OS Aqua

Open Sea Aquaculture in the Eastern Mediterranean

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Executive Summary

D11 reflects the progress of T3.2 “Oceanographic modelling” using data from D10, D13 and D18. Four (4) open sea areas (OSA’s) have been selected as potential OS AZAs for the modelling work at Xylofagou, Larnaca, and Governor’s Beach South of Cyprus and Aphrodite Hills in southwest Cyprus. These areas have no conflicts with other anthropogenic activities (with the exception of fisheries), they are situated in depths up to 200 m and they are relatively close to existing port facilities. The prevailing waves in the selected areas have been calculated from WAM model domain that covers the eastern part of the Mediterranean Sea with very high spatial resolution using significant height classes of 0-0.5, 0.5- 1, 1-2, 2-3, 3-4 and 4-5 meters. Also, the prevailing currents in the four selected areas were estimated for the depths of 5.5 m, 7.9 m, 10.5 m, 13.3 m, and 16.3m using the dataset of Copernicus from 01/01/2000 to 31/12/2019 and 3-hourly time steps.

Four technologies considered for deployment in the selected areas included (1) the OCEANIS 1 submersible cages of Badinotti Group, (2) the Innova Sea submersible cages, (3) the new open sea aquaculture station concept developed through OS Aqua that uses a single point mooring system and (4) the conventional floating HDPE open sea cage technology for comparison purposes. Three production levels were considered for 2,000, 3,000, and 5,000 tonnes per year, and they were studied to estimate the number of needed cages or structures (in the case of the Cypriot OS Aqua catamaran-like design). GIS tools were applied to estimate the coordinates of the parks and incompatible deployment patterns that could create technical challenges for the installation of the OS Aqua units identified. Potential alternative deployments are suggested.

The HCMR’s AIM model was applied following mass balance calculations in the four selected areas and considering satellite mean monthly sea-surface temperatures data for the period (2015-2018). Three nested sub-models were used to estimate the impact of aquaculture wastes on the Cypriot marine ecosystem, in terms of good environmental status, using the model simulated outputs, by means of a Eutrophication Index (with PO_4, NO_3, NO_2, NH_4 in mmol/m^3 and Chl-a in mg/m^3) and the environmental scaling of <0.04 for very good, 0.04 - 0.38 as good, 0.38 - 0.85 for moderate, 0.85 - 1.51 for poor and > 1.51 for bad. Please see D10 (Development of an environmental assessment model for ecosystem and oceanographic modelling for site selection) for details.

The preliminary model runs revealed that the operation of Open Sea farms with 2,000, 3,000 and 5,000 tonnes per year will not affect the Eutrophication Index in Aphrodite’s Hills and Governor’s Beach areas as they are good to moderate even in the vicinity of the fish farms, suggesting that aquaculture wastes are effectively dispersed by ocean currents. However, the combination of 3,000 tonnes in Larnaca and 5,000 tonnes in Xylofagou revealed a transition in the EI from good to moderate during springtime that is probably attributed to the relatively weaker currents and the anti-cyclonic pattern in Larnaca bay, indicating that the carrying capacity of the marine habitat in these areas allows only smaller production volumes.

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List of Abbreviations

Term	Description
AZA	Allocated Zones for Aquaculture
AMA	Aquaculture Management Areas
AIM	Aquaculture Integrated Model
ENE	East-Northeast
ESE	East Southeast
FCR	Feed conversion ratio
HCMR	Hellenic Centre for Marine Research
GFCM	The General Fisheries Commission for the Mediterranean
HDPE	High-density polyethylene
LAT	Latitude
LON	Longitude
NNE	North-Northeast
NNW	North Northwest
OC-UCY	Oceanography Center – University of Cyprus
OS	Open Sea
OSA	Open sea area
OSC AZAs	OS Cypriot allocated zones for aquaculture
SSE	South Southeast
SST	Sea surface temperature
SSW	South-Southwest
WNW	West Northwest
WSW	West Southwest

1 Introduction

The environmental impacts from cage farming are related to the enhanced emissions of dissolved nutrients and particulate matter, as well as the interaction of fish stocks and various diseases. Risks associated with intermittent events, such as storm-related damage to net pens and escape of domesticated fish into the wild, are also among the most commonly cited.

Sedimentation of feed and feces from net cages increase the local flux of organic matter to the sea floor (Basaran et al., 2010; Hargrave, 2010; Bannister et al., 2014; Wang et al., 2013; Nordi et al., 2011; De Gaetano et al., 2011; Mayor et al., 2011, White et al., 2017; Kalantzi and Karakassis 2006; Kalantzi et al., 2021; Tsikopoulou et al., 2018), and the manifold impacts related to increased emissions of metabolic and feed wastes from finfish culture are among the most well-documented in aquaculture (Hargrave, 2010). Enhanced sediment oxygen consumption is a direct impact of organic enrichment of the sea floor sediments underneath and around net pens, and generates conditions (redox) shifting other biogeochemical processes (Piedecausa et al., 2012; Yakushev et al., 2020). A general rule of thumb in salmon farming is a discharge of organic matter (feces) at a rate of 8.8% of dry feed weight (Bannister et al., 2014). The uneaten feed can contribute to a significant, and at times, a majority of organic solid wastes from net pens (Nordi et al., 2011; De Gaetano et al., 2011; Ballester-Molto et al., 2017). In mass balance terms, > 50% of C, N, and P from feed may be lost/dispersed to the environment in dissolved (metabolic wastes) or solid (feces, uneaten feed) forms (Wang et al., 2013).

Finfish farming in coastal waters in the Mediterranean Sea (mainly seabass and seabream farming) increases sedimentation of organic waste from sea cages to the seafloor as well as elevates the concentration of dissolved nutrients directly available for uptake in different types of marine vegetation, such as benthic seagrass. The cumulative effect of aquaculture nutrient enrichment of coastal marine habitats has an expected dose-response dependent impact, i.e., directly stimulating growth of marine vegetation at low doses, while potentially lethal effects at high doses of benthic enrichment. The impact of marine fish farms on seagrass depends on the distance from the farm. Theoretically, the released dissolved nutrients from fish cages stimulate the growth of suspended microalgae, which may pose an indirect negative effect by shading the slow-growing benthic vegetation as well as increasing the risk of oxygen depletion in sediment water when the organic material decay.

The effects of fish farming on microbenthic diversity and community structure in the Eastern Mediterranean were detectable and compatible with the Pearson and Rosenberg (1978) empirical model up to a distance of 10–25 m from the edge of the cages (Karakassis, 2013). Regarding the EU Water Framework Directive, data from Greece indicate that the benthic quality directly beneath fish farms cannot be considered as “High” or “Good” no matter what index is used (Karakassis, 2013).
Seagrasses, like *Posidonia oceanica* and *Zostera marina* (eelgrass), grow in marine coastal waters - in some areas down to 45 m water depth (Piazzi et al., 2016; Kletou

et al., 2018). Above the sediment, their leaves create beds and meadows, which are important habitats for several faunal species, while their roots in the sediment provide oxygen for many infaunal species. In the sediment, seagrass roots grow large rhizome “matte” which serve as substantial carbon sequestration storage (Campagne et al., 2015). With expanding sea cage aquaculture activities, for instance, in coastal areas of the Mediterranean Sea, the seagrass meadows may be negatively affected by the nutrient enrichment of the benthic environment and due to the smothering of the seagrass leaves by deposition of organic waste (Holmer et al., 2008). At a certain distance from the farms, the loading of organic matter to the benthic habitat stimulates mineralization processes, formation of toxic gases, and oxygen consumption which can affect seagrasses negatively (Holmer et al., 2008). While an increased concentration of dissolved nutrients in the water can positively affect growth in marine benthic vegetation, most often fast-growing ephemeral seaweeds, epiphytic seaweeds and benthic microalgae proliferate and overgrow the seagrasses and slow-growing benthic seaweeds, which causes shading and lower availability of sunlight. Thus, aquaculture nutrient enrichment of the benthic environment may lead to a shift in the associated assemblage of seaweeds inside seagrass beds with an increased abundance and biomass of ephemeral and epiphytic algae, which result in reduced growth of seagrasses (Rountos et al., 2012). This may lead to loss of seagrass depth distribution and areal coverage of this important habitat. Marine benthic microalgae grow in the top sediment layer in the marine ecosystem, where this group is an important primary producer. Shading from marine net pens and increased water turbidity from farming activity can be expected to reduce the productivity in deeper-water benthic microalgae at local-to-far range from the farming sites. However, the relative importance in the European context has not been established. Oppositely, nutrient enrichment of shallower coastal waters may stimulate increased production of epibenthic microalgae, which may have implications for benthic nutrient and oxygen fluxes.

The most important negative environmental impact of Mediterranean seabass and seabream aquaculture is its effect on *Posidonia oceanica*. *Posidonia oceanica* is a slow-growing endemic seagrass species of the Mediterranean thriving in clear oligotrophic waters with high transparency (Holmer et al., 2003), providing important ecosystem services such as shelter to juvenile stages of various marine species, protection against sediment erosion and carbon sequestration thereby reducing CO_2 fluxes towards the atmosphere. The recovery times of *P. oceanica* meadows when damaged are very long, in the order of centuries, and losses of this species are thus considered to be irreversible at managerial time scales (Karakassis 2013). The good water quality required by *P. oceanica* makes its’ habitat “ideal” for fish farming as well and therefore, there are fears that a large proportion of fish farming activity is sited above such meadows despite the existing regulations in most Mediterranean countries. Research results have provided information on the mechanisms of environmental deterioration related to the loss of *P. oceanica* sites and the spatiotemporal scales of the processes involved. A synthesis paper of the MedVeg project (Holmer et al., 2008) has examined a series of drivers of seagrass decline due

to fish farming effects and identified the sedimentation of waste particles in the farm vicinity as the main driver of benthic deterioration. Holmer et al. (2008) have recommended a safety distance of 400m for management of *P. oceanica* near fish farms followed by the establishment of permanent seagrass plots samples annually for monitoring the health of the meadows.
Posidonia oceanica are affected by fish farming (Diaz-Almela et al. 2008; Holmer et al. 2008, Apostolaki et al. 2009, 2010; Rountos et al., 2012), when the effluents from the fish cages are directed towards the meadows that are sited close to the farm (< 400 m according to Holmer et al. 2008). However, fish farming is only one of the human pressures affecting *P. oceanica* beds in the Mediterranean. A series of other very common uses of the coastal zone have been reported to affect, to varying degrees, this important habitat (Orth et al. 2006; Boudouresque et al. 2006). These include coastal eutrophication; high water temperature and reduced light; herbivory by waterfowl, urchins, and fish, which is assumed to intensify as a result of anthropogenic pressures, such as the presence of sewage discharges; invasive species, such as *Caulerpa racemosa* and *C. taxifolia*, which colonize the seagrass meadows and have shown extraordinary rapid expansion, especially when the *P. oceanica* beds are already stressed; dredging and coastal works, such as the construction of harbors or coastal protection works and artificial beach replenishment; destructive fishing activities, such as trawling, which is detrimental to various benthic habitats; anchoring by pleasure boats; use of explosives either for military purposes or for illegal fishing; coastal salinity changes resulting from altered water flow for irrigation; pulsed turbidity exacerbated by erosion due to poor land management (GFCM, 2011).

By moving farming activities offshore in the open sea, producers can take advantage of better-quality water while significantly reducing their environmental impact as additional currents mean that sediments and effluents don't accumulate near farm sites, making aquaculture more environmentally friendly (Welch et al., 2019).

Given that the environmental impact of fish farms depends significantly on the hydrodynamic regime of the wider region as well as on the location and characteristics of units (farmed species, capacity, etc.). A modelling tool developed by the Hellenic Centre for Marine Research (HCMR) has been customized and implemented in the Cyprus area to assess the environmental impact of existing and future **Open Sea (OS)** aquaculture. This is a three dimensional (3-D) hydrodynamic-biogeochemical coupled model (the **A**quaculture **I**ntegrated **M**odel -**AIM**, Tsagaraki et al., 2011) that consists of two on-line coupled, sub-models: the 3-D hydrodynamic Princeton Ocean Model (POM) and the biogeochemical model based on the European Regional Seas Ecosystem Model (ERSEM). AIM can be used to simulate the effect of aquaculture wastes from potential **Allocated Zones for Aquaculture (AZA)** either from multiple cage farms or in individual cage farms (point sources) (see D10 "Development of an environmental assessment model for ecosystem and oceanographic modelling for site selection"). This model has been used in Cyprus for the Interreg AquaPlanner project (see http://www.aquaplanner.hcmr.gr/), however, for nearshore aquaculture operations. The improved model considers open sea areas in the Republic of Cyprus, for the identification of sites with less sensitive/important/rare habitats where the impact of the aquaculture at the environment can be minimized.

A detailed data collection for marine spatial planning in WP4, revealed sites of potential interest for **Open Sea (OS)** Aquaculture (see D13). In some selected areas, there were no direct conflicts with existing manmade operations and sufficient distance from sensitive/important/rare habitats (see Annex 1). The Aquaculture Integrated Model (AIM, Tsagaraki et al., 2011; Petihakis et al., 2012), developed by the Hellenic Centre for Marine Research (HCMR), and customised for Cyprus (see D10) is now applied in order to assist the identification of sites where the impact of the aquaculture at the marine environment can be minimized.

In this approach, a series of nested models is used to consistently downscale the hydrodynamics and biogeochemistry from the coarse resolution (~few kilometres) model of the Mediterranean to an intermediate model (few hundreds of meter) of the area south of Cyprus to the high-resolution model (~few tens of meters) of the fish farm areas. The amount of nutrients entering the environment from the fish cages is calculated using a mass balance approach (see D10 for details). The model produces maps of near surface currents, Chl-a, dissolved inorganic nutrients (NH_4, PO_4 and particulate POC, PON, POP), plankton biomass and production that can be used to calculate different indicators describing the environmental status in the area, providing a tool for the sustainable management of the future OS Cypriot allocated zones for aquaculture **(OSC AZAs)**. This tool can offer significant assistance and know-how in decision making, giving the ability to objectively look at a series of parameters, make predictions about environmental impacts, design reliable monitoring protocols, and analyse scenarios to further progress good practices in management and development.

This report reflects the outcomes of Task 3.2 “Oceanographic modelling”.

1.1. Selected areas

The OS AQUA consortium made a detailed GIS mapping of all major coastal activities (see D13 “Identification of AZAs and AMAs and estimation of their carrying capacity”). The existing 11 licences for fish farms have been also mapped. A series of potential candidate OS AZAs with depths up to 200 meters have been identified for Cyprus, based on their distance from sensitive habitats (*Posidonia oceanica* meadows), NATURA 2000 areas, marine protected areas (MPAs), shipwrecks, artificial reeds, desalination plants, sewage disposal points, pipes, ship routes, anchorage areas, areas for military/defence use etc. The areas identified are in Agia Napa, Xylofagou (East and West), Larnaca, Governor's Beach (East, Center, West), Aphrodite Hills and Avdimou (see Annex 1).

After several meetings and discussions, the following four (4) open sea areas (OSA’s) have been selected as potential OS AZAs for the modelling work:

1. Xylofagou West (point 2)

2. Larnaca (point 3)
3. Governor’s Beach (Center & East) (point 6)
4. Aphrodite Hills (point 7)

A map of each area is shown in Annex 1. The above areas have no conflicts with other anthropogenic activities (with the exception of fisheries), they are situated in depths up to 200 m (average depth from 120 to 150 m) and they are relatively close to existing port facilities.

1.1.1 Prevailing waves and currents

The prevailing waves in the selected areas have been calculated witha dataset retrieved from the WAM model that runs at the University of Cyprus. The wave model domain covers the eastern part of the Mediterranean Sea with high spatial resolution. The period of the dataset is from 01/01/2001 to 31/12/2020, using 3-hourly timesteps. From the dataset, the closest grid points to the selected locations were extracted for analysis. A time series of each point was constructed using the model significant wave height and wave direction (**direction wave is coming from**). The time-series were plotted on a rose diagram, a circular histogram plot that displays directional data and the frequency of each wave height class. For this report, the directions used are North, North-Northeast (NNE), East-Northeast (ENE), East, East Southeast (ESE), South Southeast (SSE), South, South Southwest (SSW), West Southwest (WSW), West, West Northwest (WNW) and North Northwest (NNW). The significant height class used are 0-0.5, 0.5- 1, 1-2, 2-3, 3-4 and 4-5 meters.

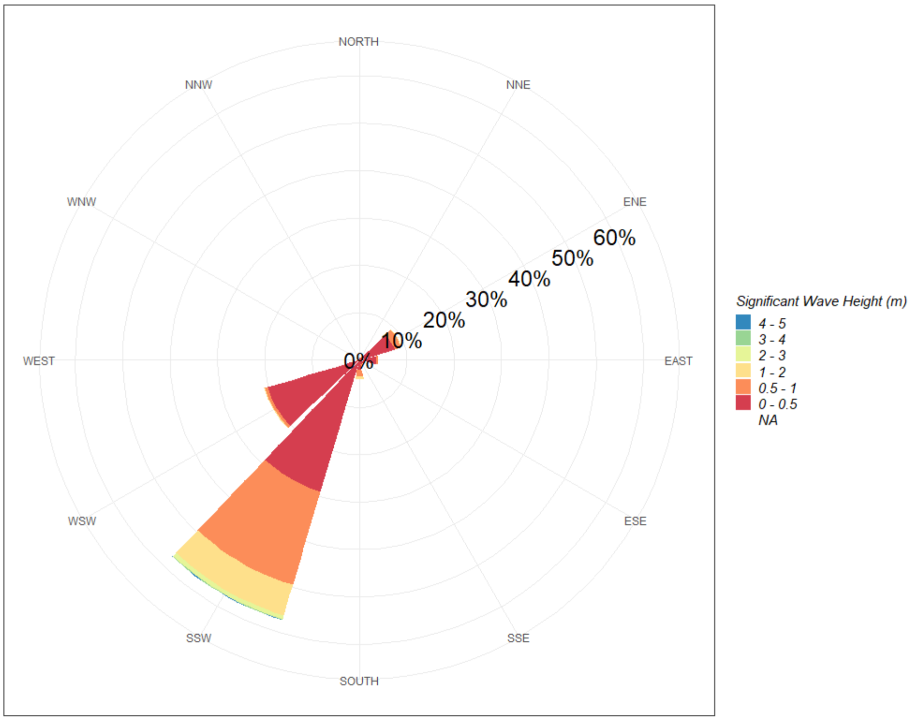


Figure 1. Prevailing wave direction for Xylofagou West (point 2) area. About 57% of the waves arrive from the SSW direction. ***Source: OC-OCY***

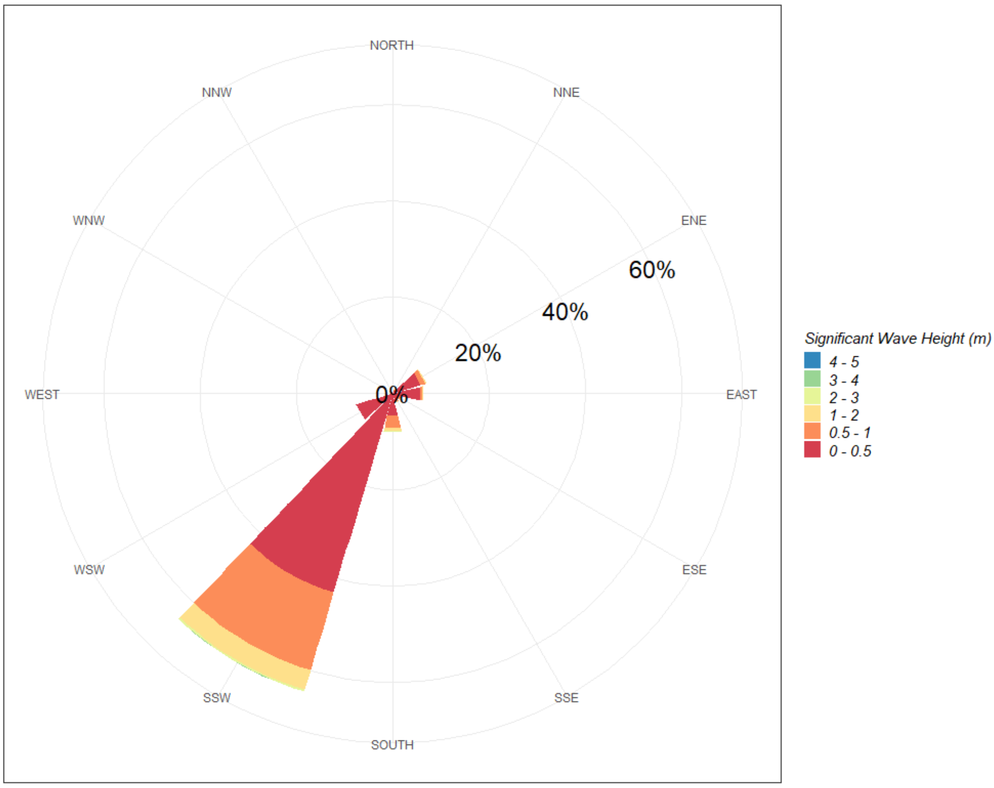


Figure 2. Prevailing wave direction for Larnaca (point 3) area. About 65% of the waves arrive from SSW direction. ***Source: OC-OCY***

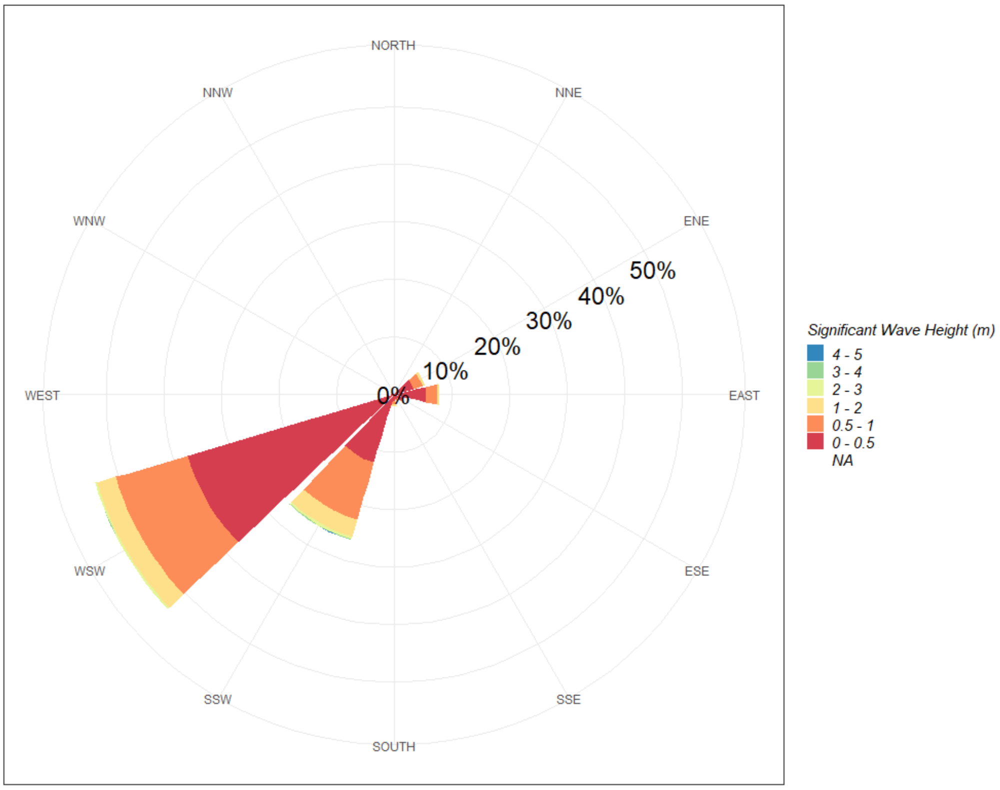


Figure 3. Prevailing wave direction for Governor's Beach (Center & East) (point 6) area. About 55% of the waves are from the WSW and about 26% from SSW. ***Source: OC-OCY***

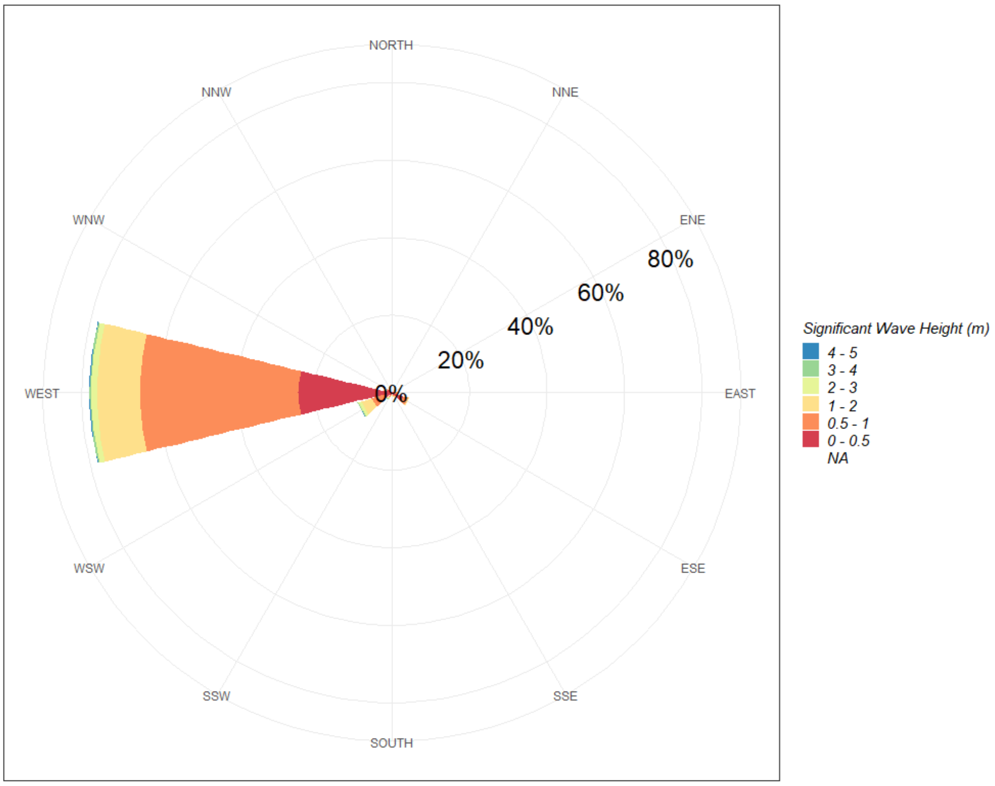


Figure 4. Prevailing wave direction for Aphrodite Hills (point 7) area. About 78% of the waves are from the West. ***Source: OC-OCY***

The prevailing currents in the four selected areas are shown in Figures 5-8. They have been estimated for the following depth levels: 5.5 m, 7.9 m, 10.5 m, 13.3 m, and 16.3m. The dataset was retrieved from the Copernicus Marine Environmental Monitoring Service (CMEMS). The reanalysis model used is Med MFC physical reanalysis product. The outcomes are generated by combining European Modelling of the Ocean (NEMO) and a variational data assimilation scheme (OceanVAR) for temperature and vertical salinity profiles and Sea Level Anomaly satellite data. The horizontal grid resolution is 1/24˚ (ca. 4-5 km), and vertical levels are 141. The current velocity from the closest grid points to the selected locations from 01/01/2000 to 31/12/2019 every 3 hours is analyzed here. The velocity components were converted to speed and direction (towards) using the following equations

$$DIR = atan(u, v) * (180/\pi) \qquad Speed = \sqrt{u^2 + v^2}$$

The results for each timestep were concentrated on a rose diagram, as explained before. This diagram indicates ocean current directional spread of each speed class. The speed class selected are 0-0.1,0.1-0.15, 0.15-0.2, 0.2-0.25,0.25-0.3,0.3-0.4 and 0.4-0.5 m/s. The direction shown on the following rose diagrams is the direction that the currents are **heading towards**.

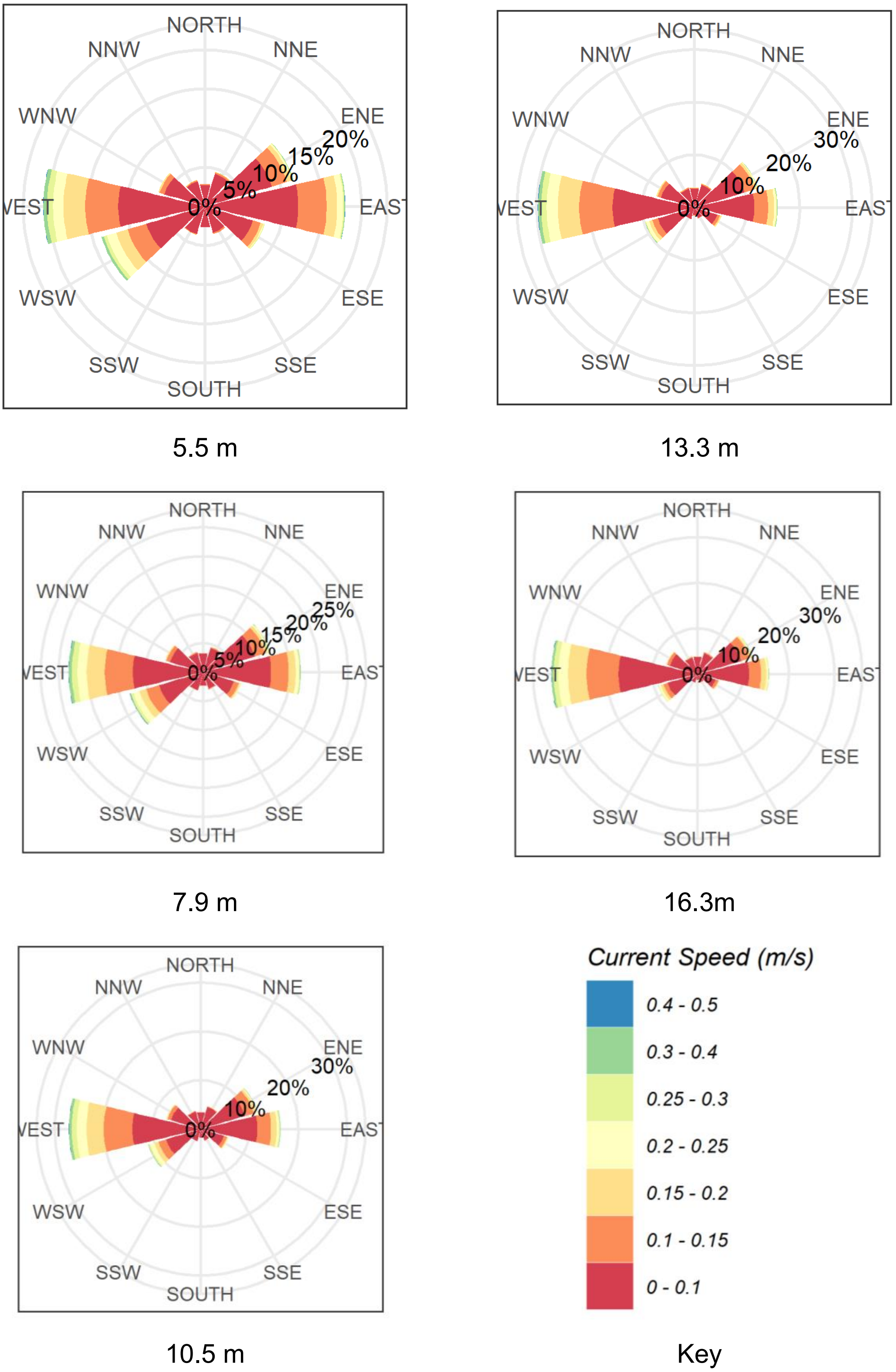


Figure 5. Prevailing current direction for Xylofagou West (point 2) area. The main current direction (to the west) becomes more dominant as the depth is increased (no significant increase in speed). When the current is not westward, it is most likely to be eastward. ***Source: OC-OCY***

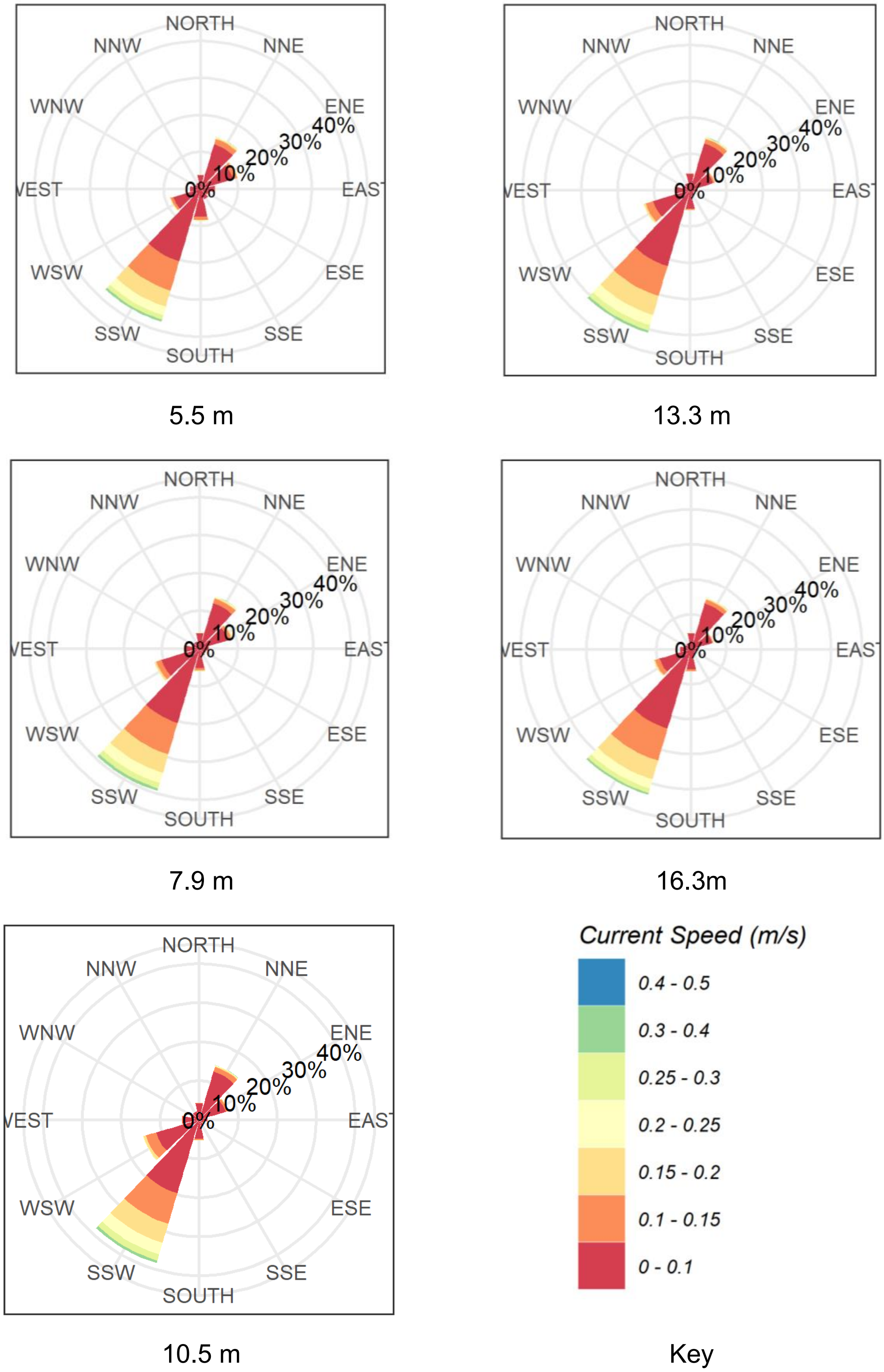


Figure 6. Prevailing current direction for Larnaca (point 3). The main current direction is the same as wave direction (to SSW). No significant changes in the current direction as it goes deeper). ***Source: OC-OCY***

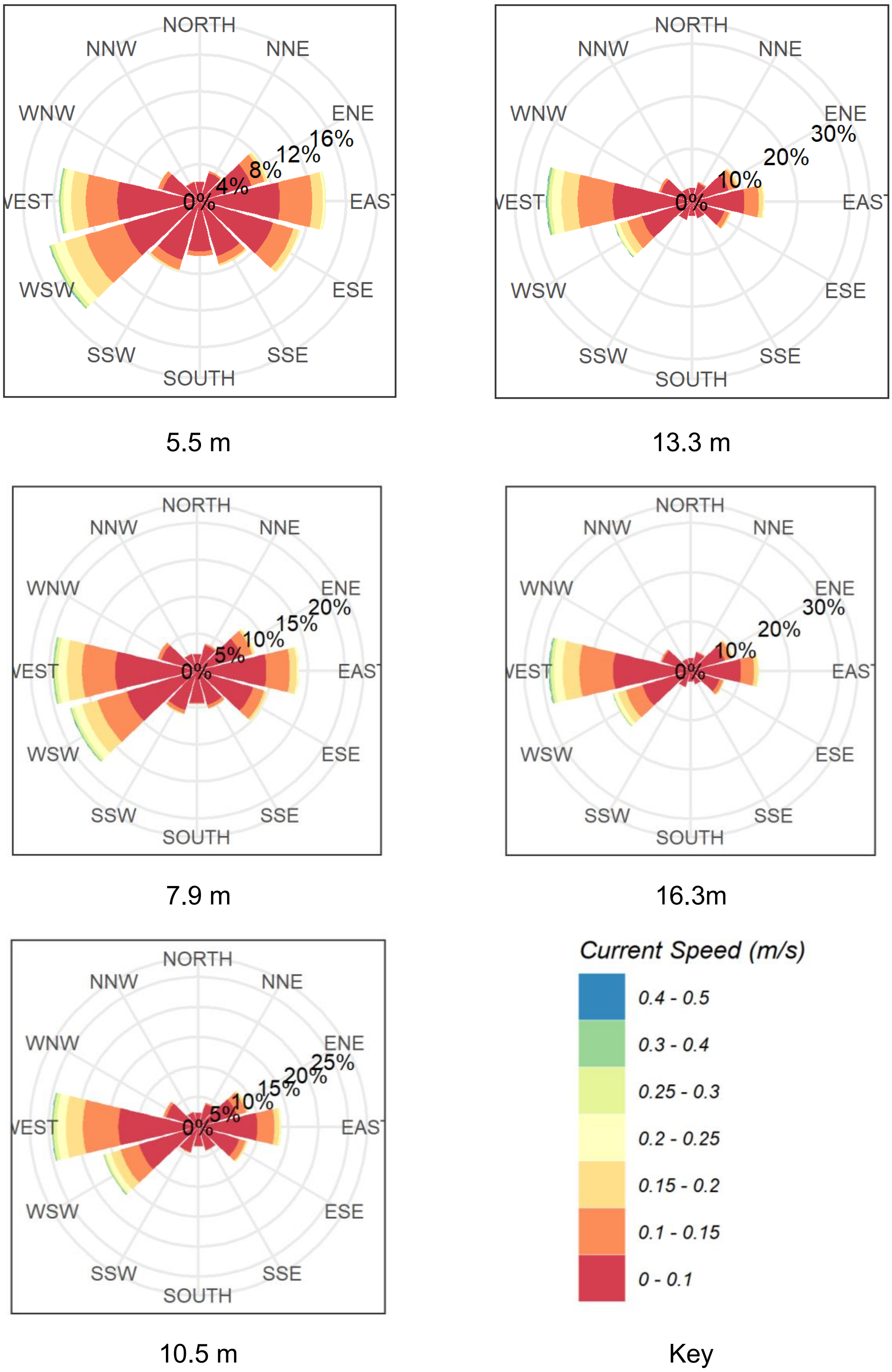


Figure 7. Prevailing currents direction for Governor's Beach (Center & East) (point 6) area. The main current direction (to west) becomes more dominant as the depth is increased (no significant increase in speed). ***Source: OC-OCY***

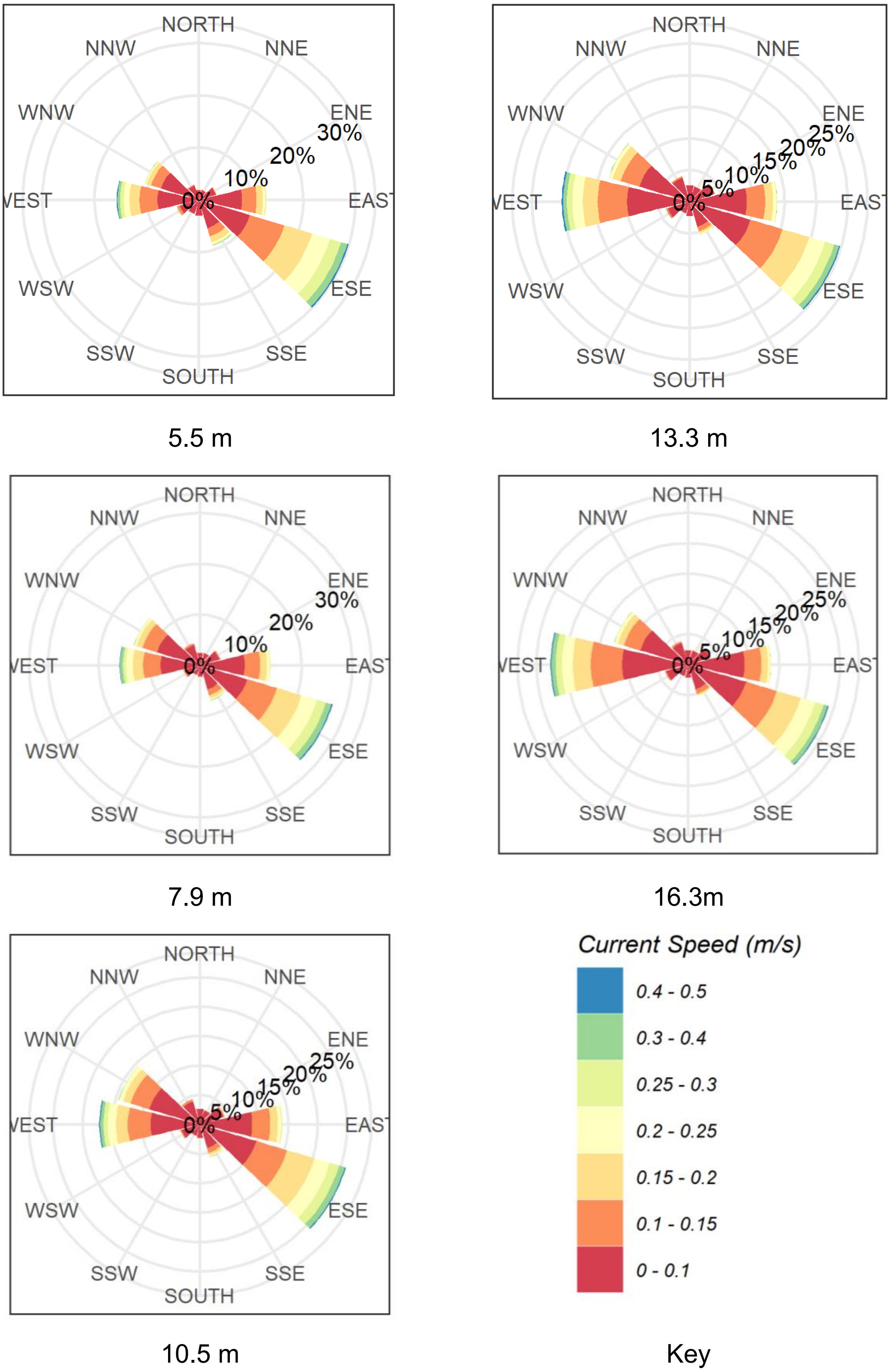


Figure 8. Prevailing current direction for Aphrodite Hills (point 7) area. The main current direction is to ESE at 5m depth, and as the depth increases, another current direction is common (to the west). Both directions have the same frequency at 16 m depth. *Source: OC-OCY*

1.2. Offshore technologies

The following technologies considered for deployment in the selected areas.

1. OCEANIS 1 submersible cages of Badinotti Group.
2. Innova Sea submersible cages.
3. The new open sea aquaculture station concept of OS Aqua that is using a single point mooring system.
4. Conventional floating HDPE open sea cage technology.

A detailed description of these technologies is given in D18. Here they are briefly described, and the layout is provided as recommended by the companies.

1.2.1 The technology of Badinotti Group SpA (Oceanis 1 submersible cages)

The Badinotti Group (Italy) has developed submersible cages that allow farmers to develop aquaculture activities in exposed and unprotected sea sites, improving the potential production of the coastal regions while ensuring the environmental sustainability of farming sites. The advantage to use a submersible cage compared to traditional floating frames is to significantly decrease the risk of loss of biomass and consequently the potential high economic loss.

OCEANIS is the Badinotti's Group Cages submersible system. The technology used in OCEANIS 1 submersible cage combines the typical features of floating cages, such as easy access and management during the daily farming activities with the safety (in terms of resistance to force of the wave-motion) allowed by a totally submersed position.

OCEANIS 1 cage comes from more than 10 years of offshore fish farming experience. The OCEANIS 1 is characterized by the following features:

1. Compensation chamber in the HDPE walkway pipes (alternately floodable by water or filled by air) located over the cage net and at the waterline;

2. A ballast (sinker tube) located below the cage net and made with a HDPE pipe filled with chains. The total weight is lower than the total buoyancy of the pipe. The cage sinks by opening the air and water valves. The water pressure pushes out the air contained in the HDPE walkway pipes. The lower ballast facilitates the sinking procedure. To make the structure floating it is necessary to carry out the reverse procedure. The inflow of air through the valves in the pipes pushes out water that was previously inside the HDPE pipes.

