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Climate variability and *Dinophysis acuta* blooms in an upwelling system

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ABSTRACT

Dinophysis acuta is a frequent seasonal lipophilic toxin producer in European Atlantic coastal waters associated with thermal stratification. In the Galician Rías, populations of *D. acuta* with their epicentre located off Aveiro (northern Portugal), typically co-occur with and follow those of *Dinophysis acuminata* during the upwelling transition (early autumn) as a result of longshore transport. During hotter than average summers, *D. acuta* blooms also occur in August in the Rías, when they replace *D. acuminata*. Here we examined a 30-year (1985–2014) time series of *D. acuta* from samples collected by the same method in the Galician Rías. Our main objective was to identify patterns of distribution and their relation with climate variability, and to explain the exceptional summer blooms of *D. acuta* in 1989–1990. A dome-shaped relationship was found between summer upwelling intensity and *D. acuta* blooms; cell maxima were associated with conditions where the balance between upwelling intensity and heating, leading to deepened thermoclines, combined with tidal phase (3 days after neap tides) created windows of opportunity for this species. The application of a generalized additive model based on biological (*D. acuta inoculum*) and environmental predictors (Cumulative June–August upwelling CUI_{JJA}, average June–August SST_{JJA} and tidal range) explained more than 70% of the deviance for the exceptional summer blooms of *D. acuta*, through a combination of moderate (35,000–50,000 $m^3\ s^{-1}\ km^{-1}$) summer upwelling (CUI_{JJA}), thermal stratification ($SST_{JJA} > 17\ ^\circ C$) and moderate tidal range ($\sim$2.5 m), provided *D. acuta* cells (*inoculum*) were present in July. There was no evidence of increasing trends in *D. acuta* bloom frequency/intensity nor a clear relationship with NAO or other long-term climatic cycles. Instead, the exceptional summer blooms of 1989–1990 appeared linked to extreme hydroclimatic anomalies (high positive anomalies in SST and NAO index), which affected most of the European Atlantic coast.

1. Introduction

Several species of the genus *Dinophysis* produce lipophilic toxins (okadaic acid, its congeners and pectenotoxins) and cause lengthy shellfish harvesting bans in Europe (Van Egmond et al., 1993). Shellfish closures are especially damaging in the Galician Rías Baixas (NW Spain), the site of intense Mediterranean mussel (*Mytilus galloprovincialis*) aquaculture with an annual production of up to 300,000 t (Blanco et al., 2013). These Rías (Fig. 1), are at the northern limit of the Canary Current Upwelling System, and subject to seasonal (spring to early autumn) upwelling pulses. Upwelling has been identified as the main factor controlling phytoplankton dominance in the Rías (Figueiras and Ríos, 1993; Pazos et al., 1995; Nogueira et al., 2000) and changes in upwelling patterns are expected to have species-specific effects on harmful algal events.

Dinophysis acuminata (Claperède & Lachmann) and *Dinophysis acuta* (Ehrenberg) are the main agents of Diarrhetic Shellfish Poisoning (DSP) outbreaks in temperate waters on the Atlantic coasts of Europe (Reguera et al., 2014). In Western Iberia the two

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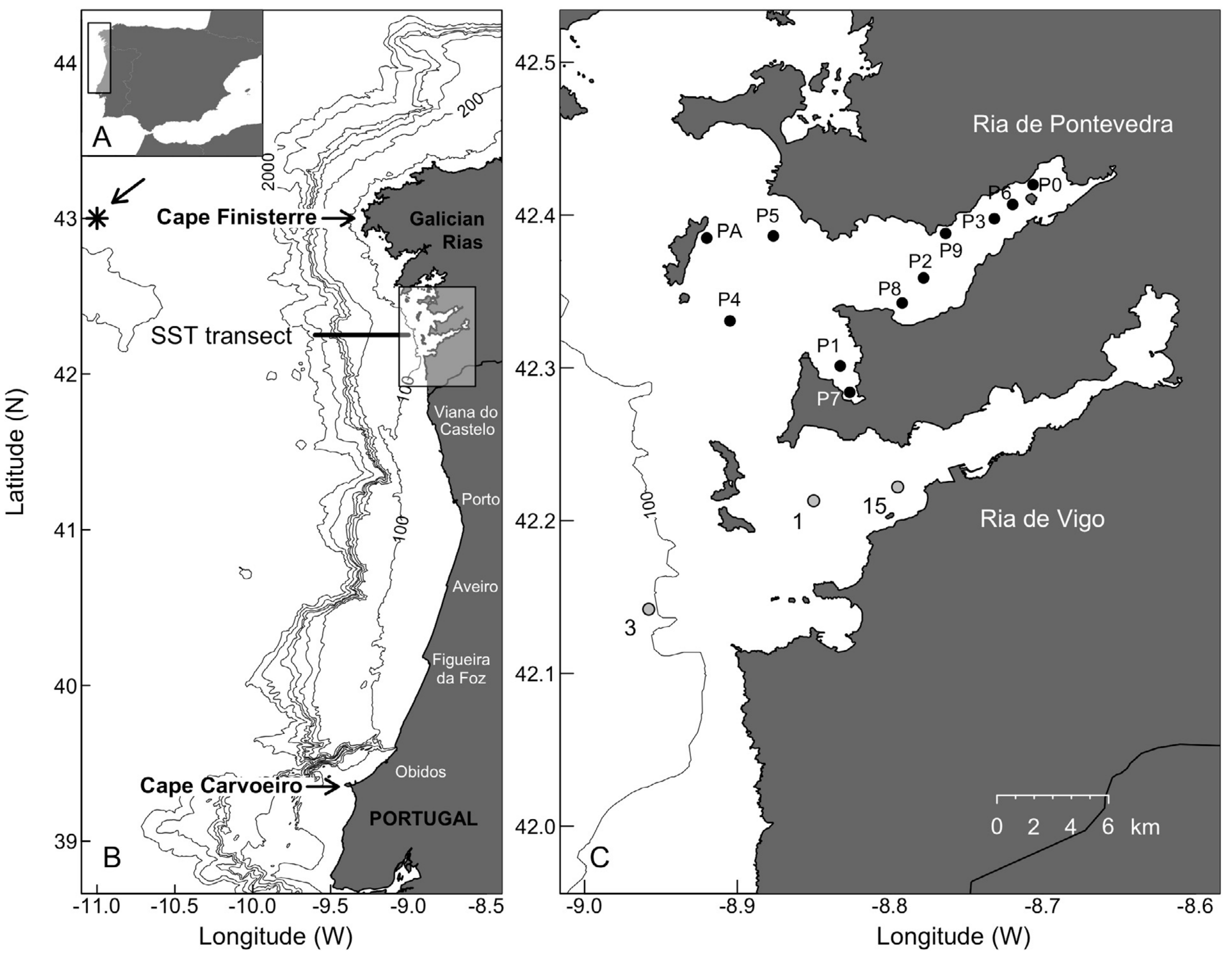

