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Distribution and dynamics of two species of Dinophyceae producing high biomass blooms over the French Atlantic Shelf

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ABSTRACT

The frequency and distribution of high biomass blooms produced by two dinoflagellate species were analysed along the French continental shelf from 1998 to 2012. Two species were specifically studied: *Karenia mikimotoi* and *Lepidodinium chlorophorum.* Based on remote-sensing reflectances at six channels (410, 430, 480, 530, 550 and 670 nm), satellite indices were created to discriminate the species forming the blooms. A comparison with observations showed that the identification was good for both species in spite of a lower specificity for *L. chlorophorum*. The overall analysis of the satellite indices, in association with some monitoring data and cruise observations, highlights the regularity of these events and their extent on the continental shelf. *L. chlorophorum* blooms may occur all along the South Coast of Brittany. All the coastal areas under the influence of river plumes and the stratified northern shelf area of the Western English Channel appear to be areas of bloom events for both species. These two species are likely to be in competitive exclusion as they share the same spatial distribution and the timing of their bloom is very close. Finally, due to the scarcity of off-shore observations, these satellite indices provide useful information regarding HABs management and the development of a warning system along the French coast.

1. Introduction

The development of an alert system for harmful algal blooms (HABs) involves a fast detection of potential blooms and not only those located in coastal waters in order to provide some real forecast capabilities. The satellite techniques provide an interesting tool and have been successfully used by warning systems over several coastal areas (Stumpf et al., 2003; Tomlinson et al., 2009, 2004). The sea color in coastal waters being very complex, it is complicated to work at the species level that is required when the system concerns with toxicity. Only species able to produce very high biomass within the surface layers can be targeted. Such a system was developed for *Karenia brevis* along the Florida coast (Stumpf et al., 2009; Stumpf et al., 2003; Tomlinson et al., 2009, 2004; Wynne et al., 2005) and *Karenia mikimotoi* over the North European shelf (Kurekin et al., 2014). Along the French Atlantic and English Channel coasts, several dinoflagellate blooms reaching high biomass have been regularly recorded during spring and summer. The most well-known blooms have obviously been associated with the toxic species *K. mikimotoi* (Vanhoutte-Brunier et al., 2008). The biggest blooms were regularly observed off Northwestern Brittany and appeared to be associated with the Ushant tidal front dynamics (Le Corre et al., 1992; Hartman et al., 2014). Additional and smaller blooms have also been observed close to the coast (Bay of Seine) and they were usually associated with river plumes (Sournia et al., 1992). However, several other species can produce colored waters along the shelf. Along the French coast, *Lepidodinium chlorophorum* has been recorded as the second dinoflagellate able to produce high biomass blooms (see Napoleon et al., 2014) and strong *Chl-a* anomalies. This non-toxic species is also an unarmored dinoflagellate (class Dynophyceae and order Gymnodiniales) with a high pigment content and detectable from satellite imagery (Morozov and Pozdnyakov, 2013). These two species (*K. mikimoitoi* and *L. chlorophorum*) are considered as eury- and thermo- haline species (Gentien, 1998; Brand et al., 2012; Elbrachter and Schnepf, 1996; Honsell and Talarico, 2004) and their life cycles are also very similar. For both species (Ouchi et al., 1994; Sournia et al., 1992) cyst production has not been observed and the existence of temporary cysts remains unclear. Like most dinoflagellates, they can also be considered as

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mixotrophic (Jeong et al., 2010, 2005; Park et al., 2013) with a high ammonium assimilation (Le Corre and L'Helguen, 1993; Iriarte et al., 2005). Both species are also able to perform vertical migration (Gentien et al., 2005; Sournia et al., 1992) and a high accumulation of cells may occur as a result of physical-biological interactions (Kamykowski et al., 1998; Le Corre et al., 1992). Thus, according to the above results, these two species were expected to share similar ecological niches along the Atlantic coast. The main difference between these species is their plastid origin: *L. chlorophorum* contains a green plastid (Matsumoto et al., 2011; Minge et al., 2010; Shalchian-Tabrizi et al., 2006; Watanabe et al., 1987) whereas *K. mikimotoi* bears a haptophyte-derived (red) plastid (Minge et al., 2010; Patron et al., 2006).

The first objective of this study was to test an automatic algorithm using satellite images to detect high biomass dinoflagellate blooms. The observed distributions of these blooms were then compared to monitoring data and in-situ observations from field data. Their phenology and inter-annual variability were finally compared to highlight potential interactions between the two species.

