OS Aqua

Open Sea Aquaculture in the Eastern Mediterranean

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Executive Summary

Open Sea Aquaculture (OS - Aqua) is a multidisciplinary project that aims at creating decision support tools for marine spatial planning and a roadmap for open sea aquaculture. This document represents deliverable D20 "Specify biological, technological, and managerial challenges for the monitoring of off-shore aquaculture". Information was gathered from a literature review and stakeholders such as local aquaculture producers and technology providers. It outlines all the monitoring challenges in the aquaculture industry and the arising challenges from moving into areas with more depth than the current aquaculture farms.

Key biological, or, in more general terms, environmental challenges include monitoring factors that affect the natural environment, such as microplastics. To establish an effective environmental monitoring system varying tools and technologies must be used. *In situ* measurements can monitor the whole water column and provide valuable information. However, they are costly and not efficient for handling the monitoring of aquaculture and the nearby area. Satellite information has large spatial and temporal coverage but cannot monitor sufficiently the entire water column. Various numerical models can provide a full image of the water column and indicate the environmental impacts of aquaculture, but they need accurate initial information.

Managerial challenges for monitoring include all operational tasks that an aquaculture farm must carry out to remain functional. The essential functions include feeding, including tracking for excess feeding and monitoring fish well-being and mortality to limit disease spread. Net cleaning monitoring for infrastructure security is also crucial for aquacultures.

Technological challenges include communication technologies such as 5G, decision-making algorithms, underwater communications, and vessels able to carry out monitoring and operational task with no excess cost.

The location selection imposes additional challenges. Those challenges are related to environmental conditions which impose more technological and managerial challenges, such as higher feed consumption and limited cage technologies. Additionally, locations near touristic locations can face managerial and environmental monitoring challenges in order to avoid conflicts. Connectivity challenges related to the distance between the shore and offshore facilities can impose challenges that can be tackled with the use of appropriate communication technologies and protocols.

Challenges that have been identified in this deliverable will be assessed at a later stage of the project. Specifically, the information gathered in this deliverable will be used for deliverable D21 "Provide best practice guidelines for environmental monitoring of off-shore aquaculture". The current report will guide D21 in implementing best practices guidelines that will tackle or avoid these challenges. The overall aim is to tackle or avoid the challenges without reducing the overall quality of the environmental monitoring strategy.

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1 Introduction

1.1 Background

Open Sea Aquaculture (OS - Aqua) is a multidisciplinary project that aims at creating decision support tools for marine spatial planning and a roadmap for open sea aquaculture. The project aims to bring together academics, local entrepreneurs, public authorities, and technology providers to tackle the drawbacks and the lack of initiatives in open sea aquaculture in Cyprus and the Eastern Mediterranean. This will be achieved by suggesting optimal technological solutions and creating solid cooperation networks for off-shore aquaculture development. By bringing stakeholders together, it will pool resources, best practices, and technology transfer. The capacity building for supporting the development off-shore aquaculture will result in the growth of the aquaculture sector and generate more work positions.

The environmental sustainability of EU aquaculture depends on the assessment, limitations, and monitoring of aquaculture impact on the environment (https://ec.europa.eu/). Those combined with tighter European restrictions, high-quality standards, and production costs challenge open sea aquaculture. A practical solution to decreasing the costs is the continuous monitoring of open sea aquaculture. Continuous monitoring is beneficial for the financial aspect of open sea aquaculture and for improving the quality of the product. Therefore, keeping high environmental standards may have a short-term negative impact on the producer, but in the long term, there is a positive impact on sustainability.

Aquaculture farms affect the environment by releasing dissolved nutrients (organic and inorganic compounds of P and N), particulate material (fish feces, fish feed), and chemotherapeutics and antifouling chemicals. Although the environmental effects of aquaculture are relatively well understood, there are different approaches for monitoring aquaculture impact on the marine environment. For effective monitoring of off-shore aquaculture in Cyprus, studies must take into account the unique ecological characteristics of the eastern Mediterranean. It is important to identify how this idiosyncratic combination of characteristics, which make them very different from north European conditions and other regional seas, influence the environmental interactions of aquaculture in the Mediterranean marine ecosystems: Such characteristics are the low trophic potential and phosphorus limited primary production, seasonal temperature variations that affect the production of farmed fish, and high biodiversity with a large number of endemic species. Further, the coastal morphology of Cyprus is very variable, seagrass meadows extend in deeper waters, and there is a high volume of marine traffic.

In addition to the environmental impact, operational activities need to be carefully planned. These activities might lead to unwanted effects that can be prevented through a well-structured monitoring strategy—for example, limiting excess feed pellets will help to minimize the impact of excess nutrient leaks to the environment and the formation of harmful algae.

This report is part of Work Package 6 "Ongoing monitoring of Offshore Mariculture stations" of the project. This Work Package aims to design best practices for a cost-efficient ongoing monitoring system to secure excellent environmental status and managerial activities. This system will balance the cost increase by moving further off-shore by automating the key monitoring and managerial requirements.

