Storm signals in coastal sediments: A review of palaeostorm archives and analytical approaches in north-west Europe

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Storm signals in coastal sediments: A review of palaeostorm archives and analytical approaches in north-west Europe

Short title: Coastal storm archives in north-west Europe

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Abstract

Coastal sedimentary archives offer key insights into past severe storms and related flooding, contributing to a better understanding of long-term coastal hazard histories. Although interest in palaeostorm reconstructions has increased in recent decades, a comprehensive overview and information for north-west Europe is missing. This synoptic literature review compiles all known sedimentary storm archives between 45°N and 75°N, outlining their geographical distribution, ages, and methodological approaches. We identified 77 sites described in 69 publications since 1985. The most frequently investigated archive types are peat bogs, followed by coastal dunes, salt marshes, coastal lakes and lagoons, and cliff-top storm deposits. Most records are concentrated in the British Isles, particularly Scotland, while data from southern Norway and the German coasts are largely absent, indicating a strong spatial bias. The ages of these records range from the Late Pleistocene (~14 ka BP) to the present, with a median sedimentary age range of 2.3 ka BP. Storm deposits are commonly identified as minerogenic sand layers embedded within organic-rich fine-grained sediments. Grain size and composition, often combined with loss-on-ignition analyses to estimate organic content, are the primary proxies used to infer depositional processes, which can generally be classified as marginal marine, overwash, or aeolian. The use of microfossils and stable isotopes remains limited across European studies. Recent studies show a growing trend toward more comprehensive laboratory analyses. Overall, this review highlights the need for standardised protocols in sampling, analysis, and interpretation to enable broader comparisons and to reconstruct long-term storm patterns across Europe more reliably.

Keywords: *Coastal archives, storminess, palaeotempestology, North Atlantic, coastal hazards, storm surge, sediment records, storm deposit, washover deposit, coastal flooding, Baltic Sea, North Sea*

1. Introduction

Severe storms and related coastal flooding are among the most destructive natural hazards, causing substantial human and economic losses worldwide (Lobeto et al., 2024). The main driver of storm-related flooding is storm surge, defined as short-term, non-astronomic variations in sea level generated by meteorological-oceanic forcing, typically associated with tropical and extratropical cyclones. Storm surge heights depend on wind strength and direction as well as bathymetry and configuration of the coastline, and may reach several metres above tidal level (Gornitz, 2005). In north-west Europe, severe storms develop from baroclinic instability along sharp temperature gradients between polar and mid-latitude air masses, producing rapidly deepening low-pressure systems (Pugh, 1987; Chaumillon et al., 2017). Unlike tropical cyclones, which draw their energy from latent heat release over warm ocean waters, these extratropical systems are driven by horizontal temperature contrasts and strong frontal dynamics. Such storms are most common in winter and dominate the mid-latitude climate belt (Minamidate and Goto, 2024). In north-west Europe, extratropical cyclones generate one of the highest degrees of storminess globally in terms of duration, intensity, and frequency of occurrence with wave heights locally exceeding 6 m at the most exposed coastlines (Lobeto et al., 2024), added on top of the storm surge. These winter storms represent one of the largest threats to European coasts, occurring far more frequently each year than tropical cyclones at low latitudes (Dullaart et al., 2021; Minamidate and Goto, 2024). Modelling studies predict more extreme storm surges for the European coasts by the end of this century in particular for regions north of 45–50°N (Beniston et al., 2007; Vousdoukas et al., 2016).

Assessing future storm hazards requires a robust understanding of long-term storm variability. However, instrumental and historical storm records extend back only 50–200 years, with sparse documentary evidence for events older than a millennium (Lamb and Frydendahl, 1991; Clarke and Rendell, 2009). This limited timespan fails to capture multi-centennial storm cycles and to identify the most extreme events. To overcome this limitation, long-term records from sedimentary coastal archives using a variety of proxy data are needed in combination with historical and instrumental data to estimate the recurrence interval of extreme storm events and to better assess future coastal risk (Chaumillon et al., 2017; Goslin and Clemmensen, 2017; Leszczyńska et al., 2025).

