Aquaculture 454 (2016) 95–108

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

Growth, biochemical profile, and fatty acid composition of mussel (*Mytilus galloprovincialis* Lmk.) cultured in the open ocean of the Bay of Biscay (northern Spain)

K. Azpeitia, L. Ferrer, M. Revilla, J. Pagaldai, D. Mendiola *

AZTI-Marine Research, Herrera Kaia, Portualdea z/g, 20110 Pasaia, Spain

ARTICLE INFO

Article history:
Received 11 September 2015
Received in revised form 14 December 2015
Accepted 18 December 2015
Available online 19 December 2015

Keywords:
Mussel
Mytilus galloprovincialis Lmk.
Open ocean
Growth
Condition index
Nutritional quality
Proximate composition

ABSTRACT

Growth performance, allometry, condition index, and biochemistry of mussel (*Mytilus galloprovincialis* Lmk.) cultured in a submerged longline system were investigated from June 2013 to August 2014. Mussels grew faster from spring to autumn. Chlorophyll-a concentration along with sea current speed will represent major factors controlling mussel seasonal growth and survival success in the case-study region. The lowest condition indices and highest ash contents were respectively found within winter; so the most favorable conditions for mussel harvesting and commercialization operations would tentatively occur within autumn, spring and summer. The positive mussel growth and low chlorophyll-a concentrations found during summer may also indicate utilization of non-phytoplankton food sources. No clear evidence of local depth associated physiological effects on the mussel individuals was detected. This contribution represents the first available information on open ocean mussel aquaculture from the southeastern Bay of Biscay.
Statement of relevance:

(1.) The present contribution fills a noticeable gap in the literature on mussel biology and aquaculture science in the Bay of Biscay.
(2.) The present contribution reports the first technical and scientific success of open ocean mussel aquaculture practices in the Bay of Biscay.
(3.) The present contribution offers scientific information for further data comparisons within the context of other case studies or hypothesis.
(4.) The present contribution offers valuable information for decision-making processes on commercial open ocean aquaculture.

1. Introduction

Blue growth is a generally accepted long-term strategy to support sustainable growth in the marine and maritime sectors. Farming in open ocean waters has been identified as one potential option to increase seafood production, and it has been a focus of international attention for more than a decade (Bridger and Costa-Pierce, 2003).

Shellfish species (mainly mollusk bivalves) have also been considered attractive candidates for open ocean farming worldwide (Buck et al., 2005; Buck, 2007; Langan, 2000). These species have been an important food source in the socioeconomic context of the southeastern Bay of Biscay (Gracia, 1996). However, during recent decades, all the mollusks (especially mussels) consumed in the region are imported. Albeit, aquaculture production of bivalve species is well established and occurs in many countries (Bayne, 1976; Norling and Kautsky, 2007; Rius and Cabral, 2004; Smaal, 1991), this activity has never been developed in the southeastern Bay of Biscay due to factors like strong hydrodynamic coastal conditions (Galparsoro et al., 2012), water-quality industrial issues on main rivers and estuaries (Chust et al., 2009), and strict regulations on marine habitats monitoring and protection (Borja et al., 2011; Pascual et al., 2011).

Mussels are generally appreciated for their nutritive quality, organoleptic properties, and economic potential (Bayne, 1976). Albeit mussel shell appearance can be decisive in market prize and purchase motivation (Brenner et al., 2012), product quality is mostly regulated by biochemical composition and condition indices (Filgueira et al., 2006; Fuentes et al., 2009; Orban et al., 2002, 2007).

The Mediterranean mussel (*Mytilus galloprovincialis* Lmk.) is widely distributed around the temperate shelf waters of the Northeast Atlantic

* Corresponding author.
E-mail address: dmendiola@azti.es (D. Mendiola).

http://dx.doi.org/10.1016/j.aquaculture.2015.12.022

Ocean and its adjacent seas, including the southern area of the Bay of Biscay (Garmendia et al., 2011; Gosling, 1992; Marigómez et al., 2007; Martínez-Pita et al., 2012; Sanjuan et al., 1994). *M galloprovincialis* can co-occur and hybridize with other mussel taxa (Brenner et al., 2014; Dias et al., 2009) when geographic areas overlap and patchy environments arise (Hilbish et al., 2002). Water temperature and food abundance are the main environmental factors regulating mussel physiology and reproduction (Seed, 1976). Specifically, the interactions among type and abundance of phytoplankton, temperature, salinity, and local hydrodynamics (currents and waves) are expected to modulate the growth rates and the condition index.

Mussel (*Mytilus* spp.) growth and allometry have been extensively studied by many authors throughout the world (e.g., Akester and Martel, 2000; Hosomi, 1985; Lauzon-Guay et al., 2005; Mallet and Carver, 1995; Pérez-Camacho et al., 1995; Seed, 1973; Steffani and Branch, 2003).

During the last decades, no studies have investigated the patterns regulating mussel growth, physiology and/or biochemistry in the open ocean of the present case-study region (i.e., Izagirre et al., 2014; Tamayo et al., 2008). Most of them have been focused on characterization of reproduction cycles (Garmendia et al., 2010; Ogueta et al., 1995; Ortiz-Zarragoitia et al., 2011; Ortiz-Zarragoitia and Cajaraville, 2006, 2010) or mussels' use as biomarkers of water quality and environmental pollution (Franco et al., 2002; Izagirre and Marigómez, 2009; Jimeno-Romero et al., 2009; Marigómez et al., 2004; Solaun et al., 2013). However, all of these investigations are based on laboratory studies or used natural specimens collected from estuaries or intertidal local populations.

