023 International Conference* (20-22 October 2023, Athens Greece) (accepted)(Scopus Indexed)
6. Hadjisolomou, E.; Rousou, M.; Antoniadis, K.; Vasiliades, L.; Kyriakides, I.; Herodou, H.; Michaelides, M. Data-driven models’ integration for evaluating coastal eutrophication: a case study for Cyprus. *Water* (submitted on 02/10/2023)
7. Marios Charalambides, Michalis Menicou and George Tryantaphyllidis. Economic Feasibility Study for the Expansion of the Cyprus Aquaculture Sector. Aquaculture Economics & Management (submitted)
8. Triantaphyllidis George, Tsiaras Konstantinos, Pollani Anna, Kyriakides Ioannis, Nikolaidis George, Abu Alhaija Rana, Hayes Daniel and Triantafyllou George. Open Sea Allocated Zones for Aquaculture in Cyprus: Modelling the environmental impact of finfish mariculture and seasonal Eutrophication Index estimation. To be submitted to Mediterranean Marine Science.
9. Nicolas Aristokleous, Marios Charalambides , and Michalis Menikou. Powering Aquaculture Operations at Sea: Can hydrogen be a sustainable solution? (submitted)

A short abstract of each paper follows and the link to access all papers/manuscripts

<https://drive.google.com/drive/folders/11jpodvMg79COTGOoGtnYIHq2Mr9AgSik?usp=drive_link>

**Wave Analysis for Offshore Aquaculture Projects: A Case Study for the Eastern Mediterranean Sea**

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**Abstract:** The investigation of wave climate is of primary concern for the successful implementation of offshore aquaculture systems as waves can cause significant loads on them. Up until now, site selection and design (or selection) of offshore cage system structures on extended sea areas do not seem to follow any specific guidelines. This paper presents a novel methodology for the identification of favorable sites for offshore aquaculture development in an extended sea area based on two important technical factors: (i) the detailed characterization of the wave climate, and (ii) the water depth. Long-term statistics of the significant wave height, peak wave period, and wave steepness are estimated on an annual and monthly temporal scale, along with variability measures. Extreme value analysis is applied to estimate the design values and associated return periods of the significant wave height; structures should be designed based on this data, to avoid partial or total failure. The Eastern Mediterranean Sea is selected as a case study, and long-term time series of wave spectral parameters from the ERA5 dataset are utilized. Based on the obtained results, the most favorable areas for offshore aquaculture installations have been identified.

**Keywords:** wave climate; extreme value analysis; bathymetry; aquaculture systems; site selection; ERA5

**A tool for the dynamic allocation of multiple marine activities**

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**Abstract**—Marine Spatial Planning is important not only for the sustainability of the marine environment but also from a socioeconomic point of view. Marine Spatial Planning can allocate marine protected areas and designate areas for spatial and temporal distribution of human economic activities that respect the natural environment. This work proposes a novel method that solves the problem of dynamic allocation of areas suitable for marine activities. The work also includes an element of conflict between activities where part of the considered area is preferred or one activity over another based on suitability criteria. The problem of dynamically allocating areas for marine activities is solved using a sequential Monte Carlo method that can handle this non-linear problem and utilize the changing weather conditions to deliver a dynamically changing outcome. The method is assessed within a simulation scenario that considers areas suitable for marine sports and leisure activities that are dynamically allocated based on the changing weather conditions. The simulation quantifies the tradeoff between computational expense and accuracy that exists in the process of allocating suitable areas. Moreover, the simulation demonstrates the ability of the method to identify the maximum available areas which are dynamically allocated based on the changing weather conditions, and successfully handle conflicts between activities competing for the same area.