The air pressure can be supplied with underwater bottles and or a low-pressure compressor of at least 300 lt/min. in outflow, with a tank of at least 100 lt. The cage floats by closing all the air valves.

Using the 25 m diameter cage OCEANIS 1, all the activities involved in the ordinary running of farms, like harvesting, sampling for biometric measurements and any other related actions are carried out, directly while cage is in floating position on the water surface.

In order to facilitate the handling procedures, the cage net is fitted with a "removable" net lid in the top. The net roof is equipped with a marine zipper and is therefore easily removable.

Considering a 25 m diameter cage and a net depth of 10 m (+1,5 m above the sea surface), an average net volume of 4,250 m^3 and a stocking density of up to 15 kg/m^3, the company suggests the following number of cages for the 3 production scenarios:

For 2,000 tons are required 130,000m^3 -> 30 x OCEANIS cages

For 3,000 tons are required 200,000m^3 -> 47 x OCEANIS cages

For 5,000 tons are required 330,000m^3 -> 78 x OCEANIS cages

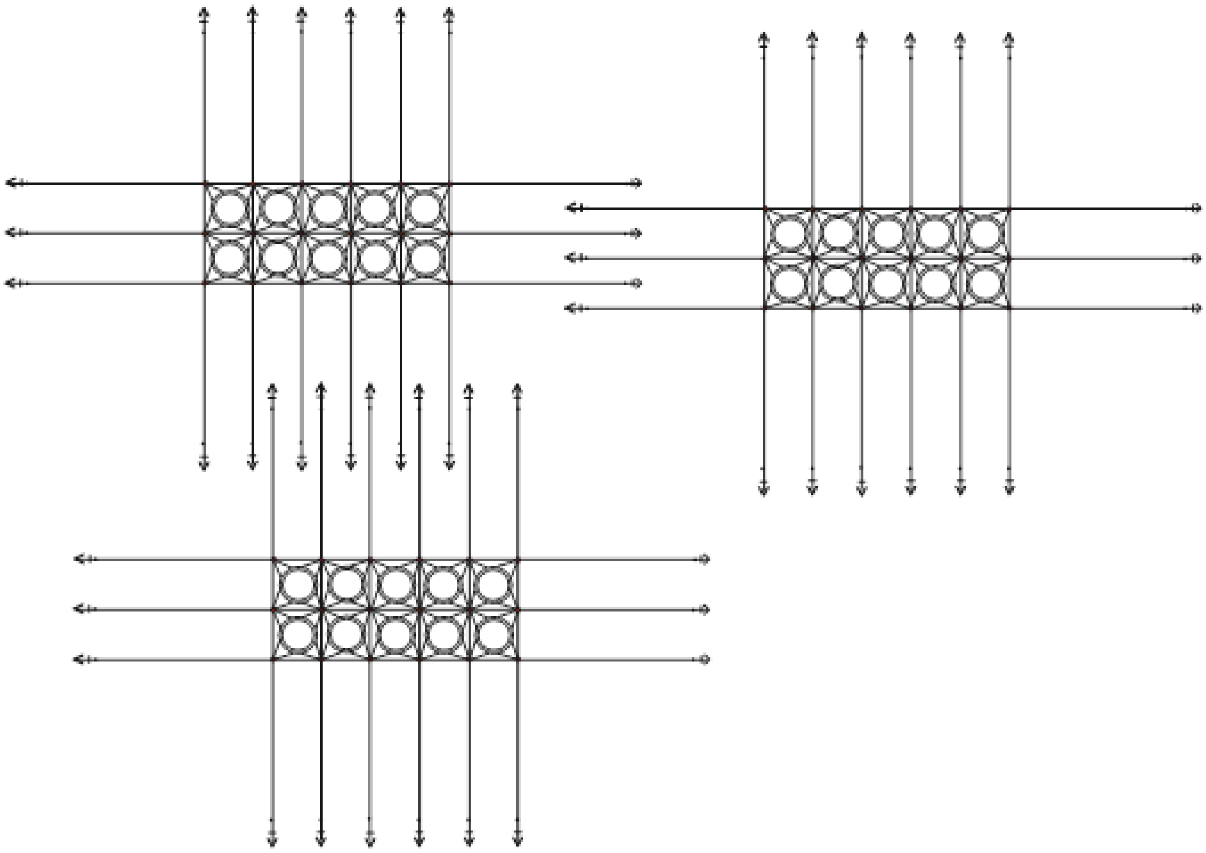


Figure 9. Indicative layout of the Badinotti's Oceanis 1 technology for a park of 30 cages able to support a production of 2,000 tonnes of seabass and seabream per year. Each park of cages has a footprint of 135x280m. *Courtesy of Badinotti Group*.

1.2.2 The technology of Innova Sea

Innova Sea (USA) has a long history of innovation for submersible pens with more than 25 years of evolution. Starting from the AquaSpar, a proven near-shore pen that's still producing salmon in Puget Sound and other locations, then to the futuristic-looking Aquapod, a geodesic dome that's become the face of offshore aquaculture and is still in use across the globe, their latest generation of pens, the SeaStation and the Evolution Pen, are a standard for offshore fish farms.

The SeaStation

The SeaStation provides the best environmental conditions for fish, reducing stress and improving their quality of life. That means a better feed conversion ratio (FCR), which can significantly reduce operating costs, and healthier fish to bring to market. When needed, the SeaStation can be raised to the surface with the aid of an air compressor to facilitate:

Harvesting – Fish are gathered into an ever-smaller area and easily collected using our proprietary harvesting system.

Sampling – Easily obtain fish samples to check growth and condition.

Desiccation – Wind and sun passively clean the pen for a convenient, once-per-week operation.

Maintenance – The shallower pen position simplifies maintenance.

The Evolution Pen

The Evolution Pen provides a solution to rough conditions and opening new areas to aquaculture. When the site is calm and quiet, it sits at the surface and is operated as a traditional pen. But when a strong storm or a large algal bloom occurs, the Evolution Pen is easily submerged to protect itself and its valuable contents.

Submerged, the pen remains secure and keeps fish stocks safe while allowing operations to continue, as usual, reducing the number of lost feed days. When the danger has passed, the pen is returned to the surface. This flexibility effectively expands the reach of aquaculture, increasing the number of available farming sites around the world and bringing them closer to strong markets. Most of the time the Evolution Pen is operated as a standard surface pen, making it easy for experienced operators to manage. But Innova Sea also added a host of improvements to ease operability, safety, and reliability:

Modular design – Enables sizes ranging from 4,000m^3 to 20,000m^3 using interchangeable parts and minimal engineering overhead.

Bottom moored – Unlike most fish pens, the Evolution Pen is connected to the grid at the bottom of the pen. This reduces wear and makes it easier for boats to access the pen without having to navigate surface lines.

Water-borne feeding system – Distributes feed evenly across the pen from multiple points.

Copper alloy mesh netting – This optional feature is long-lasting, predator-resistant, recyclable, and low-maintenance. It stays naturally clean, saving diver time and reducing insurance costs.

Nursery Net – This option simplifies the addition of smaller or younger fish without requiring a finer mesh for the overall pen.

Key safety enhancements – Full height, removable handrails and non-slip fiberglass decking dramatically reduce slip-and-fall accidents.

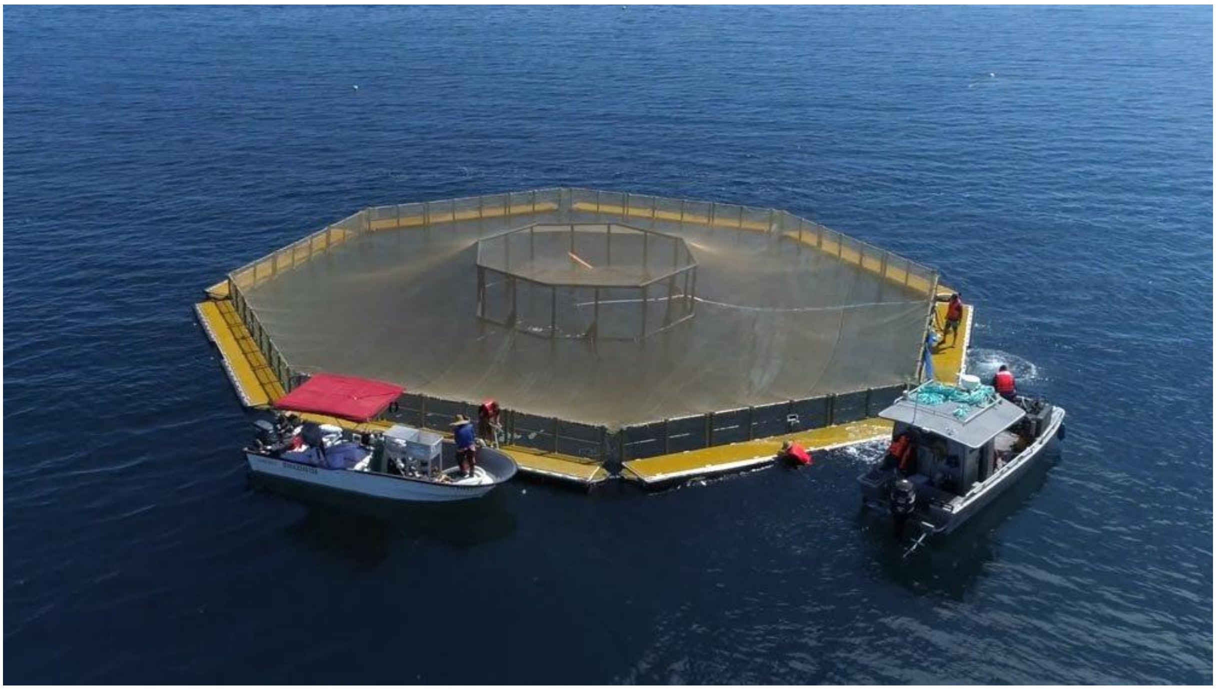


Figure 10. The evolution pen of Innova Sea. *Courtesy of Innova Sea*.

1.2.3 The new open sea aquaculture station concept of OS Aqua

Based on a desk study of available technologies, consultation with stakeholders, and the logistics of manufacturing and servicing a structure in the Eastern Mediterranean, the OS Aqua project produced an OS Aqua station design. The proposed stations have a catamaran-shaped structure of a length of 50 or 60 meters and a width of 20 meters. These structures are versatile because of the variety of cages that they can accommodate, whereas their single-point mooring system provides a competitive advantage in terms of marine spatial requirements. Below, a conceptual design is supplied for structures of 50 m length that would be built and maintained in Cyprus, providing additional socioeconomic benefits and self-sufficiency. More details and production scenarios are provided in D18.

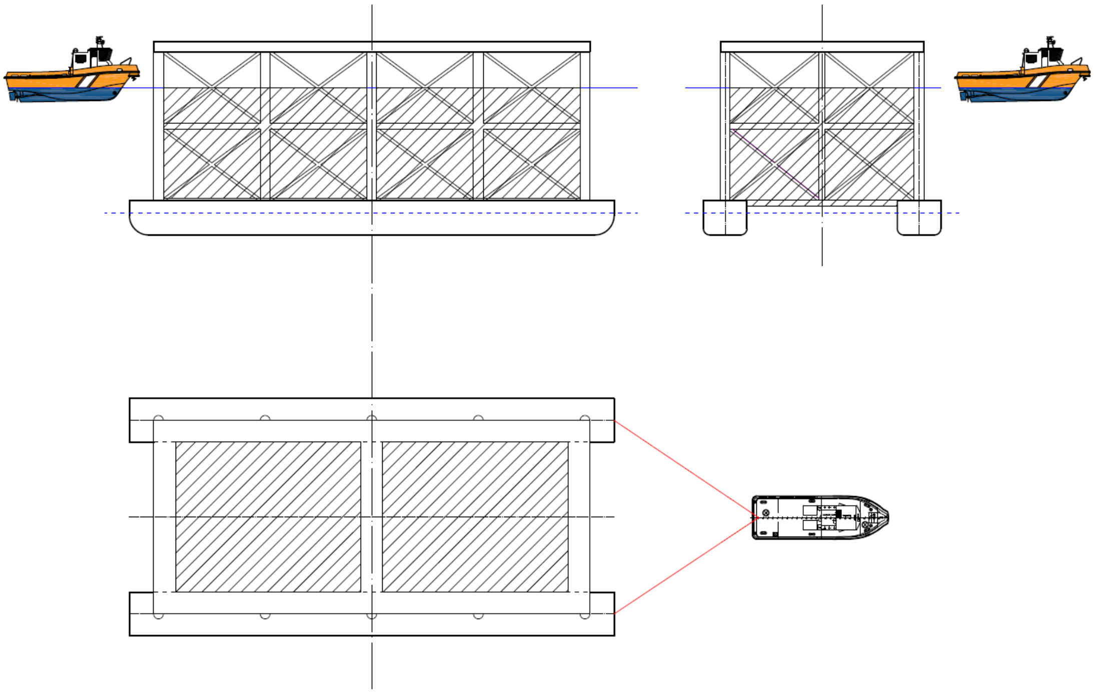


Figure 11. Concept design of the catamaran-like structure with three different viewpoints.

1.2.4 The conventional float cage technology

Another option is to adopt the most modern and proven for its operational capacity technology of high-density polyethylene (HDPE) floating cages, as they are currently widely used in modern industrial, marine aquaculture in many parts of the world owing to the versatility of the materials used, the simplicity in the various farming operations and the relatively low investment capital required. The main structural elements of these cages are the HDPE pipes, which can be assembled in various ways to produce collars of different sizes and shapes. The HDPE pipes, held together by a series of brackets with stanchions disposed throughout the entire circumference, form the floating collar ring, which is the main structure on which the fish net pen is secured. These gravity cages maintain the net pen shape and volume through a system of weights, also known as a sinker system, fixed at the bottom end of the net.

Such systems have been tested all over the Mediterranean and in Oman, Kingdom of Saudi Arabia, often in very exposed areas and in depths up to 70 m. In deeper waters, it is possible. However, a stronger (and more expensive) mooring system is required.

Figure 12: Fish farm for Tharawat Seas, Saudi Arabia. Courtesy of Stamatiou Aquaculture.

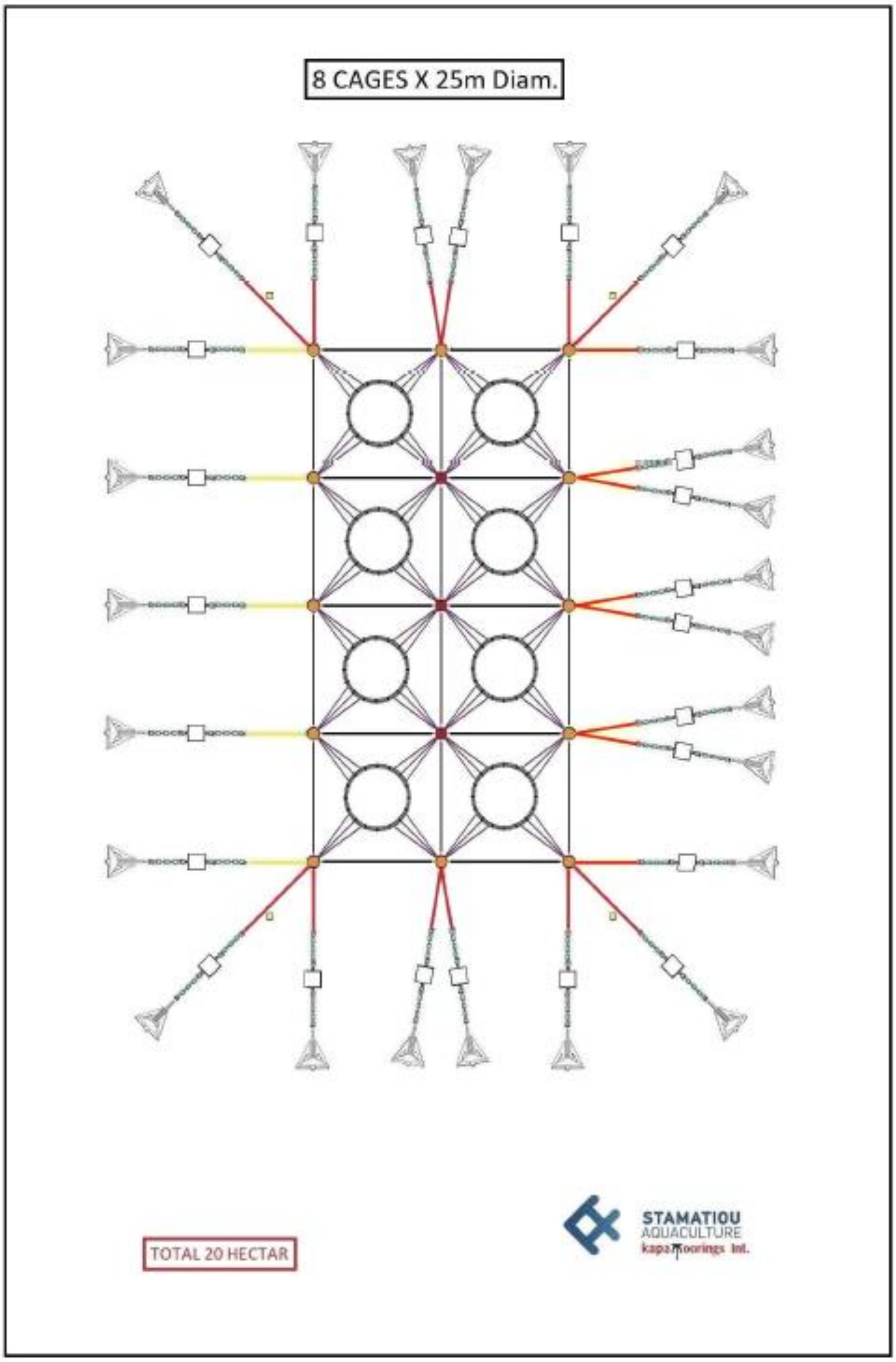


Figure 13. An example of a conventional cage farm for mariculture. ***Courtesy of Stamatiou Aquaculture*.**

The farm's footprint depends on the depth, as the greater the water depth, the larger the farm footprint will be because the length of the mooring lines is usually three to five times the depth. The mooring system design and cost depend on the site depth that may influence the equipment and materials used for moorings, including their dimensions.

1.3. Production scenarios and marine space requirements

The four selected areas (see 1.1) that have been selected for model runs have been further studied for the marine area that is required for their deployment. The centroids of the selected areas (latitude & longitude) as well as the average depths are summarised in Table 3.

Table 1. Coordinates and the average depth of the four open sea areas selected for further study.

	ID	Area-Harbor	Lat	Lon	Average depth
OS1	1	Point 2- Xylofagou West	34.940567	33.810116	120.5
OS2	2	Point 3 - Larnaca	34.85903	33.676446	161.5
OS3	3	Point 6 - Governor's Beach Center East	34.659938	33.245334	112
OS4	4	Point 7 - Aphrodite Hills	34,633645	32,562276	121

The mooring system that is used for the cages is, in most cages, a square-shaped grid system held on the seabed with an array of mooring lines. It is a dynamic system, and all of the components keep the structures moored to the seabed and are designed to dampen the forces generated by the wave motion. The mooring system is divided in two main groups of components, the mooring lines and the grid system. The mooring system can be installed using single or double mooring buoys. The first option is mainly used with a floating cage system, while the second option is used with submersible cages or in the case of high-energy sites. In the case of a submersible cage system, the submerged cages use the grid as a hanging frame while submerged, so a double line of mooring buoys is needed (the first on the mooring lines and the second on the grid corners) (Cardia and Lovatelli, 2015). The double-mooring buoy system could also be used with large cages or in high-energy sites where additional buoyancy is necessary.

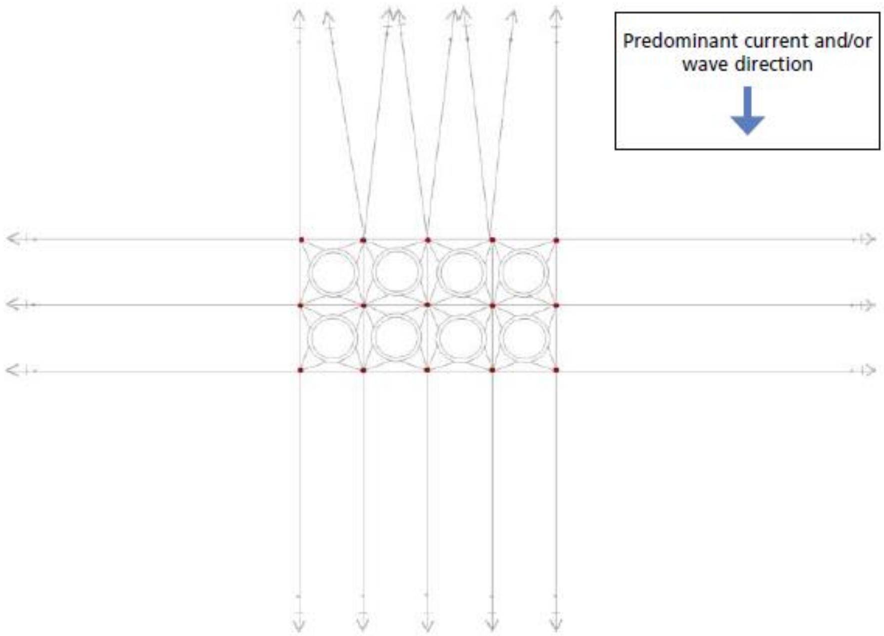


Figure 14. Deployment of the cages must be done perpendicular to the predominant currents in order to achieve better water quality in the cages, more efficient dispersion of the effluents and avoid the adverse effects in the neighboring cages. *Source of figure: Cardia and Lovatelli, 2015*.

In any case, the deployment of the cages must be done perpendicular to the prevailing currents, as illustrated in Figure 14.

Table 4 summarise 33 combinations of OS areas, technologies, cages/structures needed to produce 2, 3 or 5 thousand tonnes per year of native Mediterranean marine species and the theoretical marine space that is needed for the cages and for the mooring system.

Table 2. OS Areas, technologies and annual open sea farm capacity tested in the model runs.

OS Area and average depth	Technology	Annual OS farm capacity (tonnes)	Cages needed	Marine space needed for the cages (Km^2)	Marine space needed for mooring (Km^2)
OS1. Xylofagou West 120m	Badinotti's Oceanis1	2,000	30	0.12	3.25
		3,000	47	0.18	4.55
		5,000	78	0.30	6.71
	Innova Sea	2,000	10	0.10	1.95
		3,000	14	0.14	2.20
		5,000	24	0.24	4.16
	OS Aqua design (scenario 2)	2,000	10	0.01	0.26
		3,000	16	0.016	0.41
		5,000	24	0.024	0.61
OS2. Larnaca 160 m	Badinotti's Oceanis1	2,000	30	0.12	5.22
		3,000	47	0.18	7.25
		5,000	78	0.30	10.58
	Innova Sea	2,000	10	0.10	3.07
		3,000	14	0.14	3.39
		5,000	24	0.24	6.46
	OS Aqua design (scenario 2)	2,000	10	0.01	0.46
		3,000	16	0.016	0.73
		5,000	24	0.024	1.09
OS3. Governor's Beach	Badinotti's Oceanis1	2,000	30	0.12	3.25
		3,000	47	0.18	4.55
		5,000	78	0.30	6.71

120 m	Innova Sea	2,000	10	0.10	1.95
		3,000	14	0.14	2.20
		5,000	24	0.24	4.16
	OS Aqua design (scenario 2)	2,000	10	0.01	0.26
		3,000	16	0.016	0.41
		5,000	24	0.024	0.61
	Conventional HDPE cages	2,000	20 P100	0.13	2.90
		3,000	30 P100	0.19	3.90
		5,000	50 P100	0.32	5.63
OS4. Aphrodite Hills (near Paphos) **120 m**	Badinotti's Oceanis1	2,000	30	0.12	3.25
		3,000	47	0.18	4.55
		5,000	78	0.30	6.71

There are 15 more combinations (4 Areas x 4 Technologies x 3 production levels = 48). However, the OS Aqua Team decided to limit the various combinations due to time restrictions plus the fact that each model run takes a lot of time and computation effort. Therefore, emphasis was given to the offshore technologies, a comparison with conventional technologies, and a demonstration of these combinations that will be associated with investment costs, vicinity to ports, and existence of nearby ports or fishing shelters that will allow the servicing of the OS units.

The actual marine surface area occupied by a cage farm system is often called the farm footprint. The total area of an HDPE cage system is much larger than the visible floating components. The floating components (buoys and cages) will occupy the smaller area of the grid system, while a much larger area underwater will be occupied by the mooring lines. This is important in evaluating the license or lease area dimensions and the safety "no fishing zone" around the licensed area. To calculate this footprint, a mooring line length of at least 4–4.4 times longer than the site depth should be used. This is because the maximum loading power of anchors is generated by the angle of 9–12° between the anchor and the mooring line (Cardia and Lovatelli, 2015). Thus, the dimensions of the grid system, plus 4–4.4 times the depth of the site (for each side of the grid system) will give the actual dimensions of the marine space needed (footprint). All these are summarised in Table 4.

It is noticeable that the OS Aqua catamaran-shaped structure has a competitive advantage for the space needed compared to the other technologies due to its single point mooring system.

To decide if the potential future Open Sea Cypriot allocated zones for aquaculture **(OSC AZAs)** are technically feasible to be implemented according to the various production scenarios and the Technologies under consideration, a total of 33 combinations were studied using advanced GIS tools. Each park was deployed perpendicular to the prevailing currents, and the results are presented in Annexes 2 and 3. The GIS results are also available for the public in shapefile format (see D16. OS-AQUA GIS). 142 coordinates locations (LON, LAT) were estimated as well as the distance from the nearest port (the results from the estimation of the coordinates are presented in Annex 2, in order to be used for the HCMR modelling runs, for the accurate estimation of the effluents dispersion (in this D11 and in D12). In addition, a visual illustration of each cage technology configuration was made by means of GIS tools in order to assure that there will be no interaction with other users of the maritime space and the deployment of the various OS technologies according to the production scenario (2000, 3000 and 5000 tonnes per year) for each selected are presented in Annex 3 (Figures 25-57). This exercise will provide data and information to WP7 "Financial and Legal Frameworks" as the distance from a port facility is a crucial factor that affects the financial operations and the operational expenses of the OS farms.

The four OS Technologies have different marine space requirements that are analysed below. Some combinations require an extensive marine space and might be prohibitive for deployment as there will be a conflict with other existing activities. For example, the OS Aqua Team identified 5 deployments that might create technical issues (difficulties in mooring operations) as well as frictions and overlaps with existing maritime operations. These conflicting combinations are summarized in Table 5.

In each proposed area, there are numerous combinations of cage deployment. These can be fine-tuned as soon as a decision for the creation of an OSC AZA will be taken. The purpose of this Deliverable is to demonstrate how the environmental impact of OS mariculture can be minimized and provide some elements of maritime spatial planning. However, more detailed studies will be needed for the licensing and final deployment of the cages and/or structures.

This D11 provides some indicative deployment and production scenarios that are tested for their feasibility in terms of marine space requirement as well as potential conflicts with other maritime activities in the proposed locations.

For each technology, the number of the needed cages (or structures in the case of the Cypriot OS Aqua catamaran-like design) was estimated (see Table 4). Then, depending on the depth of each site, the marine space needed for the cages/structures was estimated as well as the marine space needed for the mooring systems. For each technology, a cage/structure deployment pattern was created for each annual production scenario. And this pattern was then oriented perpendicular to the prevailing currents in each selected OS area.

These patterns are analysed below for each technology that was evaluated.

1.3.1. The layout of Badinotti Group Oceanis 1 submersible cage Technology

1.3.1.1 Pattern for 2,000 tonnes per year

The layout of Badinotti Group Oceanis 1 submersible cage Technology for the 2,000 tonnes per year is shown in Figure 9. Thirty (30) cages are needed to achieve this annual production, and they are organized in 3 parks of 10 cages each. Each park of cages has a footprint of 280x135m. The marine space needed for the 3 parks is 0.12

km^2, whereas the marine space needed for the mooring system is estimated to 3.25 km^2 for a depth of 120m and 5.22 km^2 for a depth of 160m.

1.3.1.2 Pattern for 3,000 tonnes per year

Figure 15 depicts a possible layout for a 3,000 tonnes per year. 47-48 cages are needed to achieve this annual production and they are organized in 4 parks of 10 cages each (footprint of 280x135m) and 1 park of 8 cages (footprint of 224x135m). The marine space needed for the 5 parks is 0.18 km^2, whereas the marine space needed for the mooring system is estimated to 4.55 km^2 for a depth of 120m and 7.25 km^2 for a depth of 160m.

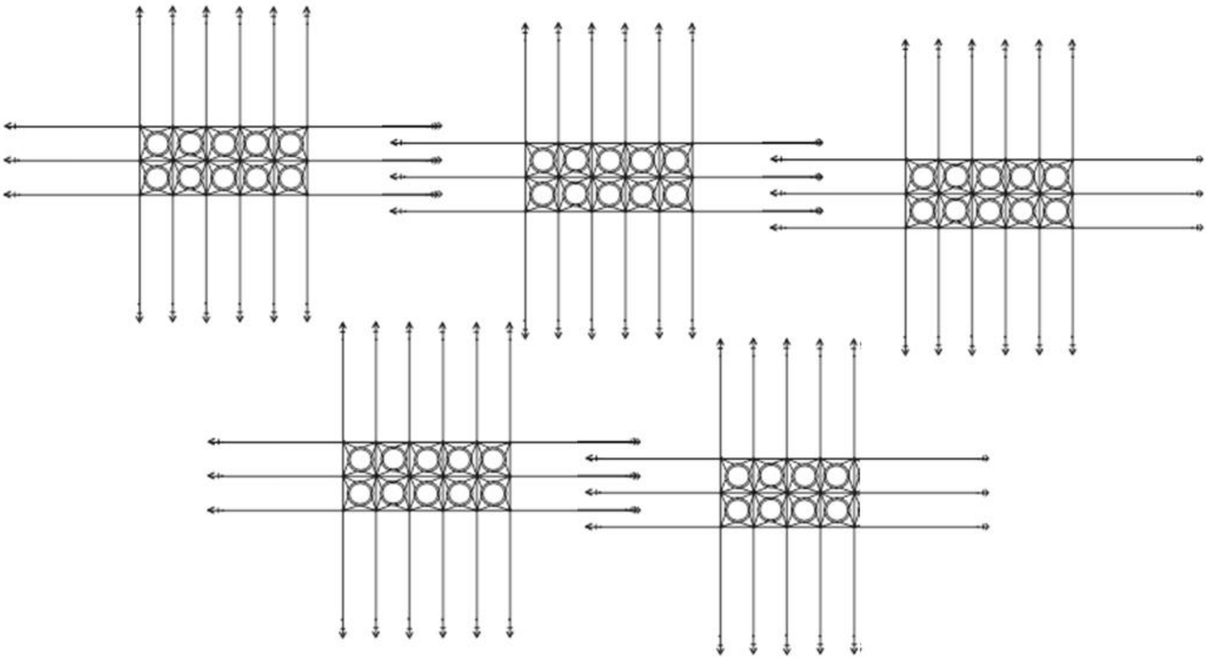


Figure 15. Indicative layout of the Badinotti's Oceanis 1 technology for a park of 48 cages able to support production of 3,000 tonnes per year.

1.3.1.3 Pattern for 5,000 tonnes per year

Figure 16 depicts a possible layout for 5,000 tonnes per year. 78 cages are needed to achieve this annual production, and they are organized in 7 parks of 10 cages each (footprint of 280x135m) and 1 park of 8 cages (footprint of 224x135m). The marine space needed for the 8 parks is about 0.30 km^2, whereas the marine space needed for the mooring system is estimated to 6.71 km^2 for a depth of 120m and 10.58 km^2 for a depth of 160m.

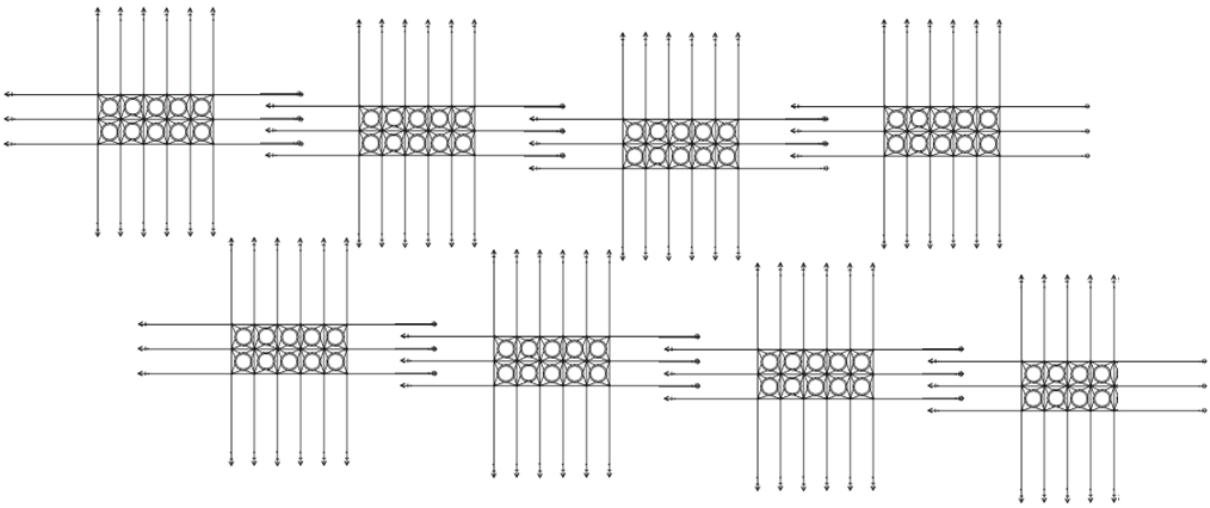


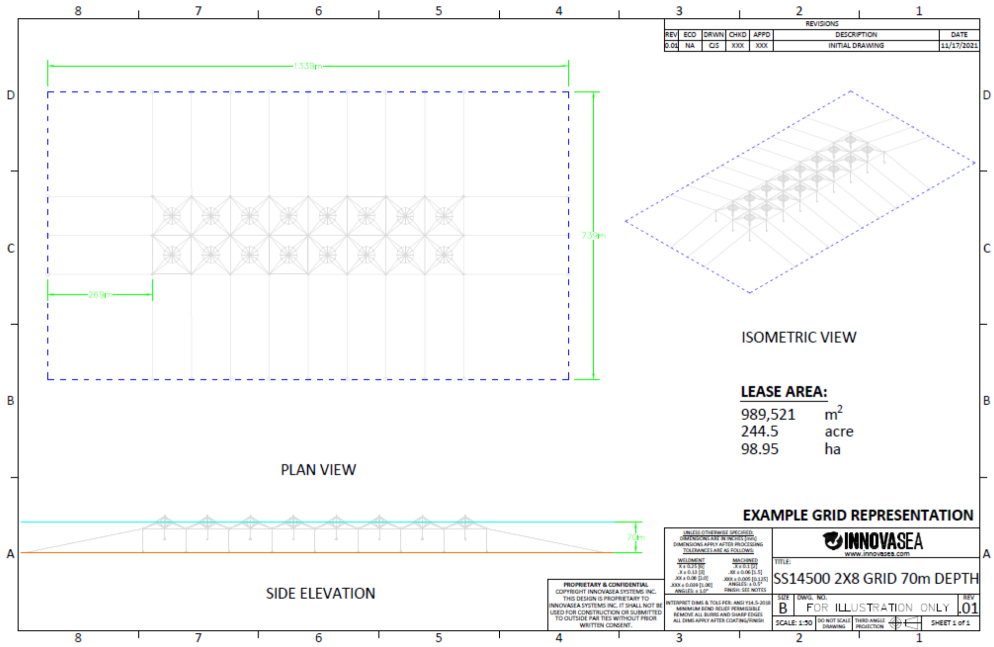
Figure 16. Indicative layout of the Badinotti's Oceanis 1 technology for a park of 78 cages able to support production of 5,000 tonnes per year.

Of course, these layouts are indicative, and a more detailed mooring system study will be needed in each area during the licensing and implementation phase. However, these layouts serve the purpose of the OS Aqua project for estimating the marine surface area needed and measuring the distance from the nearest port that is required as well as the modelling of the source points (cages) of the effluents.

It is stressed that for each production scenario, several alternatives of cage/structure deployment are possible, however, this exercise is beyond the scope of this study. A more detailed study should be made during the licensing phase and implementation of the OS Aqua proposed marine farms.

1.3.2. The layout of Innova Sea submersible cage Technology

Innova Sea shared with the OS AQUA Team an indicative grid presentation for its submergible cages technology that is depicted on the following Figure 17.



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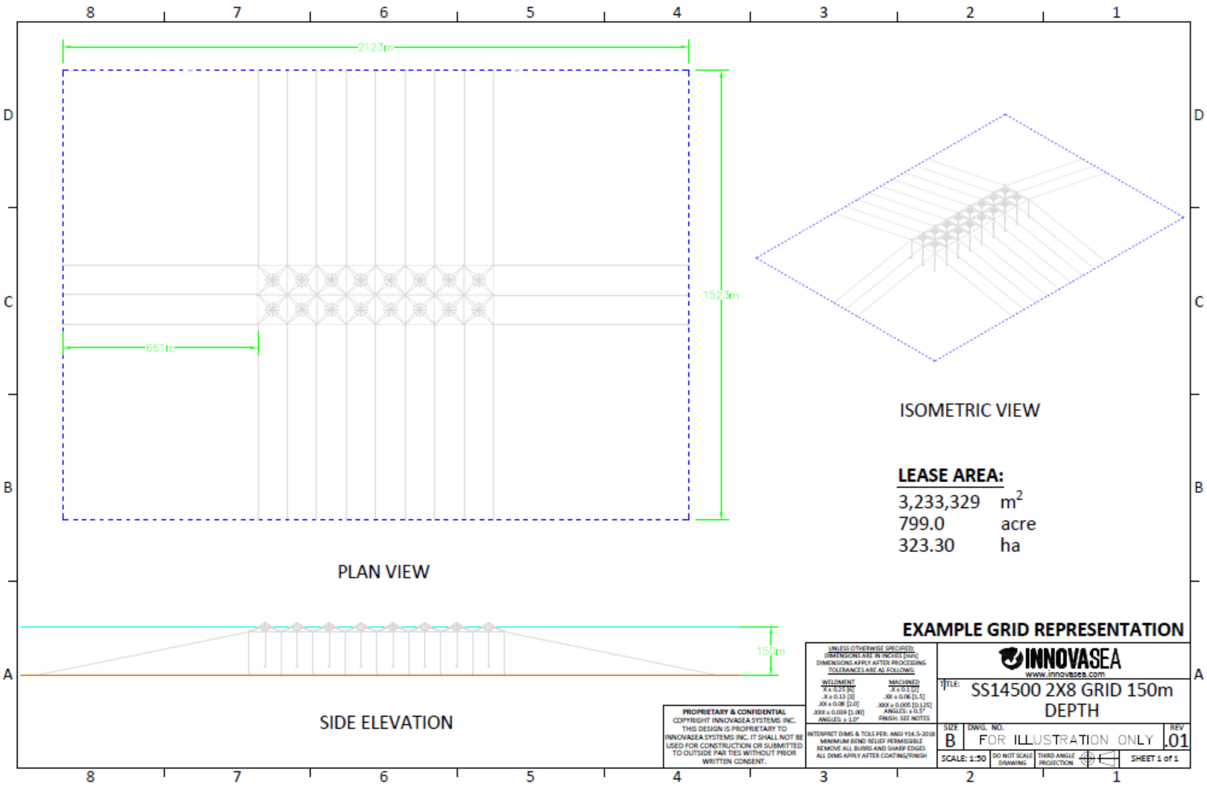


b

Figure 17. Indicative layout of the Innova Sea submergible technology for a park of 16 cages at a depth of 70 m (a) and 150 m (b). The total lease area required is 0.99 km^2 for the depth of 70m and 3,3km^2 for the depth of 150m. *Courtesy of Innova Sea.*

1.3.2.1 Pattern for 2,000 tonnes per year

Based on the above layout, the footprint of an Innova Sea submersible cage Technology farm for 2,000 tonnes per year is shown in Figure 18 that depicts a possible layout for 2,000 tonnes per year. 10 cages are needed to achieve this annual production, and they are organized in 1 park (footprint of 500x200m). The marine space needed for the park is 0.10 km^2, whereas the marine space needed for the mooring system is estimated to 1.95 km^2 for a depth of 120m and 3.07 km^2 for a depth of 160m.

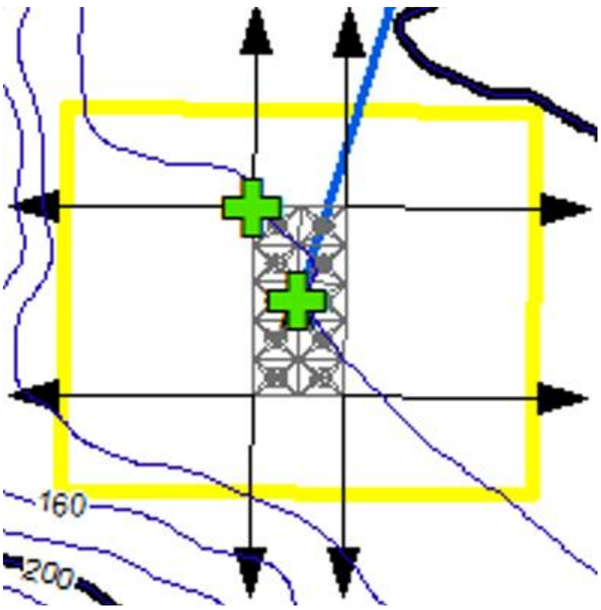


Figure 18. Indicative layout of the Innova Sea submergible technology for a park of 10 cages able to support production of 2,000 tonnes per year.

1.3.2.2 Pattern for 3,000 tonnes per year

The footprint of an Innova Sea submersible cage Technology farm for 3,000 tonnes production per year is shown in Figure 19 that depicts a possible layout for 3,000 tonnes per year. 14 cages are needed to achieve this annual production, and they are organized in 1 park (footprint of 700x200m). The marine space needed for the park is 0.14 km^2, whereas the marine space needed for the mooring system is estimated to 2.20 km^2 for a depth of 120m and 3.39 km^2 for a depth of 160m.

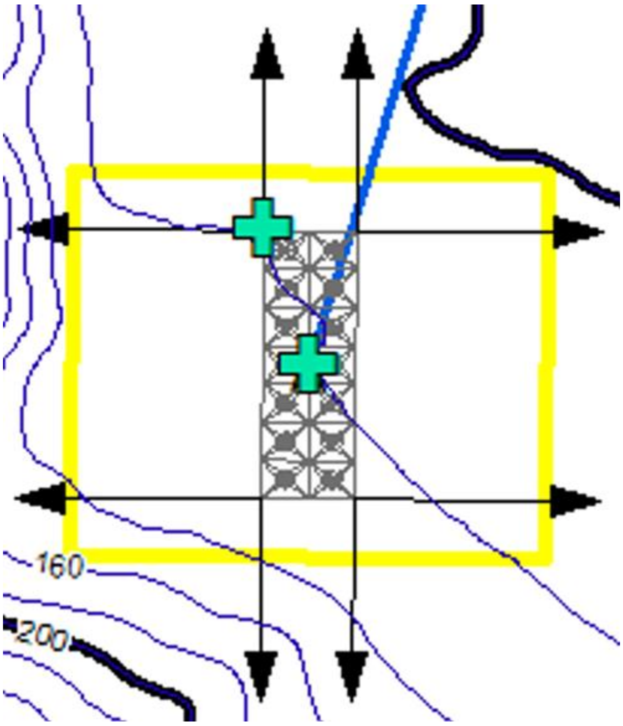


Figure 19. Indicative layout of the Innova Sea submergible technology for a park of 14 cages able to support production of 3,000 tonnes per year.

1.3.2.3 Pattern for 5,000 tonnes per year

Figure 20 depicts a possible layout of InnovaSea submersible cage Technology farm for a production of 5,000 tonnes per year.

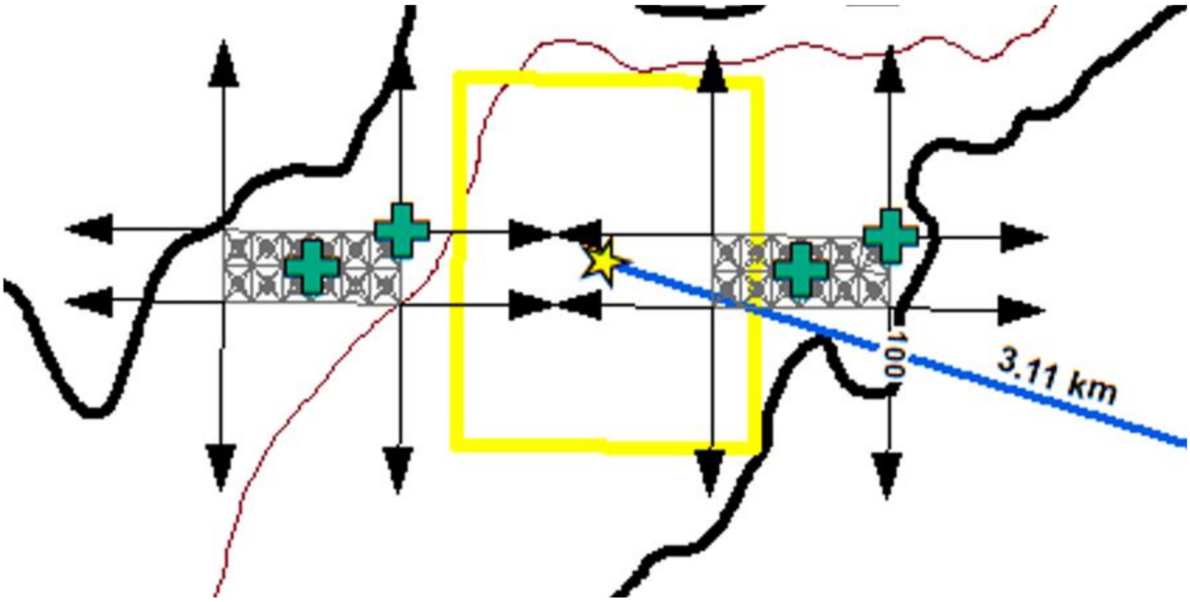


Figure 20. Indicative layout of the Innova Sea submergible technology for 2 parks of 12 cages each, able to support production of 5,000 tonnes per year.