The use of storm-wave induced signals and sedimentary proxies to reconstruct past storm flooding prior to observational records are summarised under the term palaeotempestology (Hippensteel, 2010; Goslin and Clemmensen, 2017; Donnelly, 2025). The objective of palaeotempestology is to reconstruct the local storm history including frequency and magnitude of storm events and to understand the climatology of tropical and extratropical cyclones on centennial- to millennial time scales (Minamidate and Goto, 2024). In the early 1990s, pioneering studies focused on the reconstruction of past hurricanes analysing sediments of back-barrier lakes in the Gulf of Mexico (Liu and Fearn, 1993, 2000) and along the eastern coast of the USA (Hippensteel and Martin, 1999; Donnelly et al., 2001, 2004). Over time, this approach has expanded globally and gradually other types of sedimentary archives such as salt marshes, lagoons, wetlands, beach ridges or coastal plains were also studied with different temporal resolution and time span. Yet, interpreting such records remains challenging, as each site possesses distinct sensitivity thresholds that control whether a given storm is recorded in the sedimentary archive (Goslin and Clemmensen, 2017). Consequently, multi-site comparisons are needed to identify regional storm patterns (Pleskot et al., 2023). Following the principle of uniformitarianism, key to the interpretation of sedimentary archives remain facies models based on post-storm morphosedimentary observations (Clemmensen et al., 2016; Chaumillion et al., 2017; Quix et al., 2025).

At a global scale, archives of storm deposits are increasingly studied and used by synthetic reviews to define the young discipline of palaeotempestology and analyse the regional variability of storminess (e.g., Sorrel et al., 2012; Chaumillion et al., 2017; Oliva et al. 2018; Minamidate and Goto, 2024; Donnelly, 2025; Leszczyńska et al., 2025). Despite their exposure to some of the world's most severe storms, the extratropical coasts of north-west Europe lack a comprehensive overview of storm-related sedimentary archives, their chronological frameworks, and applied analytical methods. There is no systematic assessment of the usefulness and temporal resolution reflecting the validity and reliability of sedimentary archives and proxy data to date. This gap hampers regional comparisons and limits our ability to reconstruct long-term patterns of storminess across the eastern North Atlantic realm.

Therefore, the aims of this review are (I) to compile all relevant coastal sedimentary storm archives across north-west Europe (45°–75°N), and (II) to evaluate the proxy data and geochronological methods used to extract storm signals from these records. Our discussion addresses the validity, efficacy, chronological resolution and reliability of archives and methods, and aims to inform and guide future research efforts in the field of palaeostorm research in the region of interest.

2. Method: A systematic literature review and meta-analysis

This study is based on a systematic literature review of available peer-reviewed articles until May 2025. We used the search engines Google Scholar and Web of Science using the keywords "storminess", "coastal flooding", "storm deposit", "storm surge", "storm events", "marine flooding" and "coastal waves" and any combination thereof. The relevant studies were selected according to the following seven criteria:

(1) Studies must be based on sedimentary storm deposits from an observational perspective. Thus, studies based on reanalysis data or modern instrumental data are excluded.

(2) Studies must cover a period longer than 150 years to reach beyond the period of instrumental data, which excludes some relevant studies with, however, insufficient significance in terms of long-term variability (Ehlers et al., 1993; Tsompanoglou et al., 2011; Baumann et al., 2017; Bateman et al., 2018; Jardine et al., 2022).

(3) Studies on single events, such as for the severe North Sea flood in 1775 (Cunningham et al., 2011), in 1953 (Swindles et al., 2018) or the storm flood Bodil (Xaver) in 2013 (Clemmensen et al., 2016) are excluded.

(4) The sediment record needs to be age-dated so that phases of higher and lower storm activity can be identified along a time axis.

(5) Sedimentary archives need to be located within 10 km from the coastline. Studies on inland sedimentary archives, e.g., inland ombrotrophic peat bogs (Björck and Clemmensen, 2004; Kylander et al., 2013, 2023) are excluded.

(6) Only onshore archives are included, offshore storm deposits (e.g., Polovodova Asteman et al., 2013) are excluded.

