The Influence of Climatic-oceanographic Changes in Aquaculture. A Case Review Concerning Mussel Farming from Vistonikos Bay, Greece

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Abstract. Mussel farming in Vistonikos Bay, North Aegean, constitutes an activity of high socio-economic importance. The wide area consists of three basins rich in organic material, namely Porto Lagos Lagoon, Vistonicos Gulf and Vistonida lake. Oceanographic morphology, sea currents, meteorological and climatic conditions, as well as the primary productivity of the wide marine area of Vistonikos Bay, favor mussel farming development but sometimes may affect them harmfully. In the present review, historical oceanographic and meteorological data are discussed, including seawater temperature, air temperature, monthly rainfall and wind dynamics, in an aquaculture related point of view. Supporting evidence revealed that occasional restrictions imposed to mussel farm units in the past are related to climatic factor extremes. However, overall, Vistonikos Bay demonstrates a suitable area for maintenance and further development of aquaculture of mussels and other bivalves.

Keywords: Mussel farming; temperature; Vistonikos; wetland; Aegean Sea.

1 Introduction

The wetland area of Vistonikos Bay - Porto Lagos Lagoon - Vistonida Lake extends between the Prefecture of Xanthi to the west and Rodopi to the east (Figure

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1). Specifically, Porto Lagos Lagoon is located in the center of these three reservoirs and is connected to the north with Vistonida Lake through three canals and to southwest with Vistonikos Bay through one canal (Koutrakis et al., 2005). Vistonida Lake receives to its northern part, the freshwater inflow from Kosynthos, Kompsatos and Travos streams (Tsakoumis et al., 2016), enriching the lake with significant amounts of nutrients of agricultural origin, as well as processing of domestic and industrial waste water (Markou et al., 2006), whereas its southern part is of higher salinity due to the entering seawater (Koutrakis et al., 2005).

The three reservoirs of Porto Lagos Lagoon, Vistonicos Bay and Vistonida Lake are characterized as small average depth, 2-3, 8 and 2 meters respectively (Koutrakis et al., 2005; Markou et al., 2006). Combined with the shallow depth, the tidal conditions of the area favor the development of all forms of fishing activities, including aquaculture. Furthermore, the ripple effect is negligible in the lagoon and very small on the east side of the Vistonicos Bay, near Fanari area, where mussel aquacultures are located, while the continuous circulation of water due to the presence of canals and benthic morphology constitute the major factors for sufficient water oxygenation (Dimiza et al, 2016).

The wide area is also a habitat of high ecological importance, which contributes to the numerous meadows of Posidonia and other aquatic plants, forming in many places an environment suitable for a habitat of oyster and other bivalve's offspring and juvenile fish. The whole habitat is also recognized as part of the National Park of Eastern Macedonia and Thrace, which is one of the 10 Greek wetlands protected by the Ramsar Convention and also as a protected area included in the European Union's Natura 2000 network (Dimiza et al., 2016).

The Vistonikos-Porto Lagos wetland exhibits an enormous fishing value at primary production levels. Fisheries have been for many decades a very important activity for Vistonicos, which in combination with the rest Thracian sea, Strymonikos Gulf, Kavala Bay and coasts of Thasos, accounts for more than 30% of the country's marine catches that are landed and traded (ELSAT, 2018).

Mussel farming was first developed in the region in 1999, when seven mussel farm units were environmentally and administratively licensed (Decisions DAMT 654-656/24-10-2000, 633/1-11-2001, 640/1-11-2001) (Figure 1). Given the recognition and protection of the area through the Ramsar and Natura 2000 Convention, this form of aquaculture is a fully compliant activity with these regulations as well as with the protection of the natural environment, since the burden on the marine area is negligible and derives solely from secretions of farmed mussels (Eleftheriadis, 2001). It should be also noted that the first units started with native mussel populations from the area itself, thereby avoiding biological contamination with alien species and at the same time stimulating the local shellfish. In the present review, historical oceanographic and meteorological data are discussed, including seawater temperature, air temperature, monthly rainfall and wind dynamics, in an aquaculture related point of view.