The footprint or an Innova Sea submersible cage Technology farm for 5,000 tonnes per year is shown in Figure 20, which depicts a possible layout for 24 cages needed to achieve this annual production, and they are organized in 2 parks (footprint of 600x200m each). The marine space needed for the 2 parks is 0.24 km^2, whereas the marine space needed for the mooring system is estimated to 4.16 km^2 for a depth of 120m and 6.46 km^2 for a depth of 160 m.

1.3.3. The layout of the new open sea aquaculture station concept of OS Aqua

The OS Aqua design is a different concept compared to the submergible technologies, and its main advantage is the single point mooring system. This type of mooring provides a number of advantages such as:

- Significantly less marine space is needed.
- Versatility for the configuration of the internal cage.

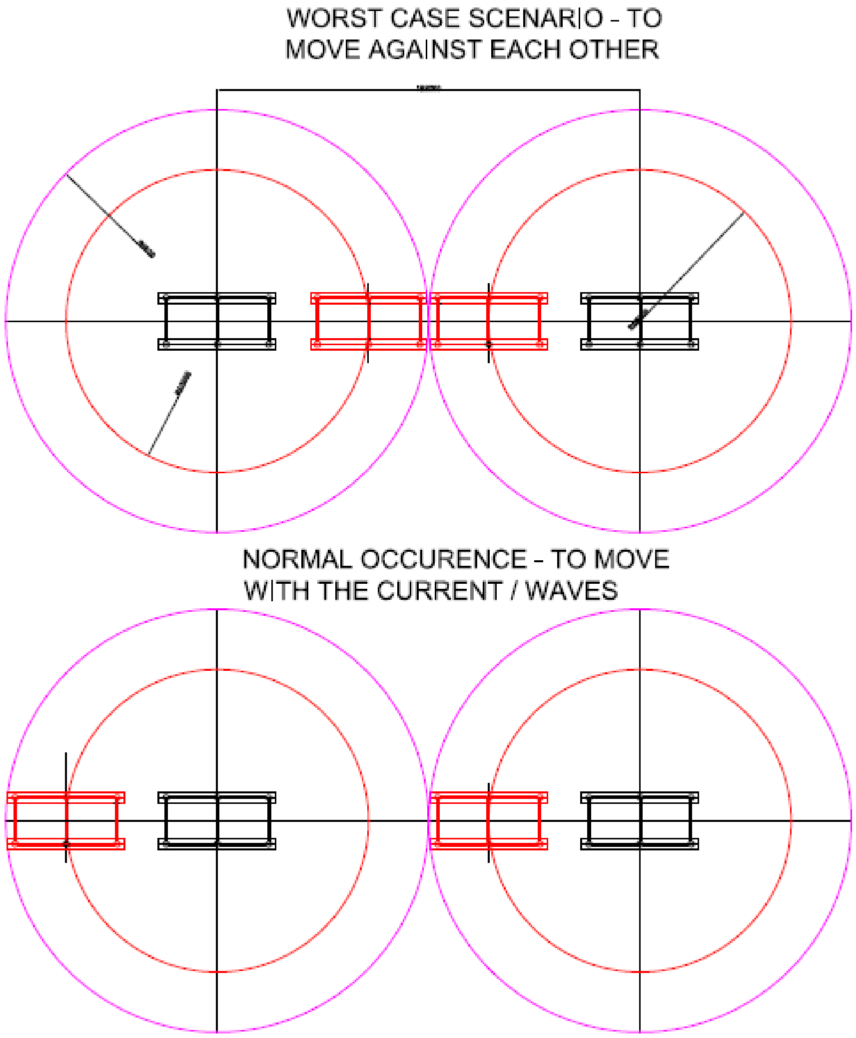
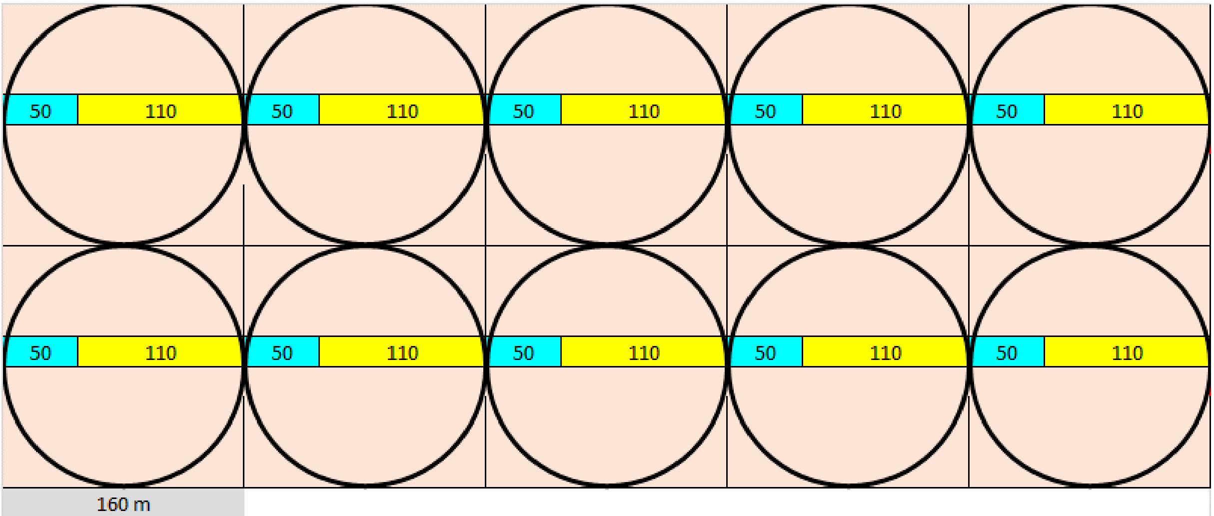


Figure 21. The new open sea aquaculture station concept of OS Aqua and the single point mooring system provides an advantage as less marine space is needed. The black rectangular is a catamaran production facility at centre position. Red is a max displacement along a circle due to single mooring, and pink is the max circle. The dimensions of the catamaran is either 50 m x 20 m or 60 m x 20 m; the watch circle depends on depth and slack allowance in the mooring for wave height. ***Courtesy of UNRF.***

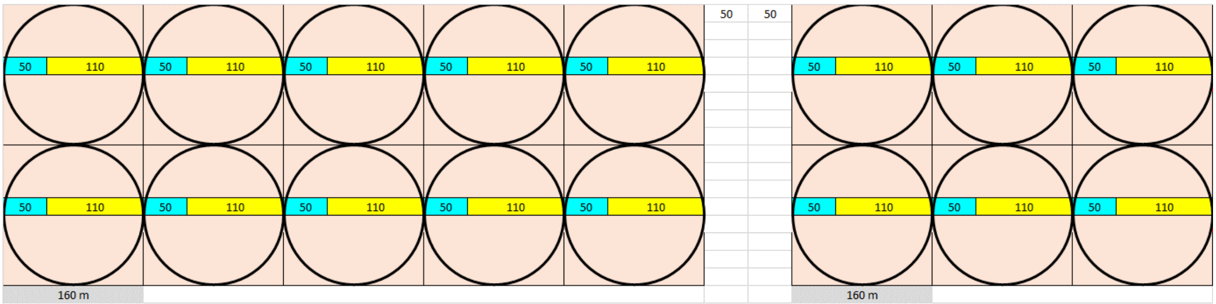
- The structures are continuously moving within a watch circle, depending on the prevailing currents and waves and thus, there is less impact to the benthic communities as there is a frequent change of the position, even at lower depths.

For the production of 2,000 tonnes per year 10 such structures are needed, for the production of 3,000 tonnes per year 16 such structures are needed and for the production of 5,000 tonnes per year, 24 such structures are needed (Scenario 2 in D18 - 50 m length and 20 m width).

Figures 22 and 23 depict the potential layouts and deployment of the new open sea aquaculture station concept of OS Aqua at a depth of 120 m and 160 m respectively.



a



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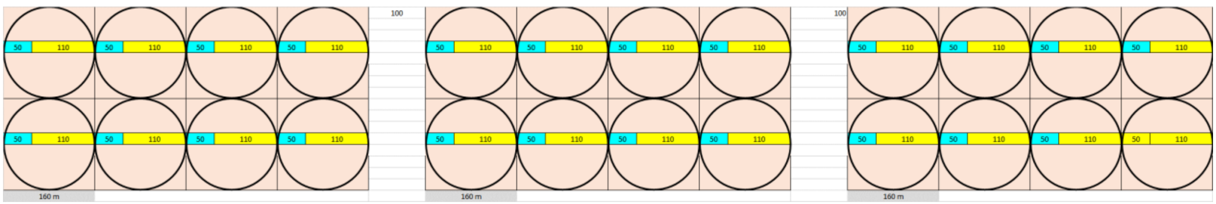
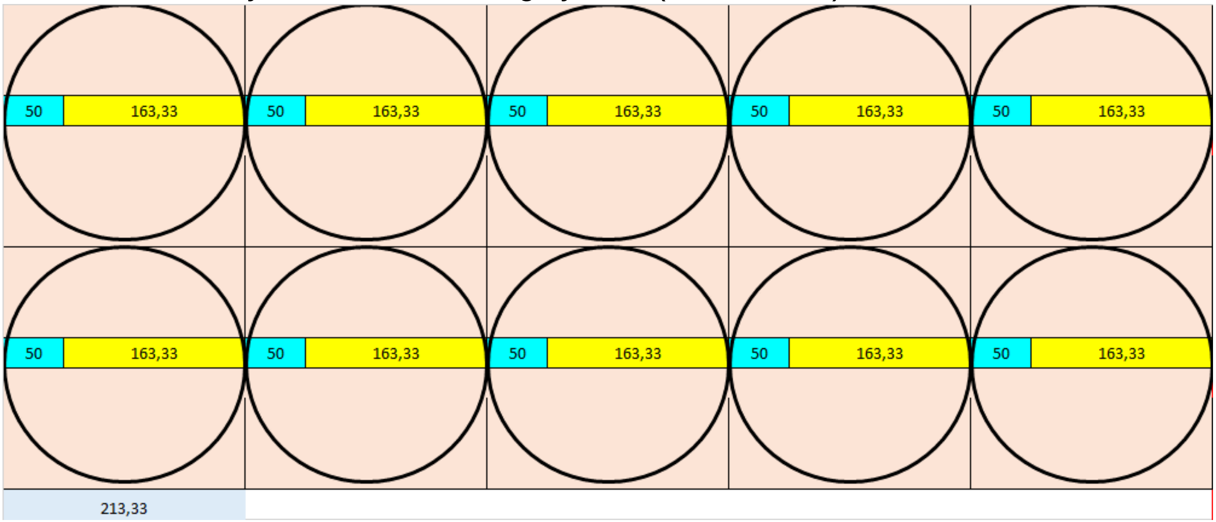


c

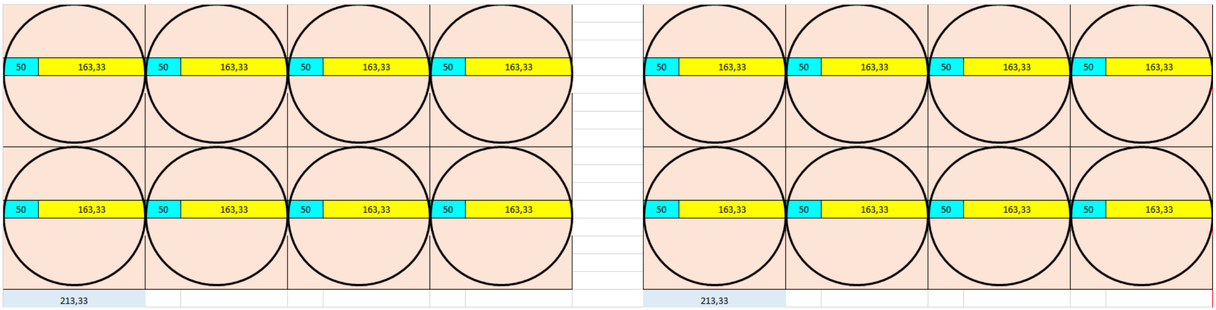
Figure 22. Potential layouts and deployment of the new open sea aquaculture station concept of OS Aqua at a depth of 120m for 2,000 tonnes per year (a), 3,000 tonnes per year (b), and 5,000 tonnes per year (c). The dimensions of the catamaran are 50 m x 20 m (blue colour), and the diameter of each circle is 160 m. The calculations are based on a cone area with a height of 120 m.

At a depth of 120 m, a diameter of 160 m will safeguard that neighboring structures will never collide with each other.

Different combinations and deployment patterns are possible for each area. Of course as the depth is increasing, a larger area is needed, however, the overall marine space that is needed is significantly less compared to the other technologies that are evaluated and rely on a fixed mooring system (see Table 4).



a



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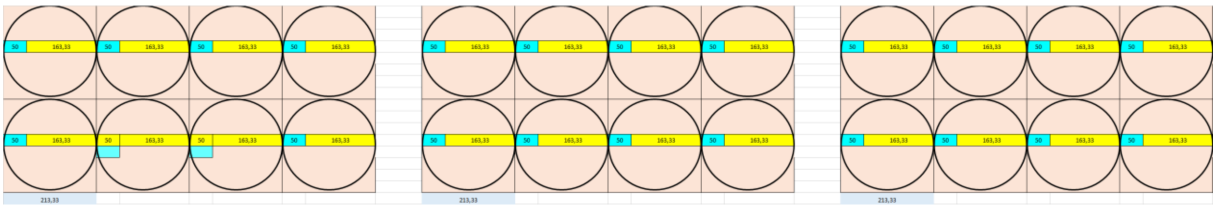


c

Figure 23. Potential layouts and deployment of the new open sea aquaculture station concept of OS Aqua at a depth of 160m for 2,000 tonnes per year (a), 3,000 tonnes per year (b), and 5,000 tonnes per year (c). The dimensions of the catamaran are 50 m x 20 m (blue colour), and the diameter of each circle is 213.33 m. The calculations are based on a cone area with a height of 160 m.

At a depth of 160 m, a diameter of about 213 m will safeguard that neighboring structures will never collide with each other.

1.3.3.1 Pattern for 2,000 tonnes per year

The footprint of the new open sea aquaculture station concept of OS Aqua farm for 2,000 tonnes production per year is shown in Figure 22 for the depth of 120 m and in Figure 23 for the depth of 160 m. 10 such structures are needed to achieve this annual production, and they are organized in 1 "park" of structures with a dimension of 50m length and 20 m width that can move freely in a circle, the area of which depends on the depth. The marine space needed for each structure is 1,000 m^2 (0.001 km^2), so 0.01 km^2 overall, whereas the overall marine space needed is estimated to 0.26 km^2 for a depth of 120m and 0.46 km^2 for a depth of 160m.

1.3.3.2 Pattern for 3,000 tonnes per year

The footprint of the new open sea aquaculture station concept of OS Aqua farm for 3,000 tonnes production per year is shown in Figure 22 for the depth of 120 m and in Figure 23 for the depth of 160 m. 16 such structures with a dimension of 50m length and 20 m width each are needed to achieve this annual production. The single point mooring offers the advantage of numerous possible deployments and configurations. A possible pattern is an organization in 2 "parks" of structures organized in batteries of 8 structures, each that can move freely in a circle, the area of which depends on the depth. The marine space needed for each structure is 1,000 m^2 (0.001 km^2), so 0.016 km^2 overall, whereas the overall marine space needed is estimated to 0.41 km^2 for a depth of 120m and 0.73 km^2 for a depth of 160m.

1.3.3.3 Pattern for 5,000 tonnes per year

The footprint of the new open sea aquaculture station concept of OS Aqua farm for 5,000 tonnes production per year is shown in Figure 22 for the depth of 120 m and on Figure 23 for the depth of 160 m. 24 such structures with a dimension of 50m length and 20 m width each are needed to achieve this annual production. The single point mooring offers the advantage of numerous possible deployments and configurations. A possible pattern is the organization in 3 "parks" of structures organized in batteries of 8 structures each that can move freely in a circle, the area of which depend on the depth. The marine space needed for each structure is 1,000 m^2 (0.001 km^2), so 0.024 km^2 overall, whereas the overall marine space needed is estimated to 0.61 km^2 for a depth of 120m and 1.09 km^2 for a depth of 160m.

1.3.4. The layout of conventional HDPE cage Technology with OS characteristics

For comparison purposes, the layout of conventional HDPE cage Technology with OS characteristics is provided. This technology could be adopted in an area with less significant wave height, such as the Governor's Beach area.

The following Figure 24 depicts a possible layout for a farm with 2,000, 3,000, and 5,000 tonnes annual production capacity.

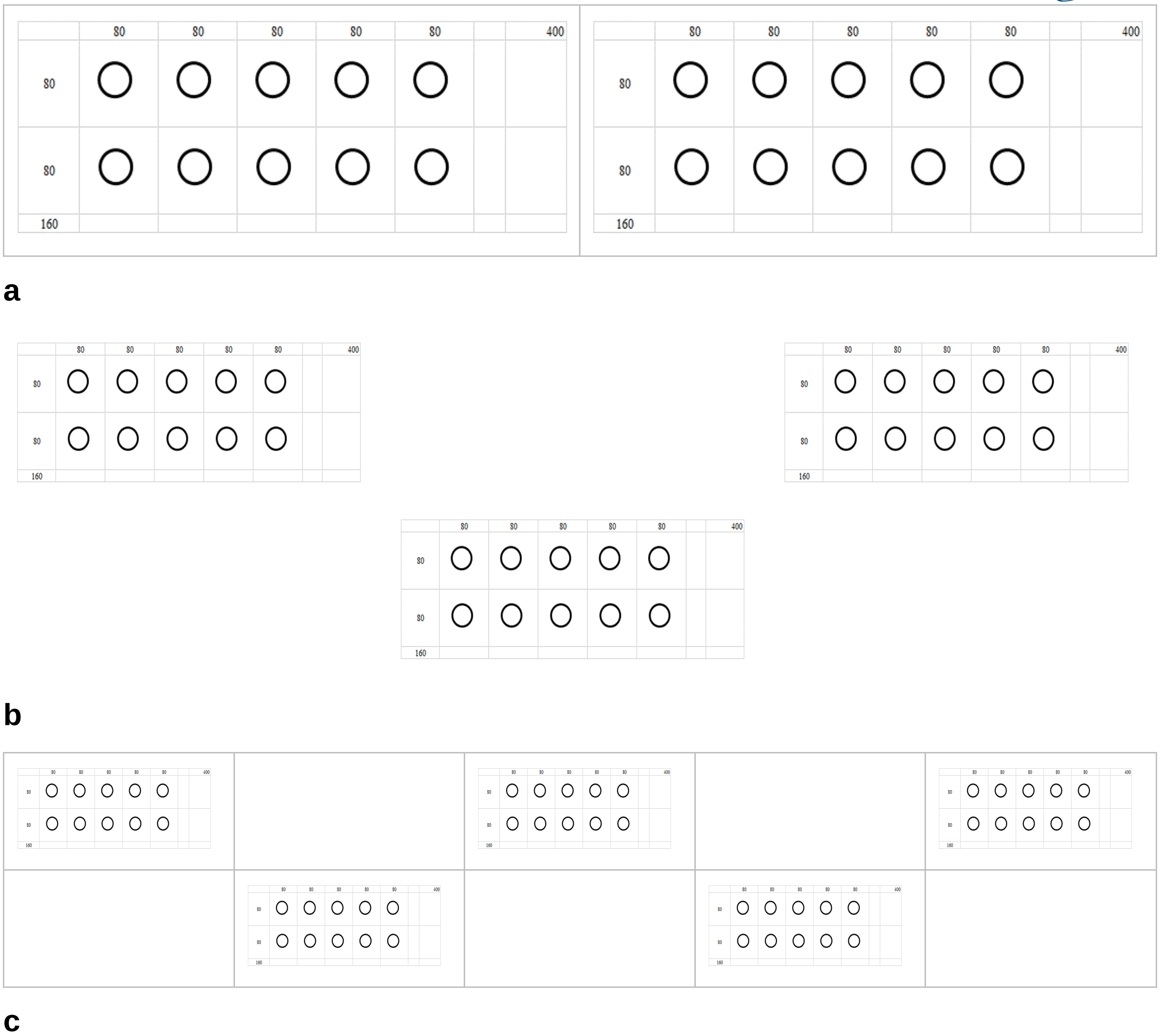


Figure 24. Potential layouts and deployment of conventional HDPE cages for 2,000 tonnes per year (a), 3,000 tonnes per year (b) and 5,000 tonnes per year (c).

1.3.4.1 Pattern for 2,000 tonnes per year

For production of 2,000 tonnes per year, 10 circular cages of 100 m perimeter (inner diameter 31.9 meters, outer diameter 33.3m) (128,000 m^2 total marine surface area for the cages for the P100s) is needed. The cages will be organised in 2 parks. Each park will have dimensions 400m x 160 m (64,000 m^2 area). The total area of marine parks: 128,000m^2. The mooring system will consist of anchors, chains, and ropes. The dimensions of the grid system of mooring system is 4–4.4 times the depth of the site (for each side of the grid system) and define the marine space needed (footprint).

1.3.4.2 Pattern for 3,000 tonnes per year

For the production of 2,000 tonnes per year, 30 circular cages of 100 m perimeter (inner diameter 31.9 meters, outer diameter 33.3m) (192,000 m^2 total marine surface area for the cages for the P100s) is needed. The cages will be organised in 3 parks. Each park will have dimensions 400m x 160 m (64,000 m^2 area)—the total area of marine parks: 192,000m^2. The mooring system will consist of anchors, chains, and ropes. The dimensions of the grid system of the mooring system are 4–4.4 times the depth of the site (for each side of the grid system) and define the marine space needed (footprint).

1.3.4.3 Pattern for 5,000 tonnes per year

For production of 5,000 tonnes per year, 50 circular cages of 100 m perimeter (inner diameter 31.9 meters, outer diameter 33.3m) (320,000 m^2 total marine surface area for the cages for the P100s) is needed. The cages will be organized in 5 parks. Each park will have dimensions 400m x 160 m (64,000 m^2 area). Total area of marine parks: 320,000m^2. The mooring system will consist of anchors, chains, and ropes. The dimensions of the grid system of the mooring system are 4–4.4 times the depth of the site (for each side of the grid system) and define the marine space needed (footprint).

Conventional HDPE floating marine cages of 100 m circumference might be a good alternative and a good value for money technology in areas with significant waves of no more than 6 m (Perez et al., 2003; Cardia and Lovatelli, 2015).

1.3.5. Issues with the deployment patterns and possible corrective actions

Table 5 summarises a number of incompatible deployment patterns that could create technical challenges for the installation of the OS Aqua units. These challenges entail technical difficulties to operate at depths of more than 200 m as well as a cost increase that might jeopardise the financial viability of the OSC AZAs. For this reason, in the implementation stage, a more detailed deployment and mooring design need to take place in cooperation with the Technology Provider that will install the cages/structures. Some potential alternative deployments are suggested and denoted with blue arrows in Annex 4.

2. Model Setup

2.1. Mass balance calculations

For the mass balance calculations, growth rates of sparidae have been considered as there is a long-lasting experience with these species. The following conditions were considered:

2.1.1. Temperature

The mean monthly seawater temperatures considered were extracted from mean satellite sea surface temperature (SST) data for the period (2015-2018) (see Table 3).

Table 3. Mean monthly seawater temperatures from satellite SST data for 2015-2018.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	17,42	16,80	16,80	18,57	19,58	23,28	26,17	26,50	26,25	25,20	22,84	19,74
2	17,49	16,87	16,88	18,64	19,58	23,29	26,15	26,52	26,30	25,25	22,87	19,78
3	17,57	16,94	17,05	18,83	19,63	23,36	26,16	26,66	26,56	25,25	22,72	19,65
4	17,55	16,92	17,04	18,84	19,59	23,34	26,11	26,61	26,53	25,24	22,69	19,64
5	17,52	16,88	17,00	18,82	19,52	23,31	26,00	26,50	26,42	25,22	22,66	19,65
6	17,52	16,88	17,01	18,82	19,53	23,31	26,00	26,51	26,43	25,22	22,66	19,65
7	17,55	16,92	17,03	18,84	19,59	23,33	26,11	26,61	26,52	25,24	22,69	19,64
8	17,56	16,94	17,05	18,82	19,62	23,35	26,14	26,62	26,56	25,25	22,71	19,64
9	17,58	16,96	17,06	18,81	19,66	23,39	26,19	26,72	26,59	25,26	22,73	19,65
10	17,81	17,32	17,19	19,05	20,08	24,17	27,20	28,01	27,25	25,21	22,53	19,17
11	17,59	16,98	17,06	18,79	19,68	23,41	26,21	26,78	26,62	25,27	22,72	19,67
OS1	17,61	17,01	17,23	18,29	20,62	23,90	26,91	28,04	27,64	25,73	22,71	19,72
OS2	17,61	16,99	17,22	18,22	20,33	23,46	26,55	27,72	27,47	25,72	22,70	19,78
OS3	17,72	16,99	17,22	18,19	20,26	22,92	25,99	27,20	27,19	25,63	22,64	19,93
OS4	17,74	17,00	17,08	18,15	20,58	23,63	27,04	27,99	27,05	25,38	22,87	20,15

Sites 1-10 correspond to the existing licenses for marine aquaculture in Cyprus (1& 2 Neo Limani-Limassol, 3 & 4 Pentakomo-Limassol, 5&6 Moni-Limassol, 7 Agios Georgios Alamanou-Limassol, 8 Governor's Beach – Limassol, 9 c, 10 Potamos Liopetriou Famagusta, 11 Vasiliko-Limasssol) whereas OS1 is Xylofagou West, OS2 is Larnaca, OS3 is Governor's Beach and OS4 is Aphrodite Hills (see also Annex 1).

2.1.2. Feed and feeding

The feed considered has a 42-47% protein, total fat 19-22%, Ash 6.3-8.3%, and 21 MJ/kg metabolisable energy, with a 6 day per week feeding.

2.1.3. Stocking of juveniles

The mass balance estimates are based on the assumption that juveniles are stocked 5 times per year on March, April, May, June, and September and that the initial fingerlings have an average weight of 7.5 gr. Like that the mortality of 2-4% of the initial stages (2-10 gr) is eliminated, and the production period is shorter by 30-45 days.

Hatcheries in Europe (e.g. in Greece) can produce up to 8 gr fry for seabass and seabream and up to 5 gr of meagre and red porgy. It is also possible that the operation of the open sea farms will be combined with the operation of the existing farms, and the initial stages (2-40 gr) can be cultivated nearshore and the actual on-growing to take place in the Open Sea installations.

2.2. The AIM Model and its sub-models in Cyprus

The Aquaculture Integrated Model (AIM, Tsagaraki et al., 2011), a modelling tool developed at the Hellenic Centre for Marine Research (HCMR), has been customized and implemented in the Cyprus area to assess the environmental impact of existing and future aquaculture. The model setup is briefly described below. More details may be found in D10.

The Aquaculture Integrated Model (AIM) consists of a comprehensive generic biogeochemical model, based on ERSEM (Baretta et al., 1995), which is coupled with a three-dimensional (3-D) hydrodynamic model, based on Princeton Ocean Model (POM; Blumberg and Mellor, 1987). A series of nested models (see Fig. 25) is used to consistently downscale the hydrodynamics and biogeochemistry from the coarse resolution (~5 km horizontal resolution) model, covering the entire Mediterranean, to fine-resolution (100-400m resolution) models in the Cyprus coastal areas. First, the basin-scale Mediterranean model (MED20) is downscaled to a model with higher resolution (~400m), covering the Cyprus extended area (Cyp-All, see Fig. 25). This model provides boundary conditions to three nested sub-models (Cyp-1, Cyp-2, Cyp-3, see Fig.25) with the same resolution (~400m) that cover the Cyprus coastal regions and are used to evaluate the environmental impact of existing and future open sea aquaculture fish farms. 11 existing fish farm units (see red dots in Fig. 25) were parameterized in sub-models Cyp-1 and Cyp-2. Additionally, four open sea fish farms were parameterised in the selected areas (see green dots in Fig.25):

1. Xylofagou West (point 2)
2. Larnaca (point 3)
3. Governor's Beach (Center & East) (point 6)
4. Aphrodite Hills (point 7)

Using the above-described mass balance model (section 2.1) and monthly data on supplied feed, the released dissolved (NH_4, PO_4) and particulate (POC, PON, POP) effluents from each fish farm location were calculated on a monthly basis and parameterized in the model, adopting an input flux (phosphate, ammonium or particulate organic matter) at the surface layer of the specified model grid points.

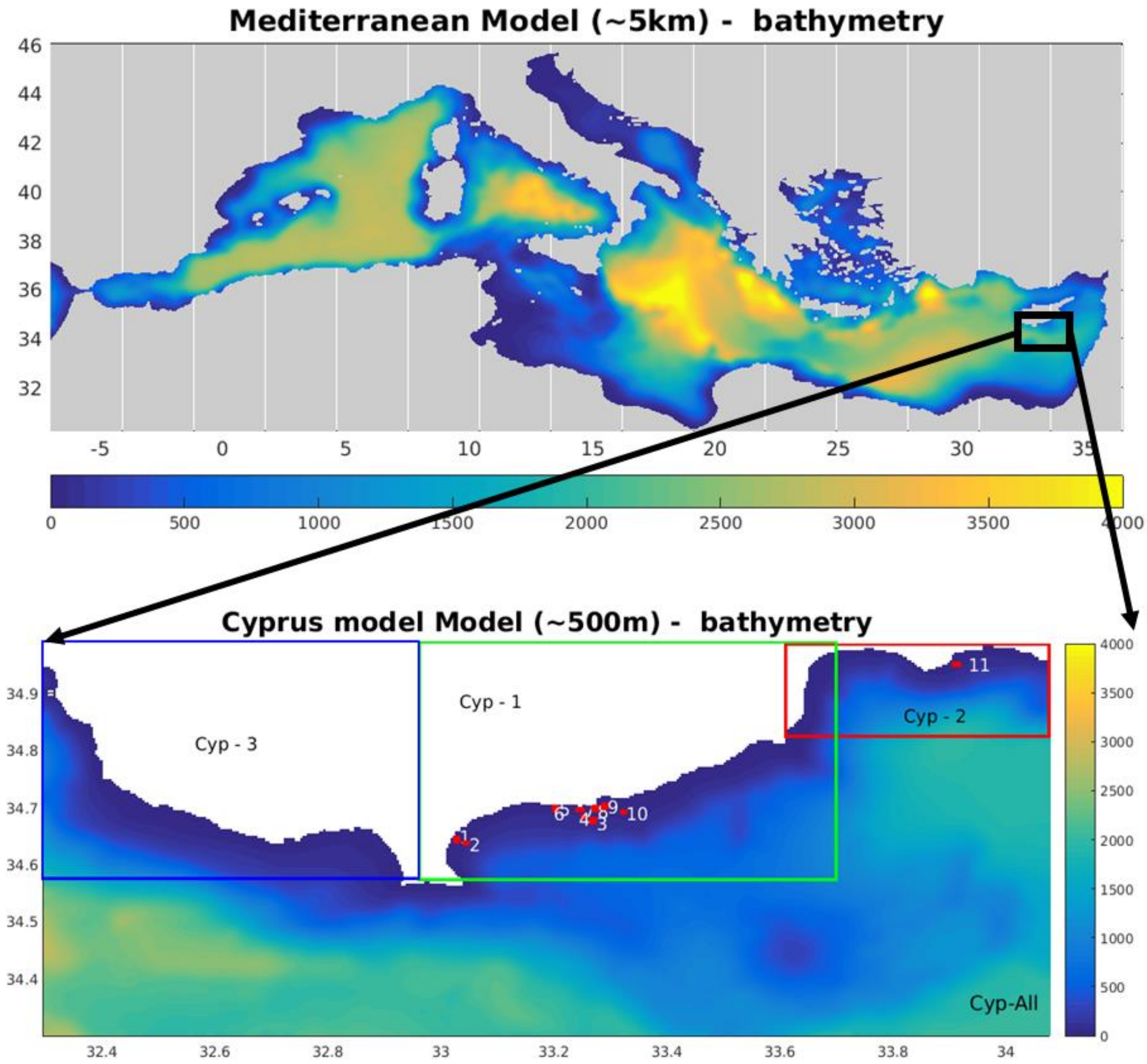


Figure 25: Domain and bathymetry of the nested models: Mediterranean Sea (~5Km horizontal resolution, top) and Cyprus Sea (~400m horizontal resolution, bottom).

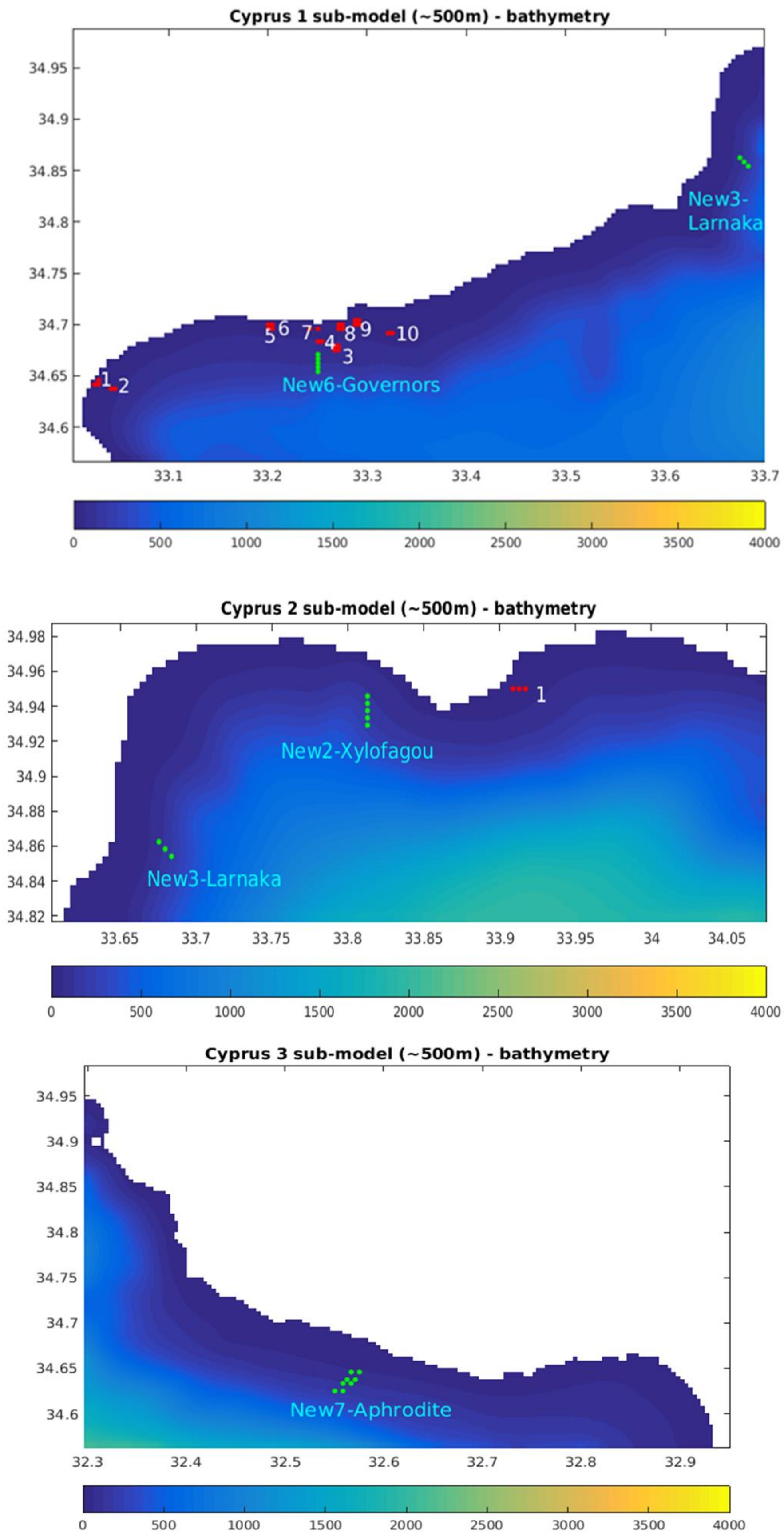


Figure 26: The three nested sub-models (~500m resolution, Sub-model 1,2 ,3) in the Cyprus domain, existing (red dots) and open sea potential new (green dots) fish farms are also indicated. The red dots represent the existing licences (see Table 3 for existing site areas 1-11).

2.2.1. The preliminary model runs

A series of scenario simulations (see Table 4) were performed with the high-resolution sub-models (Cyp-1, Cyp-2, Cyp-3), covering the selected areas (Xylofagou West, Larnaca, Governor's Beach, Aphrodite Hills) for open sea aquaculture:

Table 4. Scenario simulations, performed with Cyp-1, Cyp-2, Cyp-3 sub-models (see Fig 25 for the sub-model areas).

Production (kt)	Cyp-1	Cyp-2	Cyp-3
Ref0	No fish farms	-	-
Ref	Existing farms (8.5kt)	Existing farms (0.5kt)	No fish farms
Sc1	Existing farms (8.5kt) + Governors (2kt)/ Larnaca (2kt)	Existing farms (0.5kt) + Xylofagou(2kt)/ Larnaca (2kt)	Aphrodite (2kt)
Sc2	Existing farms (8.5kt) + Governor (5kt)/ Larnaca (3kt)	Existing farms (0.5kt) + Xylofagou(5kt)/ Larnaca (3kt)	Aphrodite (5kt)

In the reference simulations (Ref), the existing fish farms were included in Cyp-1 and Cyp-2 sub-models, as there no fish farms in the Cyp-3 sub-model area in Western Cyprus. In Cyp-1 sub-model area, an additional simulation (Ref0) was performed, with no fish farms, given the significant production (total 8kt) of existing farms in coastal areas. Two additional scenarios (Sc1, Sc2) were performed, assuming a lower (2kt) and higher (5kt) production of the Open Sea aquaculture farms. In the case of Larnaca selected area, a relatively lower production (3,000 tonnes) was adopted for the high impact scenario, as in this area there are geographical limitations and conflicts for the deployment of a 5,000 tonnes per year farm (see section 1.3.5 Issues with the deployment patterns and possible corrective actions). In almost all cases, the Open Sea aquaculture layout was based on the Cypriot design, as it requires less space compared to all the other technologies (see Table 4) and therefore could give a "boost" of effluents necessary to test the limits of the ecosystems and identify the carrying capacity in each selected area. A different layout (Badinotti's submerged cages, see section 1.3.1) was adopted in Aphrodite's hills area, as it is more exposed and perhaps a submerged technology could be adopted to address the adverse weather conditions that prevail in this area.

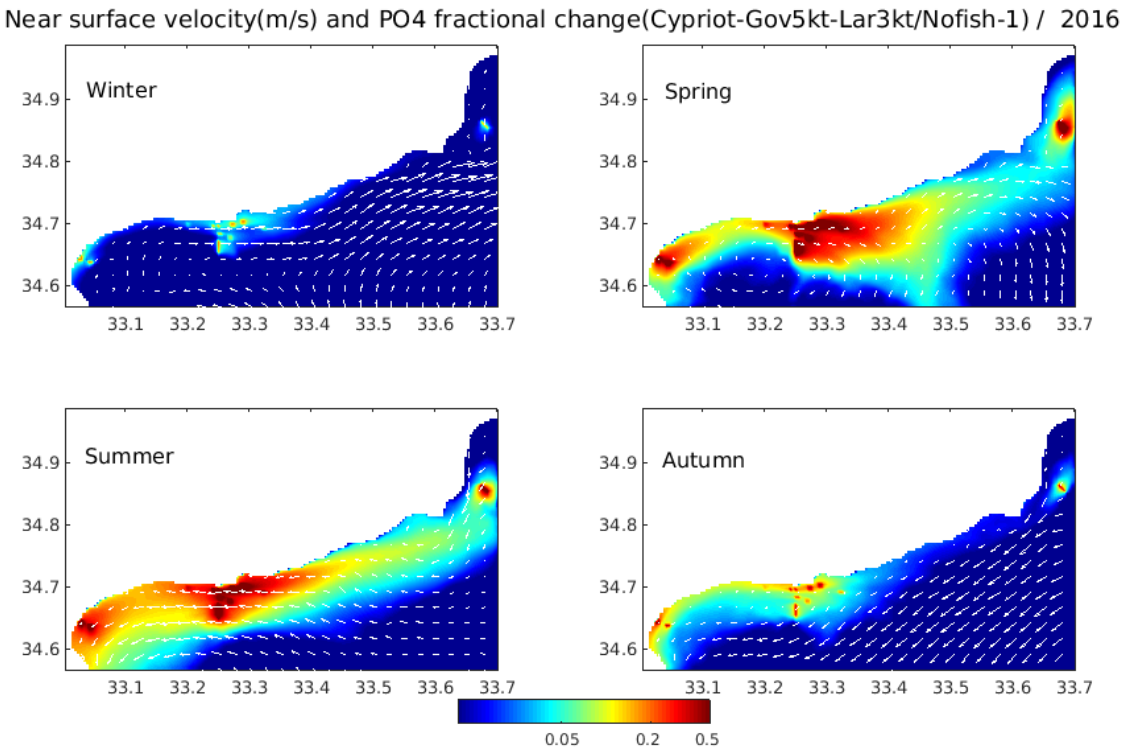


Figure 27: Simulated seasonal mean near surface current velocity and phosphates (PO_4) fractional change (Sc2/Ref0-1) during 2016. The scenario simulation (Sc2) includes the impact from existing coastal fish farms (see Fig.25 & Fig. 26) and also Governor's beach (5kt) and Larnaca (3kt) open sea aquaculture. The reference (Ref0) simulation has no fish farms. A fractional change=0.5 indicates an increase of +50%.

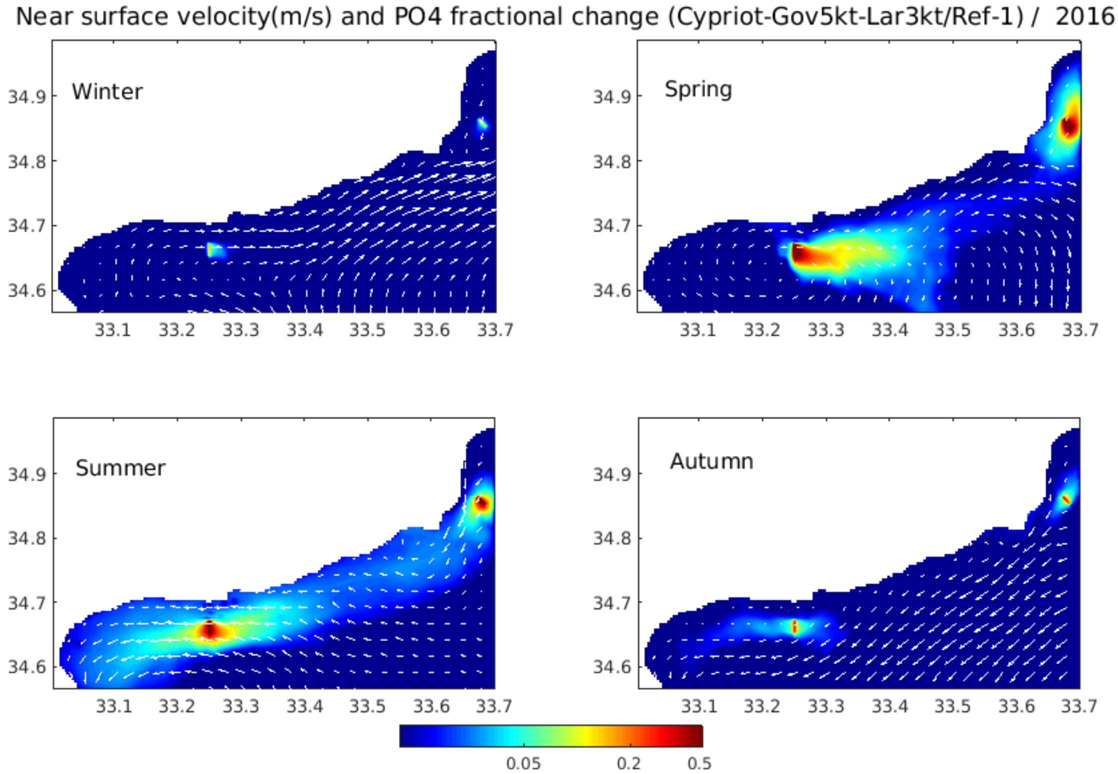


Figure 28: Simulated seasonal mean near surface current velocity and phosphates (PO_4) fractional change (Sc2/Ref-1) during 2016. The scenario simulation (Sc2) includes the impact from existing coastal fish farms (see Fig.25 and fig. 26) and also Governor's beach (5kt) and Larnaca (3kt) open sea aquaculture. The reference (Ref) simulation includes the impact from only existing coastal fish farms. A fractional change=0.5 indicates an increase of +50%.