(7) North-west Europe is defined here as the region north of 45°N and south of 75°N latitude, as this region reflects a fairly consistent storm pattern. Relevant storm records fulfilling the above-mentioned criteria from the Spanish (Borja et al., 1999; Feal-Pérez et al., 2014; Orme et al., 2017) or Portuguese (Andrade et al., 2004; Clarke and Rendell, 2006) coasts are therefore excluded. Sedimentary storm records along the Baltic Sea coast are included as most North Atlantic storm tracks pass the North Sea first before they enter the Baltic Sea (Leszczyńska et al., 2025).

The selected literature was categorised by country, type of sedimentary archive and region. Prior to assessing the methodologies in detail and examining the storm periods reconstructed by the different studies, a database was created based on the specific archive or study site (assigned an ID number) containing information on the archive type, country, region, latitude, longitude, age span and – if possible – the temporal resolution of the record. If the geographical coordinates for the location were missing, they were derived from Google Earth. If a certain location was investigated in more than one publication, a lower-case letter was added to the ID number.

Next, the various laboratory methods applied in the different studies were derived and gathered in a table and sorted according to the sedimentary archive type. The methods were sorted by dating (e.g., radiocarbon, luminescence, radionuclides, others), sedimentology (e.g., lithology, sediment structure, grain size), physical properties (e.g., bulk density, CT-scan, magnetic susceptibility), bulk chemistry (e.g., XRF elements, TC, TIC, TOC, TN, TS, ash content), and microfossils (e.g., foraminifers, diatoms, ostracods, pollen, others) following the approach of Melles et al. (2022).

3. Coastal storm deposits in north-west Europe

3.1. Palaeotempestology as a discipline in north-west Europe

In total, we found 77 locations in 69 publications from north-west Europe matching our selection criteria (Table S1). The first study, published by De Ceunynck (1985), attributed the evolution of the coastal dunes in Western Belgium to increased storm activity. Delaney and Devoy (1995) carried out the first investigations on washover deposits in Europe in machairs, coastal dunes and lagoons in Ireland. The first study to use the term palaeotempestology (or palaeo-tempestology), well-established in the research on past storm activity in tropical regions at that time, was the one on cliff-top storm deposits (CTSD) by Hansom and Hall (2009), although it is still rarely found in extratropical applications. Terminology such as 'palaeostorm activity' or 'palaeostorm research' dominates the field in north-west Europe (e.g., Sorrel et al., 2012; van Vliet-Lanoë et al., 2014a). However, the growing number of publications in these research field shows that palaeotempestology is an emerging research field in the extratropical eastern North Atlantic basin.

3.2. Sedimentary archive types of coastal storm deposits

Globally, studies from tropical or subtropical regions dominate the field of palaeotempestology. Based on this global perspective, palaeostorm archives differentiate between ponds, lakes and lagoons receiving deposits from coastal overwash, coastal karst basins, coastal boulder deposits, beach ridges and chemically and biologically formed laminae as tree rings, speleothems and banded corals (Minamidate and Goto, 2024).

However, karst basins, tree rings, coastal speleothems and corals do not exist or have not been studied in north-west Europe. In total, we identified six main categories: coastal dunes, peat bogs/peatlands/machairs, salt marshes, coastal lakes, coastal lagoons and cliff-top storm deposits (CTSD). There are further coastal palaeostorm archives in north-west Europe, such as estuaries, tidal flats, coastal plains, beach ridge sequences or spit systems (Figure 1). Since they are less frequent in publications on storm records, they were gathered in the category ‘others’.