1.2 Purpose and Scope

The project's main objective is the mitigation of aquaculture farms further off-shore, which could pose challenges using the same practices as in coastal aquaculture. This deliverable aims to compile all available information received from the stakeholders and lay down all the existing and emerging monitoring challenges of the current aquaculture industry. In addition, to map all the arising challenges from moving aquaculture farms further deep.

It furthermore outlines the specific challenges that may arise at different selected locations with different technologies used on various tonnage scenarios. Identifying the main challenges of monitoring an aquaculture station will act as a beacon at the design and implementation phase of deliverable D21.

The assessment of the challenges is beyond the scope of this report. Those challenges will be assessed at a later stage in the framework of D21.

1.3 Approach

Partners have approached this deliverable from two viewpoints to specify the current challenges of open sea aquaculture. The first direction involved collecting stakeholders' opinions and current solutions. Those meetings took place to collect information for various tasks of the project. The detailed information received are well documented in the Deliverable 6 “Stakeholder minutes”. From those minutes valuable information was collected for the current challenges of aquaculture monitoring. In addition, the consortium met with technology providers. Those stakeholders gave insights about current commercial solutions for different operations and monitoring. This direction aims to understand the current market solutions and what producers are currently using, as well as any issues arising. The second direction is a literature review.

Furthermore, the identified challenges are downscaled to a local scale. For each of the four selected locations the general managerial, environmental, and technological challenges are addressed based on the geographical location of each site.

This deliverable aims to identify current and emerging managerial, environmental, and technological challenges of open sea aquaculture and highlight them. The findings of this study will be used for the D21 "Provide best practice guidelines for environmental monitoring of off-shore aquaculture," which is due in month 32.

2 Monitoring Challenges

Monitoring an off-shore farming unit poses many more challenges than monitoring a coastal farm. The cost of daily monitoring increases exponentially with increased distance from the shore. Therefore, remote monitoring systems need to be used to collect data remotely and provide possibly real-time monitoring. Such systems include buoys that can be used for long-term monitoring at a fixed location in the off-shore farm unit. There can also be online monitoring through sensor deployment and the use of underwater robots to monitor cages and nets [1]. This section describes the main challenges in environmental, managerial, and technological monitoring.

2.1 Environmental Challenges

Compared to coastal sites, off-shore sites are characterized by greater depths and greater exposure to the natural environment. Therefore, the pressure on the environment at off-shore sites is expected to be of less intensity compared to coastal sites. This is due to the fewer interactions with other species and a larger dispersal of waste products [2] which is a major benefit for open sea aquaculture. One challenge related to off-shore farming in general, and in the area of Cyprus specifically, is the lack of background information on environmental conditions in off-shore waters, with an important setback being the high cost of organising oceanographic surveys. Off-shore waters in the Levantine have very low nutrient concentrations [3,4]. Therefore, the risk of phytoplankton blooms due to eutrophication from farming is reduced. However, when nutrients are limited, there is a risk that the nitrogen released from the fish farms will stimulate primary production [5]. In the case of the oligotrophic eastern Mediterranean, studies have shown that chlorophyll-a remains at very low levels near farm units, and grazing transfers nutrients up the food web, thus regulating phytoplankton biomass [6].

Several environmental issues have been identified in coastal and off-shore farming, in the past 20 years, with the following issues presented in a review by Holmer *et al.* [2].

Visual impact: One of the main reasons to move aquacultures off-shore in the Mediterranean is the visual impact they have on the tourist industry [7], which is much lower when the farms are moved off-shore and away from the coast.

Benthic habitats impact: Another major concern in aquaculture is the impact they have on benthic habitats, where the accumulation of organic matter in the sediment results in loss of biodiversity [8]. Even though off-shore farms are in deeper and more exposed waters, it has been found that benthic impacts can be of importance, even though less severe than in coastal farms, mostly due to the rapid sinking rates of faecal and feed pellets [9,10].

Interactions with wild populations: An impact of coastal fish farms is that they act as fish aggregation devices [11,12], as well as attract predatory mammals. This impact has been recognized in coastal farms, and it is expected to be of importance at off-shore farms as well, where larger predators, such as sharks, could cause damage to the nets. This could lead to the release of farmed fish in the wild, with implications in the natural populations that span from competition for resources [13] to transmission of disease [14]. However, moving farms off-shore could reduce the impact of escapee invasive species on the environment since the suitable habitats for their establishment are less compared to coastal areas [2].

Impact of chemicals: The use of antifoulants and antibiotics in coastal farms results in their accumulation in the sediments [15] and the development of bacterial resistance in wild populations [14]. The impact of the above on off-shore farms is expected to be lower, mostly due to better water quality and increased dispersal [2]. An issue that remains, however, is the sensitivity of benthic habitats in off-shore waters and the extent to which they could be impacted [2].

