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Absorption efficiency of mussels *Mytilus edulis* and *Mytilus galloprovincialis* cultured under Integrated Multi-Trophic Aquaculture conditions in the Bay of Fundy (Canada) and Ría Ares-Betanzos (Spain)

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ABSTRACT

Integrated Multi-Trophic Aquaculture (IMTA) is a recycling concept in which waste nutrient discharges from high trophic levels become an additional energetic input for extractive organisms such as bivalves. The aim of this study was to measure the seston levels and absorption efficiency of mussels reared in the proximity of fish net-pens. The absorption efficiency of mussels *Mytilus galloprovincialis* and *Mytilus edulis* cultured at sites adjacent to red sea bream (*Pagellus bogaraveo*) and salmon (*Salmo salar*) cages was assessed on site, using natural seston diets and compared with mussels reared distant from the cages in the Ría de Ares-Betanzos (Galicia, N.W. Spain) and the Bay of Fundy (S.W. New Brunswick, Canada), respectively. Total particulate matter and the organic and the inorganic fractions of the seston were measured simultaneously. Seston parameters were generally similar at the mussel sites close to the fish cages and at the reference sites. However, significantly higher particulate inorganic matter coupled with lower food quality (seston organic content) observed at the sites close to the fish cages suggested occasional sediment resuspension events in the Ría de Ares-Betanzos and the Bay of Fundy. Owing to the reduced food quality, 20% lower absorption efficiency was measured for mussels in the proximity to the cages during the resuspension events. No significant differences in absorption efficiency were detected between the fish cages and the reference sites outside the resuspension events. Consequently, differences in absorption efficiency were attributed to natural variations in seston organic content, and absorption increased with increasing food quality. The results showed no evidence of increased organic content of the seston resulting from proximity to the fish-farm. It was concluded that proximity of cultured mussels to the fish cages did not result in an enhancement of the absorption efficiency.

1. Introduction

The Galician coastline has a unique system of flooded river valleys called 'Rías' that benefit from cold nutrient-rich waters during the upwelling season and provide a sheltered area very suitable for the suspended culture of mussels. The raft culture of the mussel *Mytilus galloprovincialis* in Galicia produces 250,000 tons year^{-1} and is the main mariculture industry of Spain, and one of the most important in Europe (Labarta et al., 2004). During recent years fish-farming in floating cages has also been introduced in the Galician Rías, where space to allocate new culture facilities is already limited. One possible consequence of fish culture is that the discharge of unconsumed feed pellets and fish feces could lead to the eutrophication in the culture region. In areas with extensive fish aquaculture like the Bay of Fundy (SW New Brunswick, Canada), these conflicts have been addressed with the simultaneous culture of Atlantic salmon (*Salmo salar*), blue mussels (*Mytilus edulis*) and kelp (*Laminaria saccharina* and *Alaria esculenta*). These Integrated Multi-Trophic Aquaculture (IMTA) sites are currently working at a commercial pilot scale (Liutkus et al., 2012; MacDonald et al., 2011; Reid et al., 2010; Troell et al., 2009). The filter-feeding capacity of bivalves has been proposed as possible means of significantly reducing the organic effluents released from open-water fish farms. In these IMTA systems, the energy loss from the fed trophic level (caged fish) becomes an energy input for mussels, which have been reported to grow up to 50% higher when cultured in proximity to fish cages than at control sites in the Bay of Fundy (Troell et al., 2009). Mussel culture in coastal areas like the Galician Rías and the Bay of Fundy is subjected to large natural temporal and spatial fluctuations in seston quantity and quality as a consequence of the seasonal cycle of primary production, the upwelling–downwelling cycle in the Galician Rías, horizontal

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phytoplankton patchiness, and storm or tide-induced resuspension of bottom sediments (Figueiras et al., 2002). Fish effluents may represent an additional source of particulate organic matter for shellfish, particularly when ambient seston levels are low (Barrington et al., 2009; Cheshuk et al., 2003; Neori et al., 2004, 2007; Troell et al., 2003).