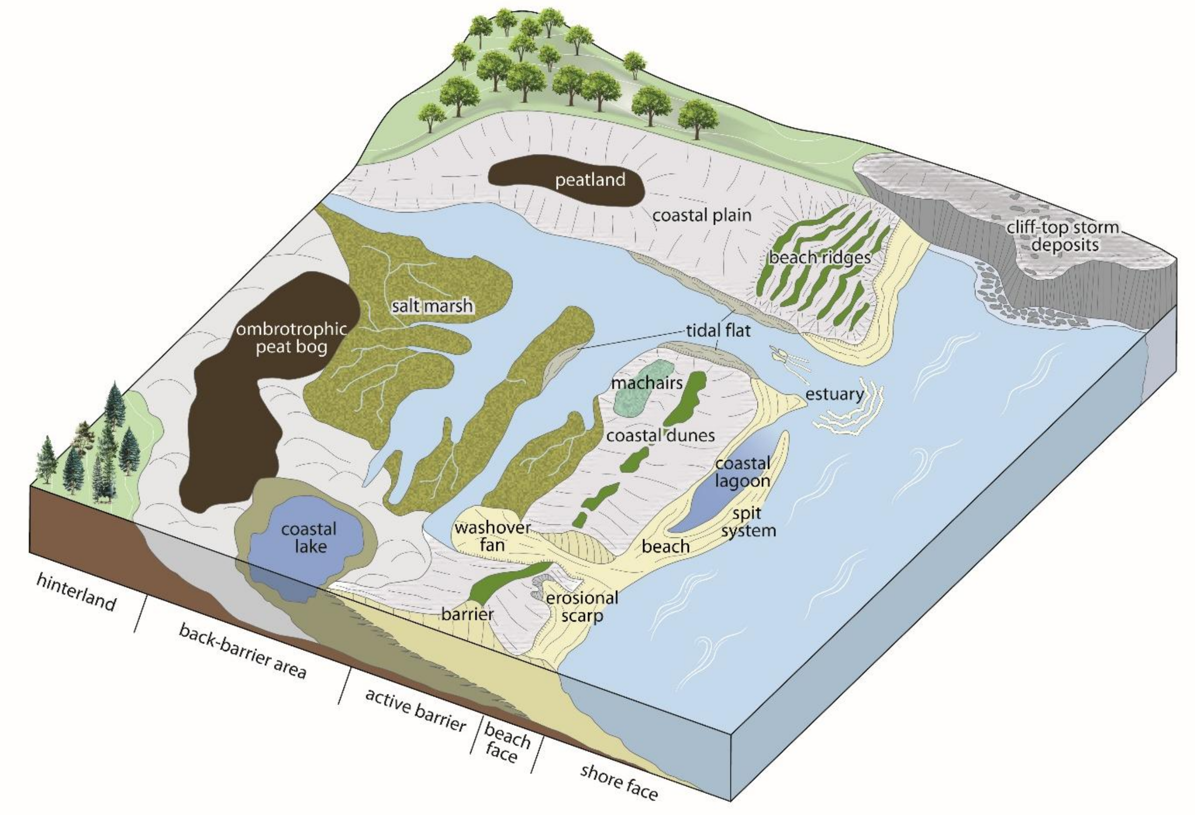

Figure 1. Schematic figure of the typical coastal archive types in north-west Europe (modified after Goslin and Clemmensen (2017) and Minamidate and Goto (2024)).

A clear distinction between the different archive types is sometimes difficult, as some coastal archives morphologically evolved over time (e.g., Gilbertson et al., 1999; Suursaar et al., 2022; Kalińska et al., 2024). Some are in a fluid transition from one archive type to another, such as some sites in France, which are in transition between coastal lagoons and salt marshes depending on the exact coring location (e.g., Pouzet and

Maanan, 2020). Machairs could have been an own category, however, we decided to put them together with peatlands as they exist only in the British Isles and have similarities with peatlands due to their high organic content (s. Section 3.2.1).

The earliest studies tend to focus on coastal dunes, while in the late 1990s salt marshes gained importance as coastal archives, particularly in the British Isles (Figure 2). Studies of storm deposits in peat bogs appeared in 2003 (Sommerville et al., 2003). Coastal lagoons and lakes did not appear until 2007 (Haslett and Bryant, 2007) and 2016 (Nielsen et al., 2016b, 2016c; Orme et al., 2016b), respectively.