Carbon footprint: The increased energy used to transport feed and materials at off-shore farms will increase the carbon footprint. However, there are ways to compensate for this by using renewable energy sources [2].

Water quality: The environmental pressure on the environment from nutrients is expected to be much less at off-shore farms due to dispersal from the exposed conditions [2]. 2

All the above demonstrate that, from an environmental perspective, off-shore farms have more benefits compared to coastal ones. However, the lack of scientific background data on off-shore hydrographic conditions, benthic communities, and wild fauna populations means that the development of off-shore mariculture has to proceed with caution until such data is made available [2].2

The current monitoring plan of Cyprus for aquaculture units is limited to studying the localized impact of aquaculture on the environment. Currently, the monitoring surveys are limited to up to 500 meters away from the aquaculture to study the impact of nearby aquaculture cages upon the nutrients, sediment, and macrofauna. The sampling surveys take place twice a year. For the traditional aquacultures, the forecasted faeces and feed displacement are limited from the shallow depth. Therefore, such surveys fulfill the objectives set at shallow areas.

For the off-shore aquaculture sites, the monitoring area must change to cover a greater area. For example, using relevant equations [16] at a depth of 200 meters with a sinking velocity of 0.48 cm/s and current speed of 10 cm/s, according to mean current values in deliverable D11, the displacement of waste and food pellets may take up to 4.17 km to reach the seabed, if the depth remains at the same level. While the longer floating time and traveling distance might help the nutrients to be absorbed. Monitoring a radius of 4.17 km away from the farm is not an easy or cost-efficient task. Monitoring the impact on a wider area is a key challenge.

The aquaculture unit capacity scenarios that are being used from the project partners are 2000 tonnes, 3000 tonnes, and 5000 tonnes. These capacities are additional of the current allowance of 8000 tonnes. Hence the total allowance may be 13 000 tonnes. The larger capacity scenario means that a greater volume of nutrients and facets will originate from a concentrated area. Increasing overall capacity and moving further off-shore creates the need to alter current monitoring plans. Among the actions that must be taken is to monitor the currents since they may differ compared to the nearshore currents, and this may impact the distribution of the nutrients.

To achieve sustainable and effective monitoring, a suitable monitoring plan must be implemented. The key objectives of the monitoring plan are to be effective both in terms of monitoring and in terms of cost. This monitoring plan must consist of *in situ* monitoring, numerical prediction models, and satellite observations. These three components for monitoring are required to understand the impacts of off-shore aquacultures. The *in situ* measurements will monitor the quality parameters and take sediment samples in key locations that cannot be monitored otherwise. Satellite observations will monitor the wider area of interest and provide a greater spatiotemporal dataset regarding surface indicators. Finally, a suitable hydrodynamic and biochemical model will be assimilating the observations to assess the impact on a 3D scale.

Each of these monitoring practices may face challenges for fulfilling its tasks. *In situ* monitoring is challenging and costly if a vessel is required. From WP5 it was realized that for sampling depths greater than 100 meters, larger vessels are required. Those vessels have high operational costs and cannot be used frequently. On the other hand, moored buoys or autonomous robots might be used with lower operational costs. Those monitoring systems face other technological challenges that will be discussed further in the following session. Satellite observations are near-real-time monitoring tools that can monitor a wider area with less cost. The challenge of remote sensing is the fact that it can only monitor the surface and cannot penetrate within the water column to give a complete image. The use of remote sensing for detecting harmful algae is not new. Several studies have already developed such processing algorithms. The use of such standardized algorithms to produce products such as early warning systems may not be suitable for the region of the ultraoligotrophic Eastern Mediterranean. This is a challenge to identify the most suitable algorithms and use them for the benefit of the monitoring system.

Using numerical models can provide credible spatiotemporal scenarios for the environmental impact of aquaculture. Numerical modeling cannot substitute *in situ* observations but is a powerful tool that allows us to enhance our understanding of the behavior of the variables that are under investigation. In this case, numerical modelling can guide us towards any preliminary impacts of the proposed aquaculture stations on the nearby environment or to any other side which is further away. The challenge with numerical modeling is the accurate replication of the physical environment for which accurate initial and boundary conditions are required. Those conditions include physical variables such as current speed and direction, bathymetry, temperature, salinity, wind speed, and direction, wave height and direction among others. In addition, biochemical variables are required that are crucial for estimating impacts. Having this information is a key challenge for the region of Cyprus. For example, bathymetric maps up to 50 m depth are quite accurate for the region. However, maps for greater depths are less accurate. The very scarce *in situ* measurements and estimations for nutrient input in the environment is challenging aspect. In order to use the model results, an evaluation of the model must be done. As mentioned earlier the *in situ* data for those areas is not available and the cost for obtaining such measurements is very high.