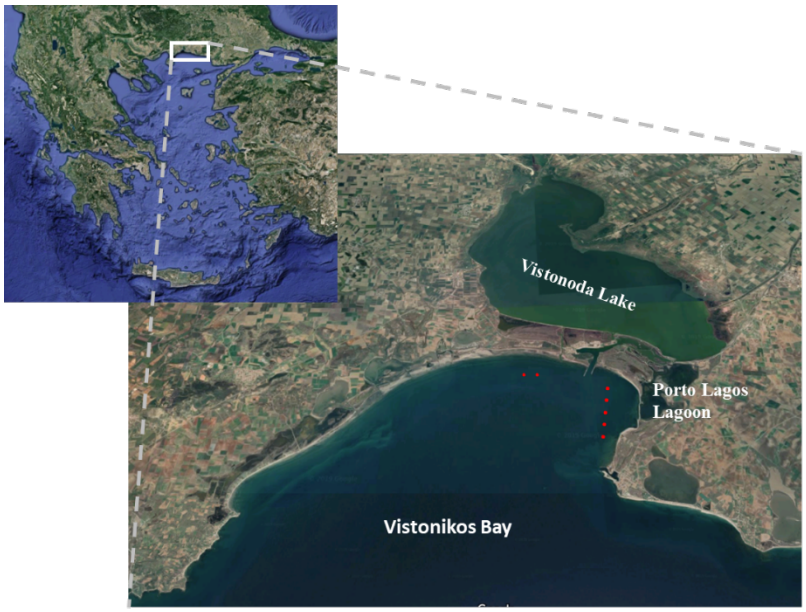

Fig. 1: The wetland area of Vistonicos bay. Red dots indicate the location of mussel aquaculture units.

2 Area properties

2.1 Oceanography

The Aegean Sea archipelago is characterized by various seabed topologies, encompassing many differential depth and relief areas. In contrast, the Vistonikos Bay exhibits a greater uniformity with lower depths (Androulidakis et al., 2017). The larger part of Vistonikos seabed is sandy, hosting many coastal areas with Posidonia meadows, while rocky areas are fewer (Dimiza et al., 2016). At Fanari Cape, an artificial reef system was constructed and installed in 1999, consisting of a protective zone (240 m3) and a core (9 Italian and 9 French artificial reefs) exceeding length of 6 km at an approximate depth of 25 km (Manoudis et al., 2005). The construction of these artificial reefs is a measure of great importance for the management of coastal marine ecosystems and has also proven to be very effective in enhancing fisheries (Pickering et al., 1998). They can also play an important role in the marine area of the coastal zone, including protection against the mechanical impacts of fishing gear,

such as trawling, habitat restoration, increased territorial heterogeneity and substrate diversity in deep seabirds (Manoudis et al, 2005).

2.2 Sea currents

The mechanisms of water circulation depend on the amount of water and other hydrological factors, such as wind intensity, thermal fluxes, salinity flows and upstream movement due to river outflows. In the North Aegean the circulation of water is cyclonic (Figure 2). The flow of the North Aegean streams is strongly influenced by the outflow from the Black Sea and the additional influx of fresh water from rivers. These inflows are low salinity and are offset by an influx of more saline waters from the eastern Mediterranean that balance the salinity of the Aegean in general (Poulos et al., 1997). In particular, the salinity of the Black Sea waters is lower (29.6‰) than the corresponding Aegean waters (38,9‰), therefore they are lighter and move superficially in the water column. On the contrary, the waters of the Aegean flow to the bottom of the water column heading towards the Black Sea, forming a countercurrent stream. However, it should be noted that the low salinity water outflow from the Dardanelles is the most important lateral buoyancy force, which exceeds that of all rivers (Kourafalou and Barbopoulos, 2003). These streams have lower temperature and higher nutrient content than the oligotrophic Aeagean (Siokou-Frangou et al., 2002), which favored the development of mussel aquaculture in the Aegean northern parts, such as Thermaikos, Vistonikos and the bay of Kavala. In particular, in the region of Vistonikos, recorded salinity values are considered normal for coastal waters near estuaries. The lowest values are found in the surface layers of the water column (0 - 4 meters deep). Also, lower salinity values are usually observed during the winter. The transfer of fresh water from lake Vistonida contributes to these lower salinity values as well.