Fig. 1. Maps of the study area. (A) Iberian Peninsula; (B) Northwest Iberia and location of the transect used for cross-shelf SST and the location (asterisk) for upwelling index estimates; (C) Location of the 11 INTECMAR sampling stations (black circles) in Ría de Pontevedra and the three stations (grey circles) of the Ría de Vigo and adjacent shelf transect (Radiales-IEO).

species show marked differences in their spatial and seasonal distributions (Reguera et al., 1993; Palma et al., 1998; Escalera et al., 2006). *D. acuminata* occurs every year throughout the upwelling season (spring to early autumn), with the first maximum (>10^3 cells L^{-1}) around early June (Pazos and Moroño, 2008). In contrast, blooms of *D. acuta* are very seasonal and do not occur every year. These develop in Northern Portugal during upwelling conditions and thermal stratification in late summer. Blooms of *D. acuta* in the Galician Rías Baixas are associated with longshore transport at the end of the upwelling season (Escalera et al., 2010). Only exceptionally, late summer development of *D. acuta* has been observed during the upwelling season in the Rías Baixas. Years of persistent blooms of *D. acuminata* followed by those of *D. acuta* may keep harvesting bans on mussel production areas for up to nine months and constitute the worst scenario for the shellfish industry (Escalera et al., 2010; Blanco et al., 2013).

The potential impacts of climate variability on interannual fluctuations on the composition and abundance of different functional groups and trophic levels of plankton have received great attention in recent decades (Fromentin and Planque, 1996; Planque and Taylor, 1998; Edwards and Richardson, 2004). On the basis of a 40-year (1960–2000) time series from the Continuous Plankton Recorder (CPR) surveys, Edwards et al. (2002) suggested that long-term variations in several North Sea plankton species were closely linked with anomalous oceanographic events occurring episodically over a timescale of decades. The intensity of the response varied considerably amongst different phytoplankton groups. Long-term variations in phytoplankton composition were identified over the last decade, in the same region, by Hinder et al. (2012) who suggested that a fundamental shift in the relative abundance of diatoms (*e.g. Pseudo-nitzschia* spp.) *versus* dinoflagellates, with a marked decline in dinoflagellates (*e.g. Prorocentrum* spp.), was driven by the combination of increasing sea surface temperature (SST) and windy conditions in summer. Changes in phytoplankton community succession, sometimes characterized by a relative increase of potentially toxic species, have been interpreted as a consequence of intensified water column stability favouring taxa of larger cell size and/or swimming capabilities (Smayda and Reynolds, 2001).

Although considerable knowledge has been gained about the seasonality and short-term responses of *Dinophysis* spp. to environmental conditions, the lack of long-term time series data has hindered progress in understanding the factors controlling their interannual variability. Multidecadal climate oscillations have been proposed to explain long-term variations in *Dinophysis* blooms in the Skagerrak, in western Swedish (Belgrano et al., 1999) and southern Norwegian coastal waters (Edwards et al., 2006; Naustvoll et al., 2012). These authors suggested that long-term changes of *Dinophysis* blooms in these areas were related to phase changes of the North Atlantic Oscillation (NAO), the most important mode of low-frequency variability of atmospheric circulation in the northern hemisphere (Hurrell, 1995). Nevertheless, *Dinophysis acuminata* and *Dinophysis acuta* respond in different ways to meteorological forcing (Escalera et al., 2006), and detailed description of the physical niche of each species is needed.