Offshore Production of Mediterranean Mussels in Southern Portugal

João Araújo, Florbela Soares and Pedro Pousão-Ferreira

Portugal has a coastline of 2,830 km, including 942 km of the mainland, 667 km in the Azores Islands and 250 km in Madeira Island, which also includes the Desertas, Selvagens and the Porto Santo islands. Portugal has the eleventh largest Exclusive Economic Zone in the world and the largest in the European Union, with an area of about 1,656,000 km^2. The continental shelf of Portugal is about 20,141 km^2 and is located in an ecological transition zone with high marine biodiversity.

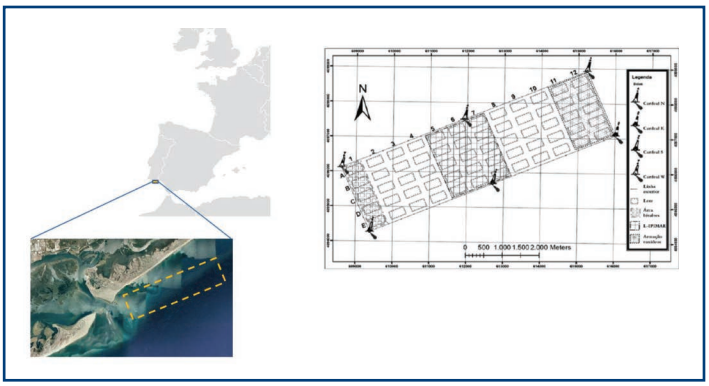

FIGURE 1. *Longline system in the Aquaculture Pilot Production Area (APPA).*

Shellfish Farming in the Algarve

The Algarve is a region of the Portuguese mainland bordered to the west and south by the Atlantic Ocean. The coastline north of Cape St. Vincent, open to the dominant maritime agitation (NW quadrant) of the Atlantic Ocean, is windy and affected by high-energy waves. The southern coast of the Algarve is sheltered from the prevailing conditions from the North Atlantic with significant wave heights generally less than 1 m. Winter storms and a southeast facing shore may cause strong sea disturbances but wave heights exceeding 3 m rarely occur (Dias 1988, Costa 1994).

The Algarve's economy has always been closely linked to the sea and fishing has been an important activity since ancient times. Portugal has a long tradition of mollusk farming and freshwater and marine fish production. Among the main species produced in aquaculture in Portugal, bivalves produced in Algarve represents around 53 percent of the total national aquaculture production. The most important species produced in this region are the clam *Ruditapes decussatus* (2,300 t), common cockle *Cerastoderma edule* (264 t), Mediterranean mussel *Mytilus galloprovincialis* (1,200 t), and the oysters *Crassostrea gigas* and *Ostrea edulis* (650 t, all in 2015). A great part of this production originates from the Algarve region (INE 2015).

FIGURE 2. *Mussel longline in the Aquaculture Pilot Production Area. Photo: Pedro Pousão-Ferreira.*

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Production of bivalves is the livelihood of many families and takes an important role in the traditional culture and economy of this region. Bivalve production is mainly carried out in lagoons, namely in the Ria Formosa and Ria de Alvor, and some offshore structures located mainly on Lagos and Armona Island in an Aquaculture Pilot Production Area (APPA).

The Aquaculture Pilot Production Area

The APPA is a production area created by the Portuguese government, with technical and scientific collaboration of IPMA, located approximately 3 km from the coast of Armona Island. This project has an estimated total production of 9,665 t/yr, of which 5,675 t corresponds to fish production in cages and the remaining 3,990 t to bivalves produced on longlines.

This site is characterized by highly oxygenated water throughout the water column and an average salinity of 36 ppt throughout the year. The average temperature of the sea oscillates between 15 C in winter and 22 C in summer, with no significant differences with depth. The maximum depth in this area is around 22 m. The dominant sea currents come from the west (Atlantic) and are associated with calm sea conditions concerning current velocity and wave height. Nevertheless, some episodes of maritime agitation may occur, when wave heights may reach

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FIGURE 3. *Sorting mussels by size aboard. Photo: Pedro Pousão-Ferreira.*

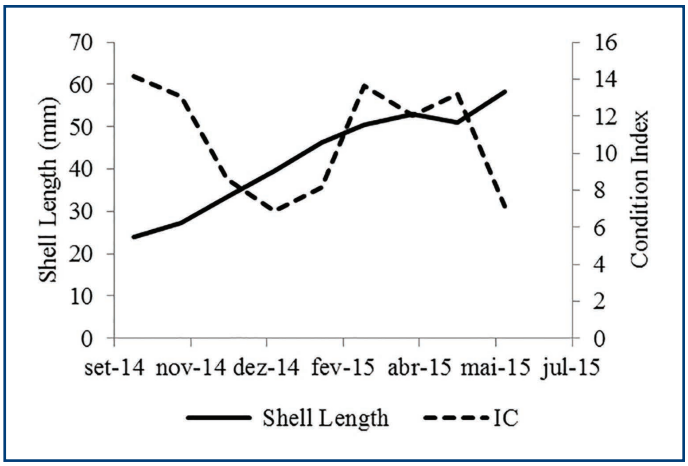

FIGURE 4. *Seasonal variation of mussel shell total length and condition index (IC).*

6-8 m. Storm conditions are mostly associated with currents and waves from the southwest and southeast. Waves from the southeast increase the influence of Mediterranean waters, which generally means an increase in salinity and seawater temperature. Upwelling events play also an important role on variation of environmental conditions on the Algarve coast and are responsible for the emergence of cold and productive waters that occur usually between April and October (Leitão *et al*. 2005).

