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Sedimentological and dendrochronological indicators of coastal storm risk in western France

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ABSTRACT

This paper compares results from two different environmental methods to observe past storm impacts: the back coastal barrier stratigraphical and dendrochronological archives. With a detailed historical database of the past 50 years storm observations, we discuss the combination of results from these two methods in a coastal study located in western France. The study shows that neither tree ring nor sedimentological results build a complete storm chronology by themselves. However, the combination of the two is sufficient to detect the strongest storms, which caused marine flooding. Comparing them with an accurate impact of storm chronology, extracted from written sources to test their robustness, we show that the combination of these two approaches offer a complete dataset. From this exhaustive historical sequence ranging from 1955 to 2016, three winters with major storms are highlighted in Traicts du Croisic: 1990, 1978 and 1972. Combining dendrochronology and sedimentology therefore enables a better understanding of extreme storm occurrences.

1. Introduction

Documenting past storm impacts on coastal environments is a methodological challenge. This challenge must be based on the analysis of various indicators and their combination to ensure accuracy in reconstructing the extreme environmental parameters creating these disturbances. Several methods were used in scientific literature (reviews in Chaumillon et al., 2017; Goslin and Clemmensen, 2017). Many indicators, such as speleothems (e.g. Frappier et al., 2007; Zhu et al., 2017), cliff top deposits (e.g. Dewey and Ryan, 2017; Hall et al., 2006; Hansom and Hall, 2009), corral (e.g. Gardner et al., 2005; Hongo, 2018; Scoffin, 1993) and diatom (e.g. Nodine and Gaiser, 2015; Stager et al., 2017) survival or disappearance, detection of marine intrusions into a back-barrier sedimentary sequence with the buildup of washover fan (e.g. Feal-Pérez et al., 2014; Liu and Fearn, 2000; May et al., 2017; Naquin et al., 2014; Wang and Horwitz, 2007), have enabled the detection of past meteorological disturbances. Another biogeographical approach, dendrochronology, can be used to document past storms from the tree-ring disturbance it encounters during its lifespan (Schweingruber, 1996; Speer, 2012). To complete the results from the sedimentological and dendrochronological approaches, historical archives of storms were consulted, adding exhaustive and precise information on past storms (Garnier et al., 2017; Gottschalk, 1977; Hickey, 1997; Lamb and Frydendahl, 1991; Lamb, 1995).

This study seeks to highlight the combination of results from washover detection into a sedimentary sequence and a dendrochronological approach. Stratigraphy in washover context has often been used to document and date past storms (e.g. Bregy et al., 2018; Donnelly et al., 2004; Kenney et al., 2016; Liu and Fearn, 1993; Sabatier et al., 2008); in the context of violent winds, dendrochronological studies are rare. Tree-ring approaches have seldom been used in coastal environments; sea-shore erosion quantification and survey is then the main interest, analyzing exposed roots (Rovera et al., 2013), as was done along mountain torrents (Gärtner, 2007; Gärtner et al., 2001; Hitz et al., 2008), gullies (Malik, 2008) or along rivers (Begin, 1990; Begin et al., 1991). Other tree-ring approaches were used recently to reconstruct past climatic variations, mostly with chemical indicators (Berkelhammer and Stott, 2011, 2008; Brienen et al., 2012). The disturbance of tree-ring patterns to reconstruct storms is seldom in international literature: one study identified past hailstorm marks using damage made in tree trunks (Hohl et al., 2002), and few others studied records of ice storms (Lafon and Speer, 2002; Olthof et al., 2003; Travis and Meentemeyer, 1991). Here, in the absence of coastal erosion and exposed roots, we focus on tree stems and adapt the tree-ring method previously used for geomorphic processes on slopes (e.g. Decaulne et al., 2014, 2012; Martin and Germain, 2016). Based on reports of

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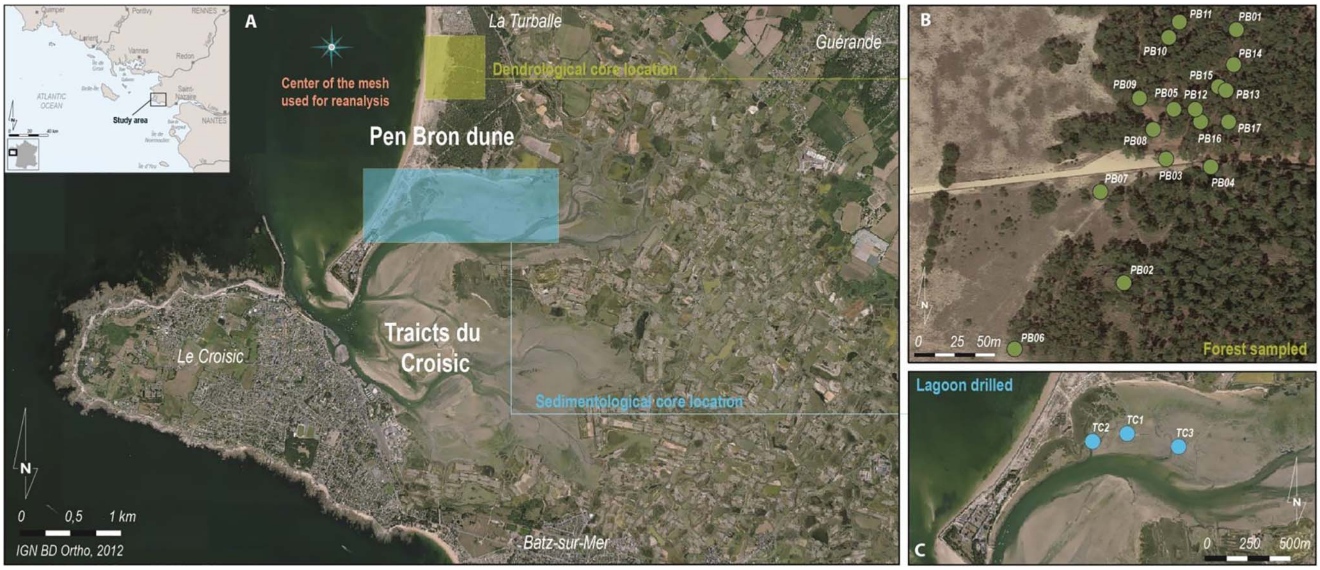