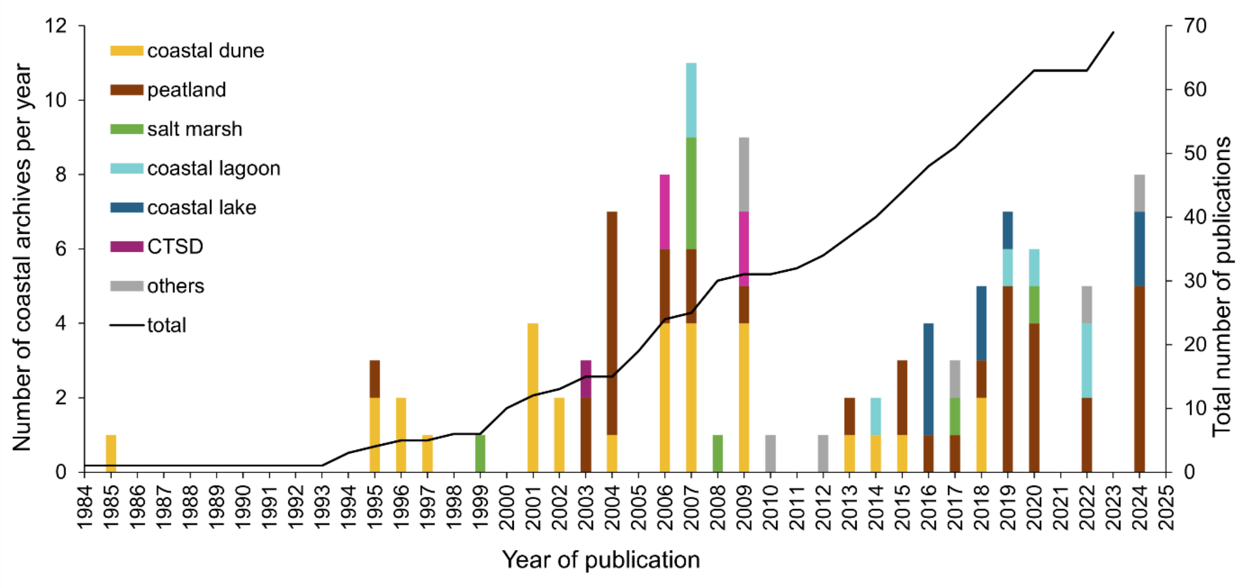

Figure 2. Number of palaeostorm publications per year in north-west Europe based on sedimentary or geomorphic archive type.

Over the last ten years, there has been a trend away from publications on palaeostorms in coastal dunes towards more studies on coastal lagoons and lakes as well as peat bogs. Viewed over the entire period, the most common archive types in north-west Europe are peat bogs/machairs and coastal dunes, with 28 and 21 locations along the north-western European coastline, respectively. Neither Minamidate and Goto (2024) nor Goslin and Clemmensen (2017) consider these archive types in their global reviews. However, both peat bogs/machairs and coastal dunes provide some of the longest and most coherent storm records on the north-west European coasts, making them one of the most relevant extratropical coastal archives.

3.2.1. Peat bogs, peatland and machairs

Peat bogs, peatlands and machairs have in common that they mainly accumulate organic matter. Minerogenic particles (mostly quartz) are found as traces within these archive types and can be used as indicator for storms. The underlying geomorphological process is predominantly aeolian. For this reason, some storm records from peat bogs are located far inland (Björck and Clemmensen, 2004; Kylander et al., 2013; Kylander et al., 2023) and are not included here. However, there also are coastal peat bog studies based on the process of overwash (Delaney and Devoy, 1995; Bondevik et al., 2019).

Some of the peat bog studies use the aeolian sand influx (ASI) (Björck and Clemmensen, 2004) as indicator for winter storminess (Mellström et al., 2015; Orme et al., 2015; Orme et al., 2016; Vandel et al., 2019; Nielsen et al., 2024; Vaasma et al., 2024). The ASI is represented by the minerogenic residue after elimination of organic matter, e.g., through loss-on-ignition (LOI) (Kylander et al., 2023), and is based on the assumption that mineral grains of a certain size are only transported into the peat bog during severe storms. Some peat bog studies use further geochemical data, such as bromine concentration as measure of sea spray, which can be regarded as an indicator of higher storminess (Orme et al., 2015; Stewart et al., 2017).