In Figure 26, the seasonal mean relative increase of phosphates, resulting from both existing and new open sea fish farms (Governor's beach and Larnaca) in Cyp-1 area is shown. This relative increase is significantly reduced (Figure 27), considering the impact from only new open sea farms. The effect from fish farms appears relatively stronger during the spring-summer period. This seasonality is mainly related to the variability of vertical mixing, being stronger during autumn-winter period and also to fish feed and aquaculture effluents, which are higher during spring period. The prevailing circulation in the area during winter-spring period is characterized by a north-eastern current, as part of the dominant large-scale anticyclonic circulation in the southeast Cyprus open sea area. During summer-autumn, coastal currents reverse to south-western, following the larger-scale cyclonic circulation in the Southeast area of the Cyprus model domain (see D10). Thus, the effluents from existing farms in Akrotiri bay and the open sea farm at Governor's beach area follow a north-eastward pathway during winter-spring, which reverses to south-west during summer-autumn (Figure 26, see also Figure 7).

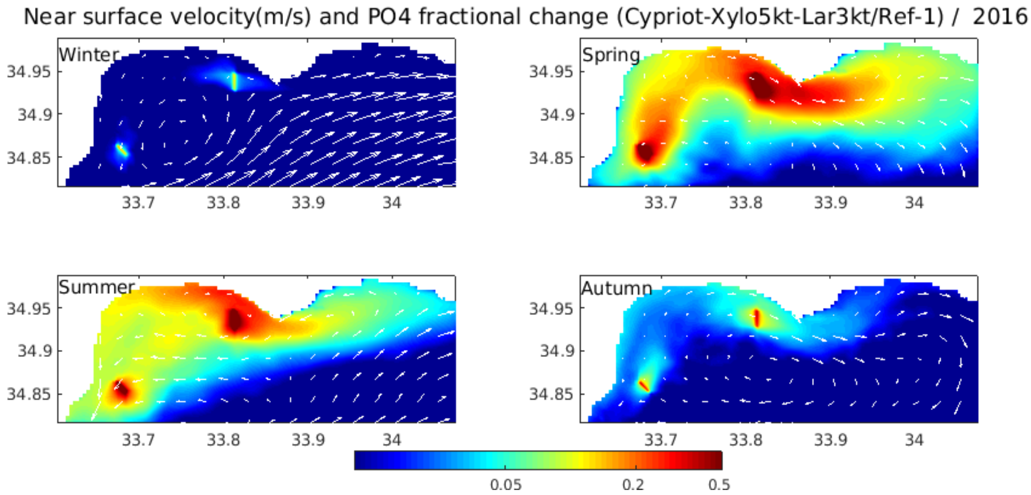


Figure 29: Simulated seasonal mean near surface current velocity and phosphates (PO_4) fractional change (Sc2/Ref-1) during 2016. The scenario simulation (Sc2) includes the impact from existing coastal fish farms (see Fig.25 and Fig. 26) and also new open sea aquaculture at Xylofagou-West (5kt) and Larnaca (3kt) sites. The reference (Ref) simulation includes the impact from only existing coastal fish farms. A fractional change=0.5 indicates an increase of +50%.

In Figure 28, the seasonal mean relative increase of phosphates, resulting from both existing and new open sea fish farms (Xylofagou and Larnaca) in Cyp-2 area is shown. Again, the effect from fish farms is relatively stronger during spring-summer period. The prevailing off-shore circulation in the area is characterized by a north-eastern current, as part of the dominant large-scale anticyclonic circulation, while the circulation in Larnaca bay is mostly anti-cyclonic, except winter period. Thus, the effluents from the open sea farm at Xylofagou area usually follow an eastward pathway that occasionally reverses to westward, while the circulation at Larnaca open sea farm is predominantly south-westward (Figure 29, see also Figure 5-6). However, there are periods (e.g. spring), when effluents from Larnaca site move to the North-East following the anti-cyclonic circulation in Larnaca bay.

In Figure 30, the seasonal mean relative increase of phosphates, resulting from the new open sea fish farm at Aphrodite's hills area in Cyp-3 area is shown. As in Cyp-1/Cyp-2 areas, the effect from fish farms is relatively stronger during spring-summer period. During autumn-winter, the effluents from the open sea farm follow a south-eastward pathway, reversing to north-westward during spring-summer, based on the large-scale cyclonic circulation in the area.

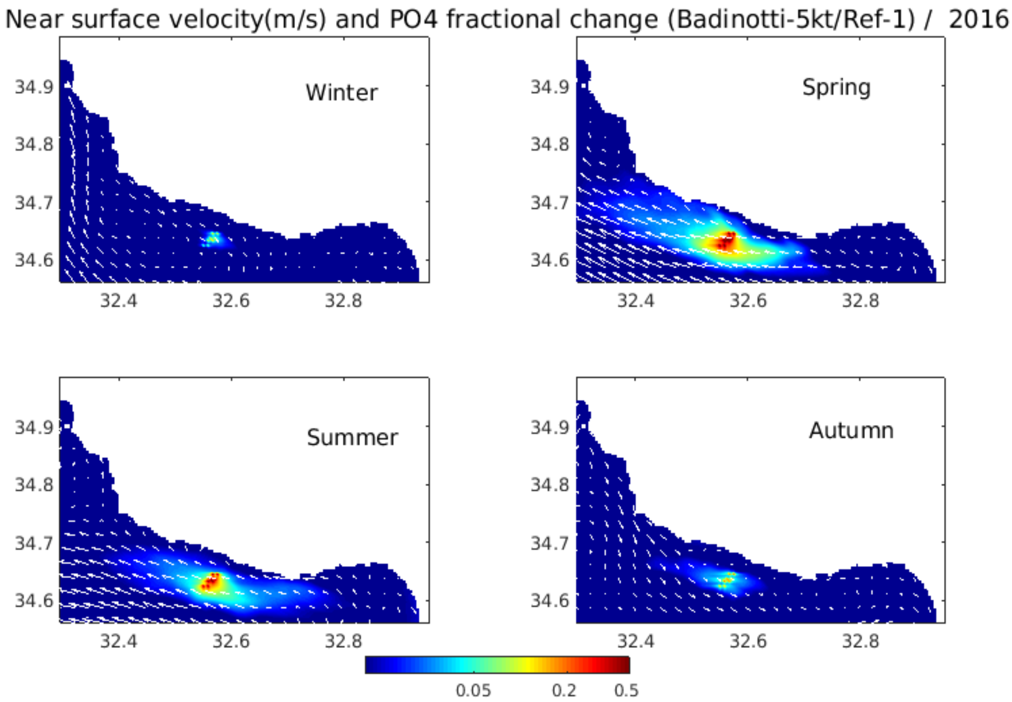


Figure 30: Simulated seasonal mean near surface current velocity and phosphates (PO_4) fractional change (Sc2/Ref-1) during 2016. The scenario simulation (Sc2) includes the impact from new open sea aquaculture (5kt) at Aphrodite's hills site. In the reference (Ref) simulation there are no fish farms. A fractional change=0.5 indicates an increase of +50%.

The impact of aquaculture wastes, in terms of good environmental status, can be assessed using the model simulated outputs, by means of Eutrophication Index (E.I., Primpas et al., 2010), an extensively used environmental indicator that is considered particularly suitable for coastal ecosystems (Pavlidou et al., 2015) :

$$E.I.=0.279*PO_4 + 0.261*NO_3+ 0.296*NO_2+ 0.275*NH_4+ 0.214*Chl\text{-}a$$

with PO_4, NO_3, NO_2, NH_4 in mmol/m^3 and Chl-a in mg/m^3) and the following environmental scaling:

<0.04 very good, 0.04 - 0.38 good, 0.38 - 0.85 moderate, 0.85 - 1.51 poor, > 1.51 bad

In Figure 30, the calculated indicator during spring-summer, the period with relatively stronger impact from aquaculture, as discussed above, is shown for different scenarios in Cyp-1 area. During spring, the E.I. indicates good to moderate environmental conditions even in the vicinity of the fish farms, suggesting that aquaculture wastes are effectively dispersed by ocean currents. One may notice the relatively small effect of open sea aquaculture at Governor's beach, as compared to the effect from existing farms, particularly for the low-production scenario (2kt). During summer, the E.I. indicates "good" conditions in the entire area, as the increased stratification results in an overall decrease of dissolved inorganic nutrients and plankton productivity. Similarly, in figures 31-32, the calculated E.I. is shown for different scenario simulations in Cyp-2 and Cyp-3 areas. Again, the E.I. indicates good to moderate environmental conditions during spring and good conditions during summer period. 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. In Figure 34, the mean current speed and E.I. value in the vicinity of different aquaculture areas is shown for different scenarios. Among the open sea aquaculture areas, Xylofagou and Larnaca areas present the relatively weaker currents, which may explain the slightly higher E.I. values, as compared to Governor's beach and Aphrodite's hills, is characterized by much stronger currents. One may also notice the relatively lower E.I. values in the later areas, as compared to the existing coastal fish farms in Cyp-1. The horizontal variability of the E.I. index in all three areas may be seen in Figure 35. Finally, the impact of the fish farm wastes on the marine ecosystem functioning in the three different areas can be seen in Figures 36-39. Dissolved inorganic nutrients (PO_4) are increased by as much as ~100% in the vicinity of the fish farms. This relative increase might seem significant, but we should note that the Cyprus Sea, as part of Levantine basin, is generally an oligotrophic area characterized by very low concentrations of nutrients. The increase of dissolved inorganic nutrients triggers a small increase in net primary production, mostly in the vicinity of fish farms (~10-50%), while phytoplankton (Chl-a) shows a slightly lower increase by as much as ~2-10% in the same areas. A stronger increase in Chl-a and other plankton groups may be seen in Cyp-1 coastal area with existing fish farms (Figure 35) and in the vicinity of Xylofagou open sea aquaculture in Cyp-2 area (Figure 38).

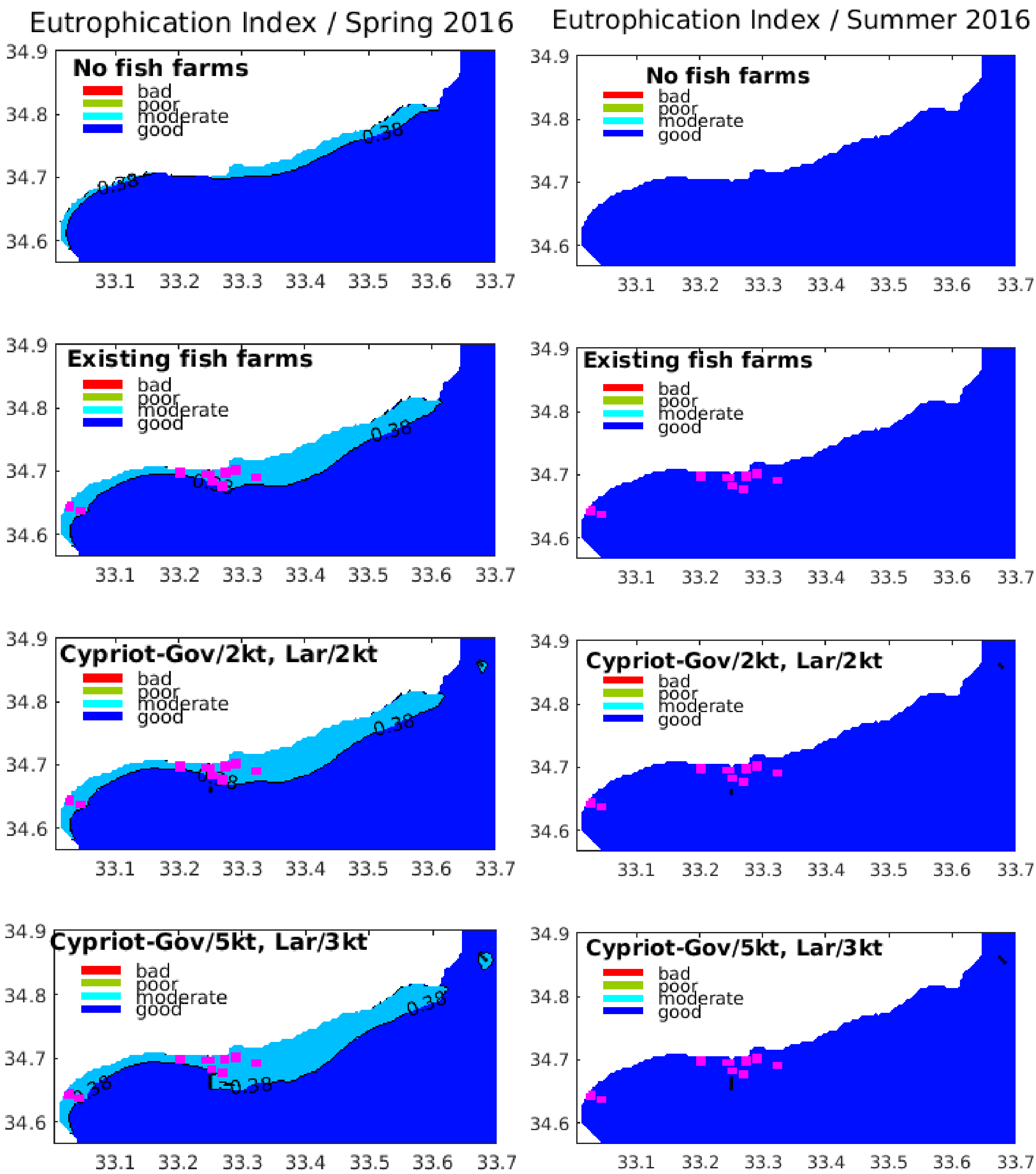


Figure 31: Simulated Eutrophication Index (E.I) with Cyp-1 sub-model, during spring (left) and summer (right) 2016, indicating environmental status (<0.04 very good, 0.04 - 0.38 good, 0.38 - 0.85 moderate, 0.85 - 1.51 poor, > 1.51 bad) in different scenario simulations: no fish farms (top row), existing fish farms (second row), existing fish farms+Governor's beach (2kt) and Larnaca (2kt) open sea farms (third row), existing fish farms+Governor's beach (5kt) and Larnaca (3kt) open sea farms (bottom raw) (see Table 4). Existing (red dots) and new (black dots) OS farms are indicated.

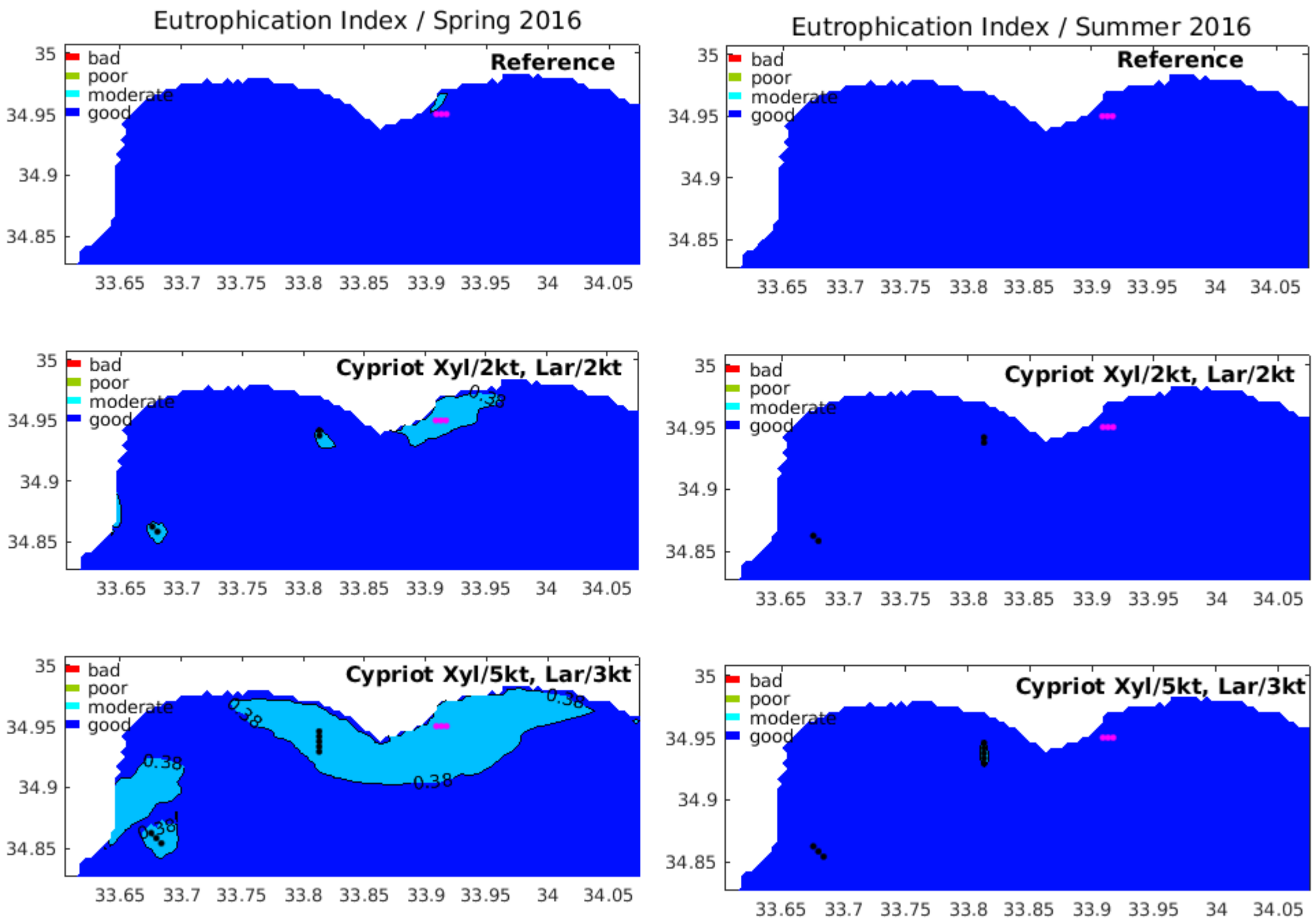


Figure 32: Simulated Eutrophication Index (E.I) with Cyp-2 sub-model, during spring (left) and summer (right) 2016, indicating environmental status (<0.04 very good, 0.04 - 0.38 good, 0.38 - 0.85 moderate, 0.85 - 1.51 poor, > 1.51 bad) in different scenario simulations: existing fish farms (top), existing fish farms+Xylofagou (2kt) and Larnaca (2kt) open sea farms (middle), existing fish farms+Xylofagou (5kt) and Larnaca (3kt) open sea farms (bottom) (see Table 4).

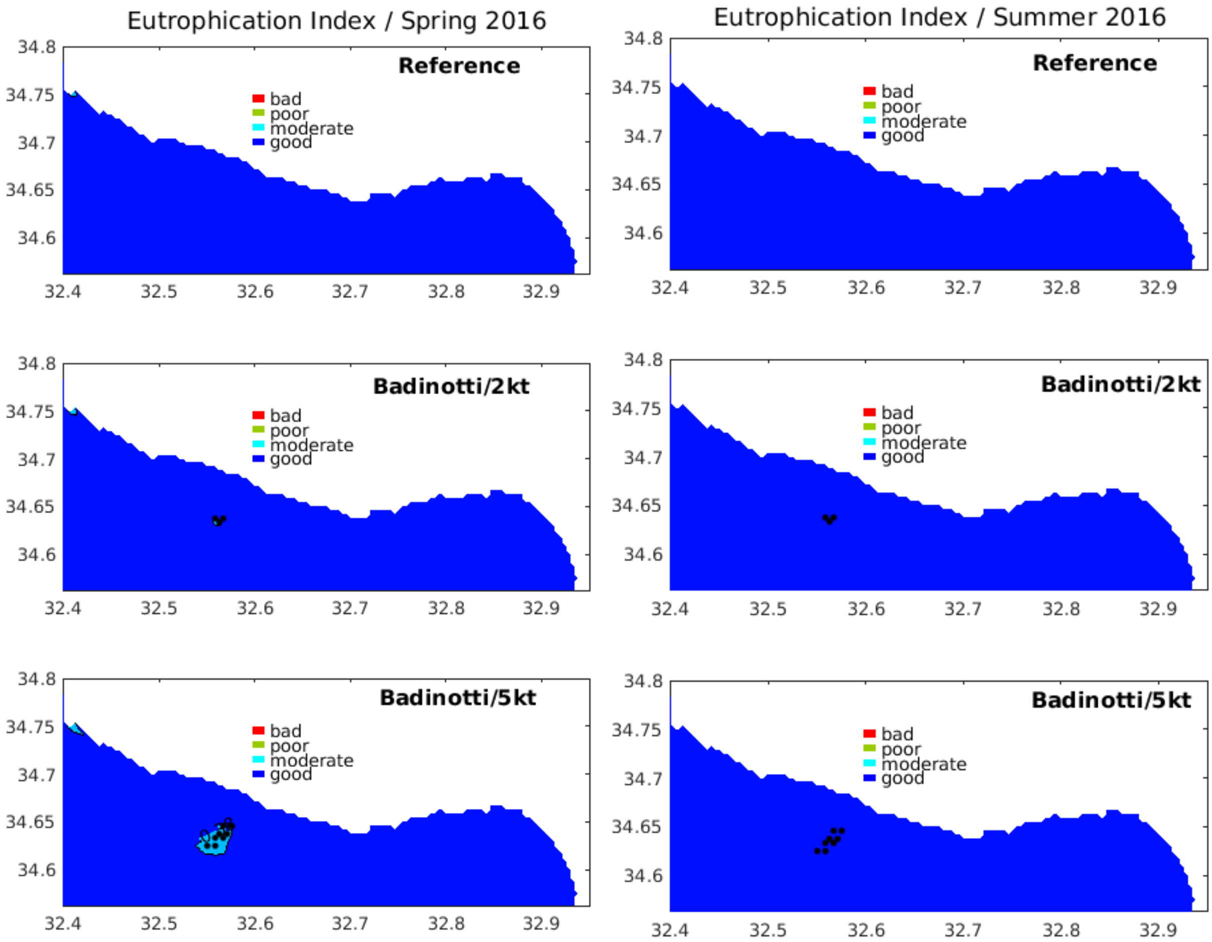


Figure 33: Simulated Eutrophication Index (E.I) with Cyp-2 sub-model, during spring (left) and summer (right) 2016, indicating environmental status (<0.04 very good, 0.04 - 0.38 good, 0.38 - 0.85 moderate, 0.85 - 1.51 poor, > 1.51 bad) in different scenario simulations: existing fish farms (top), existing fish farms+Xylofagou (2kt) and Larnaca (2kt) open sea farms (middle), existing fish farms+Xylofagou (5kt) and Larnaca (3kt) open sea farms (bottom) (see Table 4).

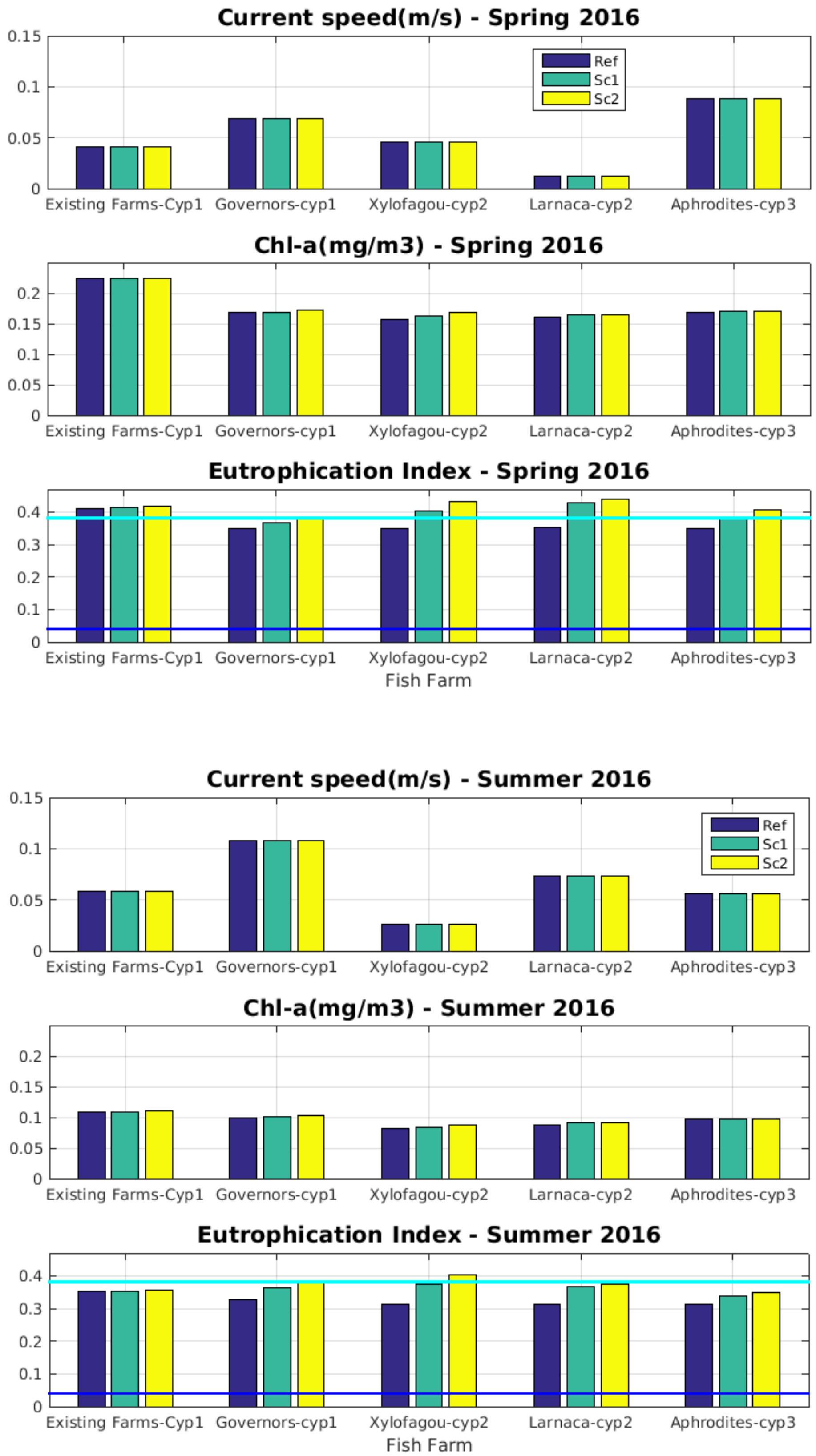


Figure 34: Simulated current speed (m/s, top), Chl-a (mg/m^3) and Eutrophication Index (E.I), indicating environmental status (<0.04 very good, 0.04 - 0.38 good, 0.38 - 0.85 moderate, 0.85 - 1.51 poor, > 1.51 bad) in the vicinity of fish farms for different scenario simulations: (Ref, Sc1, Sc2, see Table 7), during spring (top) and summer (bottom) 2016.

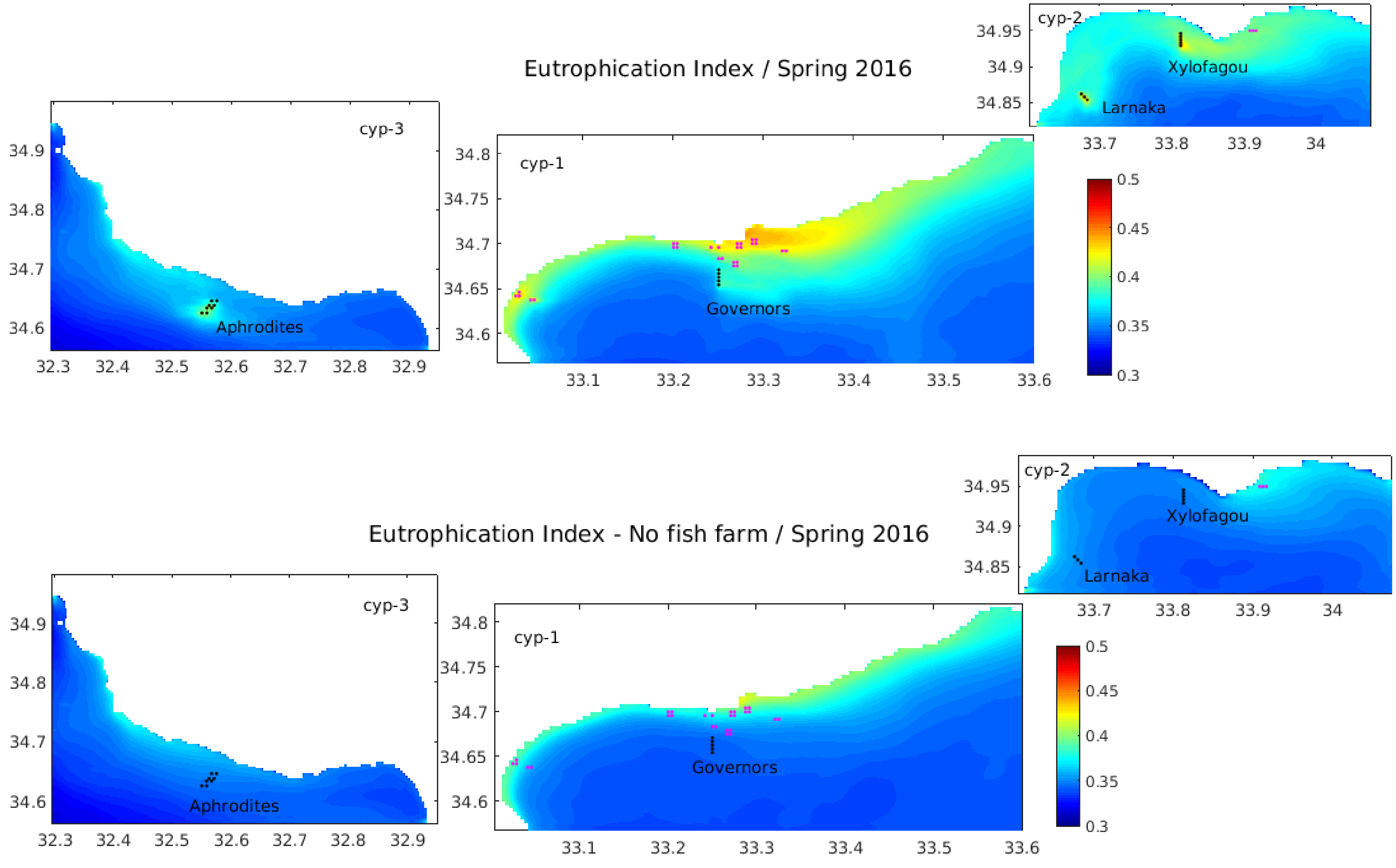


Figure 35: Simulated Eutrophication Index (E.I), indicating environmental status (<0.04 very good, 0.04 - 0.38 good, 0.38 - 0.85 moderate, 0.85 - 1.51 poor, > 1.51 bad) in all three areas (Cyp-1, Cyp-2, Cyp-3) during spring 2016, for the high production scenario (Sc2, see Table 7, top) and without fish farms (bottom).

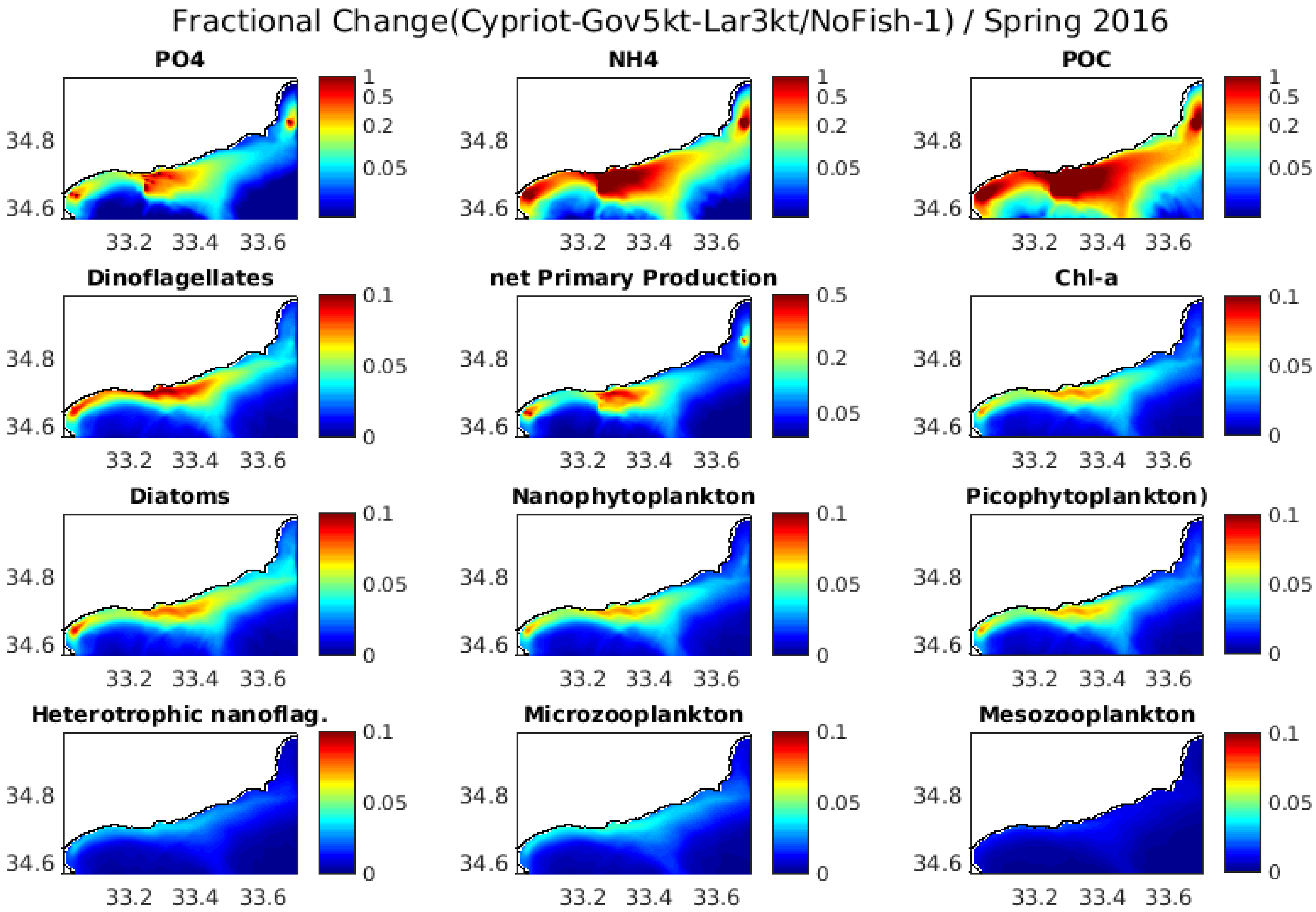


Figure 36: Simulated fractional change (Sc2/Ref0-1, see Table 4) of near surface PO_4, NH_4, POC, Chl-a, net primary production and biomass of diatoms, dinoflagellates, nanophytoplankton, picophytoplankton, mesozooplankton, microzooplankton and heterotrophic nanoflagellates with Cyp-1 model during spring 2016. This figure indicates the relative increase due to existing and new open sea farms.

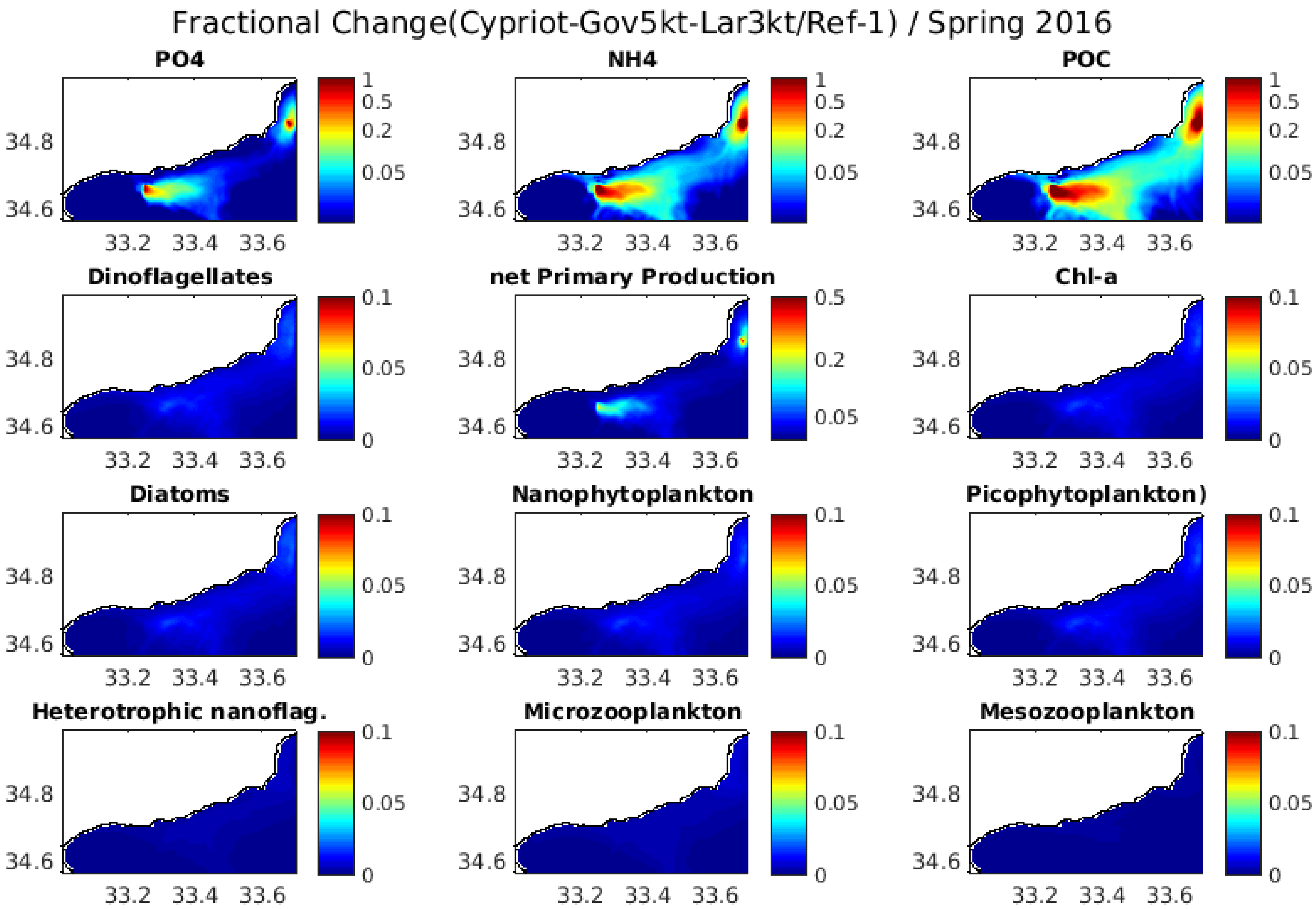


Figure 37: Simulated fractional change (Sc2/Ref-1, see Table 4) of near-surface PO_4, NH_4, POC, Chl-a, net primary production and biomass of diatoms, dinoflagellates, nanophytoplankton, picophytoplankton, mesozooplankton, microzooplankton and heterotrophic nanoflagellates with Cyp-1 model during spring 2016. This figure indicates the relative increase due to new open sea farms only.

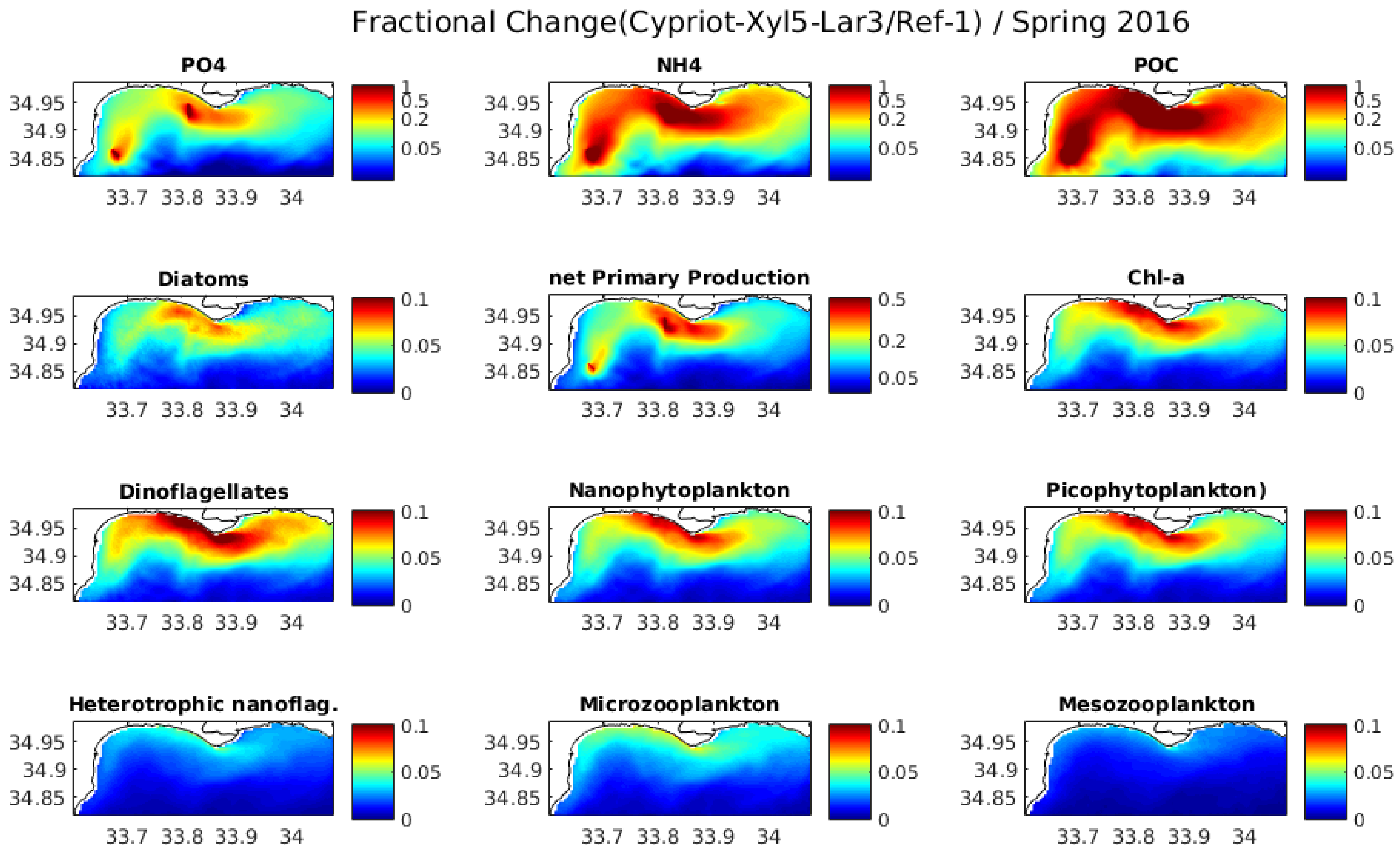


Figure 38: Simulated fractional change (Sc2/Ref-1, see Table 4) of near-surface PO4, NH4, POC, Chl-a, net primary production and biomass of diatoms, dinoflagellates, nanophytoplankton, picophytoplankton, mesozooplankton, microzooplankton and heterotrophic nanoflagellates with Cyp-2 model during spring 2016.

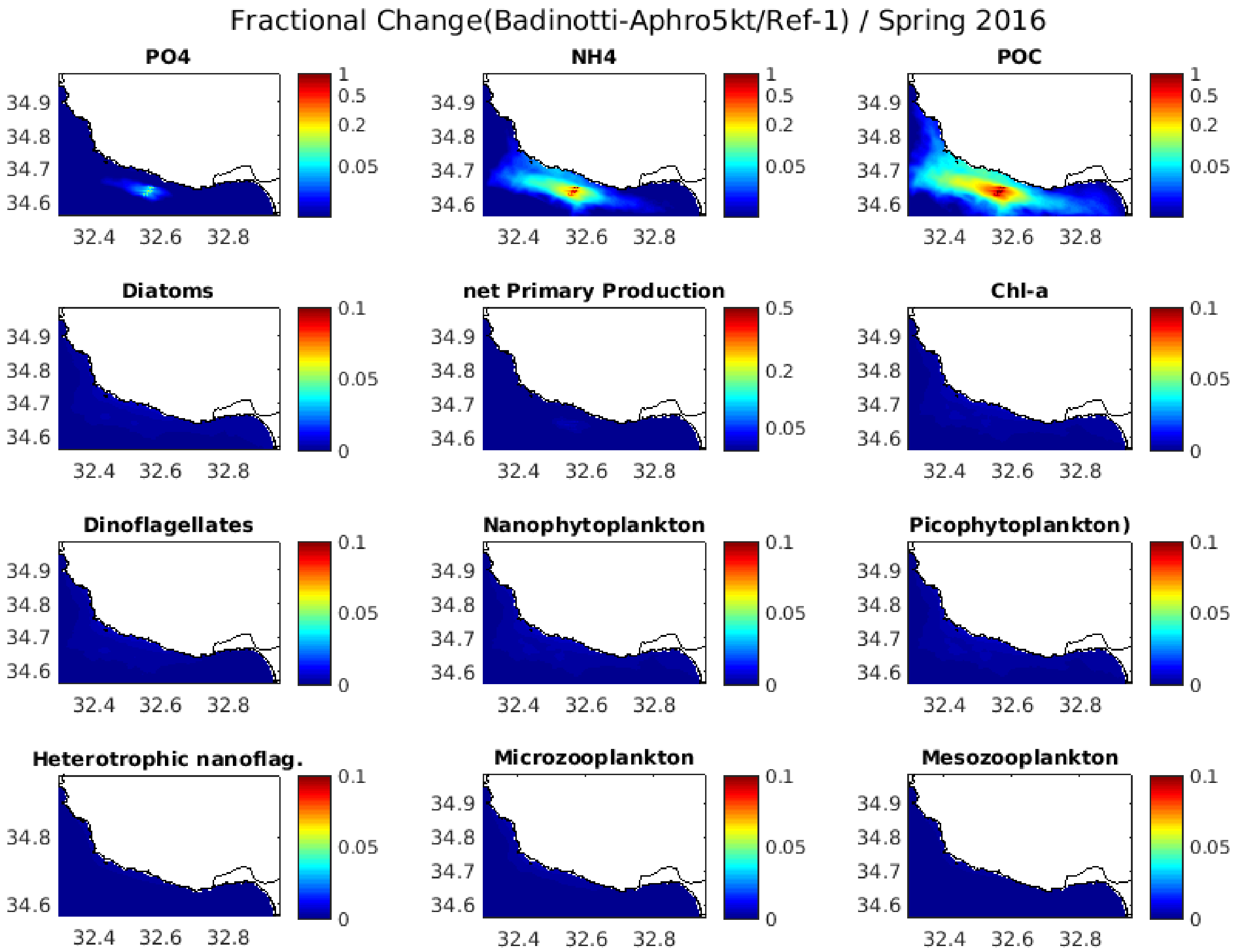


Figure 39: Simulated fractional change (Sc2/Ref-1, see Table 4) of near-surface PO_4, NH_4, POC, Chl-a, net primary production and biomass of diatoms, dinoflagellates, nanophytoplankton, picophytoplankton, mesozooplankton, microzooplankton and heterotrophic nanoflagellates with Cyp-3 model during spring 2016.