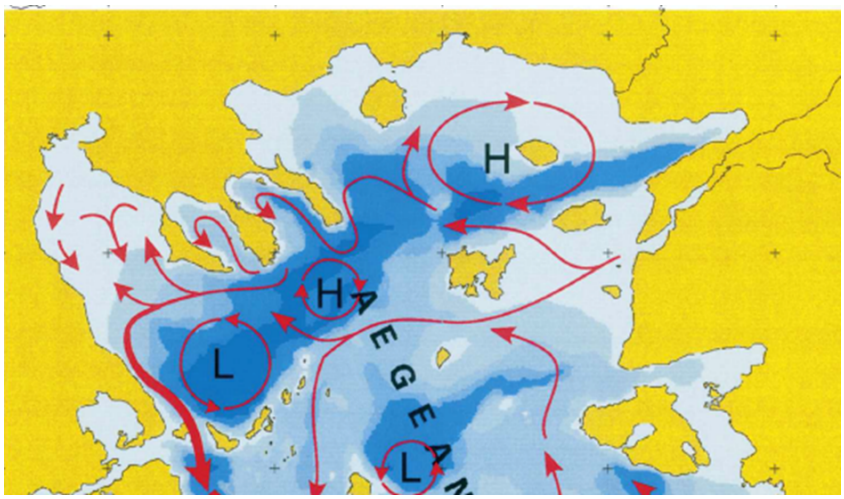

Fig. 2: The cyclonic flow of streams in the North Aegean (modified image by Olson et al., 2007)

The precise determination of the hydrodynamic circulation in the Vistonicos Bay presents many difficulties. The currents depend on many causes, most notably winds, tides and densities (Manoudis et al., 2005). The tidal effect within the Vistonikos Bay is generally low, however it plays an important role in the rotation of the maritime masses, but also, in conjunction with underground currents, in the transporting of pollution outward to the bay. Density differences play an important role in the local movement of water (surface - bottom). They occur mainly during the hot season when the surface layers of water are heated, thus becoming lighter than the deeper layers. As a result, there is a lack of oxygenation of the deeper marine masses. On the contrary, during the winter season, the surface layers of water get cooler, become heavier and sink, disturbing water stratification, thus homogenizing the water column and helping the oxygenation of water throughout the column. This is particularly important for the survival of mussels, which are susceptible to low concentrations of dissolved oxygen (Anestis et al., 2007), whereas the general cyclonic water flow of the North Aegean is, among other factors, responsible for the genetic homogeneity of the mussel populations (Giantsis et al. 2014). Although winds are the main cause of water circulation, they are of variable direction and intensity on a small-time scale. Therefore, currents also follow this variable state. The prevailing winds are the northeast, from which mussel cultivation units are protected. Surface currents are correlated with the direction of the winds, while the deeper currents have usually an opposite direction.

2.3 Meteorological and climatic data

The climate of Eastern Macedonia – Thrace is generally typical Mediterranean with mild winters and a dry, warm summer. During winter the general circulation of the atmosphere brings to the region winds of western origin, which are closely linked to cyclonic crossings and polar air intrusions. Also, winter months are mostly rainy, due to the meet up of tropical warm winds with polar cold winds, and they have more than twice of the average rainfall over the rest of the months (Figure 3).