The Gaelic term 'machair' describes a coastal field or inland plain consisting mainly of a mixture of calcareous shell fragments and organic material, making it a very fertile dune grassland. It is exclusively used along the coasts of Scotland and Ireland (Crawford, 1991; Gilbertson et al., 1999). Here, we attribute coastal machairs to the category of coastal peatland due to its similar characteristics. In total, we found 22 and 6 locations with storm deposits in coastal peatlands and machairs, respectively.

3.2.2. Coastal dunes

Some of the earliest sediment-based studies on palaeostorms in north-west Europe focus on the dynamics of coastal dunes (Delaney and Devoy, 1995; Jelgersma et al., 1995; Wilson and Braley, 1997; Clemmensen et al., 2001). To use coastal dunes as archives for storms they need to be fixed by vegetation and incorporated into a continuous dune belt behind the beach. The crest line must be higher than the most extreme storm surge and waves to prevent overtopping and erosion of the morpho-sedimentary archive. Last, active dune accretion is necessary, so there must be sufficient sediment supply to allow the dunes to recover after an extreme storm event (Bateman et al., 2018). Most coastal dune studies are based on organic soil development, such as peaty palaeosols which is related to stable periods with low storm frequency. In contrast, periods of high sand accumulation are associated with higher storminess. The chronology, mostly based on radiocarbon dates, often originates from the phases of land surface stability and soil development (e.g., Wilson et al., 2004; Clemmensen et al., 2009). Another approach is to investigate the erosion of the foredune ridge to detect storm surges (Aagaard et al., 2007; McIlvenny et al., 2013).

3.2.3. Washover deposits: Coastal lakes, lagoons and salt marshes

Coastal lakes, lagoons and salt marshes are usually located in the low-energy back-barrier area. Coastal lakes are freshwater bodies embedded in topographic depressions and separated from the sea by a sand to gravel barrier. Lagoons are enclosed or semi-enclosed water bodies with limited tidal exchange and brackish to saline conditions (Sabatier et al., 2022). Washover deposits form when storm waves and surges transport marine sediments landward across the barrier during coastal flooding. Three principal flooding mechanisms are distinguished: inundation or overflowing, wave overtopping or overwashing, and barrier breaching (Sallenger et al., 2000; Sabatier et al., 2022). Washover deposits usually consist of one or multiple sedimentary (sand) layers from the beach or nearshore zone, showing an inland thinning and fining trend (Liu and Fearn, 2000;

Chaumillon et al., 2017; Minamidate and Goto, 2024; Sharrocks et al., 2025). During a severe storm surge, the waves partially erode and overtop the beach and barrier, and transport coarser (and heavier) material towards the low-energy environment behind, which is typically characterised by fine-grained, organic-rich sedimentation (Bregy et al., 2018, Sabatier et al., 2022; Sharrocks et al., 2025). Coastal lakes, lagoons, and salt marshes are common coastal landforms in north-west Europe, where we identified seven sites containing lagoon or coastal lake archives, respectively, and six from salt marshes. In some more distal or steep-sided lakes, ASI has been used as an indicator of storminess when direct washover deposition is absent (e.g., Nielsen et al., 2016b, 2024; Goslin et al., 2018, 2019).

3.2.4. Cliff-top storm deposits

Coastal boulder deposits play a major role in palaeostorm research on rocky coasts with high cliffs, e.g., along the North Atlantic coast in Scotland (Sommerville et al., 2003; Hall et al., 2006; Hall et al., 2008; Hansom and Hall, 2009), Ireland (Williams and Hall, 2004; Cox et al., 2012), and France (Autret et al., 2018). However, we only identified three studies that pass the criteria of this study (Sommerville et al., 2003; Hall et al., 2006; Hansom and Hall, 2009), as the transport of CTSD is very challenging to age-date (e.g., Rixhon et al., 2018). The studies considered here use sand layers for luminescence dating or organic material for radiocarbon dating beneath the boulders to determine a *terminus post quem* for the last transport of boulders. However, this method is rather imprecise, and the datable material experiences strong erosion by wind on the exposed rocky coasts. The only dating method that is directly linked to the larger boulders is lichenometry, which was applied in some studies in addition (Hall et al., 2006; Hansom and Hall, 2009).

