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Human-induced river runoff overlapping natural climate variability over the last 150 years: Palynological evidence (Bay of Brest, NW France)

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ABSTRACT

For the first time a very high resolution palynological study (mean resolution of 1 to 5 years) was carried out over the last 150 years in a French estuarine environment (Bay of Brest; NW France), allowing direct comparison between the evolution of landscapes, surface water, and human practices on Bay of Brest watersheds, through continental (especially pollen grains) and marine (phytoplanktonic microalgae: cysts of dinoflagellates or dinocysts) microfossils. Thanks to the small size of the watersheds and the close proximity of the depositional environment to the mainland, the Bay of Brest represents an ideal case study for palynological investigations. Palynological data were then compared to published palaeo-genetic analyses conducted on the same core and to various available instrumental data, allowing us to better characterize past environmental variability since the second half of the 19th century in Western Brittany. We provide evidence of some clues of recent eutrophication and/or pollution that affected phytoplankton communities and which appears linked with increased runoff (higher precipitations, higher percentages of riparian forest pollen, decline of salt marsh-type indicators, and higher values of the XRF Ti/Ca signal), mainly explained by the evolution of agricultural practices since 1945 superimposed on the warming climate trend. We assume that the significant relay observed between dinocyst taxa: *Lingulodinium machaerophorum* and *Spiniferites bentorii* around 1965 then followed by *Spiniferites membranaceus* after 1985, attests to a strong and recent eutrophication of Bay of Brest surface waters induced by high river runoff combined with abnormally elevated air temperatures, especially obvious in the data from 1990. The structure of the dinocyst community has thus been deeply altered, accompanied by an unprecedented increase of *Alexandrium minutum* toxic form at the same period, as confirmed by the genetic quantification. Despite this recent major anthropogenic forcing, the fossil pollen sequence also records natural climate variability. We highlight, for the first time, a possible connection between climate (AMO modes) and fossil pollen records (especially tree pollination rates) in coastal sediments using tree percentage fluctuations as an indirect proxy for past sea surface and atmospheric temperatures.

1. Introduction

During the past few decades, coastal environments have been increasingly studied worldwide due to natural fluctuations (e.g. climate variability and geomorphological changes) and anthropogenic pressures (e.g. eutrophication, soil artificialisation, CO_2 rejects) in order to better evaluate human forcing and future climate trends (e.g. IPCC, 2014). Furthermore, the effects of soil fertilization on the composition and structure of microbial coastal communities is one of the major topics of present-day environmental sciences, taking into account that changes in pH, moisture, and nutrient rates are assumed to greatly affect biodiversity over many trophic levels (Guillaud and Bouriel, 2007; Diaz and Rosenberg, 2008).

North-western European coastal environments are interesting case studies because of their connection to the main Atlantic atmospheric (e.g. North Atlantic Oscillation, NAO; and East Atlantic pattern, EA) and oceanic (e.g. Atlantic Multidecadal Oscillation, AMO; and Atlantic Meridional Overturning Circulation, AMOC) patterns that govern

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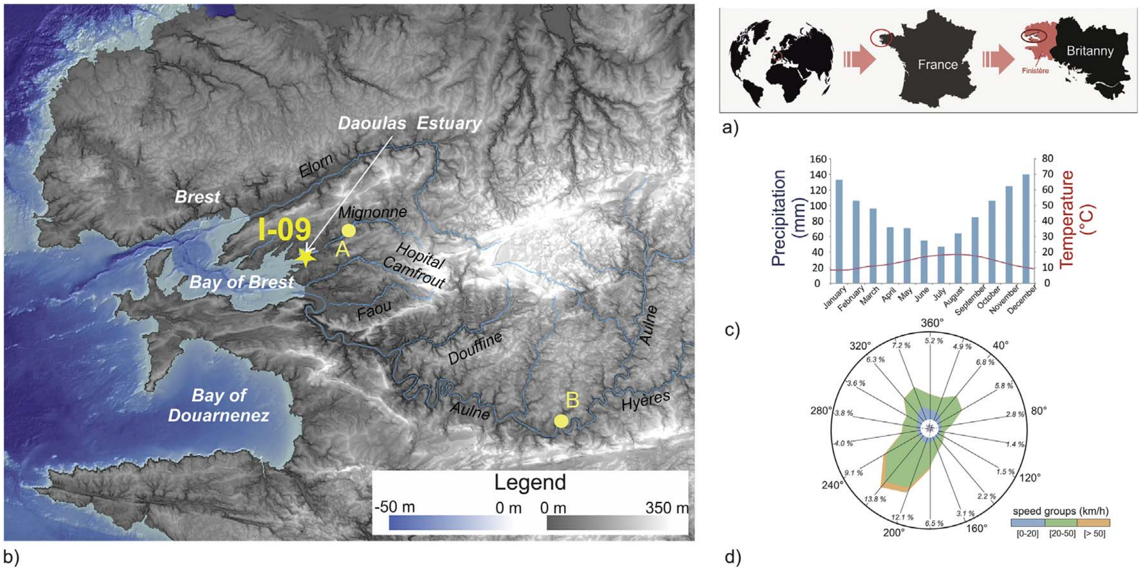