2. Materials and methods

2.1. Species identification and coastal monitoring

Data from 1996 to 2012 were extracted from the national monitoring data base. The samples were acquired through the national phytoplankton monitoring network REPHY (http://envlit.ifremer.fr/surveillance/phytoplankton_phycotoxines/presentation) and the selected area covered the whole French Atlantic coast (Fig. 1). As noted by Sournia et al. (1992), numerous areas along the coast are potential sites for dinoflagellate blooms. An initial screening of the REPHY database showed that only two dinoflagellate species of the same class (dinophycae) had reached very high densities (>10^6 cells l^{-1}) over the last twenty years:

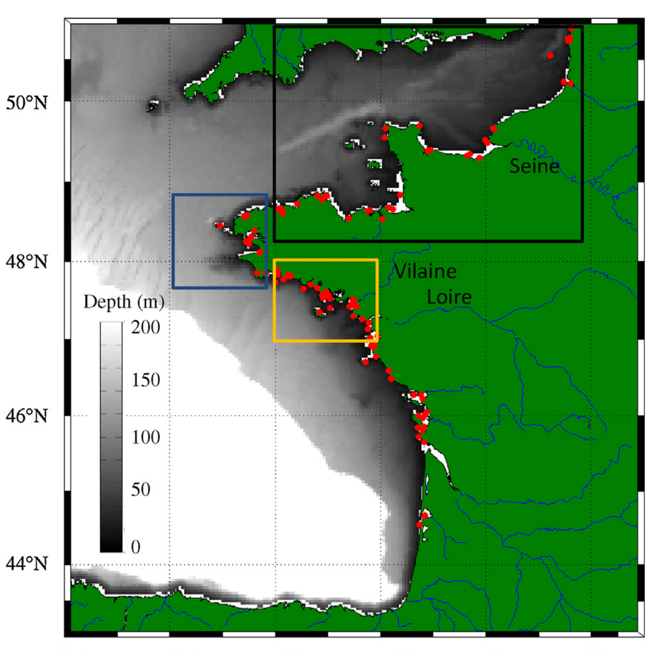

Fig. 1. Monitoring stations along the French Atlantic coast and the English Channel where either *L. cholorophorum* or *K. mikimotoi* have been observed at least once since 1996. Limits for the selected areas (Bay of Biscay, Iroise Sea and English Channel for the yellow, blue and black box, respectively) and the depth over the continental shelf are indicated.

Karenia mikimotoi and *Lepidodinium chlorophorum*. These organisms were identified to the species level by the monitoring program when they bloomed. Despite some difficulties in identifying *K. mikimotoi* in fixed samples (Hansen et al., 2000), classification was checked with living samples. These two species were thus specifically extracted from the data base and all the other species from the *Gymnodinium* genus were regrouped. For each group, time series and monthly average densities (μ_j) were estimated for three areas: the Bay of Biscay area off the Loire and Vilaine estuaries (2°N to 4°N 47 to 48°N), the Iroise Sea (6 to 4°W, 47.5°N to 49°N) and the English Channel (4°W to 2°E, 48.5°N to 51°N). Null values were not used for the estimation of the average densities. The threshold to reach high densities was fixed at 10^5 cells l^{-1} and standard deviation (σ) was used to provide the 68th percentile (P_{68},$\sigma + \mu$) as a proxy sensitive to bloom events (assuming a typical bloom duration of one week per month).

2.2. Observations over the shelf

Several high density blooms of these dinoflagellates were observed during research cruises but only two cruises (EDILOIRE and PSEUDOMO2) were selected for this study due to the very high cell densities encountered and the spatial resolution of the sampling. However the results of only one cruise are presented (Fig. 2) to avoid redundancies. The cruises were conducted respectively in September 2005 and 2010 and were not initially planned to observe these events. However, due to the exceptional densities observed, the station grid was slightly modified and the resolution was increased to give a better overview of the bloom size. Basically, the stations covered all the Southern part of Brittany. Conventional sampling stations were set up using a custom-built pelagic profiler with standard sensors (CTD SBE 25, Fluorometer, Par) and specifically designed optical sensors (diffraction and video) allowing an in-situ detection and characterization of the phytoplankton community according to their morphological and fluorescence properties (Lunven et al., 2012). Over some stations, a high-resolution vertical sampling (Fine Scale Sampler—FSS, Lunven et al., 2005) was carried out when a marked vertical stratification was found. Densities were then estimated by microscopic observations. Some additional water samples were taken at different depths chosen according to the CTD profiles. Nutrients (nitrate, phosphate and silicate) were then analyzed in

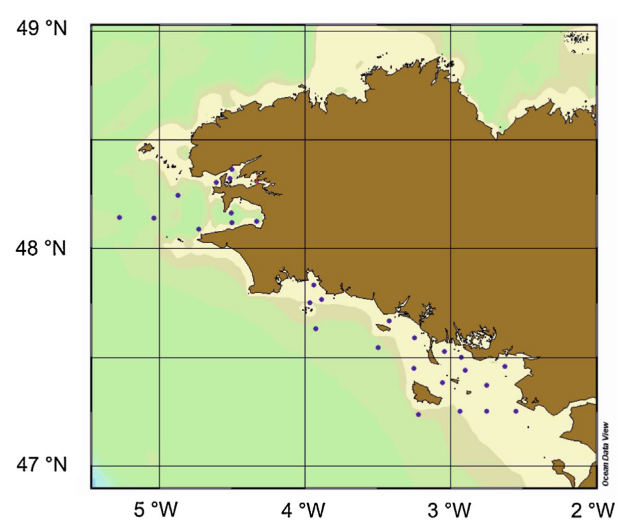

Fig. 2. Location of the sampling stations for the cruise PSEUDOMO2 in September 2010.