The emergence of microplastic pollution is a potential challenge to the environmental monitoring of an aquaculture station. The identified sources of microplastics in the marine environment mainly originate from land-based sources. Those sources include land transportation, marine transportation, fishing vessels and equipment, aquaculture and atmospheric deposition [17]. So far, the environmental monitoring strategies of aquacultures are focused on the impact that the unit has upon the environment. The progressive need of monitoring the impact that the environment has upon aquaculture is a challenge. The challenge is to establish a relationship between the concentration of microplastics in the environment and the expected concentration within the fish. This index must be derived from empirical relationships of observed microplastic observations and examination of aquaculture species. This monitoring is not yet mandatory. However, being able to monitor the microplastic inflow into aquaculture will substantially increase the quality standards. Based on this monitoring and future technological advance, this may be used for limiting the microplastic contamination and hence increase the quality of the final product.

2.2 Managerial Challenges

Among the most challenging issues of moving aquacultures, off-shore is the managerial operations. Due to the current frequency of those operations, the cost of moving further off-shore significantly increases. This section will introduce the main managerial activities that must be closely monitored and explain the challenges of achieving that.

Feeding: Feeding represents 20 to 50% of the operational cost with a limited source of sustainable raw materials. Feed waste is not yet well-monitored, even in traditional aquaculture. The lack of datasets from current aquacultures regarding the farming environment is complicating the issue. Excess feed waste can lead to eutrophication which leads to bad water quality and degrades the aquatic environment in the surrounding area [1]. In addition, not suitable feed can lead to unhealthy fish growth and loss of income. The lack of smart feeding systems is a great challenge in the sector. Upcoming feeding systems are driven by environmental indicators. Tackling the challenge requires increasing feeding efficiency and the provision of advanced management control for the different fish kinds and farming environments. This can be achieved by incorporating IoT and machine learning into the monitoring system. Collecting information regarding the fish, the environment, and various parameters that influence the diet of the fish will allow analyzing it and optimizing the feeding strategy in an aquaculture station [18].

Fish health: Diseases caused by different pathogens is a major issue for the aquaculture industry, which is causing great losses in fish stock. Hence, an effective way to monitor, detect, and control the different diseases can lead to an increase in profit by limiting the losses and increasing the quality of the product [19]. Emerging fish diseases are among the crucial challenges reported in the FAO latest report of aquaculture statues. Monitoring fish health and the prevention of disease spread in the farm and the wide population is among the most critical challenges of the sector. A lot of environmental organizations object to the development of open-sea aquaculture based on this issue [20].

Net cleaning: This is a major challenge in the industry. The importance of net cleaning is related to the weight an aquaculture cage can withstand. Cleaning is the mechanical process that removes the attachments on the nets. This process eliminates further excessive deposits and marine life attached to the nets, which can lead to the increase of net weight, threatening the balance of the farm and the net buoyancy of the structure [21]. This process in traditional aquacultures is mostly monitored with a diver or an ROV. This process must be automated for remote monitoring and cleaning.

Fish harvesting: Harvesting off-shore is the ultimate task. All processes mentioned above cannot overcome the importance of the fish harvest. An automatic fish harvesting is a must for open sea aquaculture. The traditional fishing methods by artificial nets are not efficient and harm production. The challenge is to identify the best technological equipment that will lead to efficient fish harvesting without causing any issues to the remaining fish population in the cage. Automatic harvesting technologies exist and vary among the characteristics of individual fish farms.

- Centrifugal suction pump: This is a high-performance pump that can suck up to 200 tonnes per hour. It was produced by a US company. It is characterized by high work efficiency, high body injury rate and is mainly used for small fish [22].
- Vacuum suction pump: This is a pump that is automated to a high degree. It does not cause damage to the body of the fish but it has low efficiency. It is produced by Environmental Technologies Inc (ETI). Its maximum suction is between 200 to 260 tonnes per hour. Energy requirements are between 23 to 190 kWh [23].
- Jet suction pump: is a high-efficiency pump that can easily harm the fish's body. It is mainly used for dead fish. It is produced by ETI and it consumes energy of 190 kWh. It can harvest 300 to 360 tonnes per hour [23].

Energy Management: It has a key role in the sustainability of open sea aquaculture. Being further away from cost the supply of energy can be a challenging issue. All above mentioned systems for monitoring and aquaculture control are using energy. For a farm to perform 24/7, it needs to secure sufficient energy for the system. The usage of renewable energies and storage seems to be the most suitable solution. This brings together another challenge of storing the energy to be available at the time required.

The idiomatic topography in the easter Mediterranean is causing further issues since the depth is higher than in other regions. Floating mechanisms can be used. Incorporation between blue energies and the food industry can be challenging.