Fig. 1. Locations of: a) the Bay of Brest in north-western France, as well as of: b) I_09 study core (yellow star) in the Daoulas Estuary, and of the hydrological stations (yellow points A and B) from which river discharge data are discussed in the manuscript. c) Present-day climate data with an ombrothermic diagram (temperatures and precipitations). d) wind rose showing prevailing mean annual wind directions averaged over 10 years. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
(Source: Météo France.)

regional and global climates over different timescales. In Brittany (NW France), weather regimes and North Atlantic Sea Surface Temperatures (SST), are the main mechanisms that drive precipitation patterns and related river discharges (Tréguer et al., 2014; Ruprich-Robert and Cassou, 2015), as well as storm surges (van Vliet-Lanoë et al., 2014). As a major consequence, this region is today characterized by intense soil weathering, leading to intensive nutrient discharges in the coastal waters (Meybeck et al., 2006; Tréguer and De La Rocha, 2013).

In this context, palynological studies can provide essential information about past environmental conditions through combined analyses of phytoplanktonic microalgae (especially dinoflagellate cysts or dinocysts) and pollen grains (Turon, 1984; Sanchez-Goñi et al., 2000; Turon et al., 2003; Mudie et al., 2007; García-Moreiras et al., 2015). However, these studies, that are numerous for the Holocene, rarely cover the last century for which environmental changes can also be approached by instrumental data allowing comparison with palynological proxies.

Concerning pollen analysis, a well-known bias exists (i.e. over or under-representation) regarding the continental surface covered by vegetation and fossil pollen percentages calculated from modern sediment archives (e.g. Gaillard et al., 1998; Mazier et al., 2015; Ganne et al., 2016), as recently discussed for Bay of Brest watersheds versus modern sediments retrieved within the bay (Lambert et al., 2017). Furthermore, some studies highlight a large influence of climate-driven processes on the pollination rates of some trees (van Vliet et al., 2002; García-Mozo et al., 2006; Besancenot and Thibaudon, 2012), as well as on the transport of pollen grains through temporal variability of precipitation and thus river runoffs. These fluvial discharge variations in water volume and nutrient load, according to natural and/or anthropogenic factors, may also be responsible for the recrudescence of toxic algal blooms over the past decades (Klouch et al., 2016a, b). Dinocyst analysis then represents an indirect approach to the reconstruction of the palaeobiodiversity of dinoflagellate communities and thus of one of the major components of primary productivity known to be very sensitive to environmental changes. Both signals (marine for dinocysts and continental for pollen grains) are often studied together in palaeoenvironmental reconstructions (Combourieu-Nebout et al. 1998; Turon et al., 2003; Sangiorgi and Donders, 2004), constituting a land-sea continuum involving a large number of natural (oceanic and atmospheric) and human forcings. The comparison between the palynological data carried out along the last century and the instrumental dataset collected in the same area will allow us to thus precisely identify the different factors driving pollen and dinocyst variations, and to better interpret these palynological tools for future Holocene palaeoecological reconstructions.

In this study, a core from the outlet of the Daoulas Estuary in the Bay of Brest has provided a very high-resolution palynological record from 1870 CE to present. The Daoulas Bay records today the most intense toxic bloom of dinoflagellates *Alexandrium minutum* within the Bay of Brest (Klouch et al. 2016a). Furthermore, the palaeobiodiversity of dinoflagellate communities has been recently reported on the same sampled Daoulas core with molecular data (Klouch et al., 2016b), suggesting a great increase in bloom frequency of this toxic species *A. minutum* over the past decades. We then expect to find clues of recent eutrophication (i.e. nutrient enrichment of the aquatic system; Andersen et al., 2006) in the dinocyst assemblages study.

Main objectives of this study, connected to societal impacts for coastal ecosystems and North Atlantic climate knowledge, consist in:

i) comparing palynological proxies and instrumental data available at a North Atlantic (SST, AMO modes), regional (atmospheric NAO/EA modes), and local scales (river flows, atmospheric temperatures),
ii) deciphering natural climate variability from recent huge human impacts on Bay of Brest watersheds by cross-correlating the whole set of data including pollen, dinocysts, but also all other non-pollen palynomorphs such as freshwater microalgae.

2. Bay of Brest environmental settings

2.1. Geomorphological and geographical contexts

The Bay of Brest is located in north-western Brittany (NW France, W Europe; Fig. 1a, b) and is a shallow semi-enclosed basin of 180 km^2 surrounded by a 230 km long coastline. Its bedrock consists of Proterozoic igneous rocks in the north and Brioverian (Neoproterozoic, possibly Early Cambrian) to Palaeozoic (Ordovician, Devonian and locally Carboniferous) sediments in the south and east. Present-day low reliefs (few hills reach 330 m high) are inherited from the peneplanation of the