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Water flows through mussel rafts and their relationship with wind speed in a coastal embayment (Ría de Ares-Betanzos, NW Spain)

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ABSTRACT

Knowledge of water flows through mussel rafts and their controlling factors is required for an ecosystem approach to the sustainable management of this culture in the Galician rías. With this aim, 4 acoustic 2D-ACM current meters were hung from the bow of 4 rafts located in the mussel cultivation areas of the Ría de Ares-Betanzos (NW Spain) during autumn 2007. Simultaneously, an Aanderaa DCM12 Doppler profiler was moored in an area free of rafts in the middle ría. There were differences in the subtidal and tidal dynamics of the middle channel and mussel farm areas. The tide explained 51.5% of the total variance of the surface current in the middle ría. The explained variance in the seed collection areas of Redes (inner ría) and Miranda (outer ría), where only 2–3 rafts are anchored, were 64.1% and 16.8%, respectively. In the cultivation areas of Arnela (inner ría) and Lorbé (middle ría), where 101 and 40 rafts are anchored, 14.3% and 53.4% of the total variance was explained by the tide. These disparities in the contribution of the tide are likely due to a combination of topographic and bathymetric differences among sites and distortions of the natural flow by the rafts and their hanging ropes. Furthermore, there was a marked influence of winds on the subtidal currents within the rafts; contrasting correlation coefficients and lag times between wind speed and currents were observed for the outer and inner sides of the embayment. The filtration rate of the growing mussels and the number of mussels per raft allow an efficient clearing of the particles transported across the hanging ropes by the measured subtidal currents of 2–3 cm s^{-1} characteristic of the cultivation areas of Arnela and Lorbé.

1. Introduction

Scientific knowledge of the meteorology, physical oceanography, and biogeochemistry of marine ecosystems is compulsory for an ecosystem-based sustainable management of marine living resources (Dempster and Sanchez-Jerez, 2008; Cranford, et al., 2012). In the particular case of the cultivation of the blue mussel *Mytilus galloprovincialis* on hanging ropes in the coastal embayments of NW Spain, this information is crucial to manage larvae settlement and recruitment strategies (Peteiro et al., 2011), mussel growth rates and carrying capacities (Pérez-Camacho et al., 1995; Peteiro et al., 2006; Babarro et al., 2000; Duarte et al. 2008), mussel rafts closures due to the recurrent occurrence of harmful algal blooms (Álvarez-Salgado et al., 2008, 2011; Pérez et al., 2010) and the potential environmental risks of mussel raft culture (Tenore et al., 1982; Alonso-Pérez et al., 2010).

The NW coast of Spain is at the northern boundary of the large marine ecosystem embraced by the Iberian–Canary eastern boundary upwelling system (Arístegui et al., 2009). In this area, upwelling-favourable northerly winds prevail from March–April to September–October in response to the seasonal migration of the Azores High. Downwelling-favourable southerly winds are dominant the rest of the year (Wooster et al., 1976; Bakun and Nelson, 1991; Arístegui et al., 2009). Upwelling events occur with a periodicity of 10–20 days during the upwelling season (Blanton et al., 1987; Álvarez-Salgado et al., 1993), hence modulating the entry and allowing the efficient consumption of new nutrients within the eighteen coastal embayments, collectively known as “rías”, which occupy this intricate coastline (Pérez et al., 2000; Villegas-Ríos et al., 2011).

The rías are unique systems because of their morphology and orientation that, together with the freshwater inputs, strongly influence the fate of the upwelled nutrients and the resulting biogenic materials (Blanton et al., 1987; Arístegui et al., 2009; Álvarez-Salgado et al., 2010). The Rías Baixas, located to the south of Cape Fisterra (Fig. 1), are oriented in the NE–SW direction, which favours the inflow of upwelled Eastern North Atlantic Central Water (ENACW) in response to northerly winds and are large enough (2.5–4.3 km^3) to

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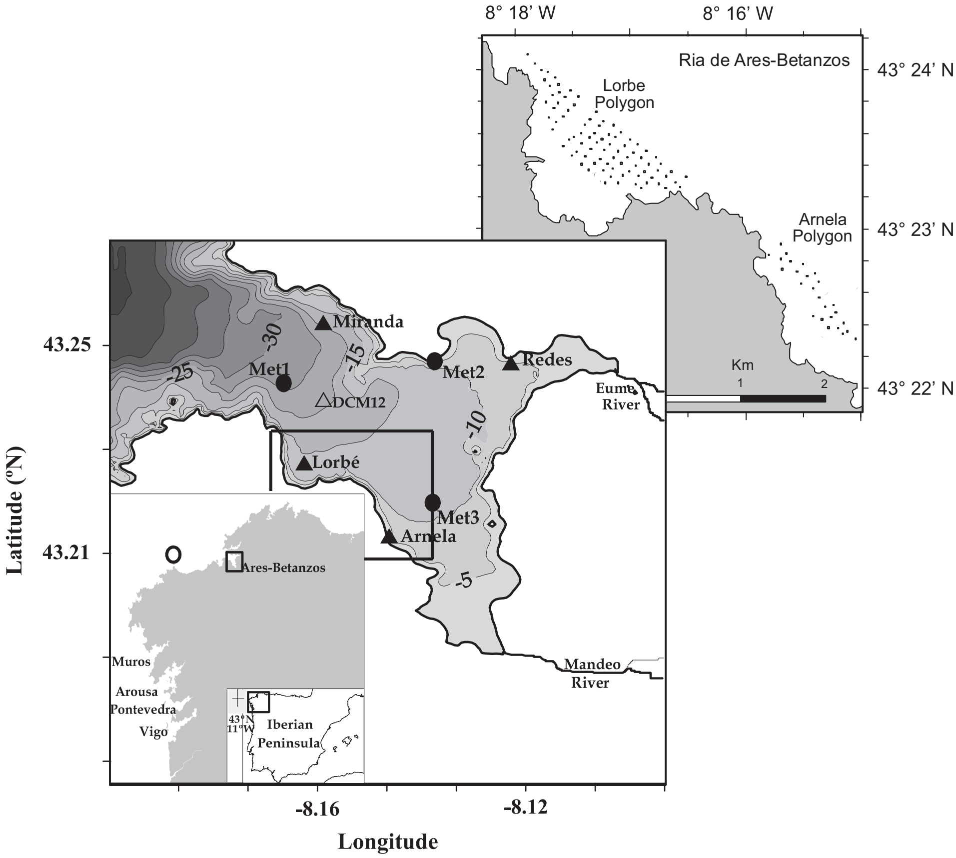