Albeit mussel growth in shell appears to be continuous during the year (Okumuş and Stirling, 1998), meat weight appears to be seasonal, with gross growth concentrated in specific seasons (Seed, 1973). Shell growth can be continuous even in the absence of undernourished feeding, as it is formed mostly from dissolved calcium present in seawater (Alunno-Bruscia et al., 2001). Among other authors, Akester and Martel (2000); Alunno-Bruscia et al. (2001) and Seed (1973) already reported that the main factors affecting on mussel shell shape morphology are density, age, wave exposure, mussel size and availability of food.

Mussel physiology and energy balance can also be inferred through the condition of individuals under given environmental scenarios (Lucas and Beninger, 1985). Likewise, the condition index in mussels is mostly affected by population density, size, gonad development, salinity, temperature, food supply, and environmental contaminants at seasonal level (Bayne and Worrall, 1980; Lucas and Beninger, 1985; Okumuş and Stirling, 1998; Orban et al., 2002; Rhoads and Lutz, 1980).

Meat quality at a particular time can reflect the composition of the daily diet of mussels, which consisting of phytoplankton (e.g., diatoms, flagellates), bacterioplankton, organic detritus, and micro-zooplankton (Alkanani et al., 2007; Hawkins and Bayne, 1991), may vary with daily temperature, water stratification, and hydrodynamics (Cartier et al., 2004). Likewise, the proximate composition of mussels undergoes a seasonal cycle characterized by phases of accumulation and depletion of reserves, reflecting the gonad development stage (Orban et al., 2002) as well as the aforementioned food availability. Nevertheless, mussel species are able to survive long periods of starvation, adjusting their metabolism to changing environments (Hernández et al., 2013).

Both temperature and food abundance regulate gametogenic cycle and associated storages of glycogen, proteins, and lipids (Gabbott and Bayne, 1973; Seed, 1976). Glycogen level represents a suitable indicator of condition related to gonad cycle (Gabbott, 1975), whereas protein content represents growth (Ojea and Pazos, 2004). Likewise, increases in the lipid content have been reported to indicate proximity to spawning (Prato et al., 2010) and favorable conditions of phytoplankton in the local environment (Freites et al., 2002a). Lipids in mussels are known to contain a wide variety of structural fatty acids, including saturated, SFAs, monounsaturated, MUFAs, and polyunsaturated, PUFAs (Martínez-Pita et al., 2012). Variations in the total fatty acid composition of mussels (*M. galloprovincialis* Lmk.) are reported to have both endogenous and exogenous origin, and depend on multiple aspects such as season, origin, zone of culture, reproductive status, temperature, and the phytoplankton profile in the diet (Dridi et al., 2007; Fernández-Reiriz et al., 1989; Fuentes et al., 2009; Ojea and Pazos, 2004; Prato et al., 2010). DHA (22:6 ω3) is known for promoting growth in shellfish (Parrish, 2013) and particularly plays an important role at the structural and functional levels of cell membranes involved in oogenesis, embryogenesis, and larval survival (Martínez-Pita et al., 2012). EPA (20:5 ω3) has been determined to have an energetic function. It acts as an energy source during gametogenesis until the end of embryogenesis (Martínez-Pita et al., 2012; Sánchez-Lazo and Martínez-Pita, 2012). There are a number of ω6 long-chain PUFA commonly found in mussels which may be nutritionally important.

The main objectives of the present study were to evaluate: (i) growth; (ii) condition index; (iii) shell shape; (iv) proximate composition; and (iv) fatty acid profile in mussels (*M. galloprovincialis* Lmk.) cultured at the open ocean conditions of the southeastern Bay of Biscay. The study aims to provide new biological information of use for the potential aquaculture development of this specie within the case-study region.

2. Materials and methods

2.1. Experimental site

The Basque coast is located in the southeastern Bay of Biscay (Fig. 1A and B). It extends along 150 km and is oriented E–W (Fig. 1). The climate is temperate, oceanic, with moderate winters and warm summers (Collins and Borja, 2004). An open ocean experimental site (43° 21.39′ N, 2° 26.90′ W), located at 2 miles off the coast (Fig. 1C and D) and fulfilling the wave energy criteria described by Ryan (2004), was established by the regional authorities aiming to develop further aquaculture activities in the region.

A suspension shellfish culture system based on a conventional long-line (i.e., subsurface structure consisting of anchors and submerged flotation from which mussel ropes can be suspended; Buck, 2007; Langan, 2000) was developed at pilot-scale. The experimental grow-out ropes system was built employing polyamide and poly-steel ropes suspended in the water column from horizontal headlines at submerged conditions. Grow-out ropes of identical length (12 m) were hung from two headline depths, 5 m and 15 m depths, at a distance of 0.5 m between ropes (Fig. 1E). That range of depths was selected to prevent any effect of the local tidal range influence (González et al., 2004).

2.2. Environmental conditions

Local environmental conditions on seawater temperature and currents were obtained from the NEMO model (Nucleus European Modeling of the Ocean). Information on waves (i.e., significant wave height, H_s, and peak period, T_p, was obtained from two metocean buoys, called Bilbao-Vizcaya and Matxitxako, owned and maintained by Puertos del Estado and Euskalmet, respectively.

Chlorophyll-a concentration (as indicator of phytoplankton biomass) was measured in situ in the water column by means of a Sea-Bird CTD (Conductivity, Temperature and Depth). The CTD fluorescence was calibrated, regularly, with water samples filtered through Whatman GF/C filters and analyzed by spectrophotometry after pigment extraction in acetone. Six field trips were conducted seasonally from March 2013 to August 2014, and continuous vertical profiles were obtained at four stations surrounding the experimental site (Fig. 1C). During processing, the data from each corresponding profile were vertically averaged for 5 and 20 m depth respectively, to provide a synthesized resolution of the mussel ropes environment (Fig. 1E).