3. Conclusions

The OS Technologies that were evaluated have different marine space requirements. Badinnoti's OCEANIS 1 submersible cages need the largest marine area, followed by the conventional HDPE floating cages technology, Innova Sea submersible cages and the Cypriot design. It is noticeable that the OS Aqua catamaran-shaped structure has a competitive advantage for the space needed compared to the other technologies due to its single point mooring system. The single point mooring system is also more environmentally friendly, making it attractive even for shallower waters as the structures are on a continuous move and thus allow a kind of fallowing i.e. they are not constantly above the same benthic community.

Choosing a site in any fish farming operation is crucial because it influences economic viability. Site selection directly affects running costs, production, mortality, and overall profitability. Compared with a land-based facility, sea cage aquaculture has less room for error regarding site selection, particularly as a wrong siting may result in the loss of the fish stock and cages.

A first general site characteristic is its exposure. This refers to the currents and waves to which the site is subjected. An offshore and exposed site location will mean higher initial investments for cages, moorings and nets, higher costs of maintenance and greater risks, resulting in greater production costs. On the other hand, an exposed site will have better ocean mixing and flushing, with a resulting lower environmental impact, better fish welfare and better product quality. A sheltered and protected site will be less exposed to waves and currents, which implies reduced maintenance and costs, but higher risks of significant environmental impacts are often associated with more sheltered sites for these very reasons.

The preliminary model runs revealed that the addition of OS Aqua farms will not impact the coastal zone in the Aphrodite's Hills and Governor's beach areas. The other two areas in Larnaca and Xylofagou show a moderate impact to the marine environment if a combination of 3,000 tonnes in Larnaca and 5,000 tonnes in Xylofagou are simulated during the spring months (not during the summer).

Additional scenarios and fine-tuning of the modelling work will be presented in D12.

4. References

Baretta, J.W., Ebenhöh and Ruridij, P. 1995. The European Regional Seas Ecosystem Model, A Complex Marine Ecosystem Model. Netherlands Journal of Sea Research, 33(3/4): 233-246.

Apostolaki, E.T., Holmer, M., Marbà, N. and Karakassis, I. (2010). Degrading seagrass (*Posidonia oceanica*) ecosystems: a source of dissolved matter to the Mediterranean. Hydrobiologia 649:13−23.

Apostolaki, E.T., Marbà, N., Holmer, M., Karakassis, I. (2009). Fish farming enhances biomass and nutrient loss in *Posidonia oceanica* (L.) Delile. Estuar Coast Shelf Sci 81: 390−400.

Ballester-Molto M, Sanchez-Jerez P, Cerezo-Valverde J, Aguado-Gimenez F. (2017). Particulate waste outflow from fish-farming cages. How much is uneaten feed? Marine Pollution BulletiN. Jun 15;119(1):23–30.

Bannister RJ, Valdemarsen T, Hansen PK, Holmer M, Ervik A. (2014). Changes in benthic sediment conditions under an Atlantic salmon farm at a deep, well-flushed coastal site. Aquaculture Environment Interactions. 5(1):29–47.

Basaran AK, Aksu M, Egemen O. (2010). Impacts of the fish farms on the water column nutrient concentrations and accumulation of heavy metals in the sediments in the eastern Aegean Sea (Turkey). Environmental Monitoring and Assessment. 2010 Mar;162(1–4):439–51.

Blumberg, A.F., Mellor, G.L., 1983. Diagnostic and prognostic numerical circulation studies of the South Atlantic Bight. Journal of Geophysical Research, 88(C8), 4579-4592.

Boudouresque, C. F., Mayot, N., & Pergent, G. (2006). The outstanding traits of the functioning of the *Posidonia oceanica* seagrass ecosystem. Biol Mar Medit, 13(4), 109-113.

Campagne, C.S., Salles J-M., Boissery, P. and Deter, J. (2015). The seagrass *Posidonia oceanica*: Ecosystem services identification and economic evaluation of goods and benefits. Marine Pollution Bulletin, 15;97(1–2):391–400.

Cardia, F. and Lovatelli, A. 2015. Aquaculture operations in floating HDPE cages: a field handbook. FAO Fisheries and Aquaculture Technical Paper No. 593. Rome, FAO. 152 pp. http://www.fao.org/3/i4508e/I4508E.pdf

De Gaetano P, Vassallo P, Bartoli M, Nizzoli D, Doglioli AM, Magaldi MG, et al. (2011). Impact of new measured Mediterranean mineralization rates on the fate of simulated aquaculture wastes. Aquaculture Research. Aug;42(9):1359–70.

Díaz-Almela Elena, Núria Marbà, Elvira Álvarez, Rocío Santiago, Marianne Holmer, Antoni Grau, Simone Mirto, Roberto Danovaro, Anthony Petrou, Marina Argyrou, Ioannis Karakassis, Carlos Manuel Duarte, (2008). Benthic input rates predict seagrass (*Posidonia oceanica*) fish farm-induced decline, Marine Pollution Bulletin, Volume 56, Issue 7, Pages 1332-1342, ISSN 0025-326X, https://doi.org/10.1016/j.marpolbul.2008.03.022.

Escudier, R., Clementi, E., Omar, M., Cipollone, A., Pistoia, J., Aydogdu, A., Drudi, M., Grandi, A., Lyubartsev, V., Lecci, R., Cretí, S., Masina, S., Coppini, G., & Pinardi, N. (2020). Mediterranean Sea Physical Reanalysis (CMEMS MED-Currents) (Version 1) set. Copernicus Monitoring Environment Marine Service (CMEMS). https://doi.org/10.25423/CMCC/MEDSEA_MULTIYEAR_PHY_006_004_E3R1

GFCM (2011). Site selection and carrying capacity in Mediterranean marine aquaculture: key issues (WGSC-SHoCMed). GFCM:XXXV/2011/Dma.9. Rome, Italy, 9-14 May 2011.

http://gfcmsitestorage.blob.core.windows.net/documents/web/GFCM/35/GFCM_XXXV_2011_Dma.9.pdf (Accessed 2/12/2021).

Hargrave BT. (2010). Empirical relationships describing benthic impacts of salmon aquaculture. Aquaculture Environment Interactions. 1(1):33–46.

Holmer M, Argyrou M, Dalsgaard T, Danovaro R, Diaz-Almela E, Duarte CM, et al. (2008). Effects of fish farm waste on *Posidonia oceanica* meadows: Synthesis and provision of monitoring and management tools. Marine Pollution Bulletin, 56(9):1618–29.

Kalantzi Ioanna, Andreu Rico, Kyriaki Mylona, Spiros A. Pergantis, Manolis Tsapakis (2021). Fish farming, metals and antibiotics in the eastern Mediterranean Sea: Is there a threat to sediment wildlife? Science of The Total Environment, Volume 764, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.142843.

Kalantzi, I. and Karakassis, I., (2006). Benthic impacts of fish farming: meta-analysis of community and geochemical data. Marine Pollution Bulletin, 52, 484–493, doi: https://doi.org/10.1016/j.marpolbul.2005.09.034.

Kalaroni, S., Tsiaras, K., Petihakis, Economou-Amilli, A., Triantafyllou, G., 2020a. Modelling the Mediterranean Pelagic Ecosystem using the POSEIDON ecological model. Part I: Nutrients and Chlorophyll-a dynamics. Deep-Sea Research Part II, doi:10.1016/j.dsr2.2019.104647.

Kalaroni S., Tsiaras K., Petihakis G., Economou-Amilli A., Triantafyllou G., 2020b. Modelling the Mediterranean Pelagic Ecosystem using the POSEIDON ecological model. Part II: Biological dynamics, Deep Sea Research Part II, 171, 104711, https://doi.org/10.1016/j.dsr2.2019.104711.

Karakassis, I. (2013). Environmental interactions and initiatives on site selection and carrying capacity estimation for fish farming in the Mediterranean. In L.G. Ross, T.C. Telfer, L. Falconer, D. Soto & J. Aguilar-Manjarrez, eds. Site selection and carrying capacities for inland and coastal aquaculture, pp. 161–170. FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, 6–8 December 2010. Stirling, the United Kingdom of Great Britain and Northern Ireland. FAO Fisheries and Aquaculture Proceedings No. 21. Rome, FAO. 282 pp.

Kletou D, Kleitou P, Savva I, Attrill MJ, Antoniou C, Hall-Spencer JM. (2018). Seagrass recovery after fish farm relocation in the eastern Mediterranean. Marine Environmental Research, 140:221–33, doi: 10.1016/j.marenvres.2018.06.007.

Mayor DJ, Solan M.(2011). Complex interactions mediate the effects of fish farming on benthic chemistry within a region of Scotland. Environmental Research. 2011 Jul;111(5):635–42.

Nordi GA, Glud RN, Gaard E, Simonsen K. (2011). Environmental impacts of coastal fish farming: carbon and nitrogen budgets for trout farming in Kaldbaksfjorour (Faroe Islands). Marine Ecology Progress Series. 431:223–41.

Orth Robert J., Tim J. B. Carruthers, William C. Dennison, Carlos M. Duarte, James W. Fourqurean, Kenneth L. Heck, A. Randall Hughes, Gary A. Kendrick, W. Judson Kenworthy, Suzanne Olyarnik, Frederick T. Short, Michelle Waycott, Susan L. Williams, (2006). A Global Crisis for Seagrass Ecosystems, BioScience, Volume 56, Issue 12, December 2006, Pages 987–996, https://doi.org/10.1641/0006-3568(2006)56[987:AGCFSE]2.0.CO;2

Pavlidou, A., Simboura, N., Rousselaki, E., Tsapakis, M., Pagou, K., Drakopoulou, P., Assimakopoulou, G., Kontoyiannis, H., Panayotidis, P., 2015. Methods of eutrophication assessment in the context of the water framework directive: Examples from the Eastern Mediterranean coastal areas. Cont. Shelf Res. 108, 156–168. https://doi.org/10.1016/j.csr.2015.05.013.

Pearson, T. H. & R. Rosenberg, (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology: An Annual Review 16: 229–311.

Pérez O.M, T.C Telfer and L.G Ross (2003). On the calculation of wave climate for offshore cage culture site selection: a case study in Tenerife (Canary Islands). , 29(1-2), 0–21. doi:10.1016/s0144-8609(03)00031-1

Petihakis, G., Tsiaras, K., Traintafyllou, G., Korres, Tsagaraki, T.M., Tsapakis, M., Vavillis, P., Pollani, A. and Frangoulis, C. 2012. Application of a complex ecosystem model to evaluate effects of finfish culture in Pagasitikos Gulf, Greece. Journal of Marine Systems, 94, S65-S77.

Piazzi L, Balata D, Ceccherelli G. (2016). Epiphyte assemblages of the Mediterranean seagrass *Posidonia oceanica*: an overview. Marine Ecology, 37(1):3–41, doi: 10.1111/maec.12331.

Piedecausa MA, Aguado-Gimenez F, Cerezo Valverde J, Hernandez Llorente MD, Garcia-Garcia B. (2012). Influence of fish food and faecal pellets on short-term oxygen uptake, ammonium flux and acid volatile sulphide accumulation in sediments impacted by fish farming and non-impacted sediments. Aquaculture Research. Jan;43(1):66–74.

Primpas, I., Tsirtsis, G., Karydis, M., & Kokkoris, G. D. 2010. Principal component analysis: Development of a multivariate index for assessing eutrophication according to the European water framework directive. Ecological Indicators, 10, 178–183.

Rountos KJ, Peterson BJ, Karakassis I. (2012). Indirect effects of fish cage aquaculture on shallow *Posidonia oceanica* seagrass patches in coastal Greek waters. Aquaculture Environment Interactions. 2012; 2(2):105–15.

Tsagaraki, T.M., Petihakis, G., Tsiaras, K., Triantafyllou, G., Tsapakis, M., Korres, G., Kakagiannis, G., Frangoulis, C. and Karakassis. 2011. Beyond the cage: ecosystem modelling for impact evaluation in aquaculture. Ecological Modelling, 222(14): 2512-2523.

Tsikopoulou, I., Moraitis, M.L., Tsapakis, M. and Karakassis, I. (2018). Can intensive fish farming for 20 years induce changes in benthic ecosystems on a scale of waterbody? An assessment from Cephalonia bay (Ionian Sea). Environmental Monitoring and Assessment, 190(8), 469. doi: s://doi.org/10.1007/s10661-018-6846-5.

Wang X, Andresen K, Handa A, Jensen B, Reitan KI, Olsen Y. (2013). Chemical composition and release rate of waste discharge from an Atlantic salmon farm with an evaluation of IMTA feasibility. Aquaculture Environment Interactions. 4(2):147–62.

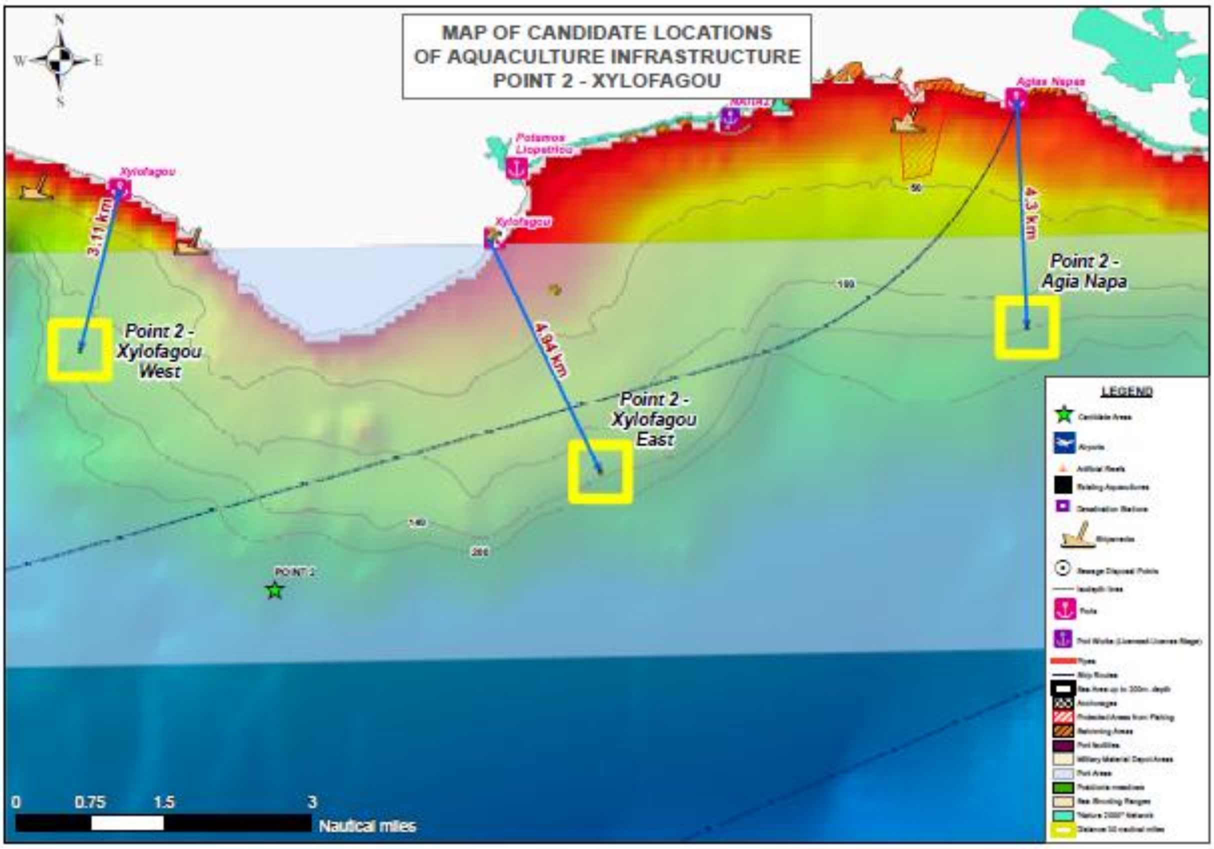
Welch, Aaron W.; Knapp, Angela N.; El Tourky, Sharein; Daughtery, Zachary; Hitchcock, Gary; Benetti, Daniel (2019). The nutrient footprint of a submerged-cage offshore aquaculture facility located in the tropical Caribbean. Journal of the World Aquaculture Society. doi:10.1111/jwas.12593

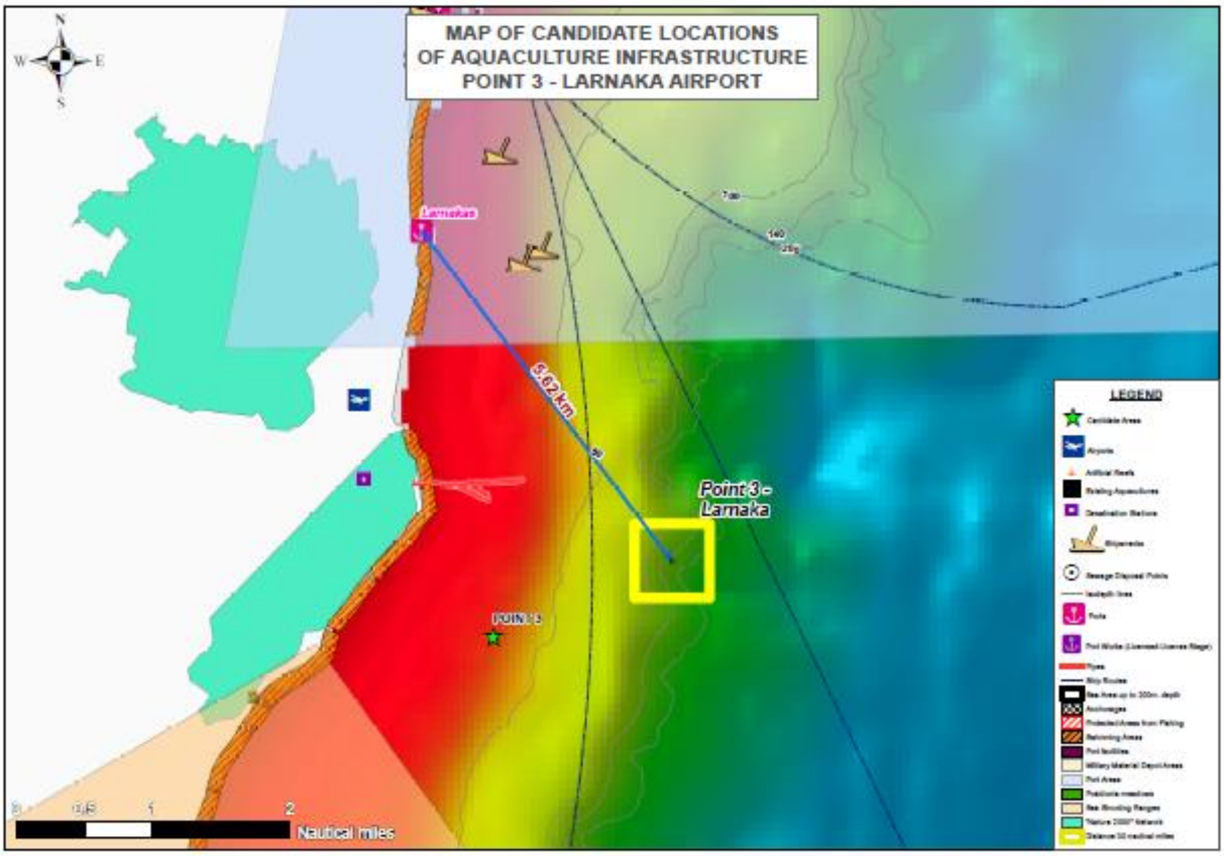
White CA, Nichols PD, Ross DJ, Dempster T. (2017). Dispersal and assimilation of an aquaculture waste subsidy in a low productivity coastal environment. Marine Pollution Bulletin. Jul 15;120(1–2):309–21.

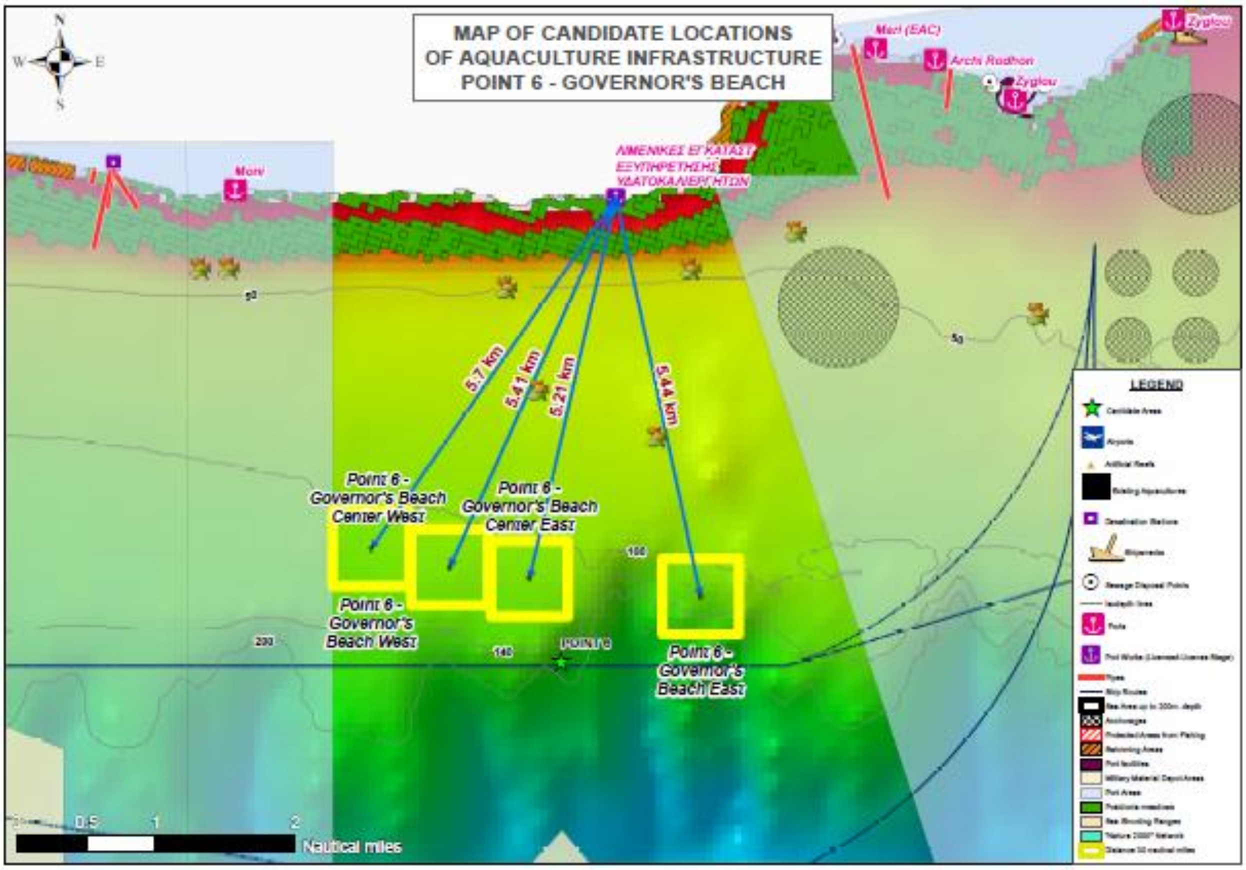
Yakushev E V, Wallhead P, Renaud PE, Ilinskaya A, Protsenko E, Yakubov S, et al. (2020). Understanding the Biogeochemical Impacts of Fish Farms Using a Benthic-Pelagic Model. WATER. Sep;12(9).

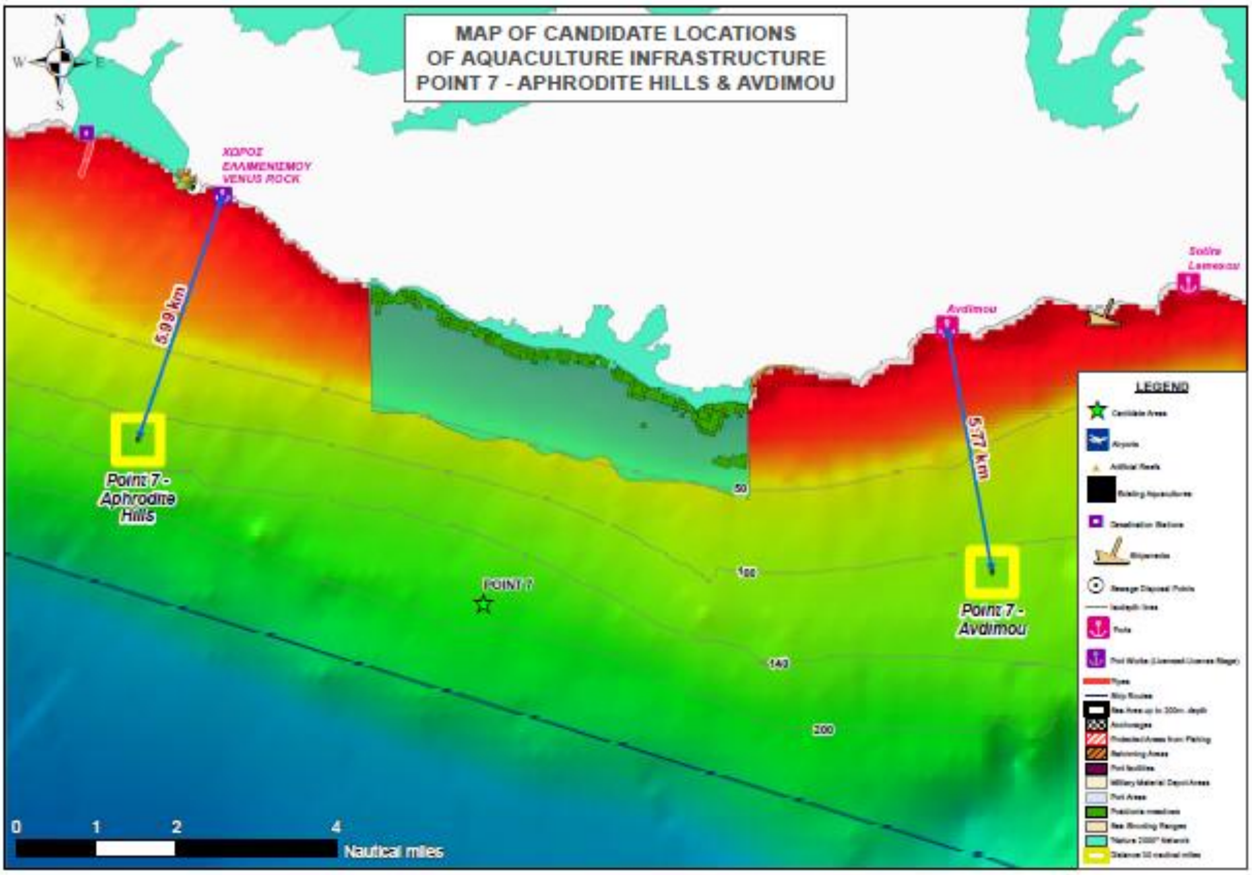
5. Annexes

Annex 1. Candidate areas for Open Sea Aquaculture in Cyprus






MAP OF CANDIDATE LOCATIONS
OF AQUACULTURE INFRASTRUCTURE
POINT 6 - GOVERNOR'S BEACH
5.7 km
5.41 km
5.21 km
5.44 km
Point 6 - Governor's Beach Center West
Point 6 - Governor's Beach Center East
Point 6 - Governor's Beach West
Point 6 - Governor's Beach East
POINT 6
Nautical miles
LEGEND


MAP OF CANDIDATE LOCATIONS
OF AQUACULTURE INFRASTRUCTURE
POINT 7 - APHRODITE HILLS & AVDIMOU
5.99 km
5.77 km
Point 7 - Aphrodite Hills
Point 7 - Avdimou
POINT 7
Avdimou
Nautical miles
LEGEND

Annex 2. Coordinates of the cage/structure parks for Open Sea Aquaculture in Cyprus

Name	LAT	LON	TECHNOLOGY	TONNES
Point 2 - Xylofagou West	34,944184	33,808397	AP Cypriot design (Sen. 2)	2kt
Point 2 - Xylofagou West	34,944184	33,808397	AP Cypriot design (Sen. 2)	2kt
Point 2 - Xylofagou West	34,940567	33,810116	AP Cypriot design (Sen. 2)	2kt
Point 2 - Xylofagou West	34,946409	33,80835	AP Cypriot design (Sen. 2)	3kt
Point 2 - Xylofagou West	34,938236	33,808342	AP Cypriot design (Sen. 2)	3kt
Point 2 - Xylofagou West	34,942731	33,810138	AP Cypriot design (Sen. 2)	3kt
Point 2 - Xylofagou West	34,936061	33,810072	AP Cypriot design (Sen. 2)	3kt
Point 2 - Xylofagou West	34,949412	33,808452	AP Cypriot design (Sen. 2)	5kt
Point 2 - Xylofagou West	34,946516	33,810175	AP Cypriot design (Sen. 2)	5kt
Point 2 - Xylofagou West	34,942742	33,808386	AP Cypriot design (Sen. 2)	5kt
Point 2 - Xylofagou West	34,939846	33,810109	AP Cypriot design (Sen. 2)	5kt
Point 2 - Xylofagou West	34,936035	33,808298	AP Cypriot design (Sen. 2)	5kt
Point 2 - Xylofagou West	34,933176	33,810044	AP Cypriot design (Sen. 2)	5kt
Point 2 - Xylofagou West	34,944047	33,813206	Badinotti	2kt
Point 2 - Xylofagou West	34,945329	33,812476	Badinotti	2kt
Point 2 - Xylofagou West	34,941902	33,805373	Badinotti	2kt
Point 2 - Xylofagou West	34,938203	33,81202	Badinotti	2kt
Point 2 - Xylofagou West	34,940635	33,806097	Badinotti	2kt
Point 2 - Xylofagou West	34,936935	33,812744	Badinotti	2kt
Point 2 - Xylofagou West	34,941317	33,812682	Badinotti	3kt
Point 2 - Xylofagou West	34,94005	33,813408	Badinotti	3kt
Point 2 - Xylofagou West	34,948381	33,813121	Badinotti	3kt
Point 2 - Xylofagou West	34,947114	33,813847	Badinotti	3kt
Point 2 - Xylofagou West	34,944872	33,806091	Badinotti	3kt
Point 2 - Xylofagou West	34,943605	33,806817	Badinotti	3kt
Point 2 - Xylofagou West	34,937808	33,805652	Badinotti	3kt
Point 2 - Xylofagou West	34,936541	33,806379	Badinotti	3kt
Point 2 - Xylofagou West	34,934253	33,812243	Badinotti	3kt
Point 2 - Xylofagou West	34,932986	33,812969	Badinotti	3kt
Point 2 - Xylofagou West	34,953618	33,813924	Badinotti	5kt
Point 2 - Xylofagou West	34,952351	33,814651	Badinotti	5kt
Point 2 - Xylofagou West	34,94991	33,806826	Badinotti	5kt
Point 2 - Xylofagou West	34,948643	33,807553	Badinotti	5kt
Point 2 - Xylofagou West	34,946319	33,813483	Badinotti	5kt
Point 2 - Xylofagou West	34,945053	33,814209	Badinotti	5kt
Point 2 - Xylofagou West	34,942611	33,806385	Badinotti	5kt
Point 2 - Xylofagou West	34,939016	33,81378	Badinotti	5kt
Point 2 - Xylofagou West	34,941345	33,807112	Badinotti	5kt
Point 2 - Xylofagou West	34,937749	33,814506	Badinotti	5kt
Point 2 - Xylofagou West	34,935308	33,806683	Badinotti	5kt
Point 2 - Xylofagou West	34,931718	33,813339	Badinotti	5kt

Point 2 - Xylofagou West	34,934041	33,80741	Badinotti	5kt
Point 2 - Xylofagou West	34,930451	33,814065	Badinotti	5kt
Point 2 - Xylofagou West	34,92801	33,806243	Badinotti	5kt
Point 2 - Xylofagou West	34,926743	33,806969	Badinotti	5kt
Point 2 - Xylofagou West	34,940567	33,810116	Innova Sea	2kt
Point 2 - Xylofagou West	34,942828	33,809044	Innova Sea	2kt
Point 2 - Xylofagou West	34,948044	33,849151	Innova Sea	3kt
Point 2 - Xylofagou West	34,943761	33,809057	Innova Sea	3kt
Point 2 - Xylofagou West	34,940567	33,810116	Innova Sea	3kt
Point 2 - Xylofagou West	34,934293	33,809165	Innova Sea	5kt
Point 2 - Xylofagou West	34,949219	33,809312	Innova Sea	5kt
Point 2 - Xylofagou West	34,946508	33,81038	Innova Sea	5kt
Point 2 - Xylofagou West	34,931562	33,810258	Innova Sea	5kt
Point 3 - Larnaca	34,86312	33,672595	AP Cypriot design (Sen. 2)	2kt
Point 3 - Larnaca	34,85903	33,676446	AP Cypriot design (Sen. 2)	2kt
Point 3 - Larnaca	34,860233	33,678569	AP Cypriot design (Sen. 2)	3kt
Point 3 - Larnaca	34,860975	33,672421	AP Cypriot design (Sen. 2)	3kt
Point 3 - Larnaca	34,856142	33,68242	AP Cypriot design (Sen. 2)	3kt
Point 3 - Larnaca	34,864579	33,669576	AP Cypriot design (Sen. 2)	3kt
Point 3 - Larnaca	34,860947	33,674641	Innova Sea	2kt
Point 3 - Larnaca	34,85903	33,676446	Innova Sea	2kt
Point 3 - Larnaca	34,861403	33,673697	Innova Sea	3kt
Point 3 - Larnaca	34,85903	33,676446	Innova Sea	3kt
Point 3 - Larnaca	34,864358	33,667226	Innova Sea	5kt
Point 3 - Larnaca	34,862213	33,669504	Innova Sea	5kt
Point 3 - Larnaca	34,855203	33,686169	Innova Sea	5kt
Point 3 - Larnaca	34,853057	33,688446	Innova Sea	5kt
Point 6 - Governor's Beach Center East	34,663244	33,242867	AP Cypriot design (Sen. 2)	2kt
Point 6 - Governor's Beach Center East	34,659938	33,245334	AP Cypriot design (Sen. 2)	2kt
Point 6 - Governor's Beach Center East	34,66653	33,242175	AP Cypriot design (Sen. 2)	3kt
Point 6 - Governor's Beach Center East	34,664645	33,244344	AP Cypriot design (Sen. 2)	3kt
Point 6 - Governor's Beach Center East	34,661379	33,243259	AP Cypriot design (Sen. 2)	3kt
Point 6 - Governor's Beach Center East	34,658073	33,245726	AP Cypriot design (Sen. 2)	3kt
Point 6 - Governor's Beach Center East	34,670267	33,241389	AP Cypriot design (Sen. 2)	5kt
Point 6 - Governor's Beach Center East	34,667672	33,243707	AP Cypriot design (Sen. 2)	5kt
Point 6 - Governor's Beach Center East	34,663695	33,242772	AP Cypriot design (Sen. 2)	5kt
Point 6 - Governor's Beach Center East	34,6611	33,245089	AP Cypriot design (Sen. 2)	5kt

Point 6 - Governor's Beach Center East	34,657123	33,244154	AP Cypriot design (Sen. 2)	5kt
Point 6 - Governor's Beach Center East	34,654527	33,246472	AP Cypriot design (Sen. 2)	5kt
Point 6 - Governor's Beach Center East	34,66267	33,248688	Badinotti	2kt
Point 6 - Governor's Beach Center East	34,658251	33,242475	Badinotti	2kt
Point 6 - Governor's Beach Center East	34,664181	33,242348	Badinotti	2kt
Point 6 - Governor's Beach Center East	34,661531	33,249675	Badinotti	2kt
Point 6 - Governor's Beach Center East	34,657112	33,243462	Badinotti	2kt
Point 6 - Governor's Beach Center East	34,66532	33,241361	Badinotti	2kt
Point 6 - Governor's Beach Center East	34,66528	33,243761	Conventional HDPE cages	2kt
Point 6 - Governor's Beach Center East	34,663627	33,244995	Conventional HDPE cages	2kt
Point 6 - Governor's Beach Center East	34,657038	33,245495	Conventional HDPE cages	2kt
Point 6 - Governor's Beach Center East	34,655385	33,246729	Conventional HDPE cages	2kt
Point 6 - Governor's Beach Center East	34,666188	33,240104	Conventional HDPE cages	3kt
Point 6 - Governor's Beach Center East	34,664535	33,241337	Conventional HDPE cages	3kt
Point 6 - Governor's Beach Center East	34,663129	33,248366	Conventional HDPE cages	3kt
Point 6 - Governor's Beach Center East	34,661476	33,2496	Conventional HDPE cages	3kt
Point 6 - Governor's Beach Center East	34,657946	33,241838	Conventional HDPE cages	3kt
Point 6 - Governor's Beach Center East	34,656293	33,243072	Conventional HDPE cages	3kt
Point 6 - Governor's Beach Center East	34,666466	33,248033	Conventional HDPE cages	5kt
Point 6 - Governor's Beach Center East	34,668118	33,246799	Conventional HDPE cages	5kt
Point 6 - Governor's Beach Center East	34,669604	33,239753	Conventional HDPE cages	5kt
Point 6 - Governor's Beach Center East	34,663015	33,240254	Conventional HDPE cages	5kt
Point 6 - Governor's Beach Center East	34,660036	33,248499	Conventional HDPE cages	5kt
Point 6 - Governor's Beach Center East	34,671257	33,238519	Conventional HDPE cages	5kt
Point 6 - Governor's Beach Center East	34,661362	33,241488	Conventional HDPE cages	5kt

Point 6 - Governor's Beach Center East	34,658383	33,249733	Conventional HDPE cages	5kt
Point 6 - Governor's Beach Center East	34,65312	33,243222	Conventional HDPE cages	5kt
Point 6 - Governor's Beach Center East	34,654773	33,241988	Conventional HDPE cages	5kt
Point 6 - Governor's Beach Center East	34,662004	33,243792	Innova Sea	2kt
Point 6 - Governor's Beach Center East	34,659938	33,245334	Innova Sea	2kt
Point 6 - Governor's Beach Center East	34,662892	33,243605	Innova Sea	3kt
Point 6 - Governor's Beach Center East	34,659938	33,245334	Innova Sea	3kt
Point 7 - Aphrodite Hills	34,636726	32,558063	Badinotti	2kt
Point 7 - Aphrodite Hills	34,638124	32,558181	Badinotti	2kt
Point 7 - Aphrodite Hills	34,638255	32,566375	Badinotti	2kt
Point 7 - Aphrodite Hills	34,636857	32,566256	Badinotti	2kt
Point 7 - Aphrodite Hills	34,630825	32,561661	Badinotti	2kt
Point 7 - Aphrodite Hills	34,632223	32,56178	Badinotti	2kt
Point 7 - Aphrodite Hills	34,63919	32,561194	Badinotti	3kt
Point 7 - Aphrodite Hills	34,634832	32,564935	Badinotti	3kt
Point 7 - Aphrodite Hills	34,628847	32,560373	Badinotti	3kt
Point 7 - Aphrodite Hills	34,639419	32,56938	Badinotti	3kt
Point 7 - Aphrodite Hills	34,633434	32,564816	Badinotti	3kt
Point 7 - Aphrodite Hills	34,627449	32,560254	Badinotti	3kt
Point 7 - Aphrodite Hills	34,634603	32,55675	Badinotti	3kt
Point 7 - Aphrodite Hills	34,640588	32,561312	Badinotti	3kt
Point 7 - Aphrodite Hills	34,633205	32,556631	Badinotti	3kt
Point 7 - Aphrodite Hills	34,640816	32,569498	Badinotti	3kt
Point 7 - Aphrodite Hills	34,645875	32,574237	Badinotti	5kt
Point 7 - Aphrodite Hills	34,644477	32,574118	Badinotti	5kt
Point 7 - Aphrodite Hills	34,6455	32,565873	Badinotti	5kt
Point 7 - Aphrodite Hills	34,644103	32,565755	Badinotti	5kt
Point 7 - Aphrodite Hills	34,639687	32,569532	Badinotti	5kt
Point 7 - Aphrodite Hills	34,638289	32,569413	Badinotti	5kt
Point 7 - Aphrodite Hills	34,631799	32,565349	Badinotti	5kt
Point 7 - Aphrodite Hills	34,633197	32,565467	Badinotti	5kt
Point 7 - Aphrodite Hills	34,632821	32,557105	Badinotti	5kt
Point 7 - Aphrodite Hills	34,631424	32,556987	Badinotti	5kt
Point 7 - Aphrodite Hills	34,627008	32,560764	Badinotti	5kt
Point 7 - Aphrodite Hills	34,625611	32,560646	Badinotti	5kt
Point 7 - Aphrodite Hills	34,626633	32,552403	Badinotti	5kt
Point 7 - Aphrodite Hills	34,625235	32,552284	Badinotti	5kt
Point 7 - Aphrodite Hills	34,639312	32,561169	Badinotti	5kt
Point 7 - Aphrodite Hills	34,637914	32,561051	Badinotti	5kt

Annex 3. Layout of the deployment of the cage/structure parks for Open Sea Aquaculture in Cyprus per area, technology and production scenario

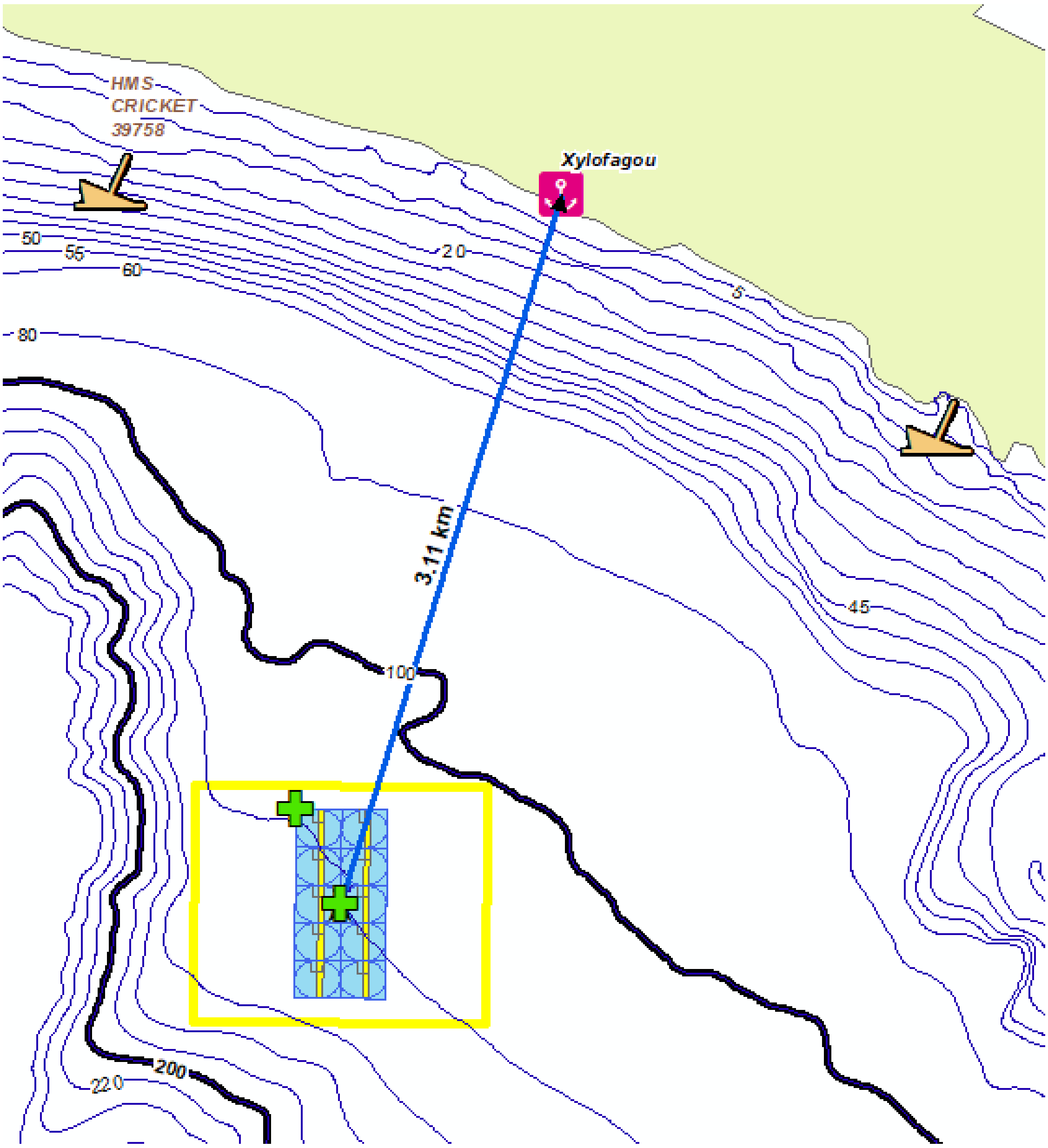


Figure 40. Deployment of Point 2 -Xylofagou West – OS Aqua Cypriot Design Technology– 2,000 tonnes per year.