The research on the effects of particulate organic fish effluents on the growth of bivalves has increased rapidly in recent years. Many studies have revealed that mussels and oysters grew faster and were able to uptake the organic waste when co-cultured with fish (Buschmann et al., 2000, 2009; Chopin et al., 2008; Handå et al., 2012; Jones and Iwama, 1991; Lander et al., 2004; Lefebvre et al., 2000; MacDonald et al., 2011; Mazzola and Sarà, 2001; Peharda et al., 2007; Reid et al., 2010; Sarà et al., 2009; Sarà et al., 2012; Wallace, 1980). On the other hand, some authors did not detect any significant growth enhancement in similar experiments integrating fish with bivalves (Cheshuk et al., 2003; Gryska et al., 1996; Navarrete-Mier et al., 2010; Parsons et al., 2002; Stirling and Okumus, 1995; Taylor et al., 1992). Two recent studies have focused on the absorption efficiency (AE) of mussels cultured under IMTA conditions (MacDonald et al., 2011; Reid et al., 2010) but knowledge of the AE of fish effluents remains limited. Effluent particle size, organic content and biochemical composition have been reported to be the most important factors determining food absorption and growth of co-cultured bivalves (Both et al., 2012; Reid et al., 2009). *M. edulis* and *M. trossulus* absorption efficiency (Reid et al., 2010) and *M. edulis* absorption efficiency, clearance rate, filtration rate and exhalent siphon area (MacDonald et al., 2011) were reported to be enhanced when exposed to salmon feed and feces particles under laboratory conditions. Further study of particulate fish effluent availability and the digestive capabilities of waste extractive species such as mussels may help to explain the inconsistency in bivalve growth responses at IMTA sites noted above.

In this study we investigated the absorption efficiency of two different species of mussels cultured in the proximity of fish farms. Two field experiments were carried out to study the seston characteristics and the absorption efficiency of mussels *M. galloprovincialis* and *M. edulis* cultured in the proximity of red sea bream and Atlantic salmon farms in Galicia and New Brunswick, respectively. The objective of this study was to compare the absorption efficiency of *M. galloprovincialis* held in suspended cultivation in rafts located both distant and close to red sea bream (*Pagellus bogaraveo*) floating cages in the Ría of Ares-Betanzos (Galicia, NW Spain) during five seasonal surveys. Seston quality and quantity were also compared between two mussel rafts. This is the first study in which these comparisons have been made under extensive, commercial-scale, mussel culture conditions. A significant and biologically meaningful increase in the AE of the cultured mussels would represent an additional source of income for Mytiliculture in Galicia, where integrated mussel–fish culture has not been investigated. In addition, comparisons between seston parameters and mussel absorption efficiency were performed on one sampling occasion at a commercial *M. edulis*-salmon (*S. salar*) IMTA system in the Bay of Fundy, Canada. IMTA in this area has been more extensively studied but additional work is needed to substantiate the ability of the IMTA concept to both increase long-term aquaculture sustainability and profitability.