2.3 Technological Challenges

New technologies are expected to have a great impact on the capabilities of aquaculture systems. Challenges in the state-of-the-art include data interpretation, which can assist producers in identifying feeding patterns and in designing effective operational procedures. Data collection for monitoring aquaculture is not sufficient if the data is not interpreted correctly or on time. Despite the emerging technologies for better monitoring of the environment and managerial operation of aquaculture, there is a lack functional decision support systems. The research is focused on developing algorithms that incorporate decision support systems to tackle this challenge. For example, Liu *et al.* [24] created a combination of buoy and ROV to monitor and operate a fish farm remotely without the need for human presence. The operations covered include automatic classification approach for fish, dead fish removal and maintenance of installed equipment. Another monitoring system submitted by Hu *et al.* [25] is focused on improving the accuracy in decision making. Many AI methods also focus on operational issues, such as [26], who proposed a new algorithm for the fish count, able to distinguish between different fish sizes. Another similar algorithm has been produced by [27], who is detecting fish fry by using image processing techniques. A complete monitoring system for open sea cage culture was integrated by [28], to observe the fish behaviour and growth patterns and to operate the farm activities remotely. Such systems may incorporate ML for pattern identification, biological model forecast, and early warning system that is derived from observations.
The harsh environmental conditions and lack of communication can also impact the system. Operating remotely is an additional challenge due to the need of sensor clean up and calibration due to their continuous exposure. Another technological challenge in the incorporation of ML is the need to transfer of a large amount of data. In the off-shore environment, continuous communication is not guaranteed. In addition, the lack of sophisticated communication technologies for transmitting real-time data is a challenge. The development of 5G networks might be a solution to the communication and the usage of IoT for aquaculture [18].
Creating a network of sensors in an exposed environment is a challenging task. This network must be operative above and below the ocean surface and be able to withstand the rough weather conditions. As a result, the continuous communications between the datalogger/data transmitters and the sensor is a challenge. In addition, sensors must not be dependent on water depths, and for this reason, an underwater communication network must also be present. Having length cables around the aquaculture is not the best option, while wireless systems are more expensive.

Another technological challenge that is directly related to environmental and managerial monitoring is the existence of a suitable vessel. As mentioned above, for monitoring depths greater than 100 m a large vessel is required. In addition, to perform managerial tasks, a suitable vessel is required to transfer big amounts of feed to a possible storage unit that must be spacious to perform any maintenance required for the operation of the aquaculture or the monitoring procedures [18].

3 Current methods and technologies

Stakeholders have provided information on currently used monitoring systems and technologies. The local aquaculture producers mentioned that currently, they are using remote systems for fish welfare and fish sampling using imaging systems also used for the establishment of a link between feeding and nutrient intake with the daily growth rates of the fish. An ROV is used experimentally to inspect infrastructure at greater depths with a human presence on site.

Monitoring and automating the feeding operation as investing in efficient feeding, off-shore storage, and feed loss decreases operational costs and feed transport costs. Local aquaculture producers continuously upgrade their feeding equipment. A net inspection monitoring technique is also used for the reduction of cost.

Technology providers are informed about their products and current advances in monitoring systems that can be currently operational. InnovaSea can offer a variety of operational and environmental monitoring solutions. Their cages are equipped with sensors and automation systems. These include automatic feed dispersion, water quality sensors, cameras, and hydrophones. Information from sensors at the site is transmitted to the base, usually through systems like LoRa, but this will depend on system setup and distance from shore. Some examples include feeding automation through water delivery, which is an efficient feeding method. A system that is removing dead fish has also been created, and it separates dead fish into a mortality trap. Finally, the company provides a vessel that is included in the station price. The price of the vessel is the biggest proportion of the initial capital expenses needed for the farm operation. The vessel is suitable to carry any activities that are required for the operation of an aquaculture farm. Another technology-providing company, Giliocean-subflex, provides automation and monitoring solutions to the sector. They use smart sensors and cloud technologies for better monitoring. They have the technology for monitoring the fish size, oxygen, and temperature, and they monitor the feed process, which is broadcast live. They have products such as the GO Smart Mortality Counter. This is a system for counting and separating dead fish which are collected by divers.

The system feature for a mortality collector with automated information transmitted to the farmer was discontinued. The company offers the GO Smart Bio Cam, which is a biomass estimation camera that can accurately estimate the fish weight and the distribution of the cage population. It fusions visual data with oxygen and temperature sensors supports the daily feeding calculation. For better monitoring, the company has produced GO Smart Software Integration with a user-friendly web application. The application collects real-time data from biomass cameras, feeding cameras, mortality counters, and other sensors that are made available to the producer. Although there is a variety of automation technology, providers mentioned that most companies visit the site daily for surveillance and do not entirely rely on monitoring systems.