Mussel Production Method and Mussel Growth

Mussel cultivation in the APPA is carried out on a series of semi-submerged longlines with an average length of 400 m (Fig. 1). Each longline consists of 250 headlines, each 12 m long, with a distance of 1-1.5 m between each. Headlines are set about 5 m below the surface. The position and buoyancy is maintained by a system of buoys and anchors. Each headline represents an annual average production of 100 kg of mussels (Fig. 2).

Seed collection is carried out during spring and autumn on larval fixation ropes. When mussel seeds reach 2-3 cm, they are placed on socking loops and around one year later most mussels begin to reach commercial size (total length of 50 mm). The sock biodegrades in 2-3 weeks, leaving mussels tightly attached to the rope. After that mussel lines are lifted up periodically for sorting and harvesting (Fig. 3). Mussels less than 50 mm are inserted into new socks and submerged until they reach commercial size.

Mussels produced offshore of Algarve have an average growth rate of 4.36 mm (total shell length) per month. However, there is a great disparity in growth due to increasing overlap of mussel beds, being difficult for the whole population to access food. Presence of small, slow-growing individuals is very significant. Periodic sorting and harvesting allows smaller individuals to obtain a new and more advantageous position, where access to food is easier (Fig. 4).

Growth rate also depends on environmental factors such as water temperature and food availability, which can fluctuate seasonally and annually. Seasonal weight variation depends mainly on weight variation of gonads (Villalba 1995). In general, the condition index of mussels is greatest between March and May, during the spawning season. After the spawning period, the condition index drops back, recovering later during the summer months. Another peak of high condition occurs in October before autumn spawning, dropping dramatically until January. Low temperatures, a decrease of food availability and gonads in the resting phase are the main reasons for the index decline (Fig. 4).

In February 2014, mussels produced offshore of Armona were certified by the Marine Stewardship Council as a sustainable seafood product. The longline system was considered to be harmless to endangered marine species and to the seabed ecosystem.

Nutritional Profile

The fatty acid profile has become a subject of an increasing importance to the scientific community and consumers in general, related to the importance of fatty acids (FA) on human health, especially the beneficial effects of ω-3 polyunsaturated fatty acids (PUFA) on human welfare. Mussels, like most shellfish, contains a rich lipid profile that includes diverse saturated fatty acids, monounsaturated and polyunsaturated fatty acids (Table 1). Variation in the fatty acid profile of bivalves depends on seasonality, gametogenic cycle, temperature and food quality and abundance and the culture site (Baptista *et al*. 2014).

Mussels produced offshore of Algarve have an average of 9.3 percent (total FA) of eicosapentaenoic acid (EPA, 20:5 ω-3) which is higher than sardines *Sardina pilchardus*. The DHA content (15.6 percent of total FA) of mussels is similar to that of tuna (Peng *et al*. 2013). Mussels also have a higher content of 18:2 ω-6 (linoleic acid), 18:3 ω-3 (alpha-linolenic acid), 20:4 ω-6 (arachidonic acid) than sardines (Hale 1984). Total fatty acid content decreases during the winter because of the decline of lipid reserves, recovering in early summer.

The variation of DHA/EPA ratio is generally related to variation of diatom concentration in the bivalve diet, and higher DHA values are generally found in warm Mediterranean waters. In Armona island, offshore DHA values are generally higher than that of EPA, but a significant increase in EPA values in the spring is generally observed due to the diatom population growth which usually occurs during spring. In general, biochemical and sensory characteristics of mussels produced offshore of Armona have good acceptability by consumers and are able to compete with mussels produced in other EU countries (Fig. 5).

TABLE 1. Summary of the fatty acid profile of Mediterranean mussels produced in the Aquaculture Pilot Production Area (APPA).

FATTY ACID TYPE	*PERCENT OF TOTAL FATTY ACIDS*
Saturated	35.6
Monounsaturated	13.8
Polyunsaturated	
20:5ω-3 (EPA)	9.3
22:6ω-3 (DHA)	15.6

Constraints and Potential

However, despite good growth rates and the valuable nutritional quality of the mussels, offshore mussel production in the Algarve presents limitations such as high maintenance costs during winter storms and capture restrictions. The southern coast of the Algarve is sheltered from the prevailing conditions of the North Atlantic. Nevertheless, maximum wave height can reach 4-8 m during major storm events. Marine agitation is also responsible for the loss of considerable amounts of mussels and gear destruction. In addition, the long periods of capture restrictions because of the high concentration of biotoxins, especially Diarrhetic Shellfish Poisoning (DSP) can be a major limitation to offshore mussel production in Armona. In 2016, captures were closed between May and November, which means a commercial intermission of local companies exploring offshore production.

The southern coast of Portugal presents favorable conditions for the establishment of offshore aquaculture production facilities. Relatively calm waters without extreme variations of temperature and salinity, good water renewal and good oxygen levels throughout the water column and excellent microbiological quality. This environmental quality provides conditions for the production of bivalves of excellent quality, able to satisfy domestic and international markets. Investing in the development of scientific knowledge and technology to minimize the effect of biotoxins on production may further enhance the commercial potential of this resource.

Notes

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FIGURE 5. *Mediterranean mussels* (Mytilus galloprovincialis) *produced in the Aquaculture Pilot Production Area. Photo: Pedro Pousão-Ferreira.*

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Despite good growth rates and the valuable nutritional quality of the mussels, offshore mussel production in the Algarve presents limitations. Marine agitation is also responsible for the loss of considerable amounts of mussels and gear destruction. The long periods of capture restrictions because of the high concentration of biotoxins, especially Diarrhetic Shellfish Poisoning (DSP) can be a major limitation to offshore mussel production in Armona. Investing in the development of scientific knowledge and technology to minimize the effect of biotoxins on production may further enhance the commercial potential of this resource.