2. Material and methods

2.1. Study site

The study was carried out in two separate regions. The first experimental site was in the Ría de Ares-Betanzos (Galicia, NW Spain) at the Lorbé mussel raft polygon (43°23′24.74″N; 8°17′48.30″W) (Fig. 1a). The Ría Ares-Betanzos is a V-shaped inlet divided in two parts: an inner shallower part consisting of the estuaries of river Eume and Mandeo, and an outer deeper part that is connected to the shelf (Álvarez-Salgado et al., 2011). Annual river discharge is 30 $m^3 s^{-1}$ and the importance of continental runoff and nutrient discharges by the rivers is greater than in the Rías Baixas (Álvarez-Salgado et al., 2011). The Ría is a partially stratified estuary with strong vertical mixing and it has a mesotidal and semidiurnal tidal cycle that ranges from 0.02 to 4.14 m during neap and spring tides, respectively (Álvarez-Salgado et al., 2011; Sánchez-Mata et al., 1999). North-easterly winds induce upwelling events from March–April to September–October (spring–summer), while south-westerly winds induce downwelling the rest of the year (Álvarez-Salgado et al., 2011; Figueiras et al., 2002). Seasonality of rainfall in Galicia ranges from moderate to dry during upwelling (average rainfall of 80 and 30 mm in May and July) to strong during downwelling (average rainfall of 110 and 102 mm in October and February) (AEMET, 2012). Frequent storms from the Atlantic Ocean hit the Galician coast during autumn and winter and are characterized by high waves that induce the mixing of the water column. The Lorbé raft polygon is situated in the southern shore of the Ría Ares-Betanzos (between 10 and 30 m) and is the main area of mussel *M. galloprovincialis* culture, with 107 rafts and a total production of 10,000 tons $year^{-1}$ (Labarta et al., 2004). The seabed in Lorbé is dominated with medium to fine sand with organic carbon contents<2.8%, indicative of high energetic conditions (Sánchez-Mata et al., 1999). The organic content of the sediments is influenced by anthropogenic inputs from sewage and industrial waste, local eutrophication by extensive mussel raft culture and continental runoff from rivers Eume and Mandeo (Sánchez-Mata et al., 1999). The inorganic fraction of the sediments is rich in silt and clay (Sánchez-Mata et al., 1999). Average current velocity in Lorbé raft polygon is 2–3 cm s^{-1} and the variance of the current direction has been shown to be dominated by the tide (Piedracoba et al., submitted for publication).

Sampling was conducted at two commercial rafts within Lorbé polygon. Raft P-14 was situated in the inner region of the polygon and 170 m north from red sea bream (*P. bogaraveo*) net cages. Raft P-46 was used as a reference site and was located in the outer region of the polygon, 550 m away from the net-pens. The rafts had a surface area of 550 m^2 (25×22 m) containing a maximum of 500 hanging ropes with a length of 12 m. Rafts were anchored by a single chain placed on one side to enable the raft to face their frontal side into the main current entering the polygon. Raft P-14 was anchored at 14 m depth while raft P-46 was at 16 m.

The red sea bream farm was located in the inner Lorbé region and consisted of 48 circular floating net cages arranged in parallel rows. The cages were 28 m in diameter with a net depth of 6 m and a total volume of 3692.64 m^3, with a stocking density of about 10 kg m^{-3}. The approximate annual production was 245 tonnes of sea bream (JACUMAR, 2011). Sea bream are kept in the cages for three years until reaching a commercial weight of 0.8 kg.

The second experiment was performed in the Bay of Fundy (SW New Brunswick, Canada) at two different sites. First, the sampling was conducted at Clam Cove Atlantic salmon (*S. salar*) farm (44°57′52.2″ N; 67°0′46.65″W) near Deer Island (Passamaquoddy Bay) (Fig. 1b). Mussels (*M. edulis*) are co-cultured in suspension next to salmon sea-cages at a pilot commercial scale. The culture site is situated within 150 m from the coast. The salmon farm consisted of 20 circular cages that were approximately 30 m in diameter and 12 m of net depth (total volume 8478 m^3), with a stocking density of 15 kg m^{-3}. Salmon are kept in cages for 16 months until they reach 4 kg.

The second site (reference) was a mussel farm situated 8.5 km distance from Deer Island (Lease MF 377: 45°02′58.2″N; 67°01′ 55.43″W) where *M. edulis* are reared following the standard (non-IMTA) long-line commercial protocols. Bivalves used in this experiment were randomly obtained from a long-line on MF 377.

2.2. Experimental design

Environmental and physiological measurements at the two Lorbé mussel rafts in Galicia were obtained over two consecutive days,