**A Novel Data-Driven Tool Based on Non-Linear Optimization for Offshore Wind Farm Siting**

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Abstract: One preliminary key step for developing an offshore wind farm is identifying favorable

sites. The process of sitting involves multiple requirements and constraints, and therefore, its feasible implementation requires either approximating assumptions or an optimization method that is capable of handling non-linear relationships and heterogeneous factors. A new optimization method is proposed to address this problem that efficiently and accurately combines essential technical criteria, such as wind speed, water depth, and distance from shore, to identify favorable areas for offshore wind farm development through a user-friendly data-driven tool. Appropriate ranks and weighting factors are carefully selected to obtain realistic results. The proposed methodology is applied in the central Aegean Sea, which has a high offshore wind energy potential. The application of the proposed optimization method reveals large areas suitable for developing floating wind energy structures. The algorithm matches the accuracy of the exhaustive search method. It, therefore, produces the optimum outcome, however, at a lower computational expense demonstrating the proposed method’s potential for larger spatial-scale analysis and use as a decision support tool.

**Predicting Coastal Dissolved Inorganic Nitrogen Levels by Applying Data-Driven Modelling: The Case Study of Cyprus (Eastern Mediterranean Sea)**

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**Abstract.** A surfeit of Dissolved Inorganic Nitrogen (DIN), which is defined as the total amount of nitrite, nitrate, and ammonium levels in water, may cause negative effects to the marine environment. For example, elevated levels of DIN may promote surplus production of algae and possible depletion of oxygen in the water column. The DIN in the marine water column is monitored as part of the Water Framework Directive (WFD), the Nitrates Directive and the EU Marine Strategy Framework Directive (MSFD). Data-driven models have been proved to be an excellent management tool for environmental issues related to coastal water quality protection and management. Based on data-drive models, and specifically the Artificial Neural Networks (ANNs), the DIN levels from coastal stations in Cyprus were predicted. To do so, three different ANNs models were created, each of them calculating nitrite, nitrate, and ammonium levels respectively with high accuracy (*r*>0.95). The results derived from these models can be used to identify hot-spot areas with increased DIN levels and to evaluate management scenarios and measures to be implemented in order to maintain the good Environmental Status and quality of the coastal waters.

**Data-driven models’ integration for evaluating coastal eutrophication: a case study for Cyprus.**

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**Abstract:** Eutrophication is a major environmental issue with many negative consequences, such as hypoxia and harmful cyanotoxins production. Monitoring coastal eutrophication is crucial, especially for island countries like the Republic of Cyprus, which are economically dependent on the touristic sector. Additionally, the open-sea aquaculture industry in Cyprus has been exhibiting an increase in the last decades and environmental monitoring to identify possible signs of eutrophication is mandatory according to the legislation. Therefore, in this modelling study, two different types of Artificial Neural Networks (ANNs) are developed based on in-situ data collected from stations located in the coastal waters of Cyprus. Theses ANNs aim to model the eutrophication phenomenon based on two different data-driven modelling procedures. Firstly, the self-organizing map (SOM) ANN examines several water quality parameters (specifically water temperature, salinity, nitrogen species, ortho-phosphates, dissolved oxygen and electrical conductivity) interactions with the Chlorophyll-a parameter. The SOM model enables us to visualize the monitored parameters relationships and to comprehend complex biological mechanisms related to Chlorophyll-a production. A second feed-forward ANN model is also developed for predicting the Chlorophyll-a levels. Based on this ANN model, several scenarios associated to eutrophication-related water quality parameters can be extracted. The combination of these two ANNs models is considered a holistic modelling approximation for the identification of eutrophication scenarios, since it enables not only the prediction of the Chlorophyll-a parameter levels, but also the “capturing” of hidden biological mechanisms associated with algal production.

**Developing Artificial Neural Networks for seasonal modelling of Coastal Dissolved Oxygen in Cyprus.**

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**Abstract:** Coastal hypoxia is a major environmental problem globally. It is defined as the dissolved oxygen (DO) depletion in the water column and is associated with catastrophic consequences for the marine environment and the aquatic organisms. Coastal hypoxia is closely related to the eutrophication phenomenon, which is promoted by anthropogenic activities. Nutrient loadings - especially dissolved inorganic nitrogen (DIN) - from agricultural activities and non-point sources are the main causes of coastal hypoxia. In this modelling study, seasonal models, specifically Artificial Neural Networks (ANNs) were developed to predict the DO levels in Cyprus. The seasonal ANNs were developed based on water quality parameters (chlorophyll-a, DIN, orthophosphate, water temperature, salinity, pH, electrical conductivity and DO), which were monitored during the period 2000-2021 by the Department of Fisheries and Marine Research of Cyprus Republic. Cypriot coastal waters are categorized as good and are characterized by oligotrophic conditions. Nevertheless, some of the monitoring stations have been strategically positioned in sites for monitoring conditions related to possible anthropogenic pressures (e.g., aquaculture units). The created seasonal, ANNs managed to predict with high accuracy (R>0.85) the DO parameter. Specific phenomena/mechanisms related to Cyprus coastal waters (e.g., winter upwelling phenomenon) were successfully “captured” by the ANNs. Therefore, based on the created ANNs several management scenarios regarding the DO levels can be created.