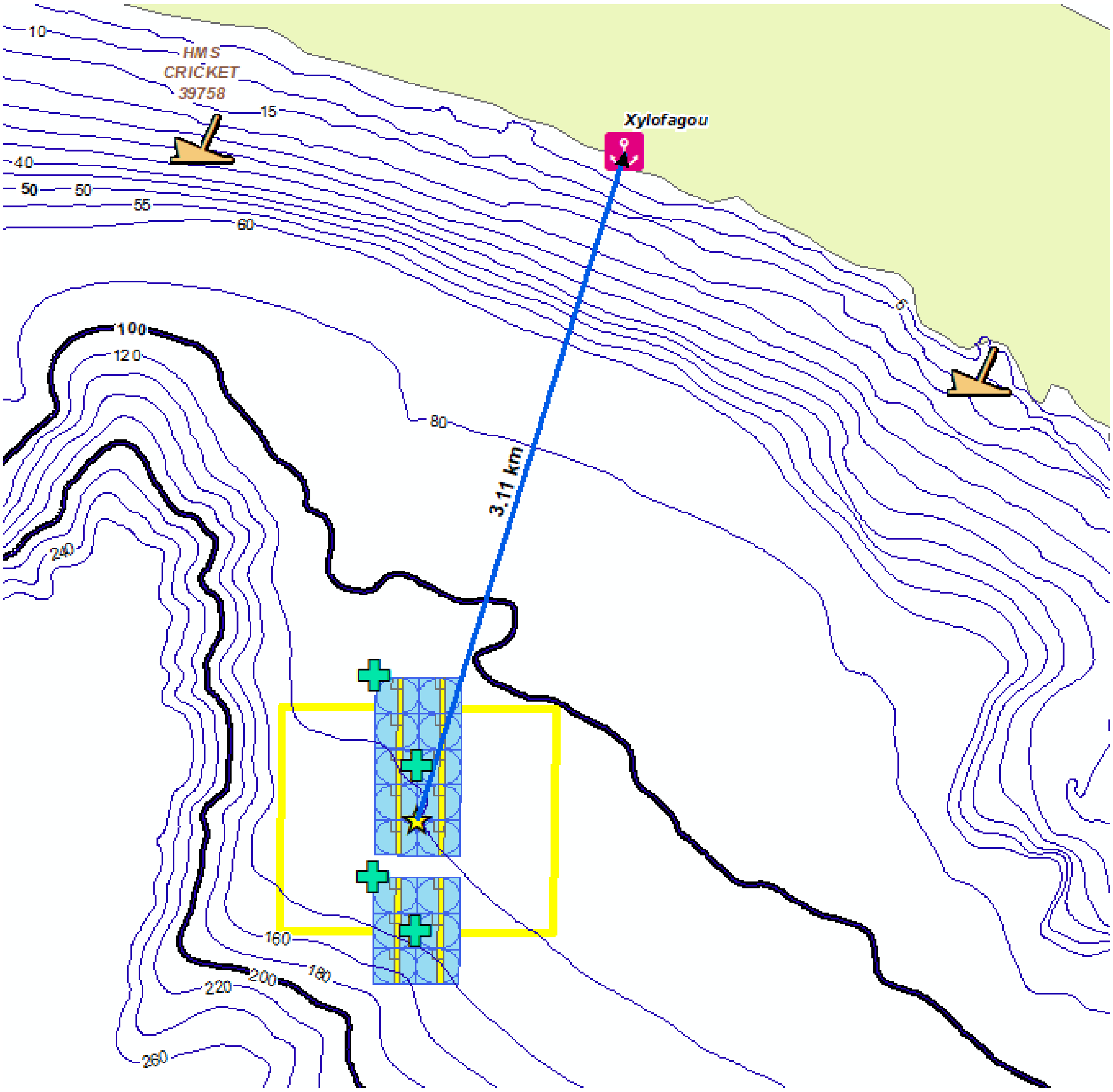


Figure 41. Deployment of Point 2 -Xylofagou West – OS Aqua Cypriot Design Technology – 3,000 tonnes per year.

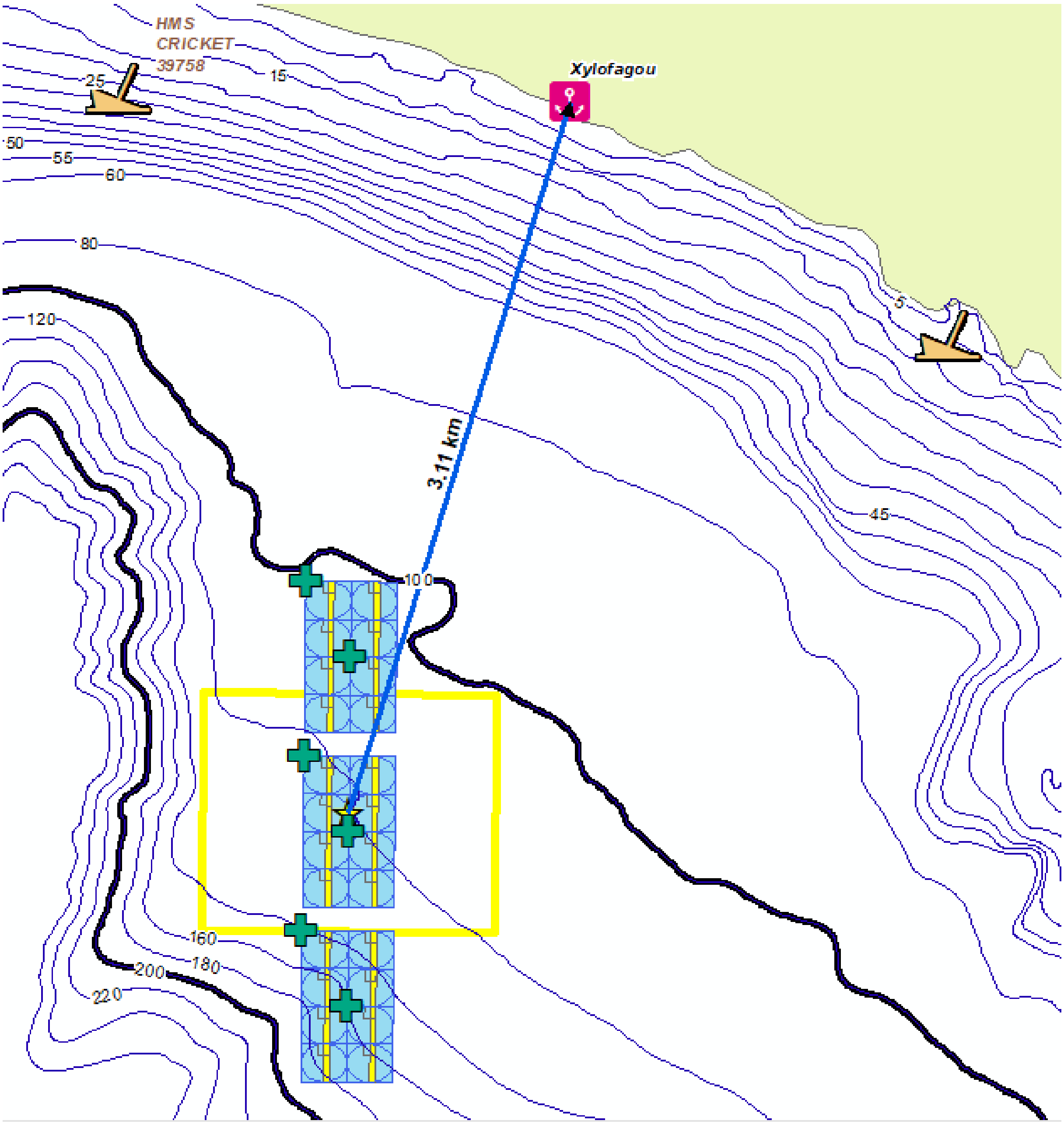


Figure 42. Deployment of Point 2 -Xylofagou West – OS Aqua Cypriot Design Technology – 5,000 tonnes per year.

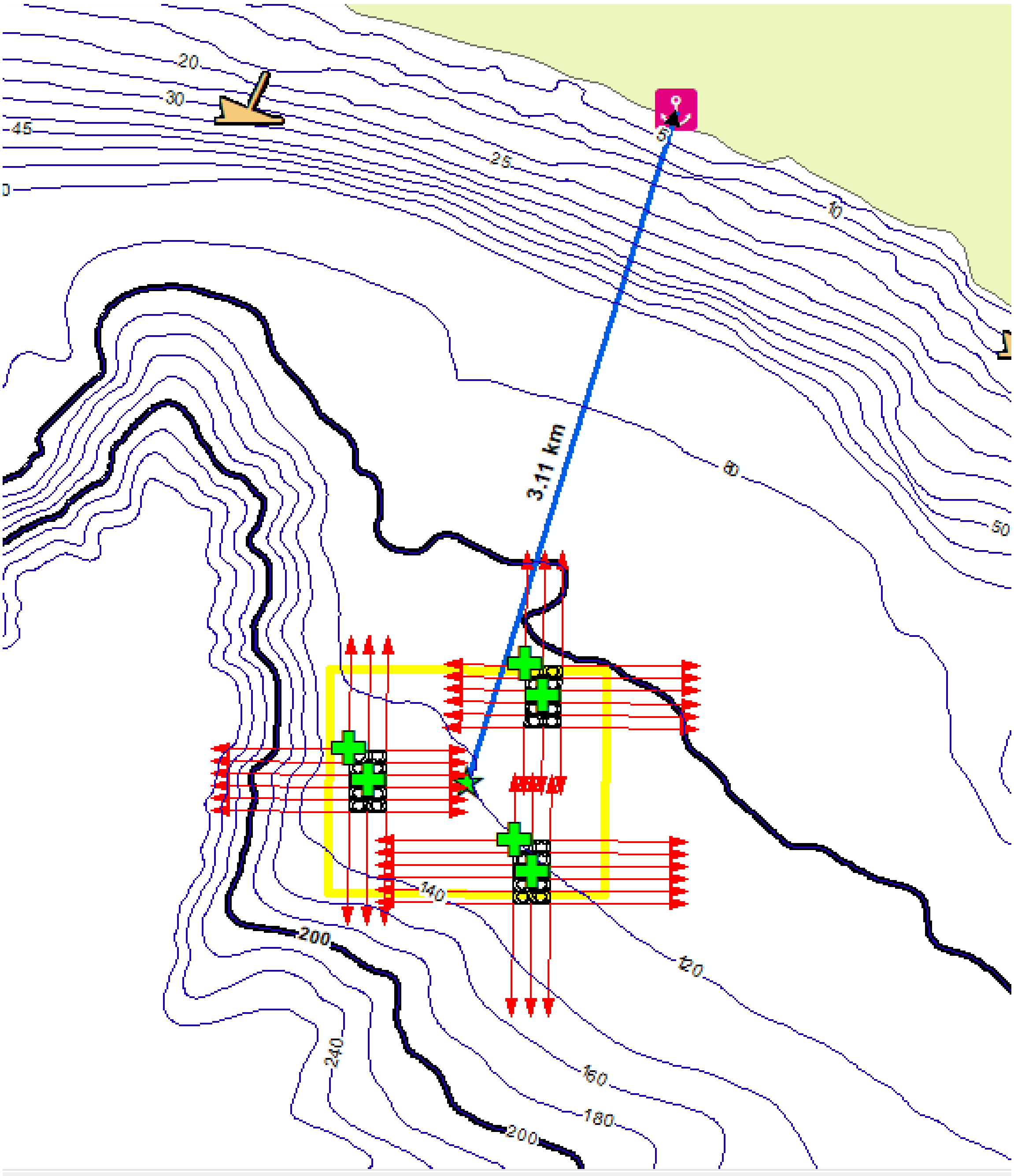


Figure 43. Deployment of Point 2 -Xylofagou West - Badinotti Technology – 2,000 tonnes per year.

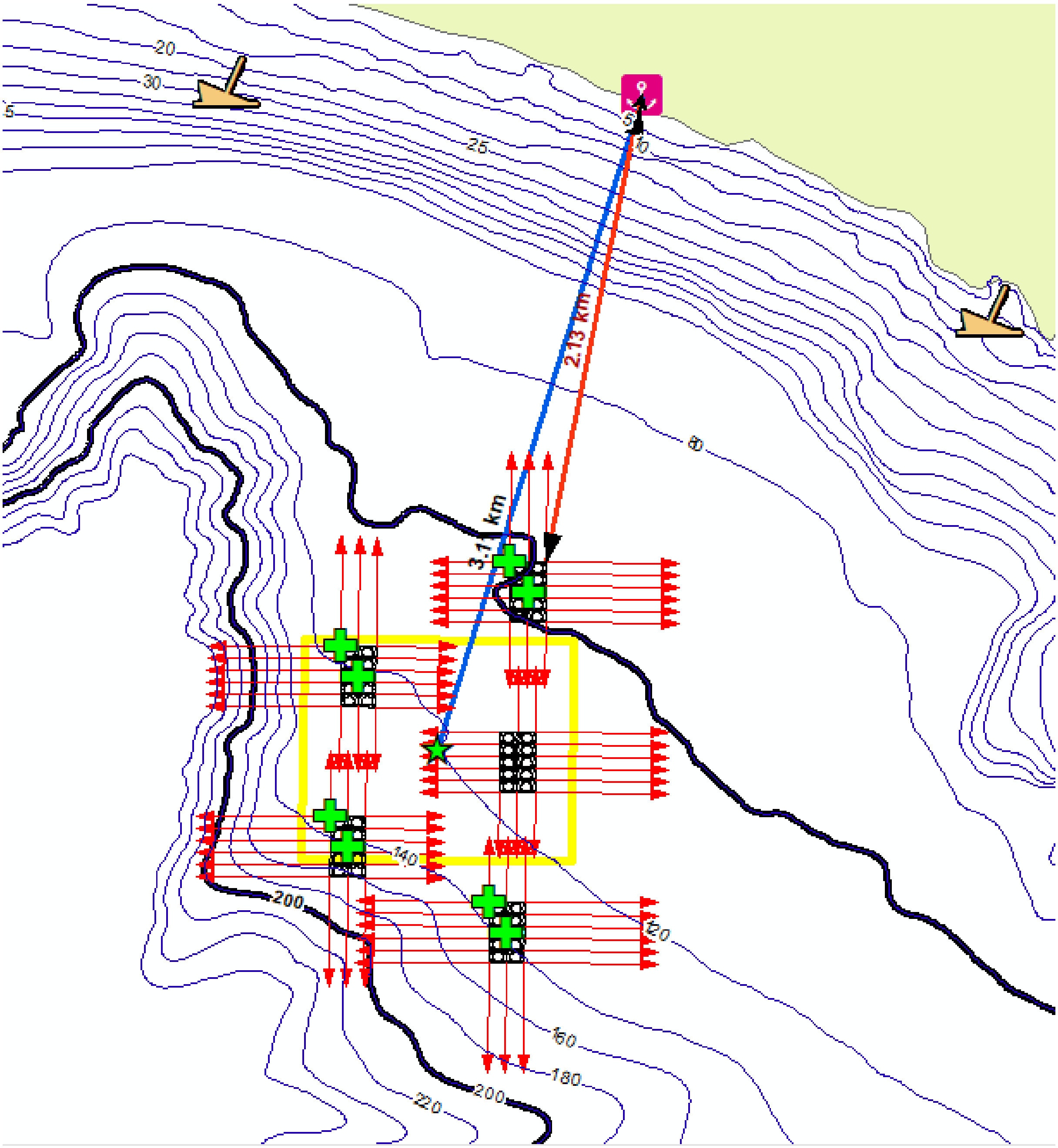


Figure 44. Deployment of Point 2 -Xylofagou West - Badinotti Technology – 3,000 tonnes per year.

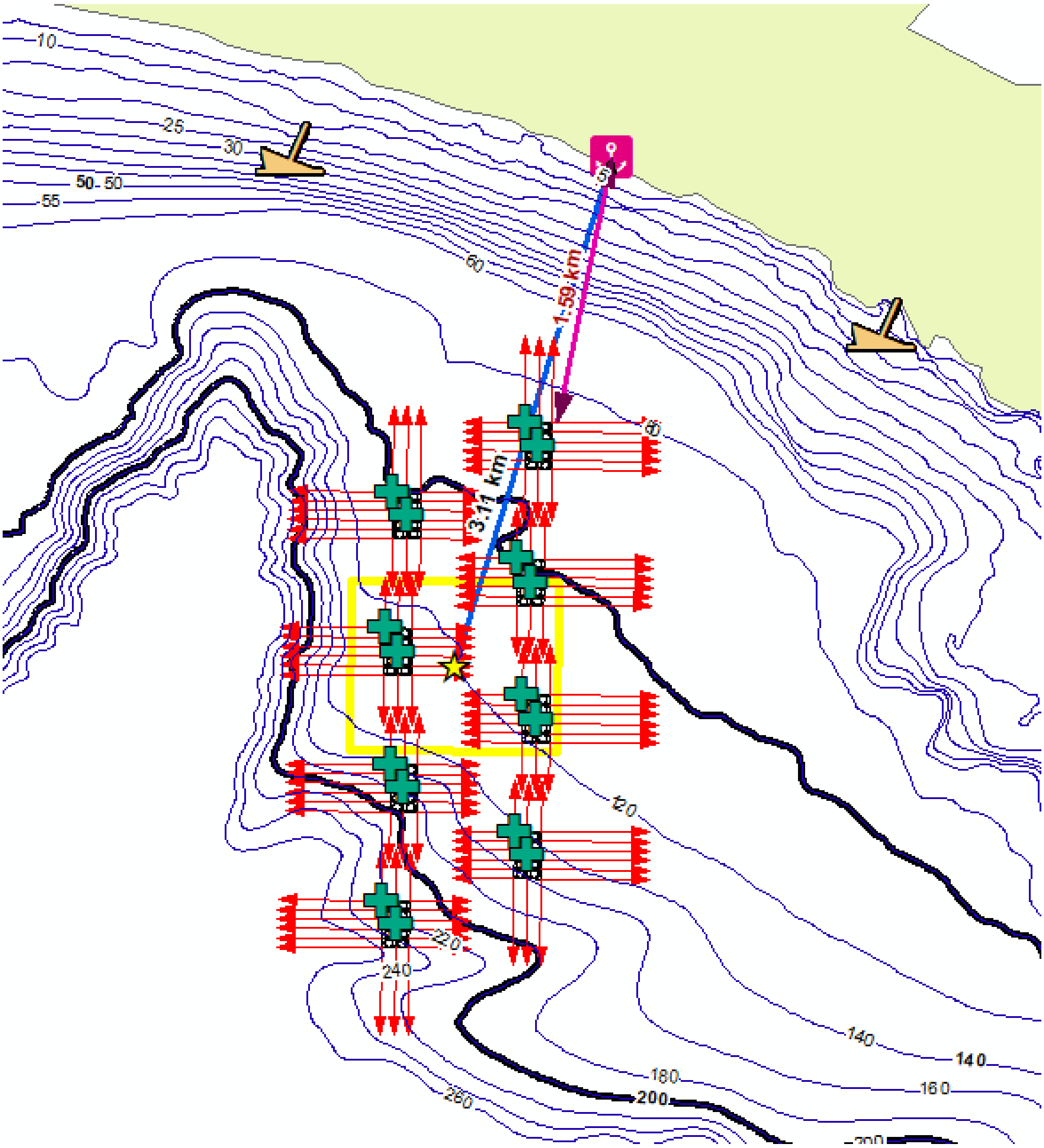


Figure 45. Deployment of Point 2 -Xylofagou West - Badinotti Technology – 5,000 tonnes per year.

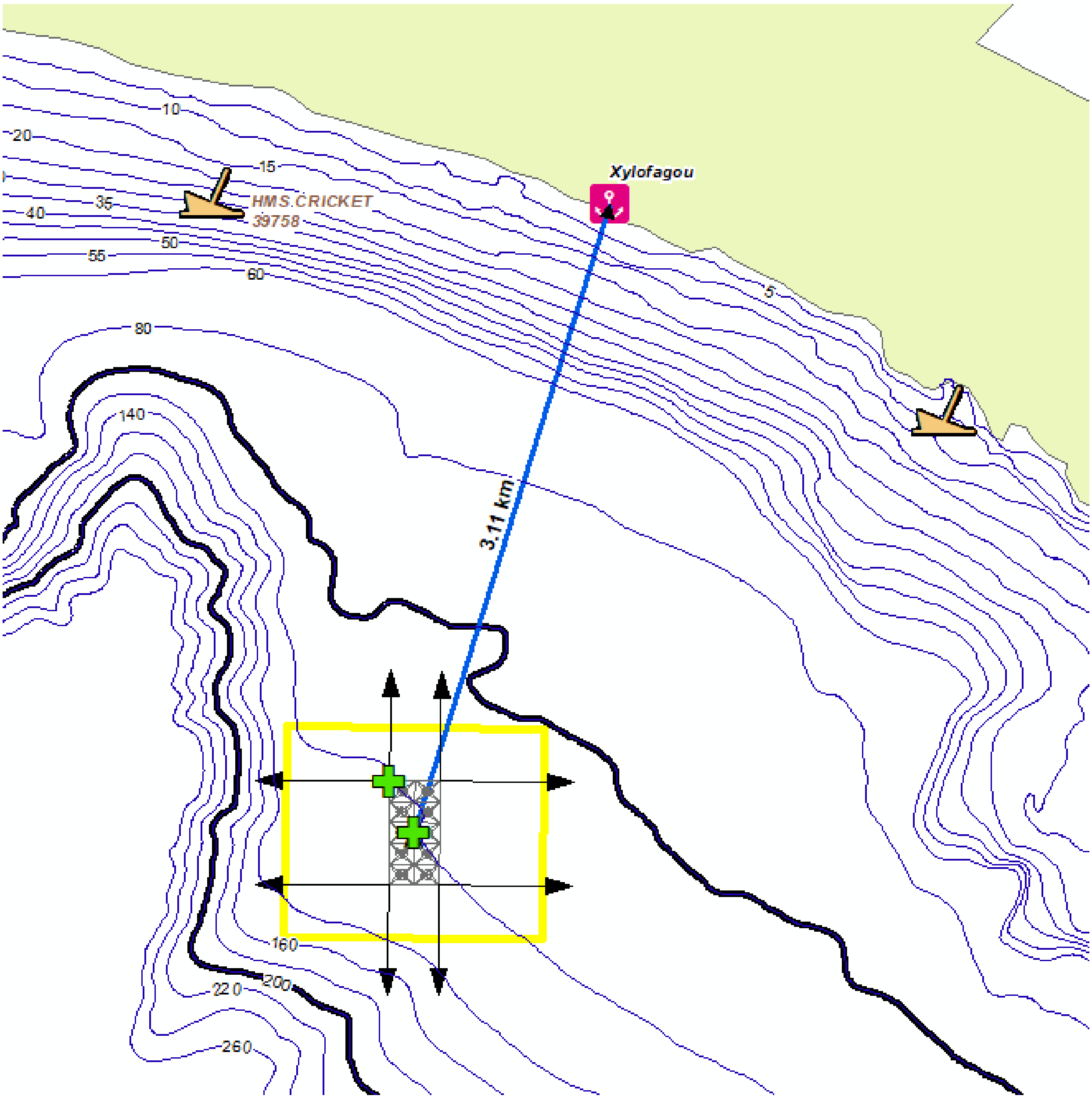


Figure 46. Deployment of Point 2 -Xylofagou West - Innova Sea Technology – 2,000 tonnes per year.

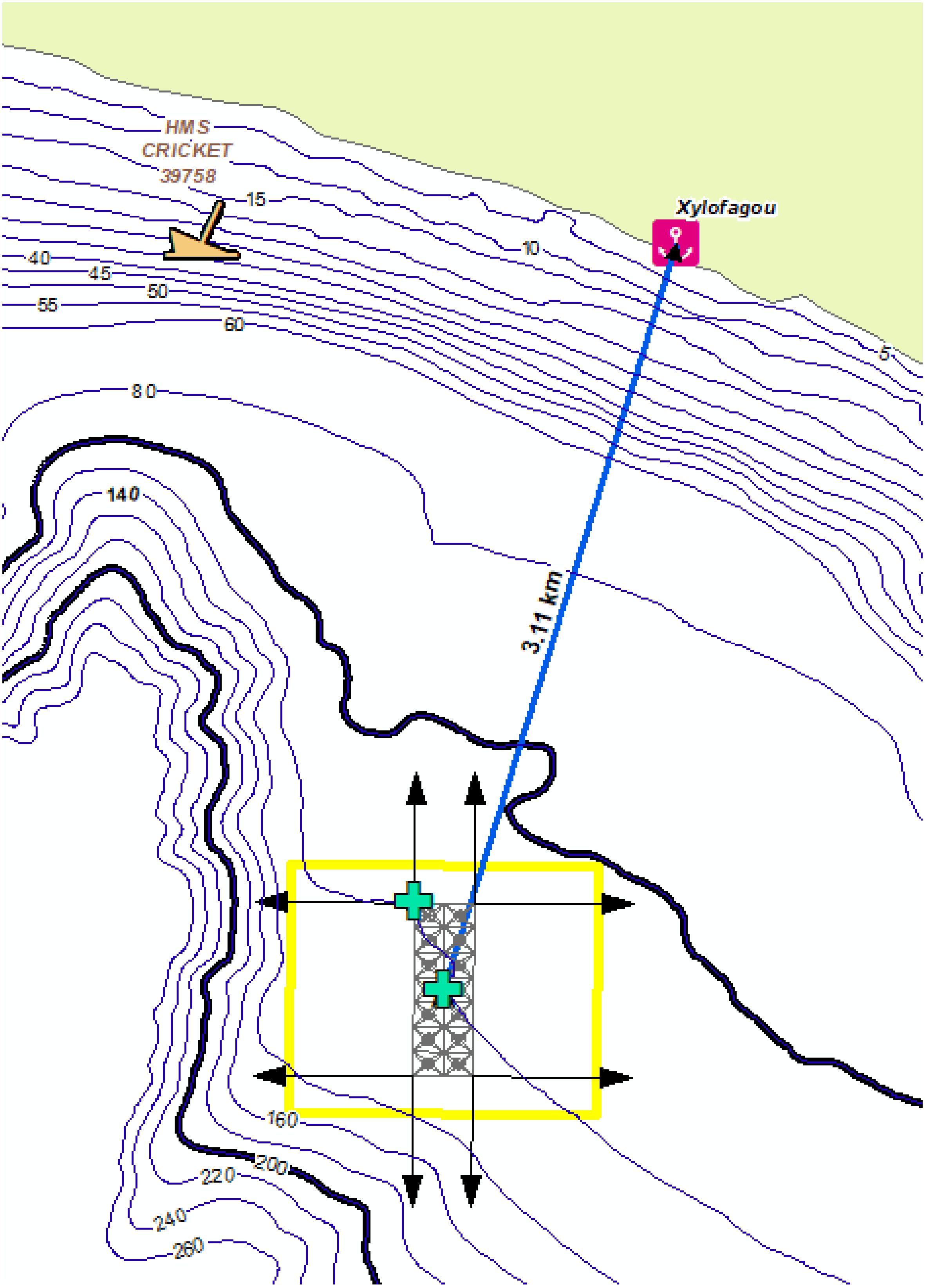


Figure 47. Deployment of Point 2 -Xylofagou West - Innova Sea Technology – 3,000 tonnes per year.

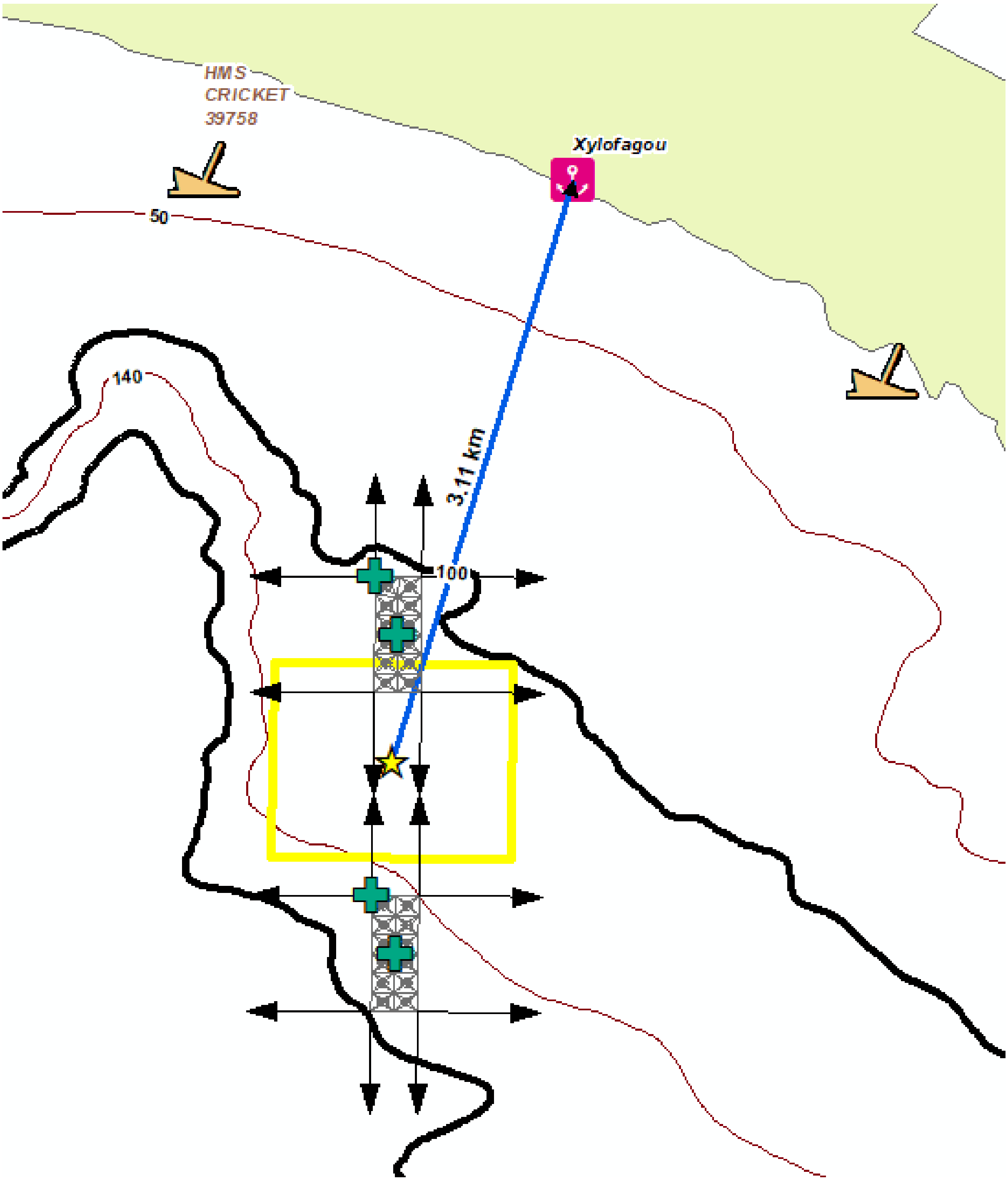


Figure 48. Deployment of Point 2 -Xylofagou West - Innova Sea Technology – 5,000 tonnes per year.

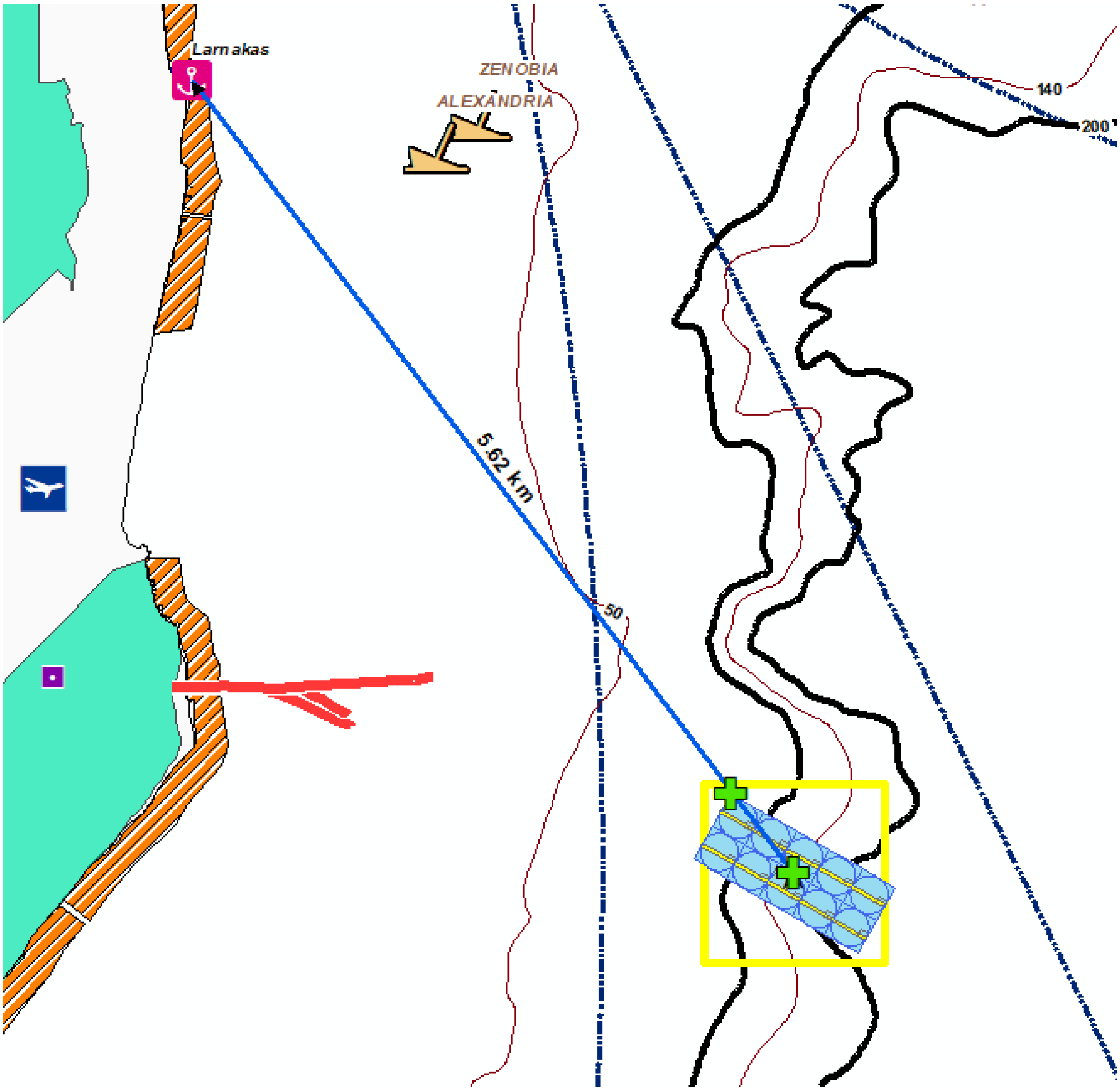


Figure 49. Deployment of Point 3 - Larnaca – OS Aqua Cypriot Design Technology – 2,000 tonnes per year.

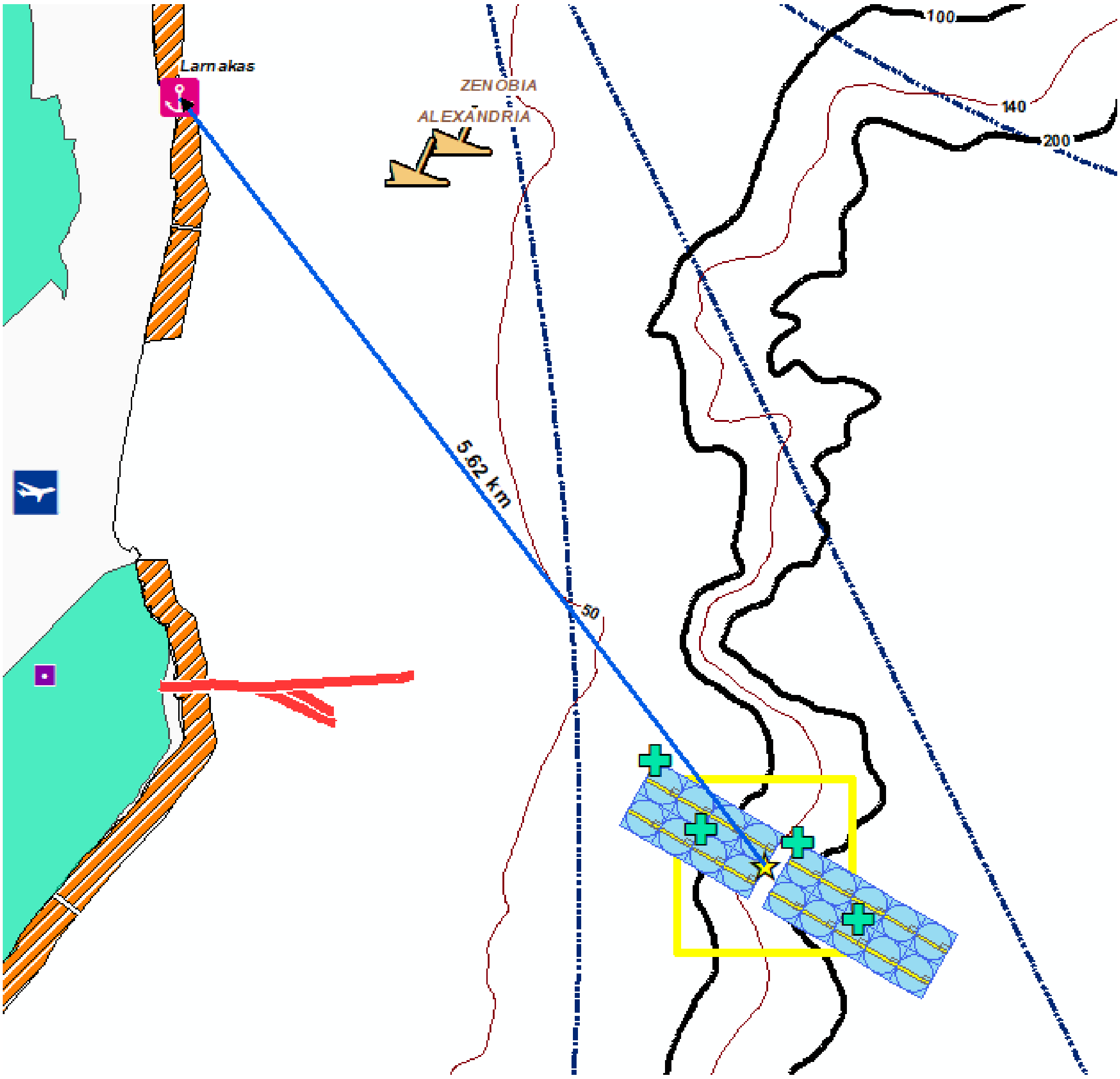


Figure 50. Deployment of Point 3 - Larnaca – OS Aqua Cypriot Design Technology – 3,000 tonnes per year.

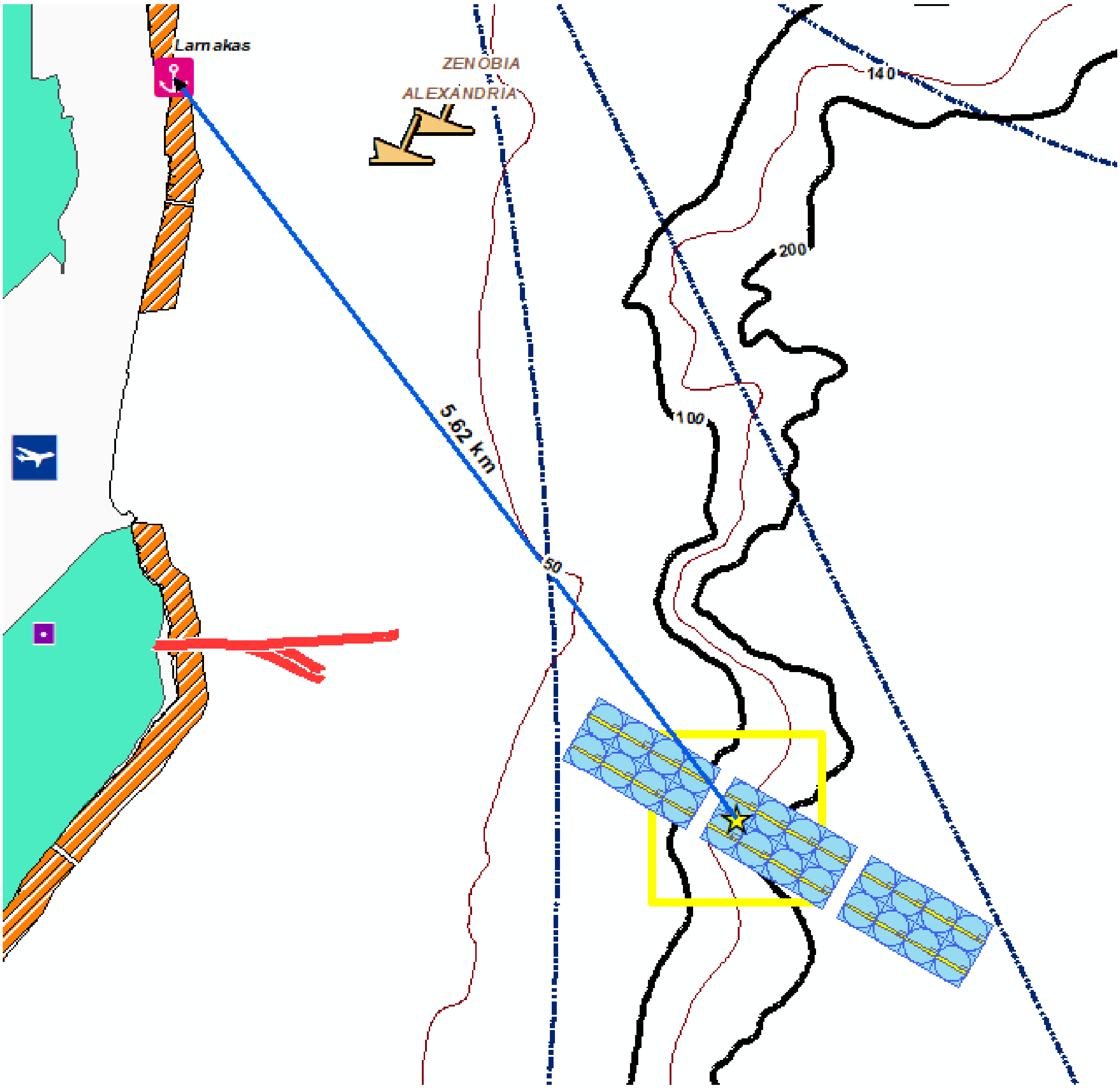


Figure 51. Deployment of Point 3 - Larnaca – OS Aqua Cypriot Design Technology – 5,000 tonnes per year.