Fig. 1. Study area. A. General overview; B. Forested area on Pen Bron dune; C. Traict du Croizic back barrier.

forest damage from strong winds, tree stability may be affected in a similar way to a snow avalanche over a short period of time (Everham and Brokaw, 1996).

We focus on the storm reconstruction of the last 50 years based on these two indicators; results are compared with historical data for each of the indicators used. We then discuss the relevance of dendrochronology and sedimentology using historical proxies, and finally question the relevance of the combination of the two methods.

2. Study area

The western coast of France is an important storm - crossed area (Chauveau et al., 2011; Feuillet et al., 2012). The selected study site is located in the central Pays-de-la-Loire region: Traicts du Croisic and the nearby Pen Bron forested dune. This area is characterized by its high morphogenic activity coastal marsh (Fig. 1), which is separated from the sea by a sandy barrier and is ideal for detecting recent storms (Baldock et al., 2008; Pierce, 1970; Switzer and Jones, 2008; Zecchetto et al., 1997). The highest tidal ranges are from 6 to 7 m (Service Hydrographique et Océanographique de la Marine). With protecting dunes reaching nearly 10 m asl, only storms which were concomitant to the high tide can be observed (Le Roy et al., 2015). The selected study site is exposed to western winds (from SW to NW) and marine flooding. This specific area was selected as the back barrier coastal depositional environment has been preserved from anthropogenic activities over the last 300 years, as highlighted in a GIS chronological analysis based on IGN (French National Geographic Institute) data, together with an historical and topographical study map that identified the urban evolution and landscape changes (with the method extracted from Pouzet et al., 2015). A few kilometers northward, dendrochronological analyses were also carried out from the *Pinus pinaster* forest in the Pen Bron dunes (Fig. 1). Precise coordinates of each dendrochronological and sedimentological core can be found in Table 1.

Table 1
Coordinates of each sedimentological and dendrochronological core.

Sedimentological cores

Name	Id	X (RGF lambert 93)	Y (RGF lambert 93)	Maximum Depth (cm)
Traict du Croisic 1	TC1	285140.145	6704373.272	84
Traict du Croisic 2	TC2	284667.764	6704419.583	71
Traict du Croisic 3	TC3	284877.807	6704445.014	85

Dendrochronological cores

Name	Id	X (RGF lambert 93)	Y (RGF lambert 93)	Disturbance direction
Pen Bron 1	PB01	284990.395	6705920.372	SW > NE
Pen Bron 2	PB02	284915.957	6705848.237	SW > NE
Pen Bron 3	PB03	284953.042	6705867.302	N.NW > S.SE
Pen Bron 4	PB04	284977.943	6705862.471	S.SW > N.NE
Pen Bron 5	PB05	284945.743	6705883.276	S.SW > N.NE
Pen Bron 6	PB06	284867.653	6705758.813	S.SW > N.NE
Pen Bron 7	PB07	284915.957	6705822.005	SW > NE
Pen Bron 8	PB08	284945.743	6705883.276	S.SW > N.NE
Pen Bron 9	PB09	284938.66	6705902.329	W > E
Pen Bron 10	PB10	284955.673	6705935.167	S > N
Pen Bron 11	PB11	284960.503	6705944.109	S > N
Pen Bron 12	PB12	284969.626	6705893.983	S.SW > N.NE
Pen Bron 13	PB13	284985.135	6705905.273	SW > NE
Pen Bron 14	PB14	284990.395	6705893.983	SW > NE
Pen Bron 15	PB15	284983.257	6705908.498	W.NW > E.SE
Pen Bron 16	PB16	284973.382	6705887.535	SW > NE
Pen Bron 17	PB17	284973.382	6705886.513	SW > NE

3. Material and methods

3.1. Historical data

3.1.1. Meteorological archives: determining storm occurrence

To rebuilt a chronology of storms that have crossed the study area, historical documents were consulted: (i) documents from libraries and archives, (ii) narrative sources (chronicles, diaries, memoires etc.), and (iii) old maps. These documents contain observational and descriptive data on past extreme weather occurrences, useful to estimate the intensity of each recent event. However, before being used to reconstruct the storms and sea flooding chronology over the last seven decades, this data was analyzed and evaluated. The reliability of a written document is evaluable on the basis of (i) the witness statement by the author and (ii) the institutional framework of the evidence record (Athimon et al., 2016; Athimon and Maanan, 2018, submitted). Moreover, it was necessary to inspect testimonies with several sources. The aim was to have a more precise and exhaustive record of each event within a precise temporal and spatial frame.

We also considered records from instrumental installations such as