**Economic Feasibility Study for the Expansion of the Cyprus Aquaculture Sector**

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**Abstract:** Global demand for seafood is constantly increasing, driven by population growth and rising per capita consumption. While wild-capture fisheries are facing limitations in meeting this demand, the expansion of aquaculture emerges as the only solution. This paper investigates the potential for increasing the aquaculture production in the Republic of Cyprus by transitioning towards offshore aquaculture farms. The study includes a detailed economic analysis coupled with sensitivity analysis to assess the feasibility of this transition considering various expansion scenarios. The results provide valuable insights into the viability and implications of this process, highlighting economic and operational issues.

**Open Sea Allocated Zones for Aquaculture in Cyprus: Modelling the environmental impact of finfish mariculture and seasonal Eutrophication Index estimation**

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**ABSTRACT**: The Aquaculture Integrated Model (AIM) modelling tool was implemented in south/southwest Cyprus in four Open Sea (OS) Allocated Zones for Aquaculture (AZAs), in parallel operation with the existing nearshore farms, to examine the fate of aquaculture wastes from multiple farms with native Mediterranean marine species (mainly European seabass/gilthead seabream/meagre) and assess their potential impacts on the surrounding ecosystem in terms of good environmental status. The model was validated against available satellite data (Chl-a, sea surface temperature and sea surface height) showing a reasonable skill in reproducing the observed range and horizontal variability. Environmental status was assessed by means of the Eutrophication Index (E.I.), calculated using the simulated outputs from 4 OS farms and combinations of OS cage technologies and structures needed in order to produce 2, 3 or 5 thousand tonnes per year of native Mediterranean marine species. During spring, the E.I. indicated good to moderate environmental conditions even in the vicinity of the fish farms, suggesting that aquaculture wastes are effectively dispersed by currents. A relatively small effect of OS aquaculture was simulated at Governor’s beach, as compared to the effect from existing farms, particularly for the low-production scenario (2kt). During summer, the E.I. indicated “good” conditions in the entire area, as the increased stratification resulted in an overall decrease of dissolved inorganic nutrients and plankton productivity. The impact of open sea aquaculture at Xylofagou and Larnaca sites appears slightly stronger as compared to both Aphrodite’s hills and Governor’s beach areas. This may be probably attributed to the relatively weaker currents and the anti-cyclonic pattern in the more enclosed Larnaca bay. Changes in the food web structure from the input of fish farm wastes were mainly characterized by an increase in dinoflagellates, an indicator for eutrophication, and also nanophytoplankton and microzooplankton. A series of scenario simulations based on fish farms annual production capacity were performed to investigate the ecological carrying capacity of the AZAs and their interaction and demonstrate the utility of the modelling system, as a management tool for AZA spatial planning and licensing of fish farms.

**Powering Aquaculture Operations at Sea: Can hydrogen be a sustainable solution?**

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**Abstract**: Marine aquaculture has shown strong growth in recent years and is considered one of the fastest growing industries worldwide. Although coastal aquaculture industry is the most predominant form of aquaculture it has caused several conflicts among stakeholders due to the limited availability of near-coast areas combined with relevant environmental issues. The latter combined with the need of increased seafood production has led to a growing trend for the industry to move further away from coast. Sustainable and competitive offshore economic activity though, faces many challenges. A critical one is related to energy requirements and how to provide this vital element uninterruptedly far from coast. This paper aims to give a brief overview of the energy requirements of an offshore aquaculture farm, review current energy supply solutions, and explore a potentially new solution with the use of hydrogen as the main fuel.