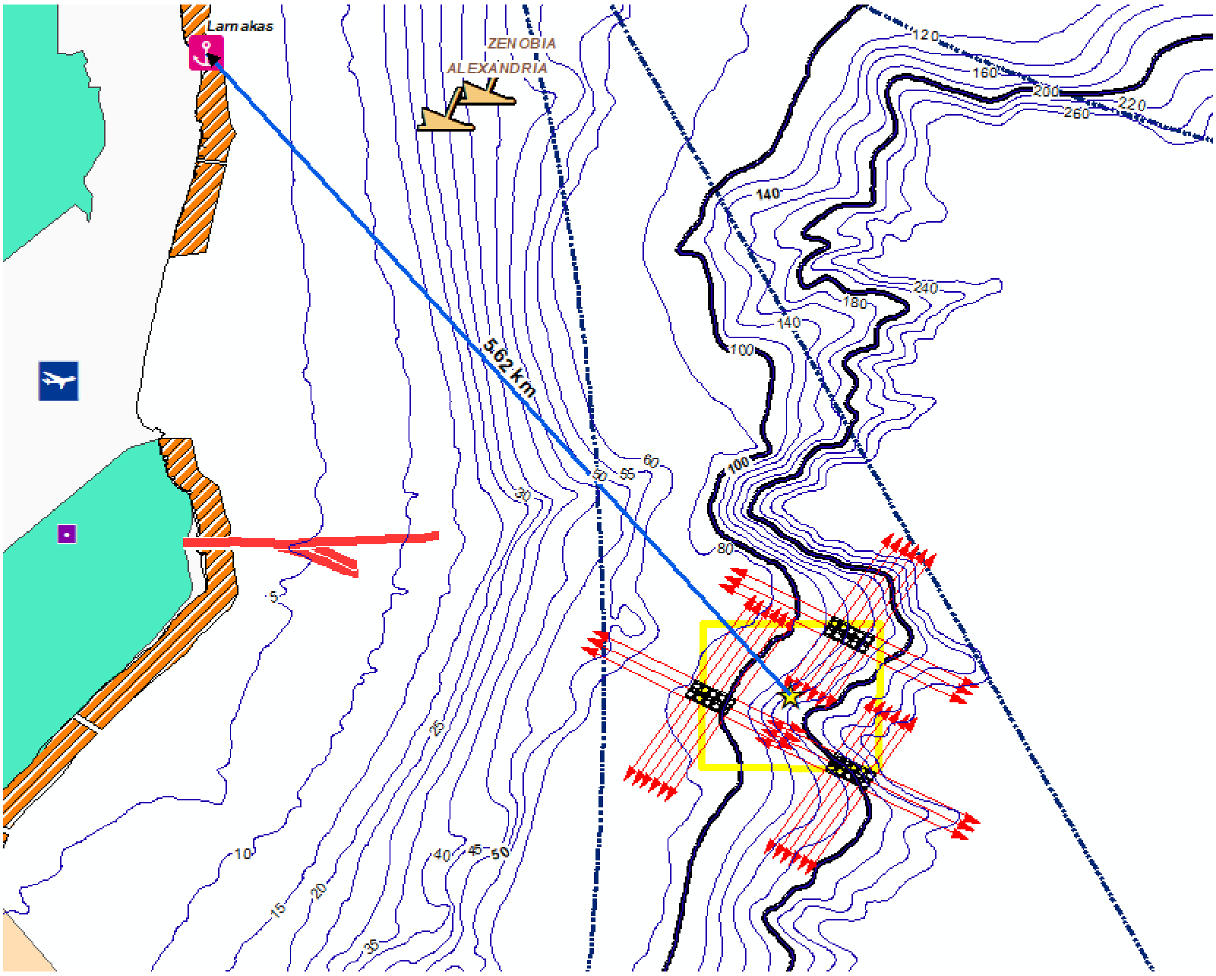


Figure 52. Deployment of Point 3 - Larnaca – Badinotti Technology – 2,000 tonnes per year. Incompatible.

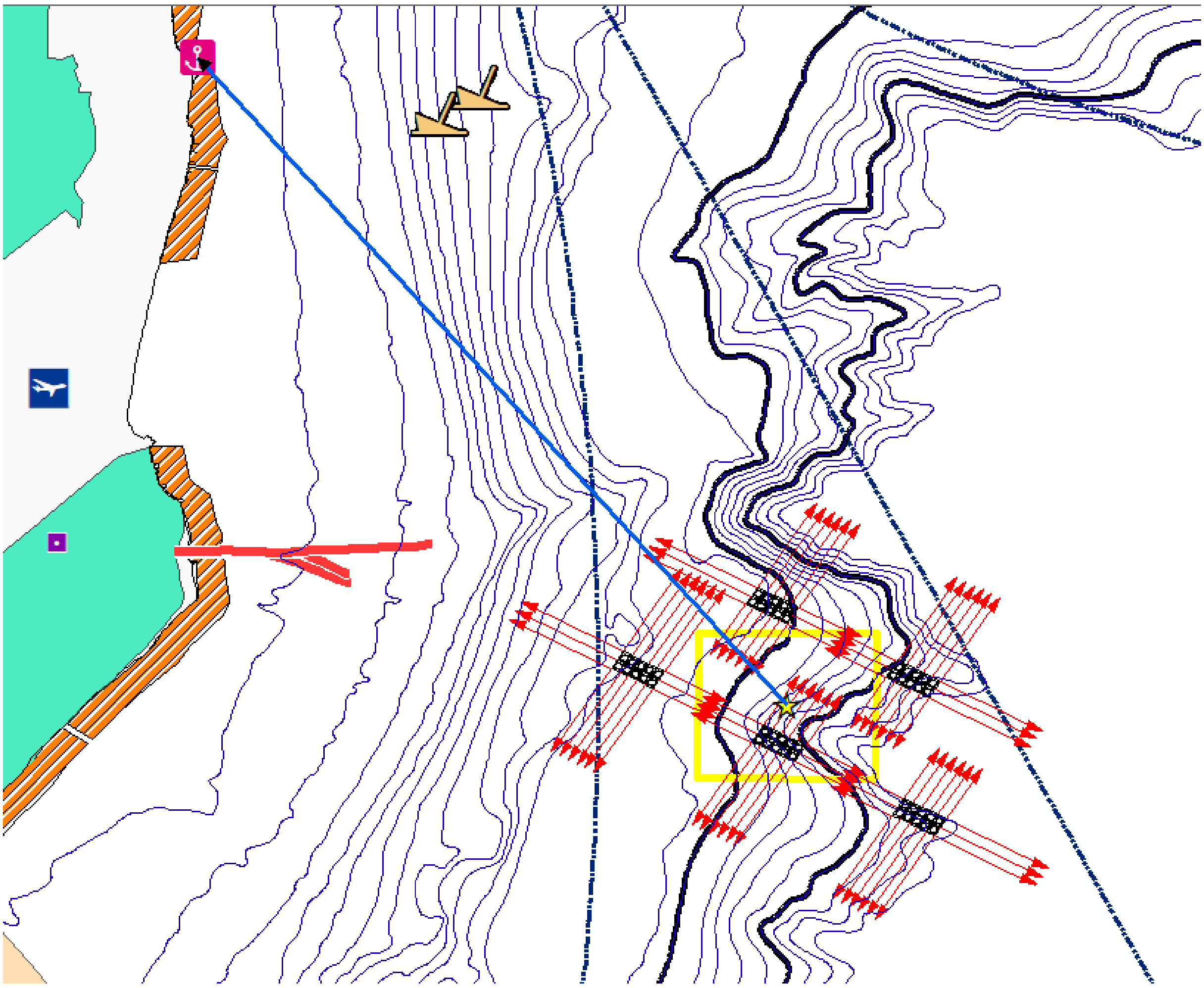


Figure 53. Deployment of Point 3 - Larnaca – Badinotti Technology – 3,000 tonnes per year. Incompatible.

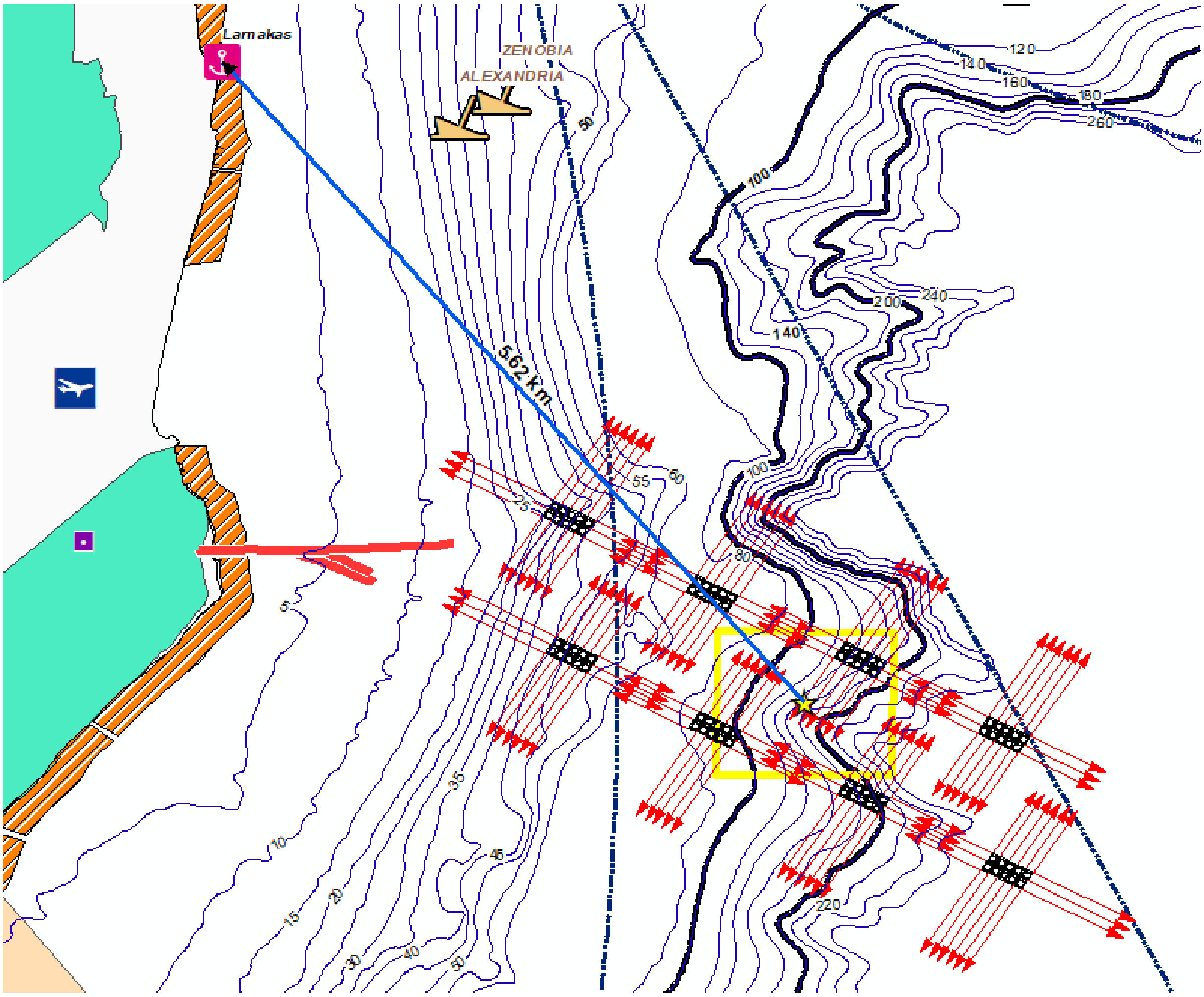


Figure 54. Deployment of Point 3 - Larnaca – Badinotti Technology – 5,000 tonnes per year. Incompatible.

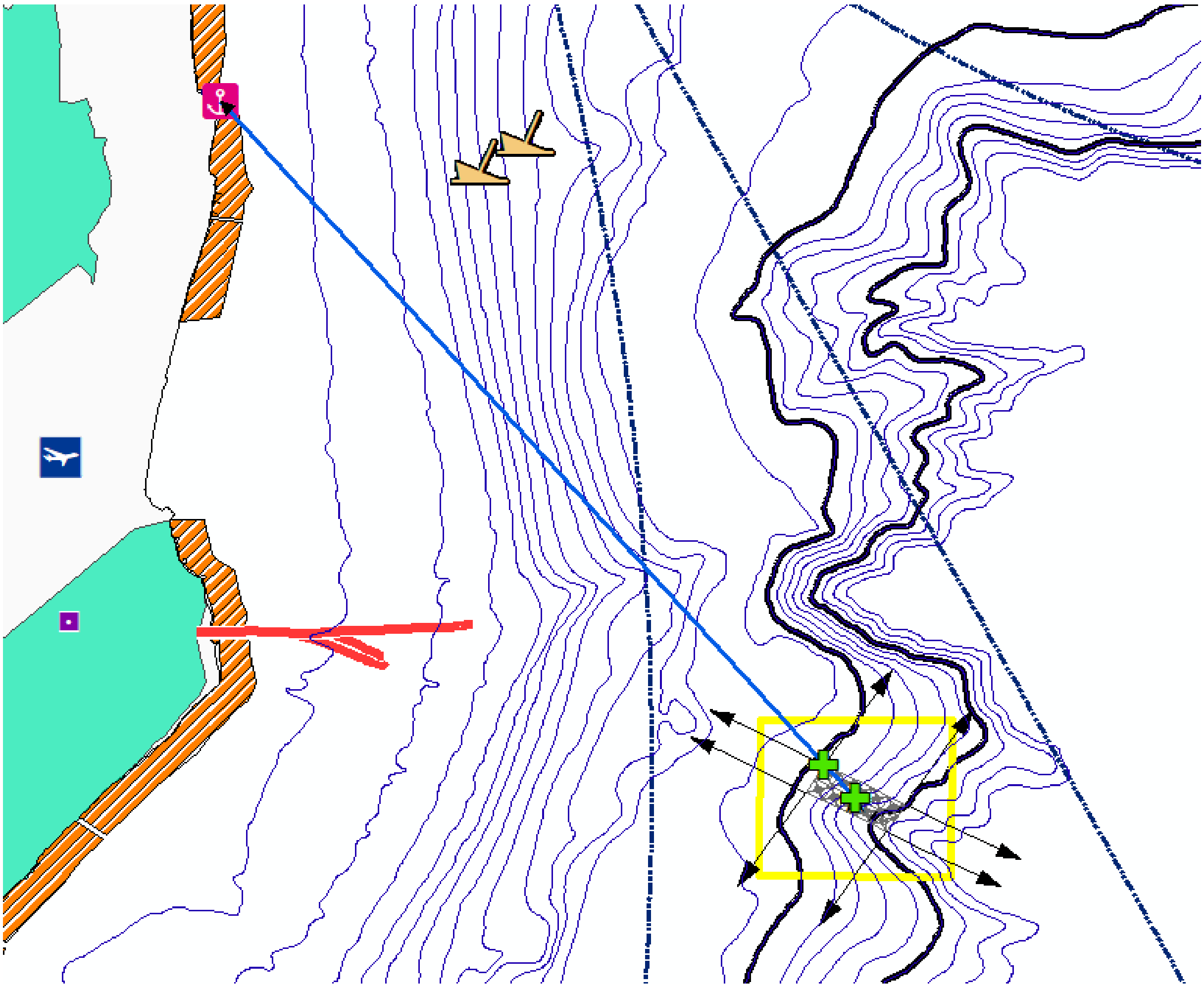


Figure 55. Deployment of Point 3 - Larnaca – Innova Sea Technology – 2,000 tonnes per year.

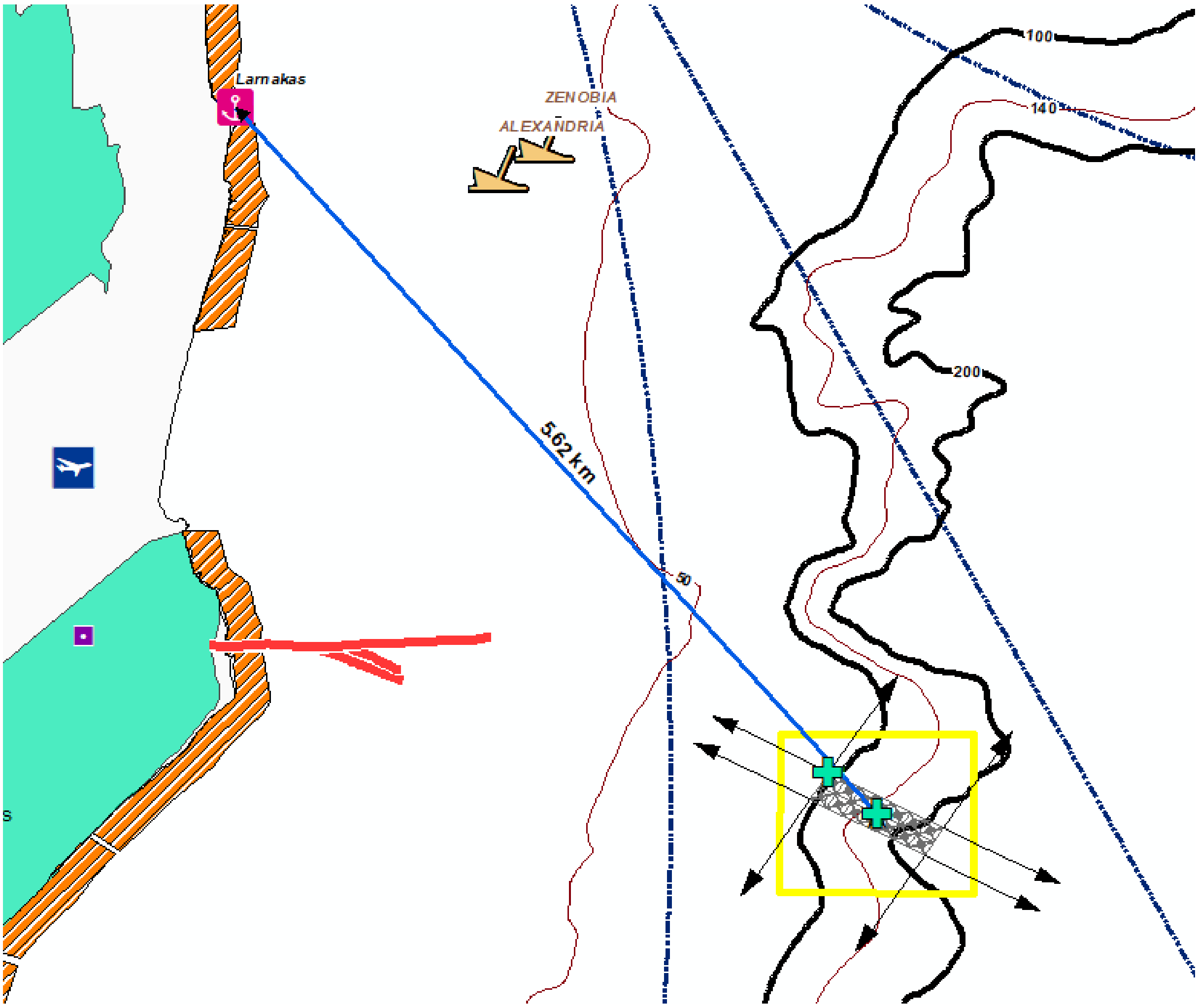


Figure 56. Deployment of Point 3 - Larnaca – Innova Sea Technology – 3,000 tonnes per year.

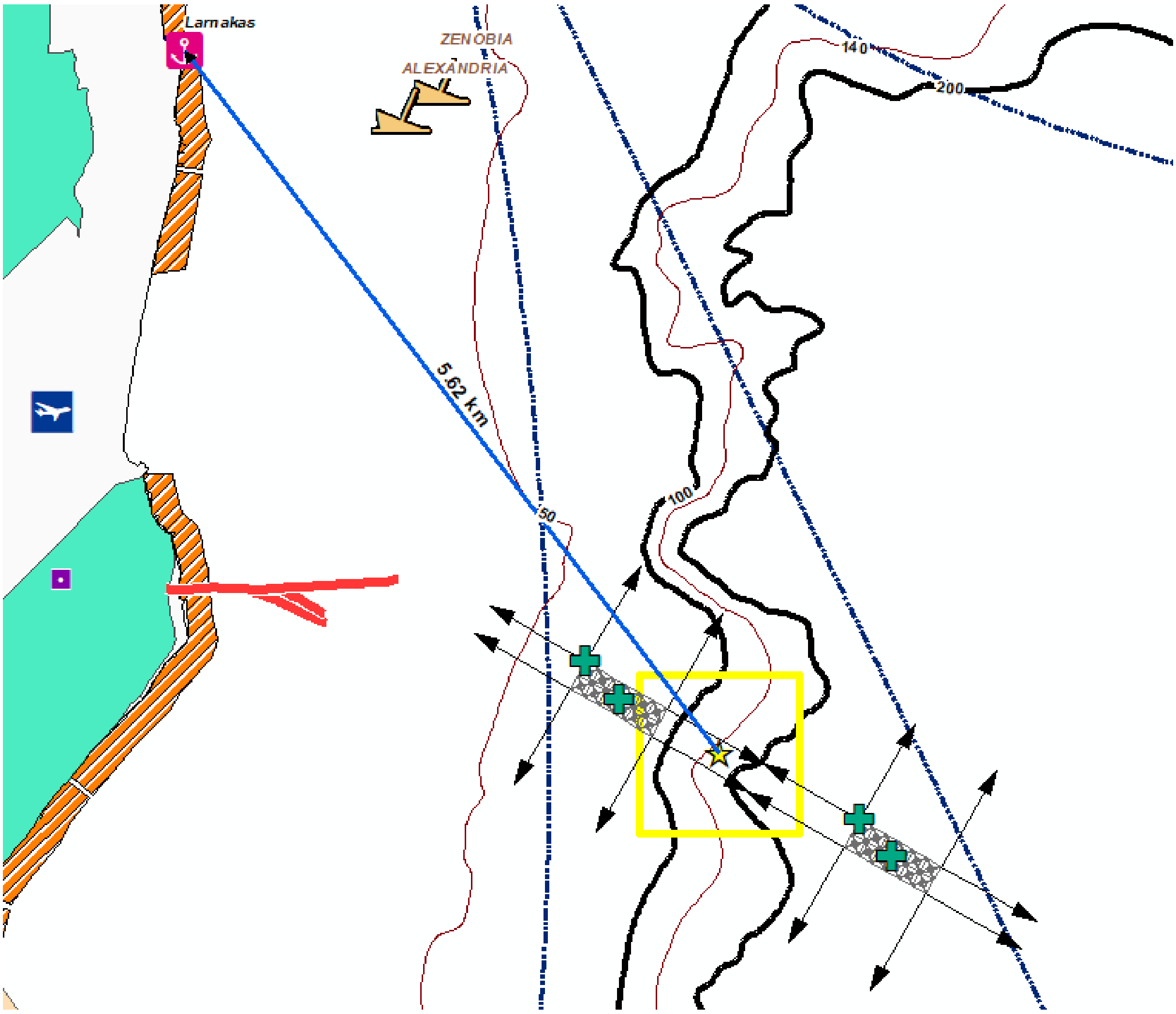


Figure 57. Deployment of Point 3 - Larnaca – Innova Sea Technology – 5,000 tonnes per year.

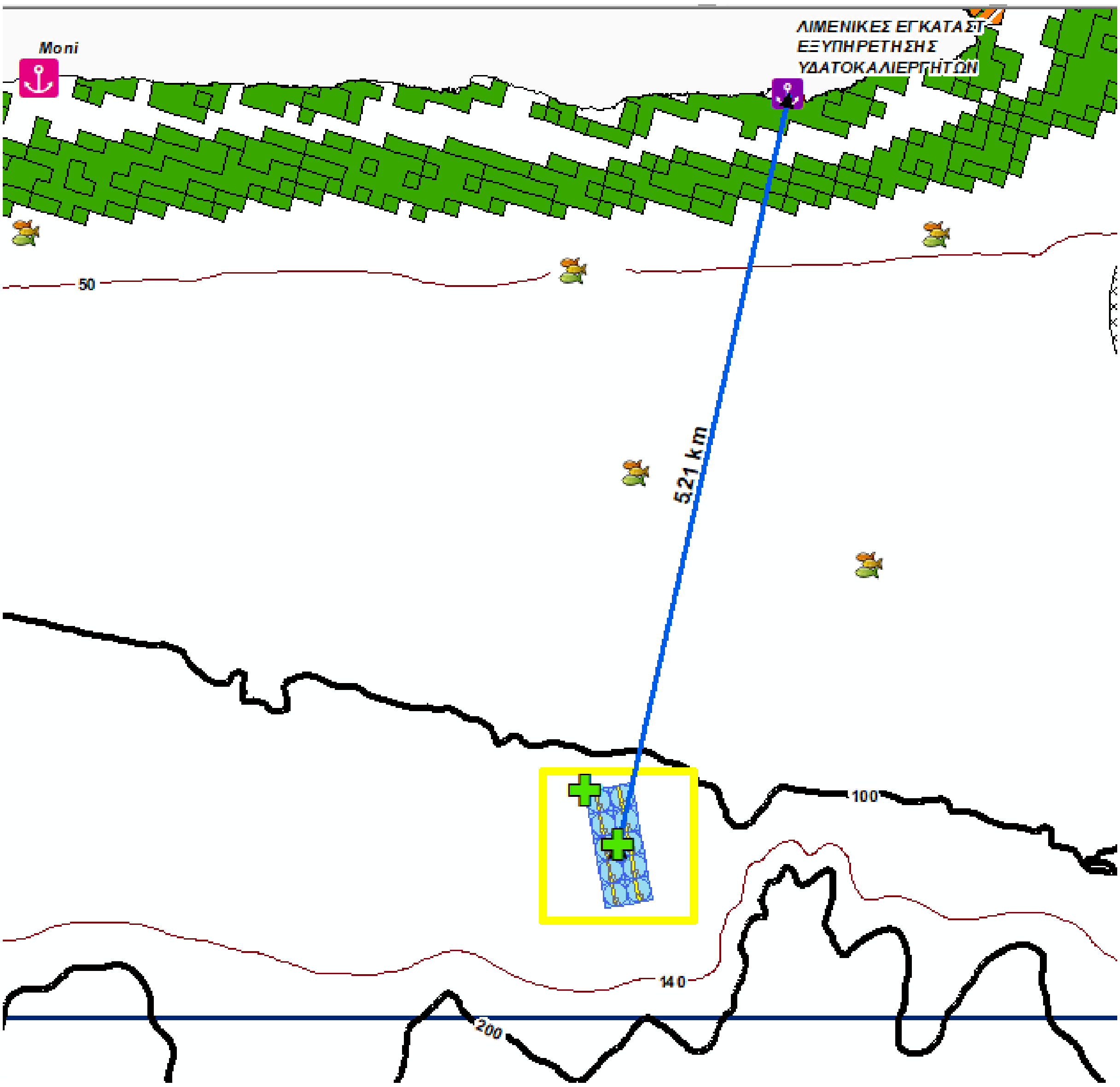


Figure 58. Deployment of Point 6 - Governor's Beach Center East – OS Aqua Cypriot Design Technology – 2,000 tonnes per year.

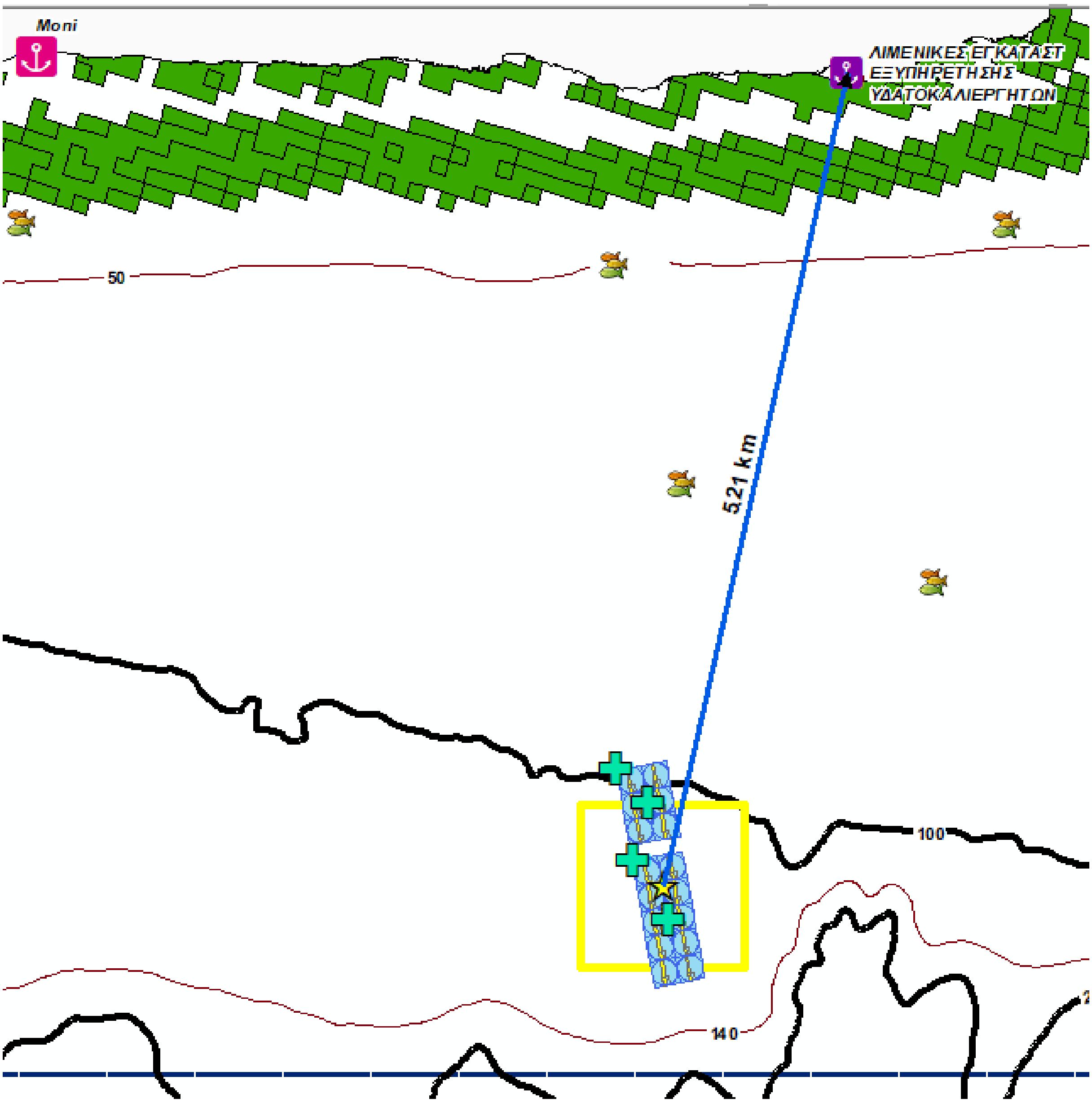


Figure 59. Deployment of Point 6 - Governor's Beach Center East – OS Aqua Cypriot Design Technology – 3,000 tonnes per year.

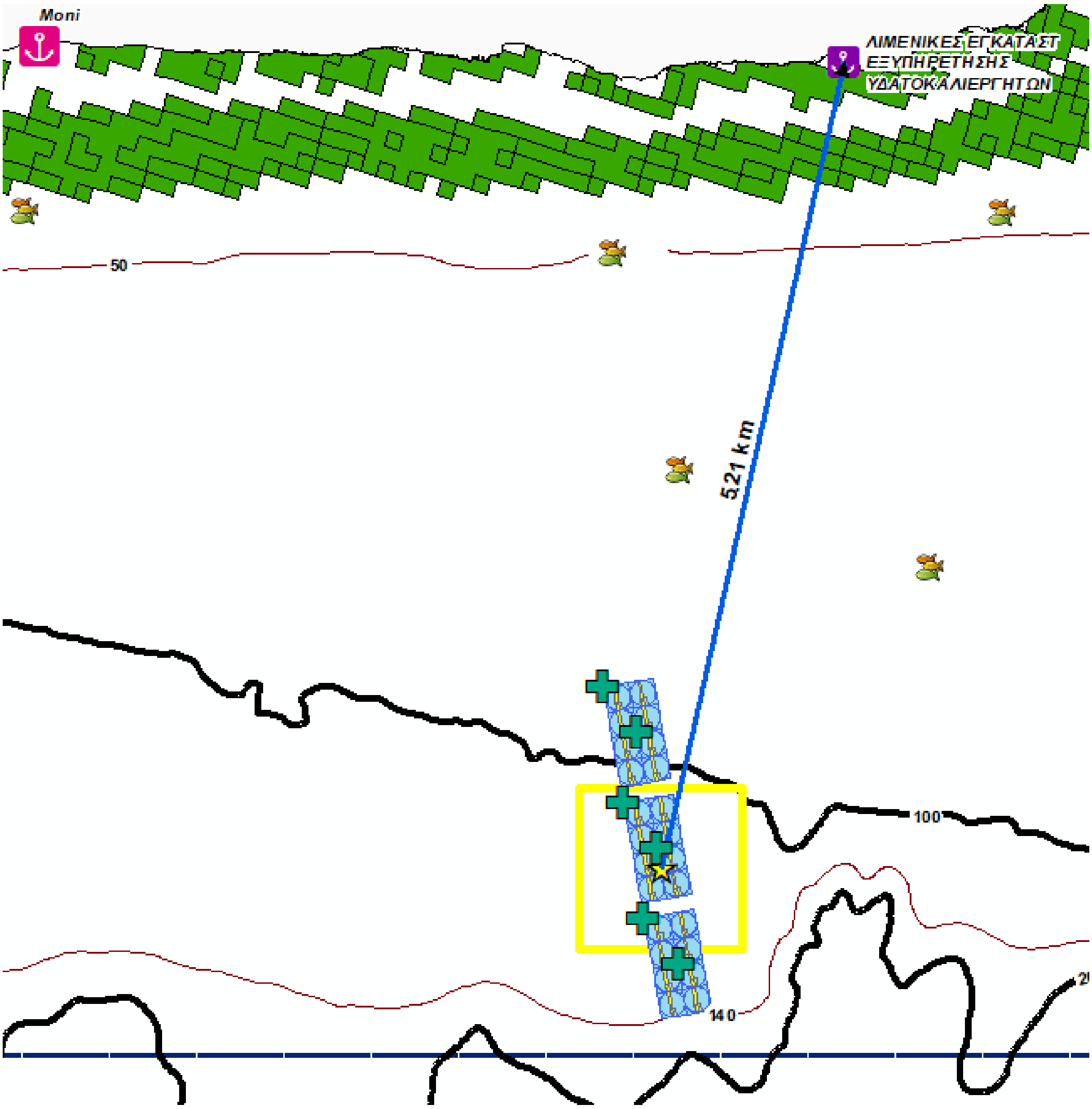


Figure 60. Deployment of Point 6 - Governor's Beach Center East – OS Aqua Cypriot Design Technology – 5,000 tonnes per year.

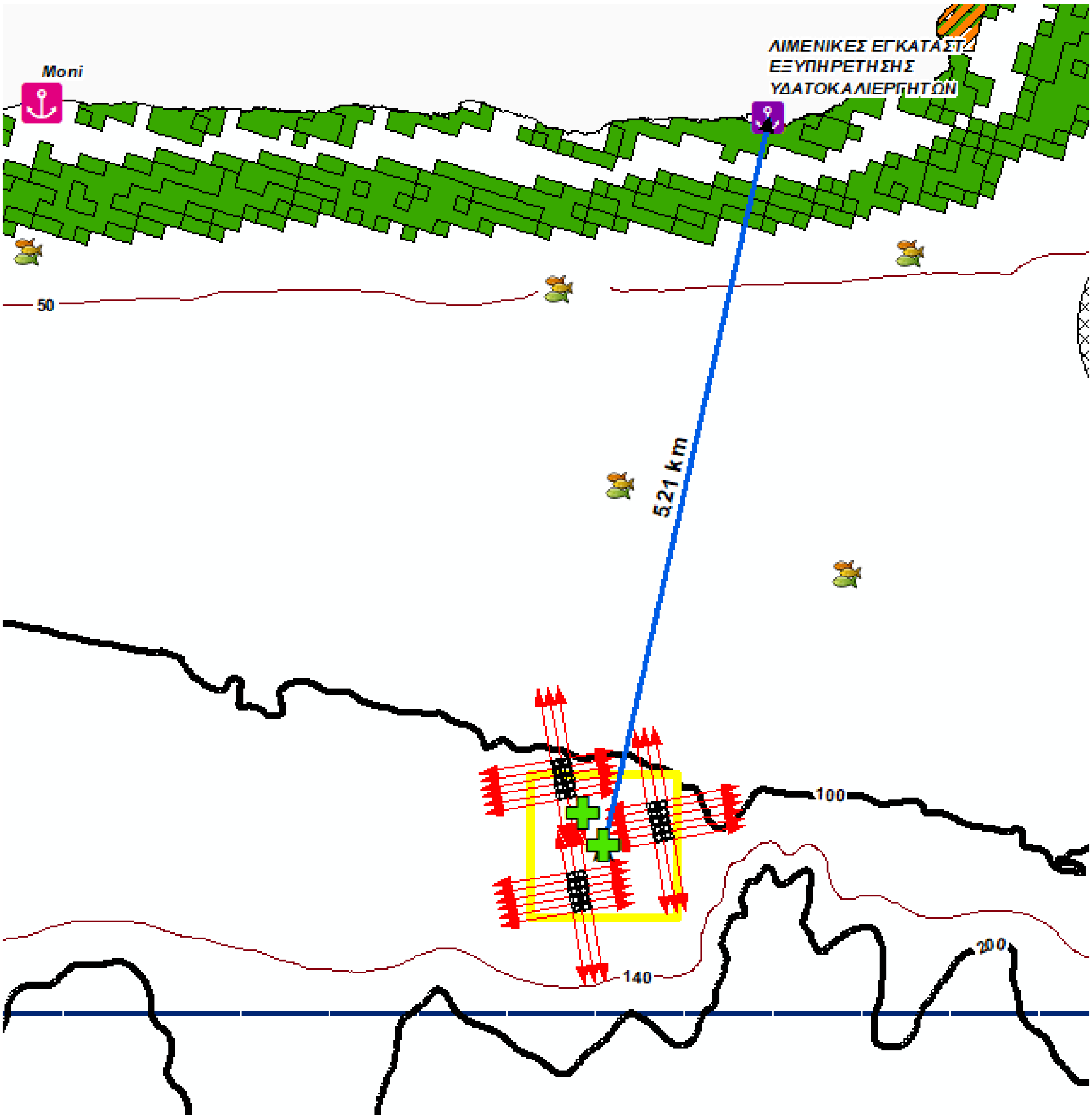


Figure 61. Deployment of Point 6 - Governor's Beach Center East – Badinotti Technology – 2,000 tonnes per year.

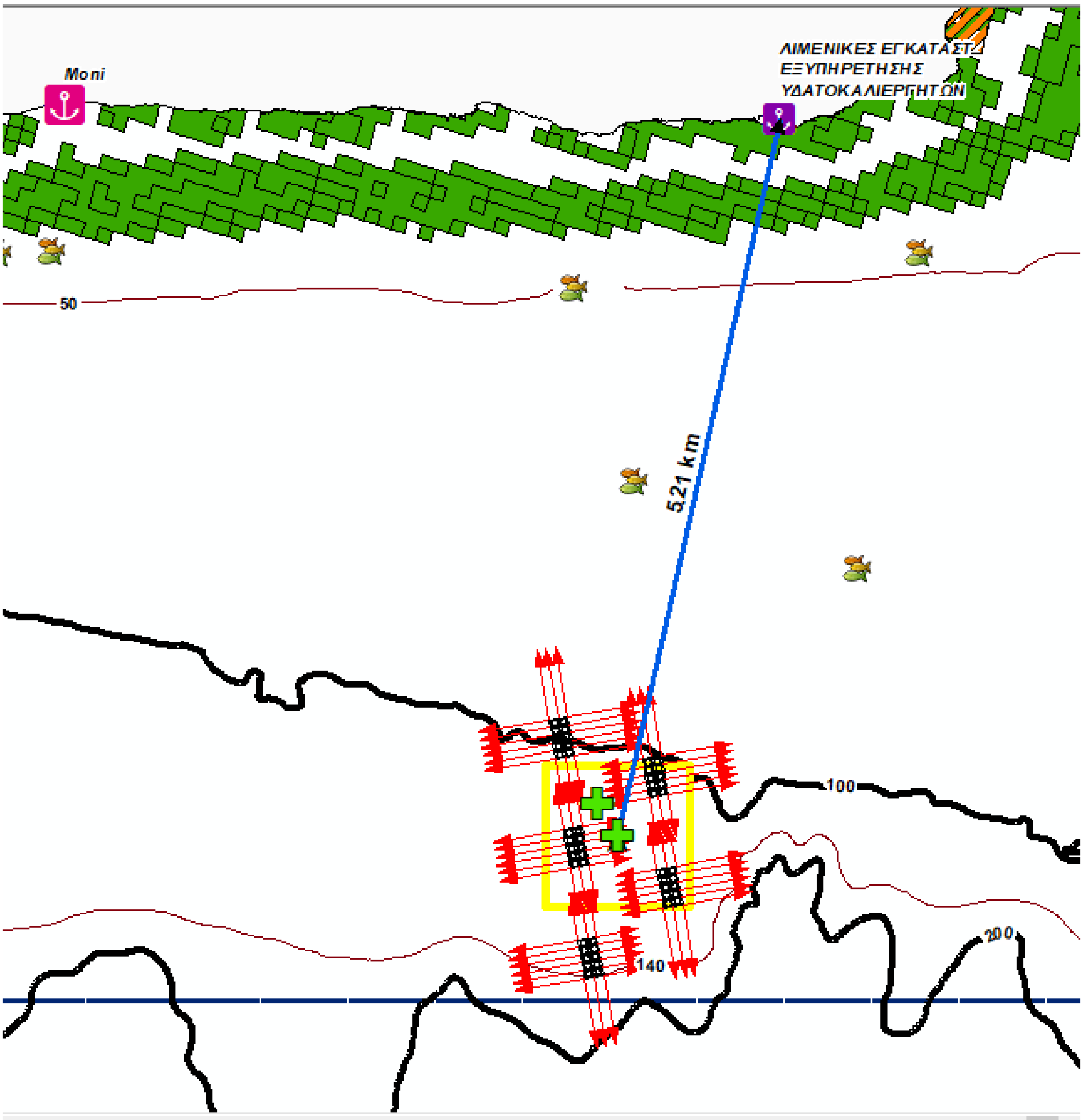


Figure 62. Deployment of Point 6 - Governor's Beach Center East – Badinotti Technology – 3,000 tonnes per year. Incompatible.

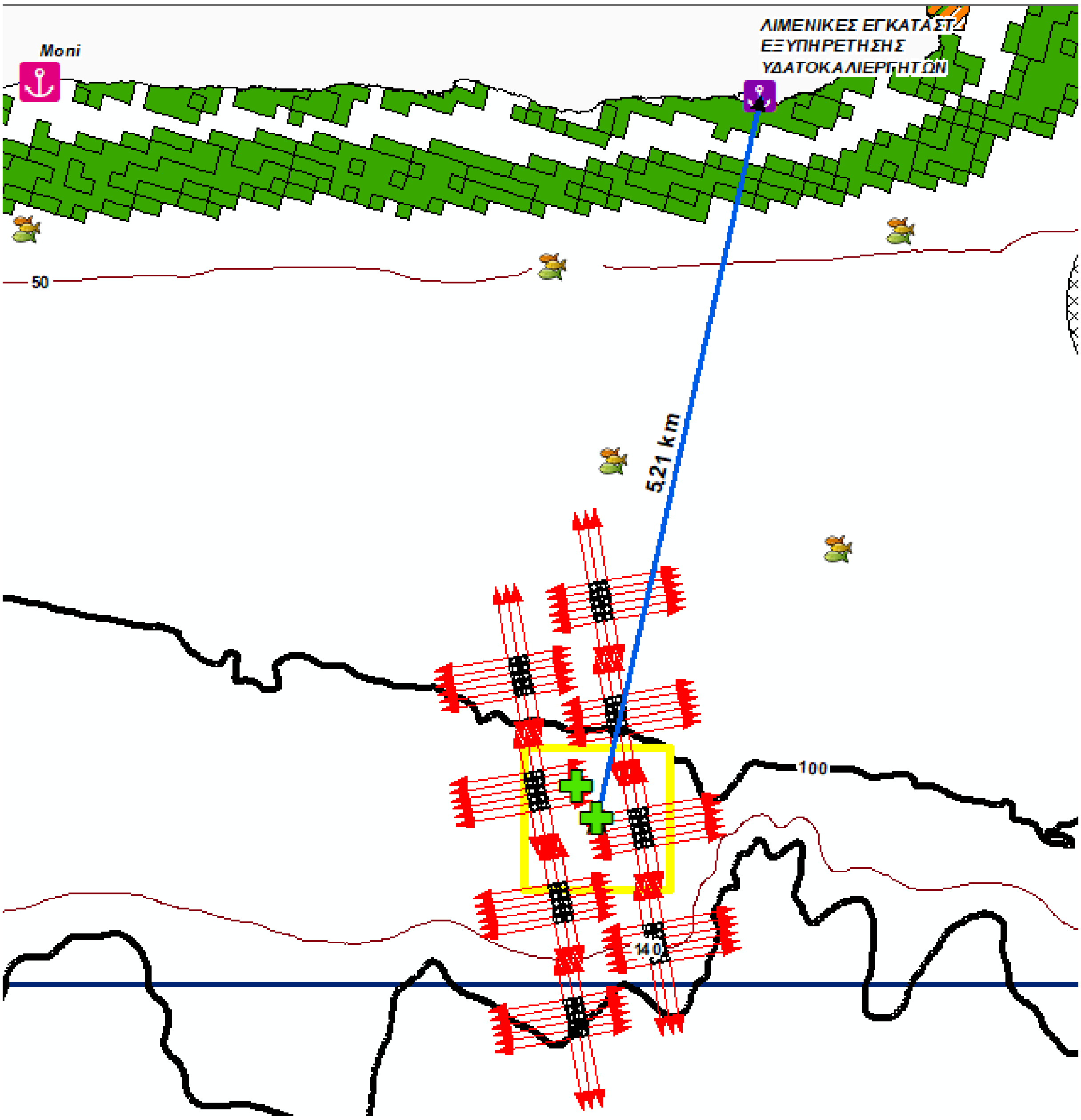


Figure 63. Deployment of Point 6 - Governor's Beach Center East – Badinotti Technology– 5,000 tonnes per year. Incompatible.

