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Environmental drivers of mussels flesh yield in a coastal upwelling system

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ABSTRACT

Eastern boundary coastal upwelling ecosystems (EBUEs) are highly sensitive to climate variability, particularly to coastal wind change. Here, we test the response of the flesh yield of blue mussels cultured in the northern boundary of the Iberian–Canary current EBUE to climate-related variables. Significant relationships were found between the annual mean, seasonal build-up and phenology of the mussel flesh yield with meteorological variables such as continental runoff, intensity and direction of coastal winds, and solar radiation. Our analysis shows that better flesh yields occur during years characterised by dry winters, accompanied by early springs and followed by summers dominated by strong northerly winds that produce intense upwelling. Compared with other EBUEs, upwelling has weakened in the study area over the last fifty years, implying an overall decrease in mussel flesh yield. However, future climate scenarios suggest that coastal upwelling will intensify over the 21th century, particularly during the summer months, which would lead to a recovery of mussel flesh yield.

1. Introduction

The flesh yield, i.e. the portion of the total weight that is soft-tissue, is a routinely used condition index of commercial bivalves feeding in dynamic coastal environments (Orban et al., 2002, 2007; Knights, 2012; Filgueira et al., 2013). The flesh yield provides a cost-effective indicator of bivalve culture performance (Sasikumar and Krishnakumar, 2011) and is commonly used as a benchmark for management strategies (Halpern et al., 2008; Polasky et al., 2011) and to assess their monetary value (Pérez-Camacho et al., 2013, 2014). The bivalve flesh yield has been also applied in environmental monitoring programs (Smaal and Widdows, 1994) as it integrates physiological responses to food availability and quality with changes in somatic growth associated to the reproductive cycle of bivalves (e.g. Mathieu and Lubet 1993; Fernández-Reiriz et al., 1996; Orban et al., 2002, 2007; Baek et al., 2014; Irisarri et al., 2015). Lucas and Beninger (1985) recommended that the flesh yield of adult bivalves would be adopted for most routine aquaculture work.

The Galician rías, a group of coastal embayments in the NW coast of Spain (Fig. 1), are a World-leading producer of blue mussels, with an annual yield of about 220,000 tons, which represents 40% of the European and 15% of the World production (Labarta et al., 2004). The intricate orography of the region, its oceanographic regimen dominated by coastal upwelling–downwelling episodes, and the particular cultivation method on hanging ropes is behind the success of these ecosystems as one of the major producers of marine proteins per square meter in the World (Tenore and González 1975; Álvarez-Salgado et al., 2011). The high productivity of the region attracted ambitious ecosystem approach studies since the 1970s in the rías of Arousa and Muros (Tenore and González, 1975; Tenore et al., 1982) (Fig. 1). In this context, Blanton et al. (1987) reported for the first time a positive linear relationship between coastal upwelling intensity and mussel flesh yield, i.e. between the regional scale weather pattern and the commercial value of mussels harvested in the Galician rías. Given this dependence, knowledge of regional changes in weather conditions under present (Álvarez-Salgado et al., 2008; Pérez et al., 2010) and future (Álvarez et al., 2016) climate scenarios would be helpful for the management of the local mussel farm industry.

Despite the importance of the Galician rías for the world production of blue mussels, studies relating the mussel flesh yield with the regional weather conditions are scarce (Blanton et al., 1987). In this work, we have used an extensive dataset of flesh yield values from mussels cultured in different areas of the Ría de Ares-Betanzos (Fig. 1) collected between the years 2001 and 2012. With this dataset, we have modelled the seasonal variability of the flesh yield and examine its inter-annual variability in the light of the weather conditions in the study area, using solar radiation, coastal winds and river discharge as explanatory variables. These meteorological variables are proposed as proxies of sea surface temperature and food availability, the latter being the environmental variables that control bivalve growth according to previous studies in the area (Aguiar et al., 2015). Our results demonstrate the usefulness of linking mussels flesh yield with the climate conditions of the area to use them as an indicator of the seasonal and interannual variability of mussel meat content.