Figure 3.2: GO Smart® BioCam (https://www.giliocean.com/copy-of-subflex)

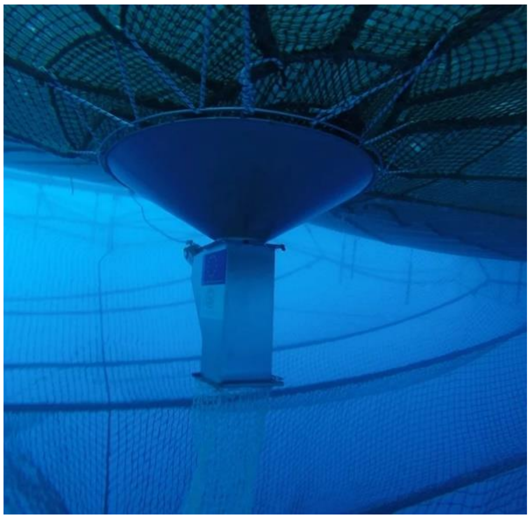

Figure 3.1: GO Smart® Software Integration (https://www.giliocean.com/copy-of-subflex)

Figure 3.3: GO Smart® Mortality Counter (https://www.giliocean.com/copy-of-subflex)

4 Challenges for selected locations

4.1 Selected locations and physical properties

In D13 "Identification of AZAs and AMAs and estimation of their carrying capacity", an extensive analysis of the selection process is lay out. In this session those areas are only presented. Among them key physical properties are presented which are crucial for specifying the challenges of each location. In figure 4.1 the selected locations are displayed and table 4.1 indicates the mean and maximum wind speed and wave height for each site.

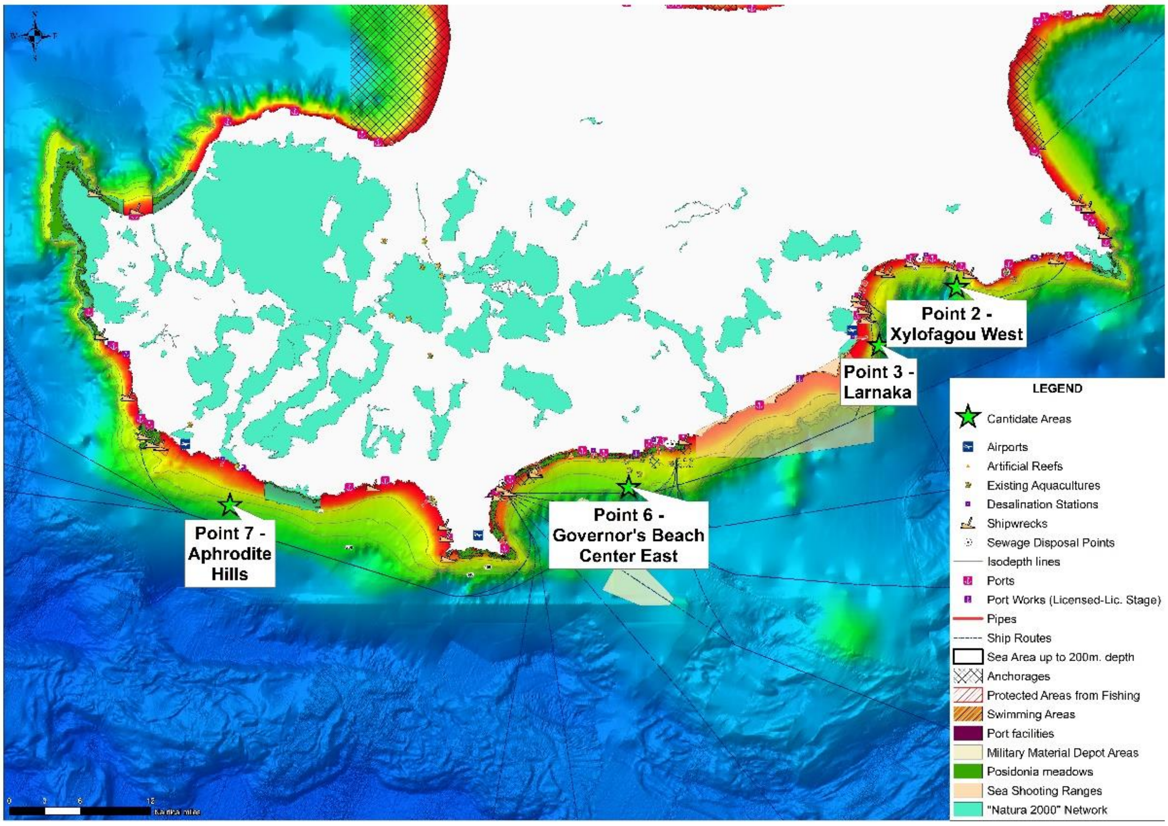

Figure 4.1 The 4 selected Open Sea Allocated Zones for Aquaculture (4 areas) (source D13, Geomatic).