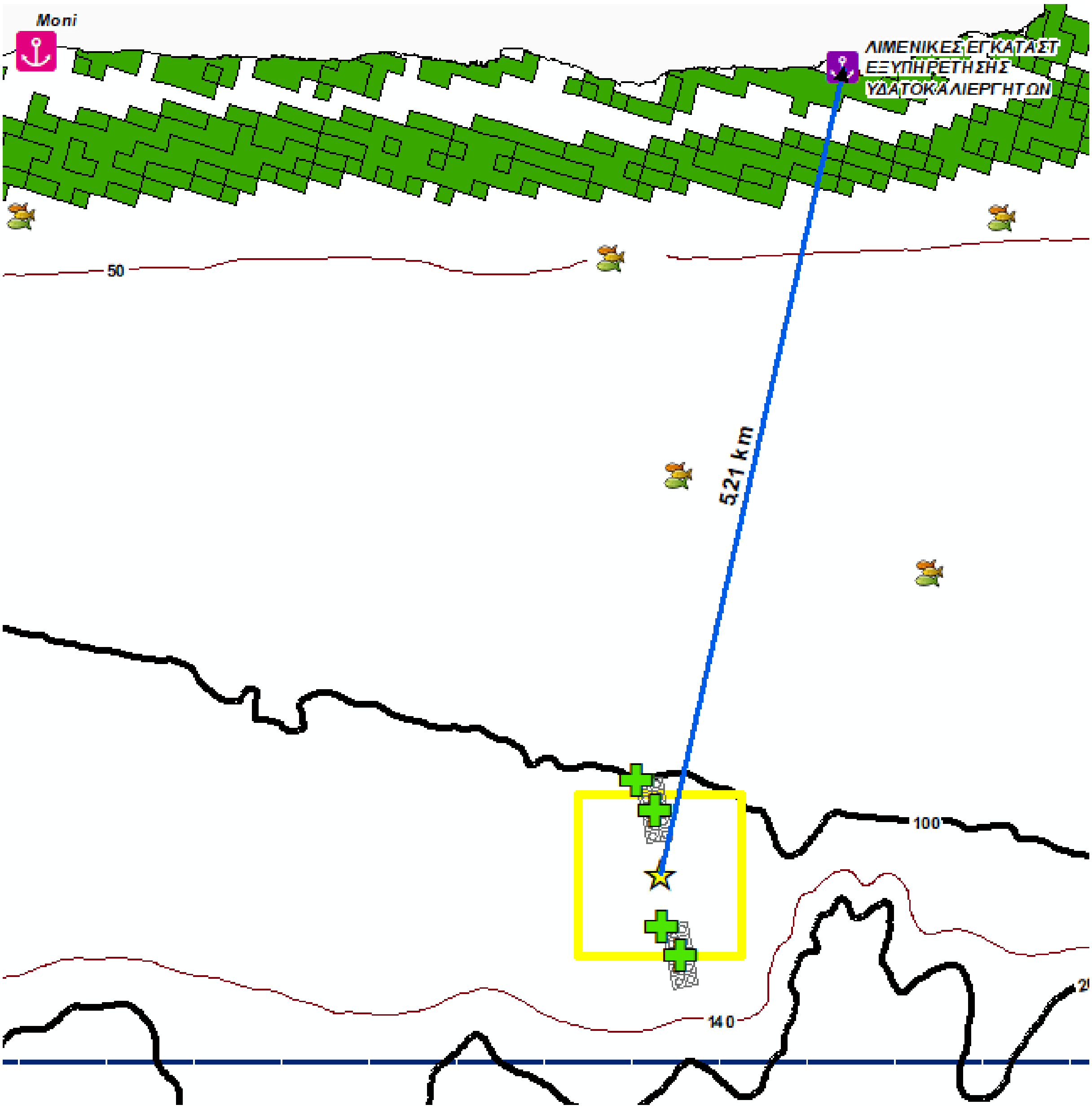


Figure 64. Deployment of Point 6 - Governor's Beach Center East – Conventional HDPE cages Technology – 2,000 tonnes per year.

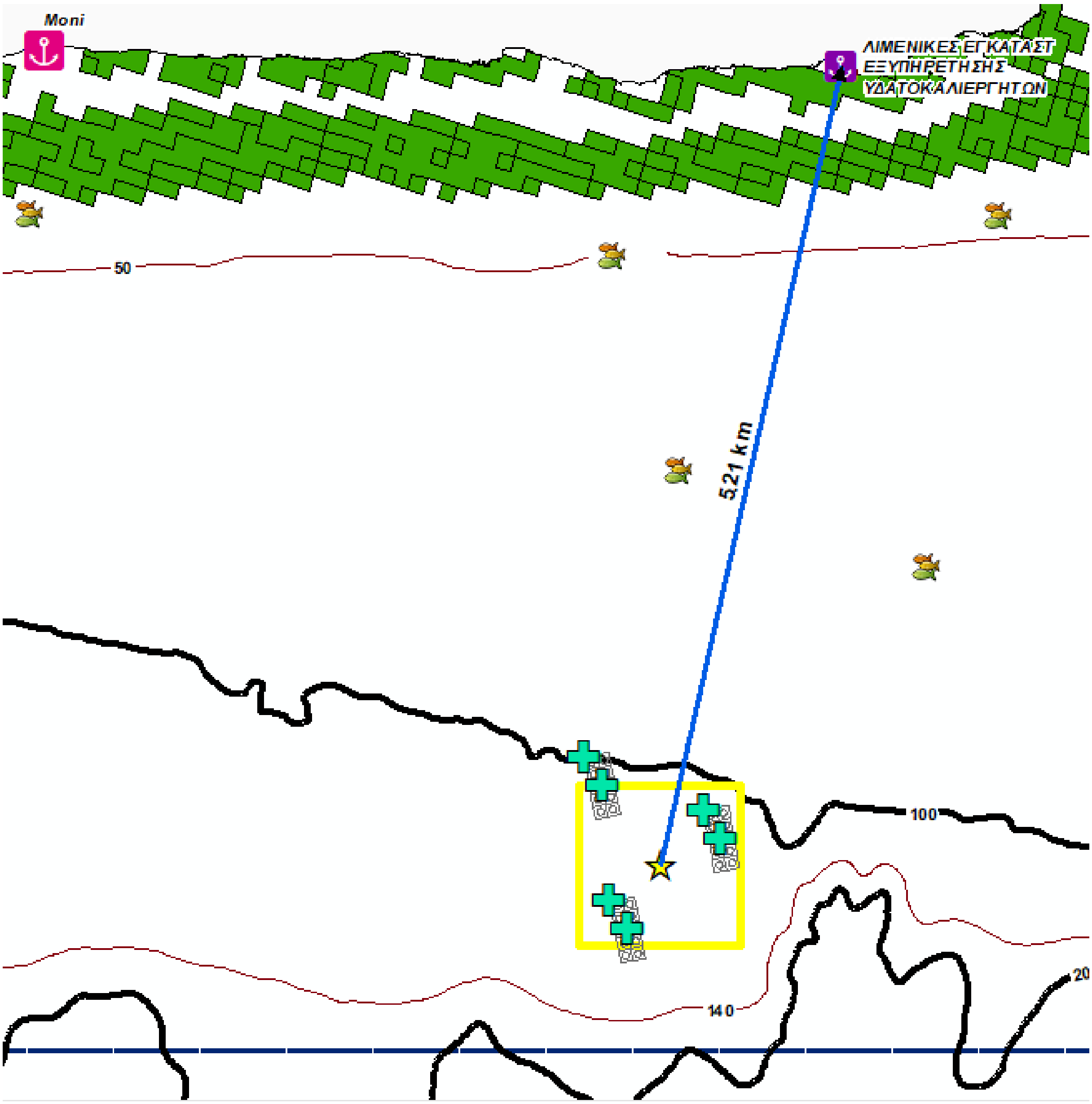


Figure 65. Deployment of Point 6 - Governor's Beach Center East – Conventional HDPE cages Technology – 3,000 tonnes per year.

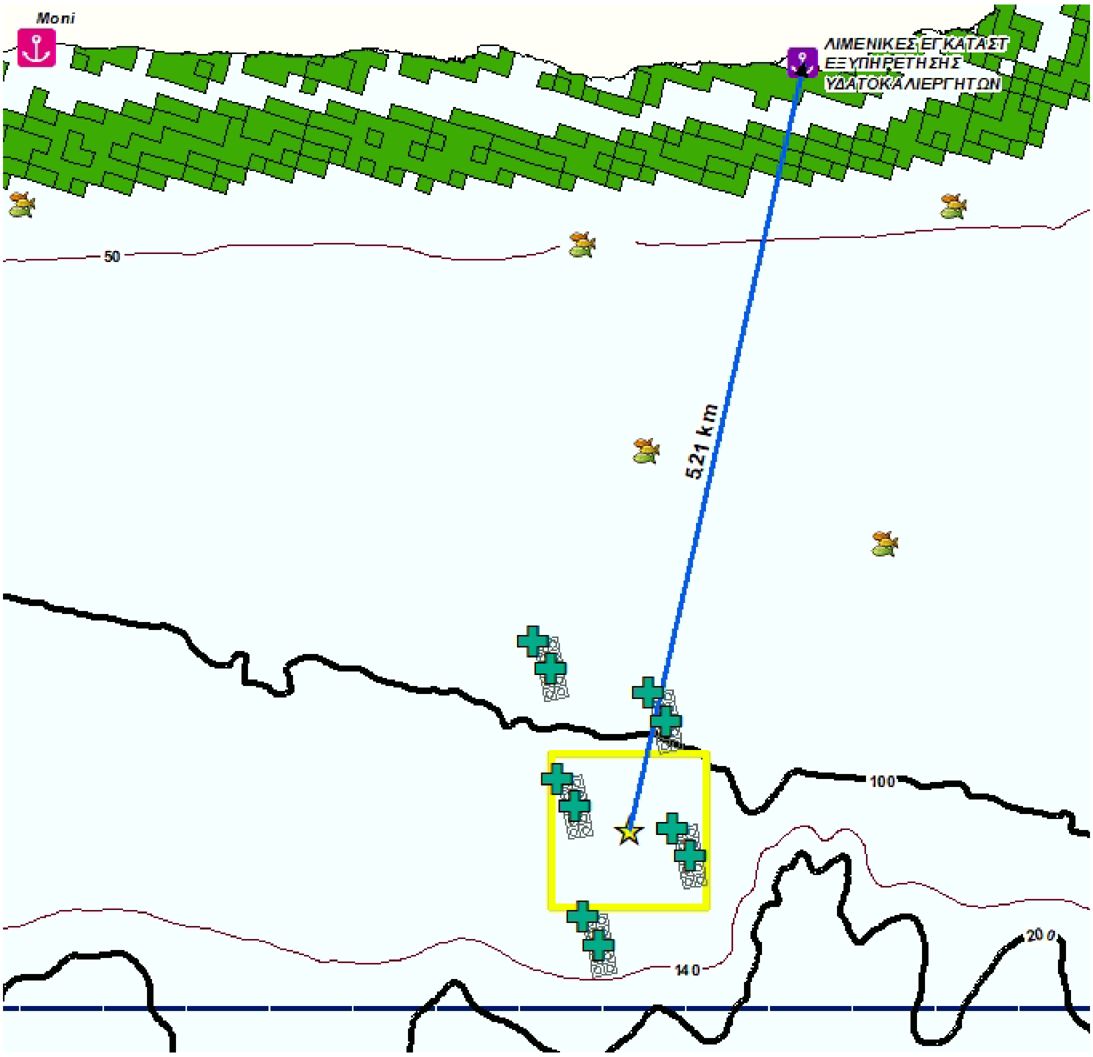


Figure 66. Deployment of Point 6 - Governor's Beach Center East – Conventional HDPE cages Technology – 5,000 tonnes per year.

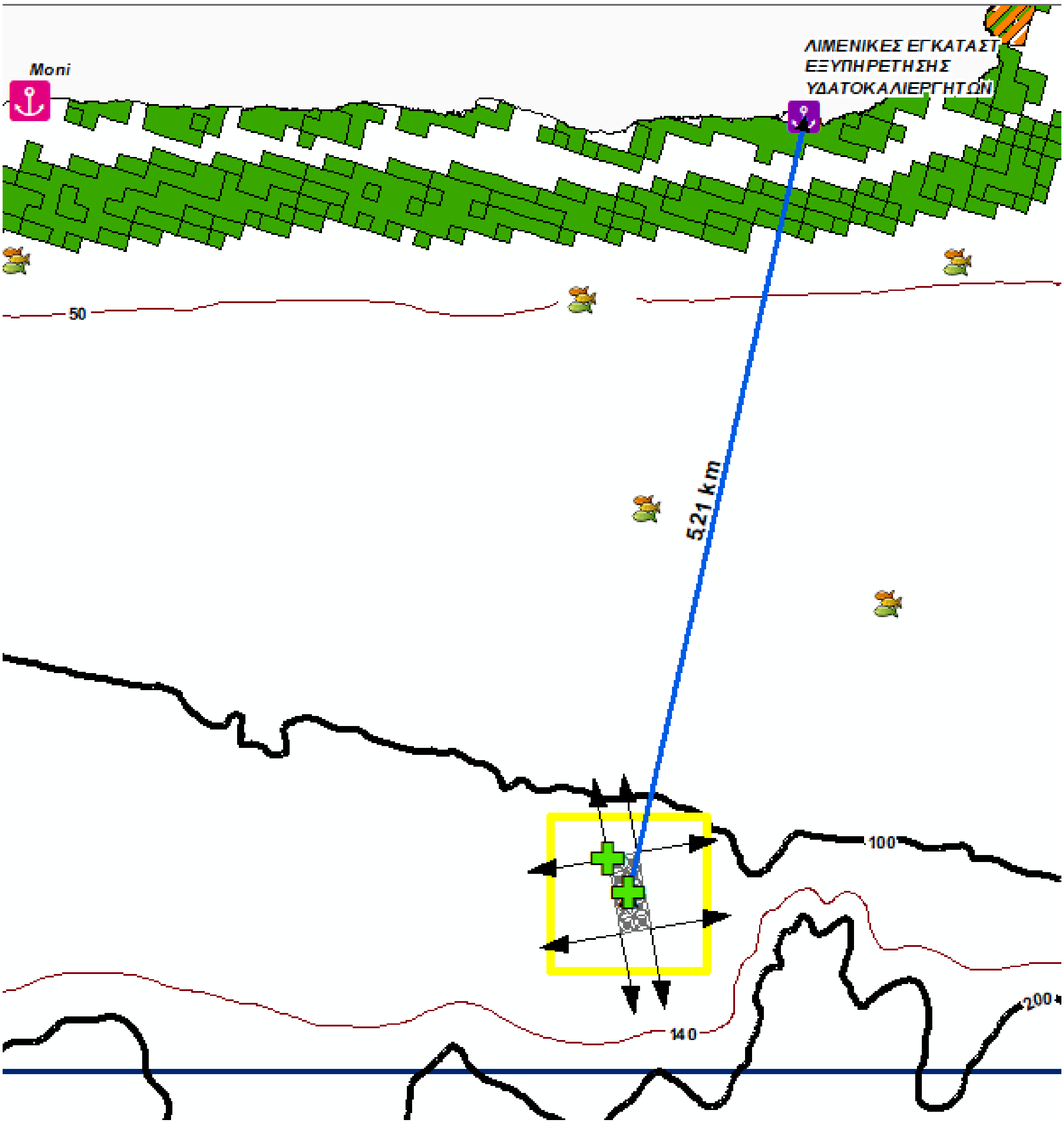


Figure 67. Deployment of Point 6 - Governor's Beach Center East – Innova Sea Technology – 2,000 tonnes per year.

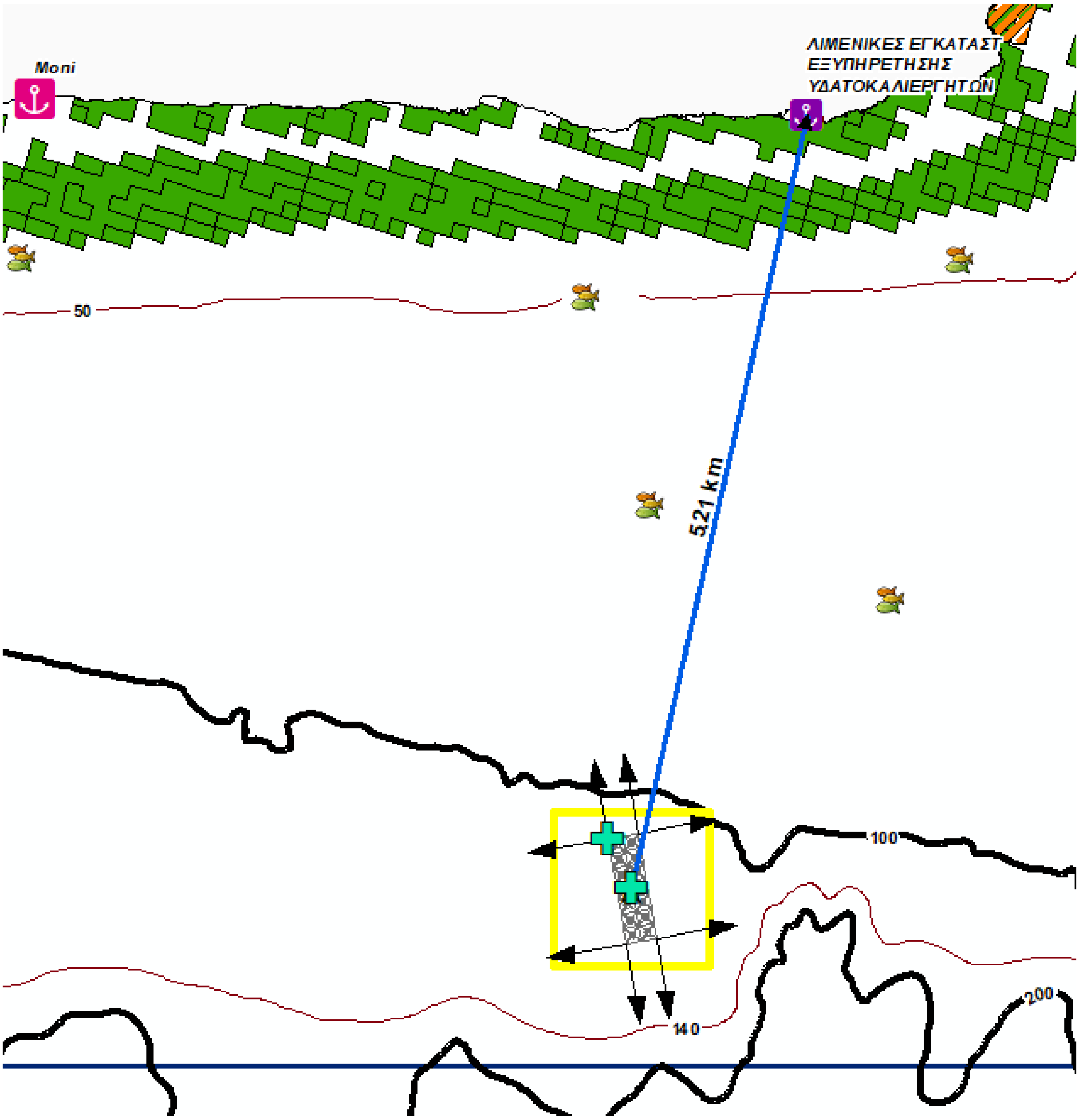


Figure 68. Deployment of Point 6 - Governor's Beach Center East – Innova Sea Technology – 3,000 tonnes per year.

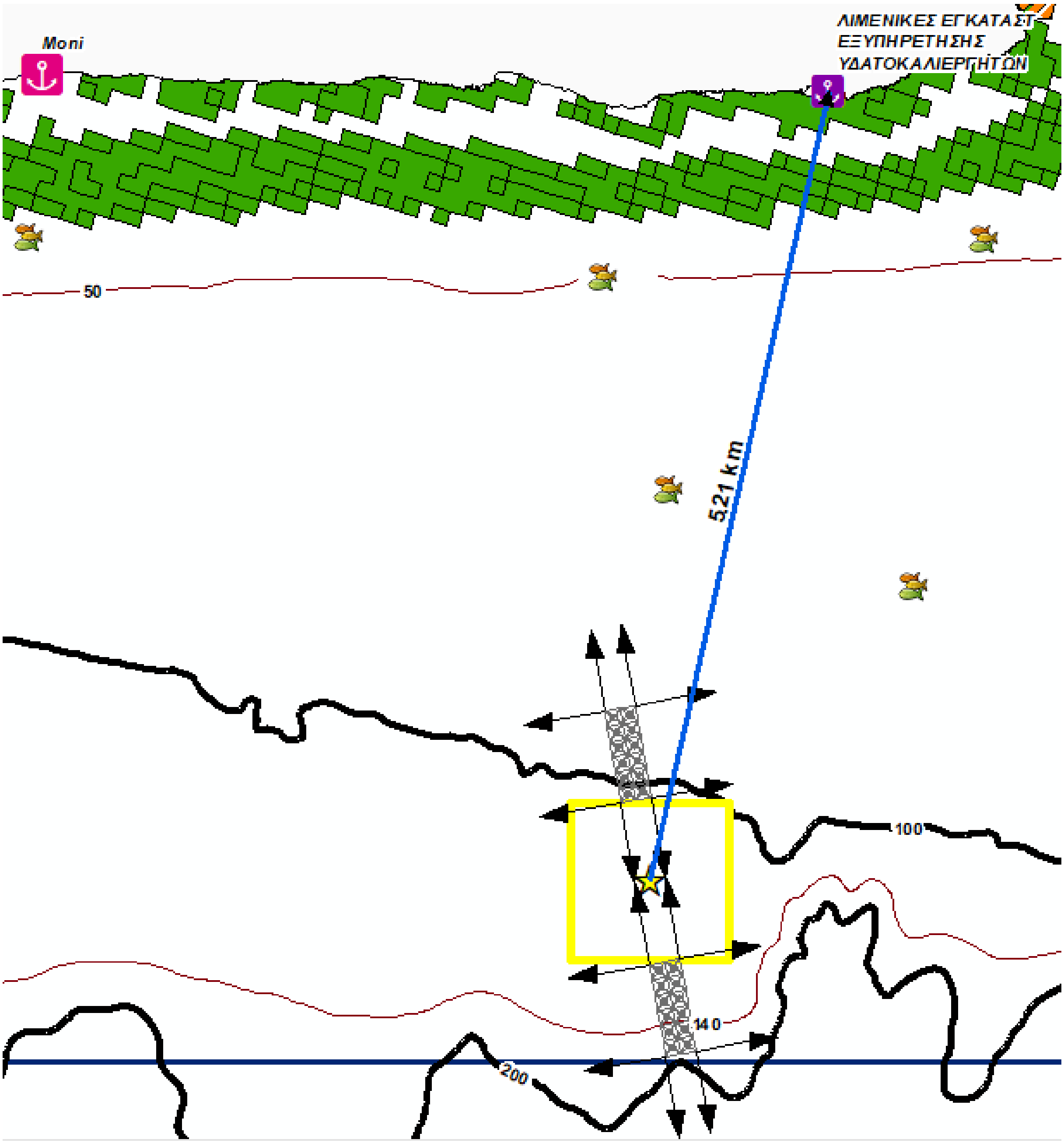


Figure 69. Deployment of Point 6 - Governor's Beach Center East – Innova Sea Technology – 5,000 tonnes per year. Incompatible.

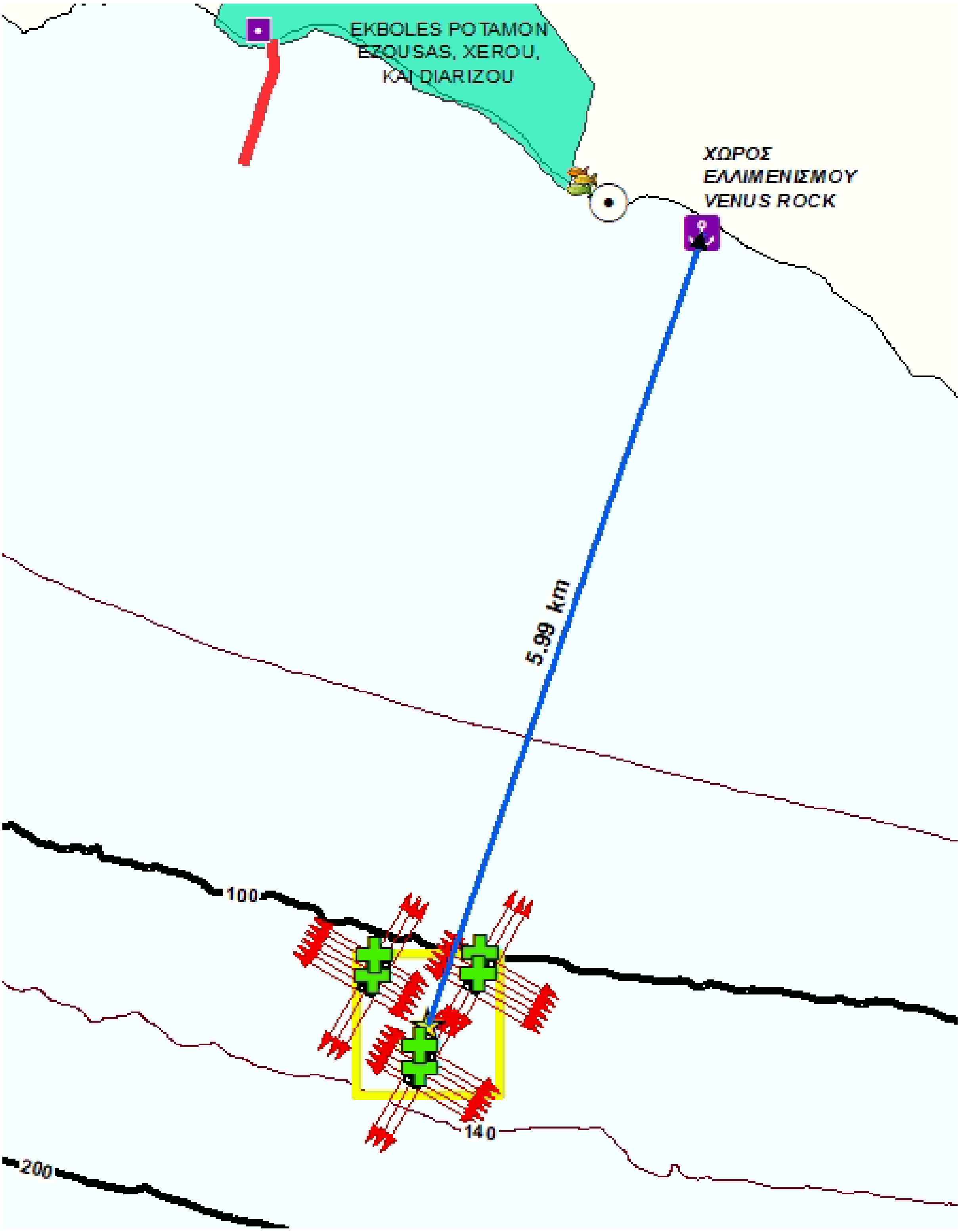


Figure 70. Deployment of Point 7 - Aphrodite Hills - Badinotti Technology – 2,000 tonnes per year.

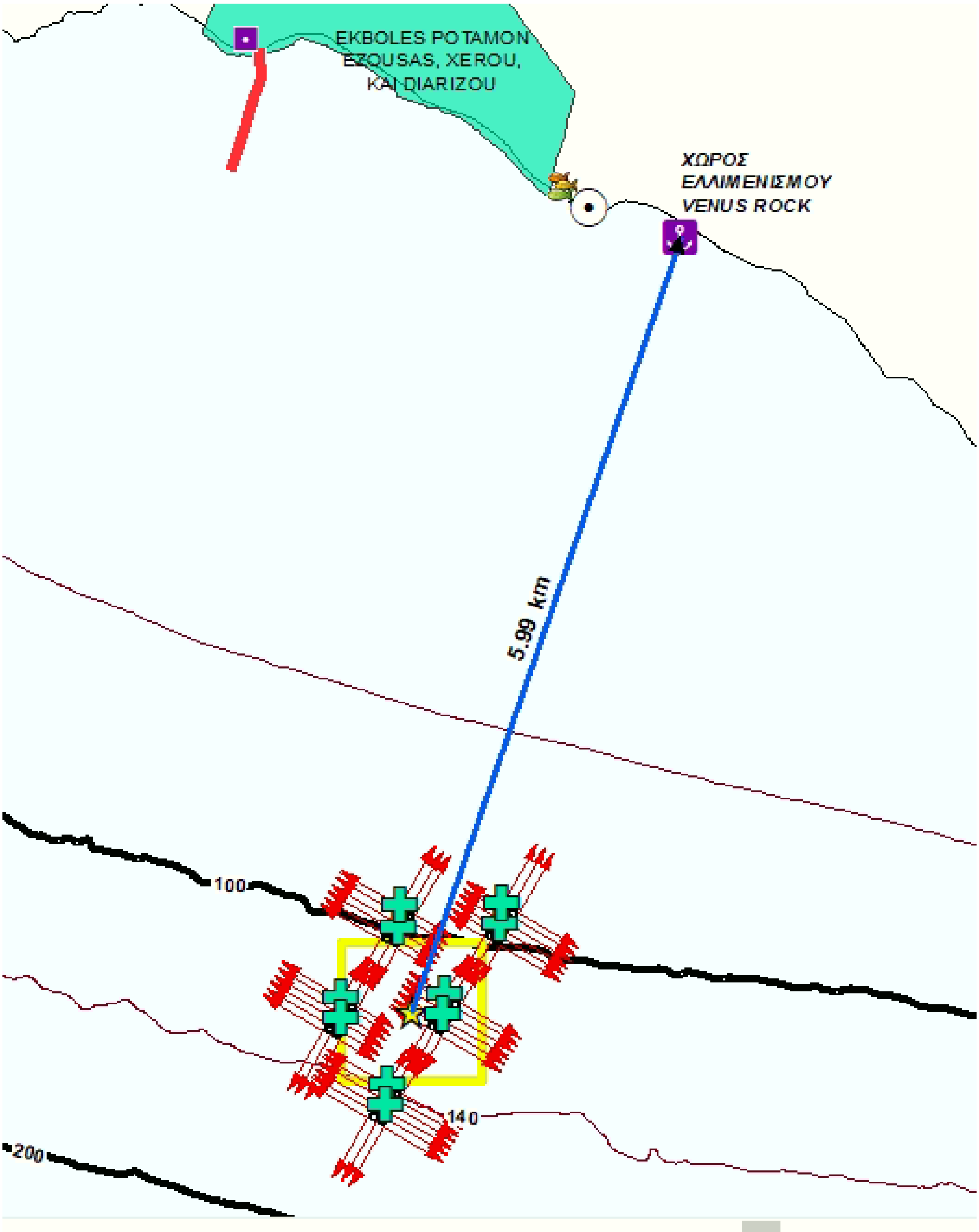


Figure 71. Deployment of Point 7 - Aphrodite Hills - Badinotti Technology – 3,000 tonnes per year.

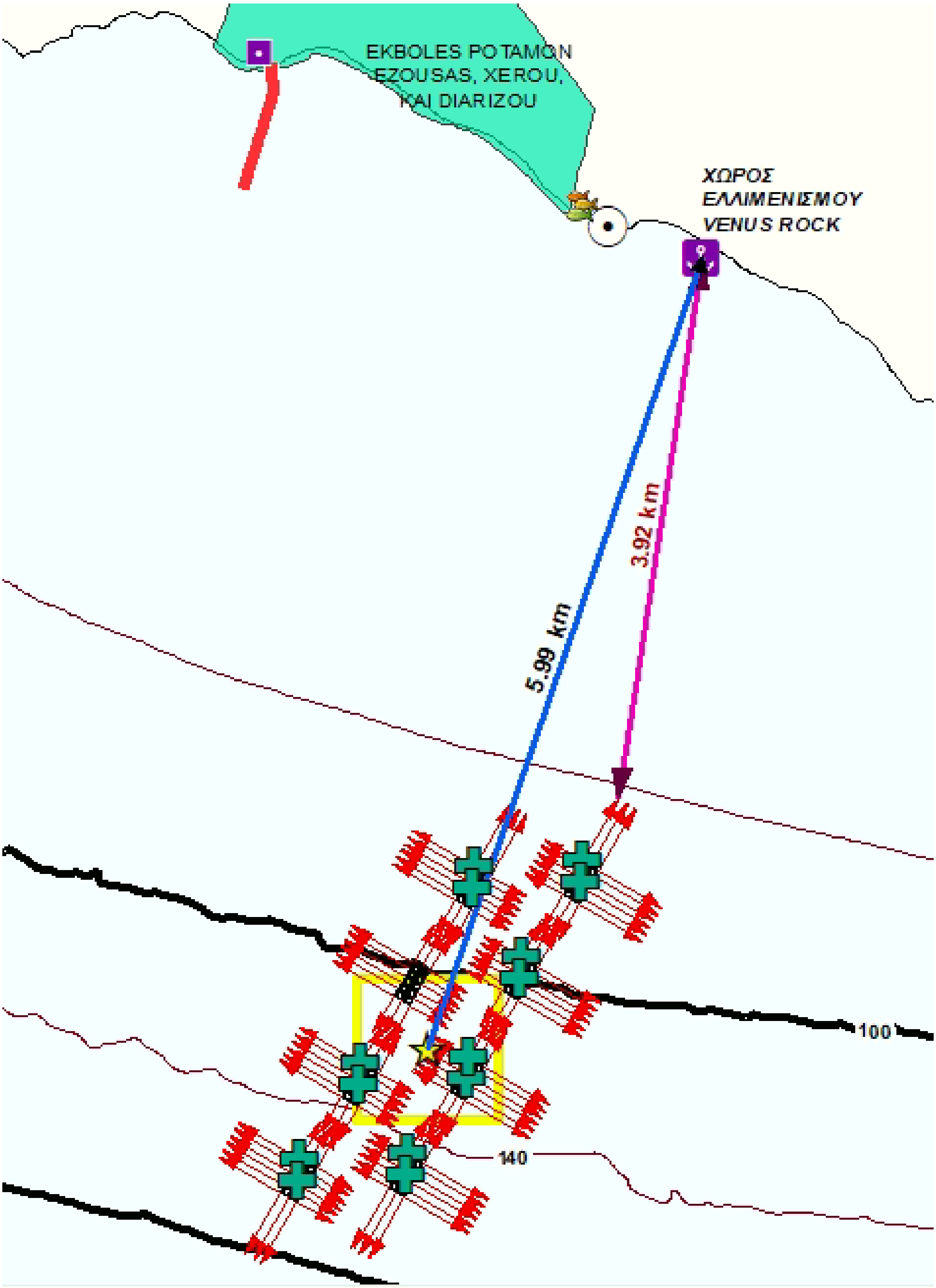
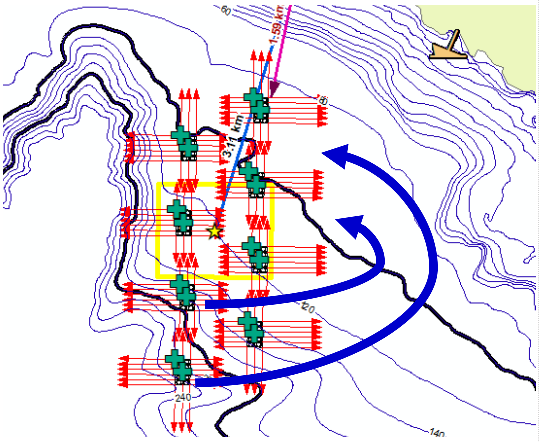
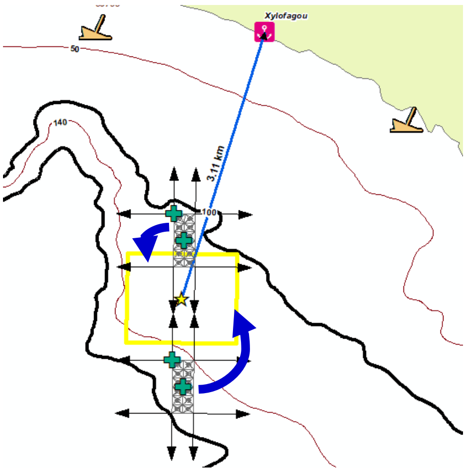
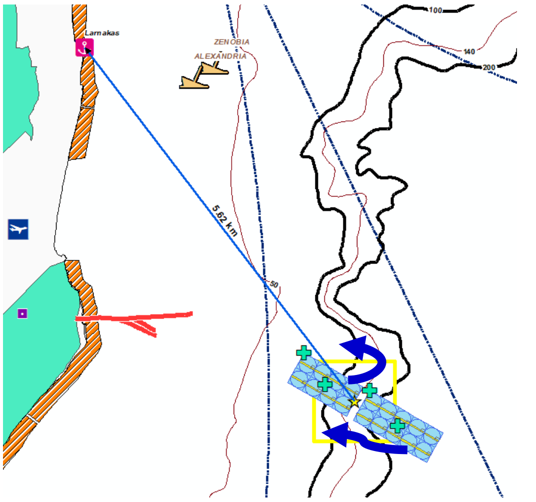


Figure 72. Deployment of Point 7 - Aphrodite Hills - Badinotti Technology – 5,000 tonnes per year.

Annex 4. Combinations of areas, technologies and production volumes that will be excluded from the modelling due to technical issues and/or conflicts with existing maritime operations and activities

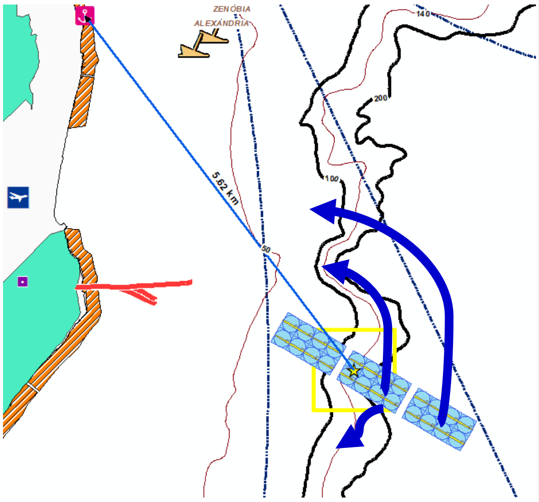
Combinations of areas, technologies and production volumes that will be excluded from the modelling due to technical issues and/or conflicts with existing maritime operations. The reasons of exclusion are briefly summarized and alternative deployment is suggested (denoted by blue arrows).

Excluded combinations from the modelling work **Suggested alternative deployment proposal:** 	**Location, Technology and production capacity.** • **Type of conflict and/or technical issue for the deployment scenarios examined**
	Point 2 -Xylofagou West - Badinotti Technology – 5,000 tonnes per year • The mooring system of two parks exceed the 200 m isobath. • A park is beyond the 200 m isobath.
	Point 2 -Xylofagou West - Innova Sea Technology – 5,000 tonnes per year • The mooring system of one park exceed the 200 m isobath.



Point 3 - Larnaca – OS Aqua Design – 3,000 tonnes per year.

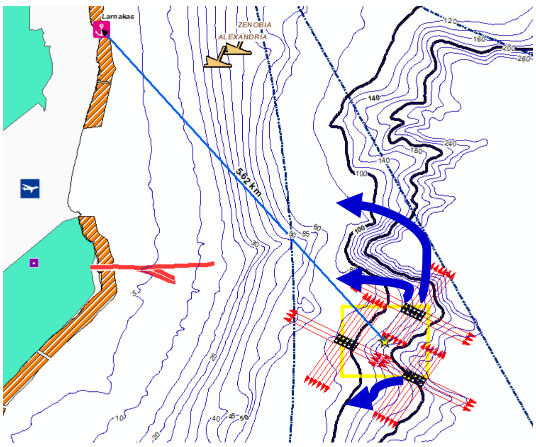
- The single point mooring of several structures exceed the 200 m isobath.



Point 3 - Larnaca – OS Aqua Design – 5,000 tonnes per year.

- The single point mooring of several structures exceeds the 200 m isobath.
- Possible conflict with existing shipping routes.
- Distance of more than 6 km for the most remote set of OS Aqua catamaran like structures.

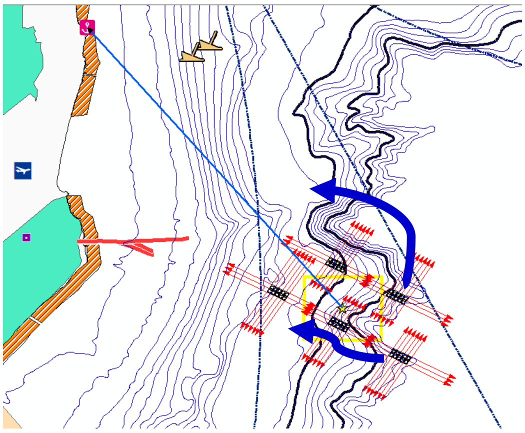
The structures cannot be moved closer to the desalination discharge pipe.



Point 3 - Larnaca - Badinotti - 2,000 tonnes per year.

- The mooring system of 2 parks exceeds the 200 m isobath.
- Distance of more than 6 km for the most remote parks.

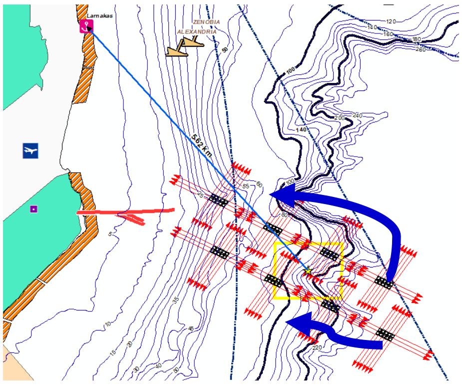
The structures cannot be moved closer to the desalination discharge pipe



Point 3 - Larnaca - Badinotti - 3,000 tonnes per year.

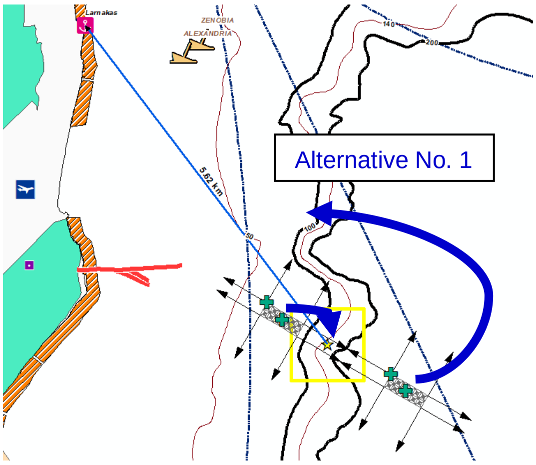
- The mooring system of 2 parks exceeds the 200 m isobath.
- Possible conflict with existing shipping routes.
- Distance of more than 6 km for the most remote parks.

The structures cannot be moved closer to the desalination discharge pipe



Point 3 - Larnaca- Badinotti - 5,000 tonnes per year.

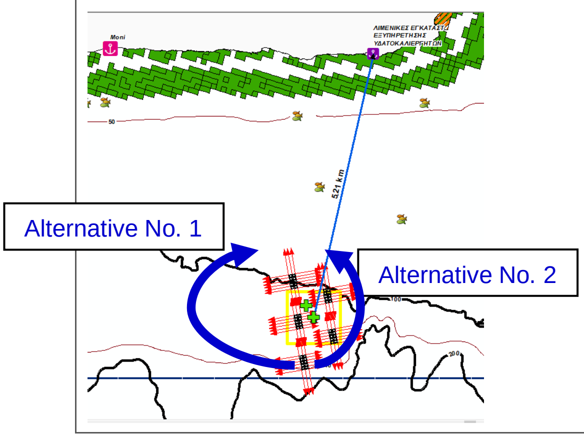
- The mooring system of 4 parks exceed the 200 m isobath.
- Possible conflict with existing shipping routes.
- Distance of more than 6 km for the most remote parks.



Point 3 - Larnaca – Innova Sea Technology – 5,000 tonnes per year.

- The mooring system and 1 park exceed the 200 m isobath.
- The southern park is very close to a ship navigation route (denoted by the blue line). It is proposed to move the southern park to the position shown by the blue arrow.

The north park to move towards the centroid and the southern to the alternative No.1.



Point 6 - Governor's Beach Center East - Badinotti - 3,000 tonnes per year.

- The southern park is very close to a ship navigation route (denoted by the blue line). It is proposed to move the southern park to the position shown by the blue arrow (2 alternative proposals are suggested).

<table>
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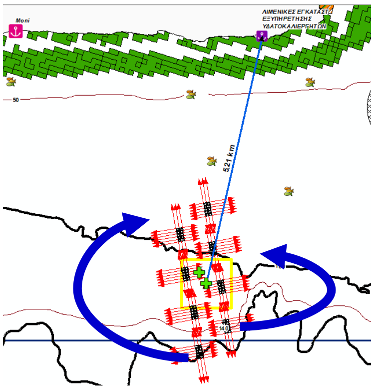
<td></td>
<td>Point 6 - Governor's Beach Center East - Badinotti - 5,000 tonnes per year.

• The mooring system of 2 parks exceed the 200 m isobath.
• The southern park is very close to a ship navigation route (denoted by the blue line). It is proposed to move the southern park to the position shown by the blue arrow.</td>
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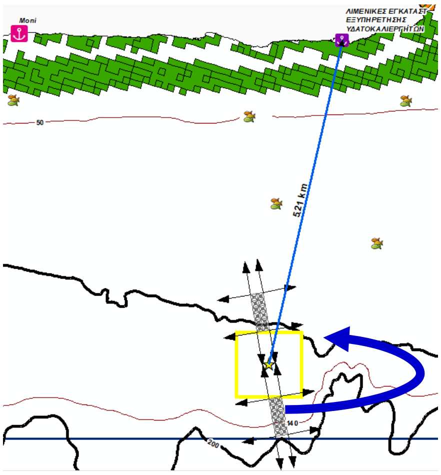
<td></td>
<td>Point 6 - Governor's Beach Center East - Innova Sea - 5,000 tonnes per year.

• The mooring system of 1 park exceed the 200 m isobath.
• The southern park is very close to a ship navigation route (denoted by the blue line). It is proposed to move the southern park to the position shown by the blue arrow.

It is suggested to move the southern park to a north eastern area.</td>
</tr>
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