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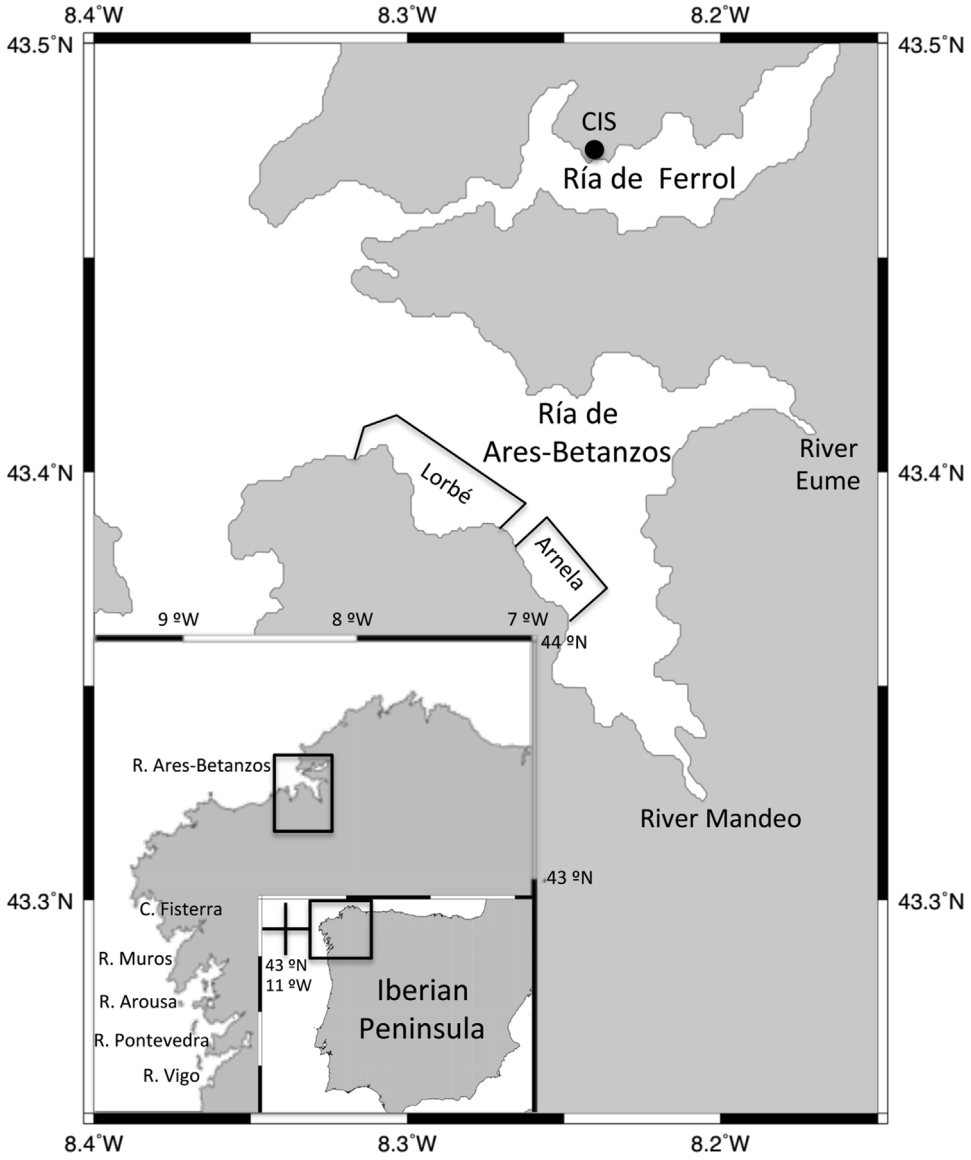

Fig. 1. The mussel cultivation areas of Arnela and Lorbé (Ría de Ares-Betanzos, NW Iberian Peninsula) are shown. Rivers Eume and Mandeo, the 2° × 2° cell centred at 43°N 11°W where geostrophic winds were calculated and the meteorological station of CIS Ferrol are also positioned.

2. Materials and methods

2.1. Mussels flesh yield

Flesh yield values used in this work were the condition index (*CI*) values provided by the mussel farmer PROINSA, who owns 95 of the 147 mussel rafts/long-lines anchored in the two cultivation areas, Arnela and Lorbé, of the Ría de Ares-Betanzos (Fig. 1). PROINSA has been monitoring the size and flesh yield of the cultured mussels that have achieved the commercial size (> 50 mm), as well as, the mussels already extracted for commercialization from their mussel rafts since 2001. The flesh yield is calculated as the percentage of the total weight of 1 kg of live mussels collected in a mussel raft that is meat weight after opening the valves with water vapour. It should be noted that this monitoring programme has been based on the strategic management of the farmer rather than a preconceived scientific design. This resulted in an uneven temporal and spatial coverage of the flesh yield data because the mussel rafts monitored and the times that they were visited depended on the presence of commercial size mussels (> 50 mm) in the trays and the occurrence of red tide events that produced a closure of the mussel cultivation areas. Table A1 and Fig. A1 in the Appendix (Supplementary material) summarises the temporal and spatial coverage of the data used in this work. The crude database, consisting of 2749 flesh yield values obtained from samples of 1 kg of live mussels, was organised in two groups, coinciding with the cultivation areas of Arnela (964 values) and Lorbé (1785 values), located in the innermost and central segments of the embayment (Fig. 1). Individual values were aggregated to obtain monthly time series over the period 2001–2012 for the two areas. This data-gathering approach allowed us to partly overcome the irregular temporal and spatial distribution of the data.

2.2. Continental runoff

Rivers Eume and Mandeo (Fig. 1) are the main tributaries of the Ría de Ares-Betanzos. The flow at the mouth of River Mandeo was estimated from gauge station n° 464 at Irixoa, hold by Augas de Galicia (Galician Government). The total drainage basin of this river is 456.97 Km^2 and the gauge station intercepts only 249.21 Km^2. Therefore, the ratio of total to gauged areas was used to estimate the flow at the mouth following the Horton's Law (Strahler, 1963). Concerning River Eume, its flow is a combination of regulated and natural flows. Daily volumes of the Eume reservoir, which controls 80% of the