		Mean SWH (m)	Max SWH (m)	Mean Wind (m/s)	Max Wind (m/s)
POINT 2	Annual	0.48	5.05	3.85	21.30
	Autumn	0.35	3.48	3.27	15.87
	Spring	0.47	3.03	3.70	14.82
	Summer	0.50	2.00	3.87	12.74
	Winter	0.61	5.05	4.58	21.30
POINT 3	Annual	0.41	4.75	3.79	20.23
	Autumn	0.30	2.77	3.23	15.07

	Spring	0.41	2.55	3.67	13.67
	Summer	0.43	1.61	3.90	11.91
	Winter	0.52	4.75	4.37	20.23
POINT 6	Annual	0.49	5.16	4.44	19.51
	Autumn	0.37	2.89	3.76	16.09
	Spring	0.49	2.98	4.37	15.60
	Summer	0.49	1.59	4.75	12.63
	Winter	0.63	5.16	4.88	19.51
POINT 7	Annual	0.75	6.66	4.93	21.60
	Autumn	0.61	5.09	4.32	17.58
	Spring	0.73	4.45	5.00	15.63
	Summer	0.73	3.23	5.39	11.55
	Winter	0.92	6.66	5.00	21.60

Table 4-1: Mean and maximum wind speed and wave height for selected locations

4.2 Environmental Challenges

In addition to the monitoring challenges identified in the previous session each point has its uniqueness and hence must be examine separately in order to identify any hidden challenges.

Point 2 (Xylofagou West) was selected due to its favourable oceanographic and weather conditions. Previous current and water circulation analysis, shown in D13 & D11, demonstrated that wave and current exposure is moderate [29], thus, it can be assumed that water refreshment would minimise the risk of eutrophication and phytoplankton blooms. However, the lack of detailed oceanographic studies in the greater area of Cyprus for depths exceeding 10.5m, presents a significant environmental challenge in accurately assessing the possible environmental impacts and the length of possible damage aquacultures and nutrient release would cause in the area. Point 3 (Larnaka) was another selected location, mainly due to the satisfactory level of its environmental and technical (proximity to disposal pipes and port infrastructure areas) criteria. Point 3 is located approximately 2-3km southwest of a desalination pipeline, monitoring the water quality of the area followed the construction of aquacultures is of major importance. Moving on, Point 6 (Governor's Beach) was also considered very satisfactory based on the environmental and technical criteria assessment. Point 6 is located near-by numerous existing nearshore farms, raising concerns regarding the water quality and the environmental impacts that multiple aquacultures might have on the proposed OS aquaculture and its surrounding environment. However, due to the all year round strong south-eastern current in the area and the significant distance of the proposed OS aquaculture, environmental impacts will be minimum, providing the best possible conditions for the fish regarding animal welfare. Point 7 (Aphrodite Hills) presents the last selected location that was chosen for research purposes as outlined in D13.

Regarding other important environmental issues highlighted by Holmer et al., [2] such as visual and aesthetic concerns with aquacultures, all the selected locations are located at least 5km offshore at depths ranging from 50 to 200 meters depth, satisficing the visual criterion. An additional environmental challenge, is the accumulation of organic matter in the sediment, resulting in the loss of benthic biodiversity [8]. Sedimentation analysis from fish farms in the Mediterranean [9,10] demonstrated that dispersion of particle waste products under the net cages occurred at a rate of 8-25 times faster in comparison to control sites that were located 1km away. It's important to note here, that fish farms in the presented studies were located at much shallower depths (16-28m) in comparison to chosen locations for the OS-Aqua project, significantly affecting sedimentation rate. However, water exchange, ambient seston and general hydrodynamic characteristics at the reference locations [9,10] additionally affected sedimentation and dispersal rates. Such a detailed analysis lucks for the greater area of Cyprus, presenting another challenge in understanding the possible impacts on benthic communities in close proximity to the nets. Given the mentioned environmental challenges that can be faced upon the construction of aquacultures for the OS-Aqua project, and the lack of background scientific data for off-shore locations at depths up to 200m, off-shore mariculture should proceed with caution until further field data would be made available.

4.3 Managerial Challenges

This session will assess the managerial challenges that may arise using different cage technologies, the capacity scenarios, uniqueness of selected location.

Managerial challenges on local level arise for various reasons defined by aspects like environment/topography, available onshore facilities and uses of the area. Beginning with point 7 which is characterized by high wave and current intensity. This will cause excess feed loss and generates additional challenges such as having enough feed supply on site. The feed loss challenge can be reduced using optimal feeding procedures or by feeding at periods of time were the current speed and wave height are at the lowest value. For this suitable decision support systems can be used to minimize the impact. An indicative approach of those systems is given by Cooney et al. [30]. Those systems are taking into consideration multi criteria including environment to assist the producer.

In addition, such environments can cause equipment loss that can impose additional challenges. This can be limited by selecting suitable sensors and appropriate mooring techniques.

Furthermore Point 7 does not have suitable port for aquaculture operations nearby. This is quite challenging since it will require higher vessel time. Not being able to reduce the vessel time the producer much increase its production cost. This challenge can be mitigated by either reducing the travel times or by modifying the nearby ports, which implies an additional cost from the producer.