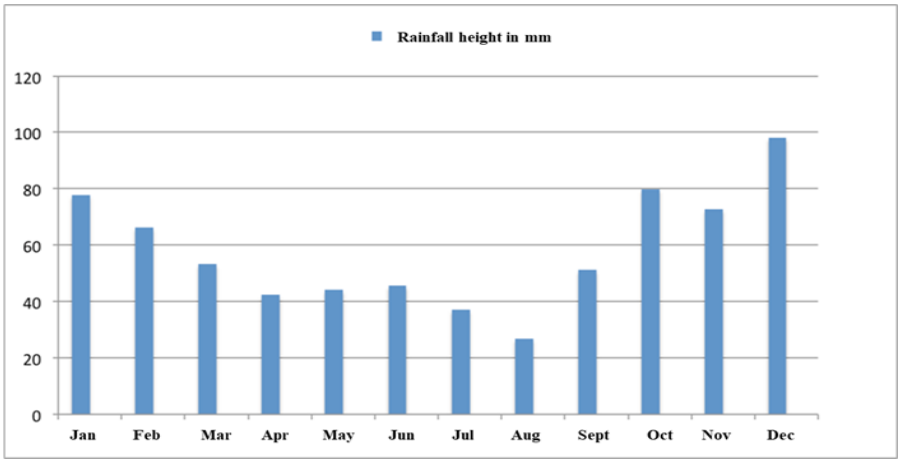

Fig. 3: Average monthly rainfall based on a weather station in Imeros Rodopi belonging to the Meteorology and Climatology Department of AUTH as well as on a weather station in Genisea Vistonida, belonging to the Greek Ministry of Agriculture

In contrast, during summer, northern winds weaken locally due to the action of the sea breeze. While the mean monthly air temperature during summer does not exceed 26 °C, instant daily temperature often reaches 40 °C (Figure 4). The average seasonal temperature range is between 15 °C and 26 °C in surface waters in the Aegean (Figure 5) and can adversely affect mussel survival during summer months, occasionally causing direct mortality to mussels, increase of harmful microorganism populations and reduce of dissolved oxygen availability. The maximum critical temperature limit of *Mytilus galloprovincialis* mussels depends on the residence time and has been calculated at 28 °C for a few days or at 26 °C for a period of 2 weeks (Mavridou et al, 2016).

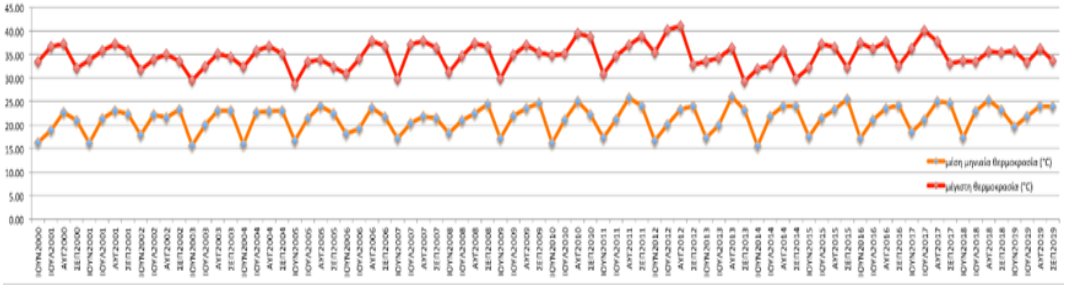

Fig. 4: Average (orange) and maximum (red) air temperature values of the four hottest months during the last 20 years