Fig. 1. Map of the Ría de Ares-Betanzos, showing the location where the acoustic 2D-ACM current meters were hung (black triangle) at Miranda, Lorbé, Redes and Arnela and the DCM12 mooring site in the middle ría (open triangle), the position where shelf winds were recorded by the buoy of Puertos del Estado at Cape Vilano (open dot), and the 4 km × 4 km cells where the Galician meteorological agency MeteoGalicia reconstructed the local winds (black circles). The inset shows the Lorbé and Arnela raft polygons.

efficiently consume the upwelled nutrients leading to average daily primary production rates as high as 3 g C m^{-2} d^{-1} during the upwelling season (Arístegui et al., 2009). Continental runoff gains importance during the downwelling season, contributing significantly to the dynamics and biogeochemistry of these embayments (Nogueira et al., 1997; Álvarez-Salgado et al., 2000, 2010). The Rías Altas, located to the north of Cape Fisterra, display a wide variety of sizes, from 0.01 to 0.75 km^3, and coastline orientations, and they receive proportionally larger freshwater inputs than the Rías Baixas (Álvarez-Salgado et al., 2010, 2011; Villegas-Ríos et al., 2011). The Rías Altas, specifically the Ría de Ares-Betanzos (Fig. 1), also support a significant number of mussel rafts and local fisheries, although their total yield is lower than that of the Rías Baixas (Bode and Varela, 1998).

The hydrodynamics of coastal waters, especially in semi-enclosed bays, together with the nutrient and plankton loads transported by the dominant currents, are the major factors determining the balance between suspended particles depletion and renewal in marine farms. In fact, the ingestion capacity is a function of phytoplankton concentration and current speed (Frechette et al., 1989). Furthermore, marine farm structures cause drag reducing water flows within farmed areas (Plew et al., 2005; Strohmeier et al., 2005; Fan et al., 2009). It has also been shown that shellfish farms induce changes in the estuarine circulation patterns, with important implications for local food depletion (Duarte et al., 2008; Plew et al., 2005). Consequently, it is important that the effects of farm structures are considered when estimating water flows within a cultivation area. In our particular case, by measuring the current velocity within a mussel raft, the drag effects of both the raft where the current meter is hung and the surrounding structures are implicitly included. Therefore, our measurements would reflect the currents as experienced by the mussels in the hanging ropes. This information will allow calculating the real fluxes experienced by mussels and are also suitable to validate numerical models that predict intra-rafts currents.

There are only two studies of currents through rafts based on empirical data (Blanco et al., 1996; Boyd and Heasman, 1998) and another one based on a numerical model (Grant and Bacher, 2001). Other studies emphasize how the number of ropes per raft in a mussel farm together with the thousands of mussels on each rope can modify the local flow (Plew, 2011; Stevens et al., 2008; Strohmeier et al., 2005) and, consequently, the food availability.

As a first step to monitor the matter and energy flow through the mussel raft cultivation areas of the Ría de Ares-Betanzos, current meters were simultaneously hung in four mussel rafts located in two areas where the mussels are cultured, Arnela and Lorbé, and two areas of mussel seed capture, Redes and Miranda (Fig. 1). In addition, a Doppler profiler was moored in an area free of rafts in the middle channel of the ría (DCM12, Fig. 1) over the same period. We measured the water flow through these singular cultivation platforms in order to study the spatial similarities and differences at tidal and subtidal scales between the currents measured at the four cultivation areas and the middle channel of the ría in relation with: (1) natural spatial differences related with both steady (topography, bathymetry) and transient (continental runoff, remote and local winds) main forcing agents; and (2) man-made differences derived from the distortion of the natural flow due to the dense array of mussel rafts in the cultivation areas (see inset of Fig. 1). However, freshwater discharges were so low and invariable (CV ~ 2%) during the study period (data not shown) that this forcing had to be excluded from the analysis.

We should emphasize that our measurements are indicative of velocities within the rafts, which are more relevant to mussel