Tourism is a local factor that can also cause managerial challenges. Point 3 is characterized by its proximity to tourism areas. This proximity requires additional precautious measures in order to avoid any conflicts with the tourism sector. The point is located nearby the newly built Ayia Napa marina. The conflicts that are mostly impacting the tourism sector is rather aesthetic, like visual impact. This proximity issues additional managerial challenges in order to avoid those conflicts. For instance, if over feeding is taking place on the site it might cause unpleasant visual impacts to the nearby areas. Those visual impacts are not necessarily harmful for the environment by it can cause conflicts with the tourism sector. Those challenges can be avoid by using decision support tools and having a good monitoring strategy.

Managerial challenges differ according with the scenarios of capacity and technologies used. According to D13 different technologies have different capacity in fish. This requires different number of cages and hence greater effort for feeding and monitoring. This increases the managerial effort in order to maintain the facilities. This effort can either minimised using best practises, selecting technologies that require less coverage area or to be transformed into additional cost.

4.4 Technological Challenges

The hydrodynamical characteristics of the selected locations can impose technological issues also. As mentioned earlier point 7 is characterized as high energy environment. In such environment not all the identified cage technologies can be placed. In fact the only cage technology that is suitable is the one proposed from Badinotti. For the rest regions all technologies can be used. The limitation to a single cage technology can impose other managerial issues.

Another challenge is the distance between onshore facilities and the aquaculture farm. As mentioned earlier, the key component of a sustainable offshore aquaculture are the automatizations. Automatizations rely on monitoring equipment that must transmit the data to the onshore stations. The onshore stations process the data received and send information to the offshore facilities for their next moves. Additionally, sensing and communications rely on the energy supply. Therefore, if connectivity and energy supply are scarce the operation of the aquaculture will be affected. The suitable method for communication for the distances from the shore considered in this project is satellite which is associated with a significantly higher cost compared to mobile communications. However, with the increase of satellite communication options and investment in satellite technology the communication cost is expected to increase. Mobile or LoRa communications have a higher range and could only be used through relays offered by drones. WiFi offers a fast and reliable communication, however, it is expected to reach less than 10 Km and when using a directional high power antenna. Moreover, supplying power to sensing systems can be covered using renewable energy sources such as photovoltaics and battery-based energy storage. Heavy equipment such as cranes will need, at present, to utilize fossil fuels.

5 Conclusions

Monitoring aquaculture is a legal obligation and an essential aspect of proper operation and efficiency. Keeping high-quality standards on environmental protection increases the value of the final product. The impacts of aquaculture on the environment are relatively well understood. The impacts include the inflow of pharmaceutical/antibiotics in the water column, chemicals, and carbon footprint, alteration of benthic habitats, and interactions of cultivated fish with wild populations. Similar impacts are expected in the open sea aquaculture, however, to a lesser extent due to increased circulation. The estimated distribution of fish waste is expected to be up to 4.15 km away from the fish farms. However, the concentration of the waste is decreased by distance. It is also necessary to include microplastic monitoring into the monitoring plan. A new monitoring plan must be adapted for the better evaluation of local and wider impacts to achieve effective environmental monitoring. The key components that will contribute to the effectiveness and cost-efficiency of a new monitoring plan are monitoring systems that include *in situ* observations, remote sensing observations, and model outcomes. The first two components can improve the model outcomes and produce a complete view of the aquaculture's impact on the environment.

Aquaculture managerial challenges include daily operations management. The monitoring of those automated operations is a key challenge for the cost-efficient operation of off-shore aquaculture. Among them is feeding monitoring, which is an expensive operation. Excess feeding can cause serious environmental issues such as eutrophication. Therefore, to be able to monitor the amount of excess feed is a key challenge and a prevention measure for limiting environmental impact. Among the most cited challenges in the literature are fish health and disease control. Monitoring fish health will limit the disease transportation between the fish population and avoid the transmission into the wild population. Monitoring net cleaning is a challenge in off-shore installations. Since most of the operations must be remote, monitoring such operations must be efficient.

Technological challenges for monitoring are crucial for fulfilling the task. Initially, a suitable vessel able to carry daily operations and monitoring surveys is required. Sampling depths over 200 meters is a challenging task for a small vessel. The need for large data transmission onshore relies on effective communication technologies. Such technology is 5G which is currently under deployment. Improvement of decision support systems and processing algorithms is beneficial for monitoring purposes. Improving such algorithms will assist in the better accuracy of observations.

For most of the challenges described market has already solutions that can be used. Those solutions must be adapted accordingly for each location proposed by the project. This adaptation will optimize the performance of those tools and it may also reduce the operational costs.

The information in this deliverable will be used for deliverable D21 "Provide best practice guidelines for environmental monitoring of off-shore aquaculture". This report will guide D21 through the challenges for implementing guidelines that can tackle or avoid these issues without reducing the overall quality of the monitoring strategy. D21 will address the challenges identified by D20 and will provide the best practises and guidelines in order to avoid or tackle the identified issues.

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