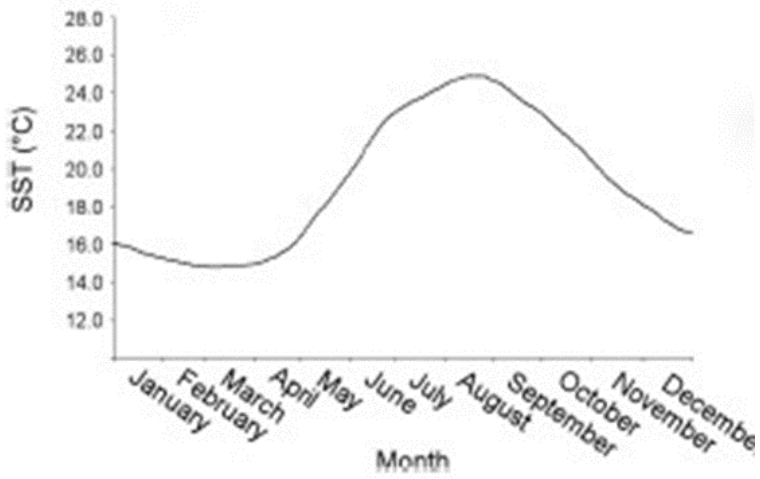

Fig. 5: Diagram of average monthly seawater surface temperatures in the Aegean (Ciappa, 2019)

2.4 Primary productivity

Primary marine productivity is defined as the production of chlorophyll phytoplankton (Smetacek et al., 2002), a property of great importance for the development of mussels. These organisms synthesize, via photosynthesis, organic compounds from inorganic salts dissolved in seawater, like nitrogen, phosphoric and

silicon salts, and carbon dioxide. These nutrient inorganic salts represent higher concentrations in coastal waters and estuaries as well as at high depths. Also, these concentrations are even higher during winter season, due to the mixing of water column, and in mid-autumn when the thermal sea water column is completed.

Usually nitrogen and phosphoric salts in the seas are limiting factors for the production of biomass (primary production). On the other hand, silicon does not appear to be a limiting factor except for diatoms (Smetacek et al, 2002).

In Vistonikos Bay the concentrations of orthophosphate range from zero, during summer season, to the highest concentrations of 75.1 μg/l (Eleftheriadis, 2001), which are observed from the end of winter to the middle of spring. As for nitrates concentrations, they represent the highest values during winter, and they drop during summer (less than 10 μg/l). Also, the concentrations of ammonium salts are higher than those of nitrate and nitrite, with the highest values being observed during winter, as well as in spring. All these above values of inorganic salts can be characterized as suitable for aquaculture, providing ideal nutritional conditions for the growth of mussels.

3 The effect of meteorological-climatic data on mussel farming in Vistonikos Bay

The reasons that contributed to the development of mussel aquaculture in Vistonikos Bay can be summarized (a) in the presence of natural shellfish populations, (b) in the quality of water in combination with the sea currents and shoreline morphology and (c) the presence of the Porto Lagos port and the Fanari fishing harbor.

However, in 2010, the production of "all mussels" in the area was completely destroyed due to the emergence of phytoplankton. The high concentrations of toxic phytoplankton in seawater occurred at the end of summer and early autumn, periods when the highest temperatures were observed (Figure 4). Also, in 2012, a series of unexplained deaths in experimental mice were observed, that were attributed to lipophilic toxins with nerve symptomatology (Vlamis et al., 2015). Increased concentrations of harmful microorganisms, such as toxic phytoplankton and toxin-secreting bacteria, are positively correlated with high temperatures (Jay, 2000). Such problems can be avoided in mussel aquaculture by monitoring the physicochemical properties of seawater and the early collection or transport of cultivated populations during periods of increased risk.

Generally, near heat stress limits, mussels show a decrease in aerobic capacity. This decrease is not necessarily caused by the decrease in ambient oxygen levels, but mainly by the limited capacity of oxygen delivery mechanisms, such as the exchange of gases with the surrounding environment (Anestis et al., 2007).

4 Conclusion

Mussel aquaculture is a particularly lucrative form of primary production in Greece. The oceanographic characteristics, the water physicochemical properties, the meteorological and climatological data of Vistonikos Bay and Porto Lagos, as summarized above, demonstrate the suitability of the area for the development of the aquaculture. However, occasionally, as marked in 2010-2012, production may be influenced by secondary factors that are directly dependent on the climate. Therefore, accurate monitoring of the temperature and physicochemical characteristics of seawater in mussel farms may be a valuable solution to such kind of problems and limitations and contribute as new tools for the rational management of mussel aquaculture.

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