3.2.5. Others

The most frequent archive type within the category of ‘others’ are estuaries (Haslett and Bryant, 2007; Sorrel et al., 2009; Sorrel et al., 2012) or tidal flats (Billeaud et al., 2009), which represent the boundary between marine and onshore deposits in the macrotidal regimes of Brittany, France or southern UK. Studies on beach-ridge systems are relatively rare in north-west Europe (Clemmensen et al., 2012, 2016; Goslin and Clemmensen, 2017; Kalińska et al., 2024). Coastal plains (Piotrowski et al., 2017) and spit systems (Lindhorst et al., 2010; Suursaar et al., 2022) are also relatively rarely used, only in Poland, Germany, and Estonia, respectively. Beyond that, there are three studies from caves using the stable isotopic signature of speleothems to infer storminess (Sundqvist et al., 2010; Fohlmeister et al., 2012; Baker et al., 2015) which are located far from the coasts and are not considered for further analyses here.

3.3. A process-based classification of coastal storm deposits

A typical feature to identify palaeostorms in coastal sediment archives is coarser sediment – mostly sand – embedded in finer-grained deposits, usually (organic-rich) mud, which is common for e.g., lakes (Kalińska-Nartiša et al., 2018; Hess et al., 2024), salt marshes (Szkornik et al., 2008; Poirier et al., 2017) or machairs (Gilbertson et al., 1999; Dawson et al., 2004). Except for cliff-top storm deposits and coastal boulders, sand plays a major role for all overwash-related back-barrier archives (washover terraces, lagoons, lakes, ponds, salt marshes), as well as for peat bogs and peatlands (Liu and Fearn, 1993; May et al., 2013; Orme et al., 2016). Beach-ridge systems, however, respond through erosion and subsequent reformation of a new ridge (Tamura, 2012), whereas coastal dunes have a more complex and less consistent way to record storm impacts (s. Section 3.2.2). All depositional storm archives have in common that grain size and type are important factors of reconstructing the origin and processes of the event deposits (Sharrocks et al., 2025). In sum, three different processes providing *ex-situ* sediment into the coastal archives can be classified: marginal marine (e.g., for estuaries, tidal flats), overwash (e.g., coastal lakes, lagoons, floodplains) and aeolian (e.g., peat bogs, coastal dunes). Marginal marine transport is usually driven by tidal currents or gravity/storm waves, which might be difficult to disentangle, especially for longer timescales. While overwash occurs due to coastal flooding and is therefore directly related to storm surge, wave setup (and potentially tidal level), and predominantly independent from precipitation or wetness of the sediment source, for aeolian processes the wetness of the sediment source may have an influence on the transport capacity. Therefore, the site-specific transport and depositional dynamics need to be addressed before the analysis of sedimentary storm records.

3.4. Geographical distribution and sedimentary ages of north-west European storm deposits

This study separates north-west Europe into six subregions similar to the scheme of Vousdoukas et al. (2016) and based on the spatial clustering of study sites i.e., the Norwegian Sea, British Isles, North Sea, Skagerrak/West Baltic Sea, East Baltic Sea and Bay of Biscay/English Channel. The coastal storm records show an uneven spatial distribution (Figure 3). The region with the most coastal sedimentary records of storm variability is the British Isles (30 sites), followed by the southernmost region Bay of Biscay/English Channel (13 sites). On the British Isles, most of the sites are located in Scotland, particularly on the Outer Hebrides (n=9), mainland Scotland (n=4), the Orkney Islands (n=4), and the Shetland Islands (n=3). These areas have the highest exposure to the open North Atlantic Ocean and are the first to capture landfalling westerly to northerly storms. The other subregions comprise 11 (Skagerrak/West Baltic Sea), 11 (North Sea), 7 (East Baltic Sea) and 5 (Norwegian Sea) coastal sedimentary archives, respectively.

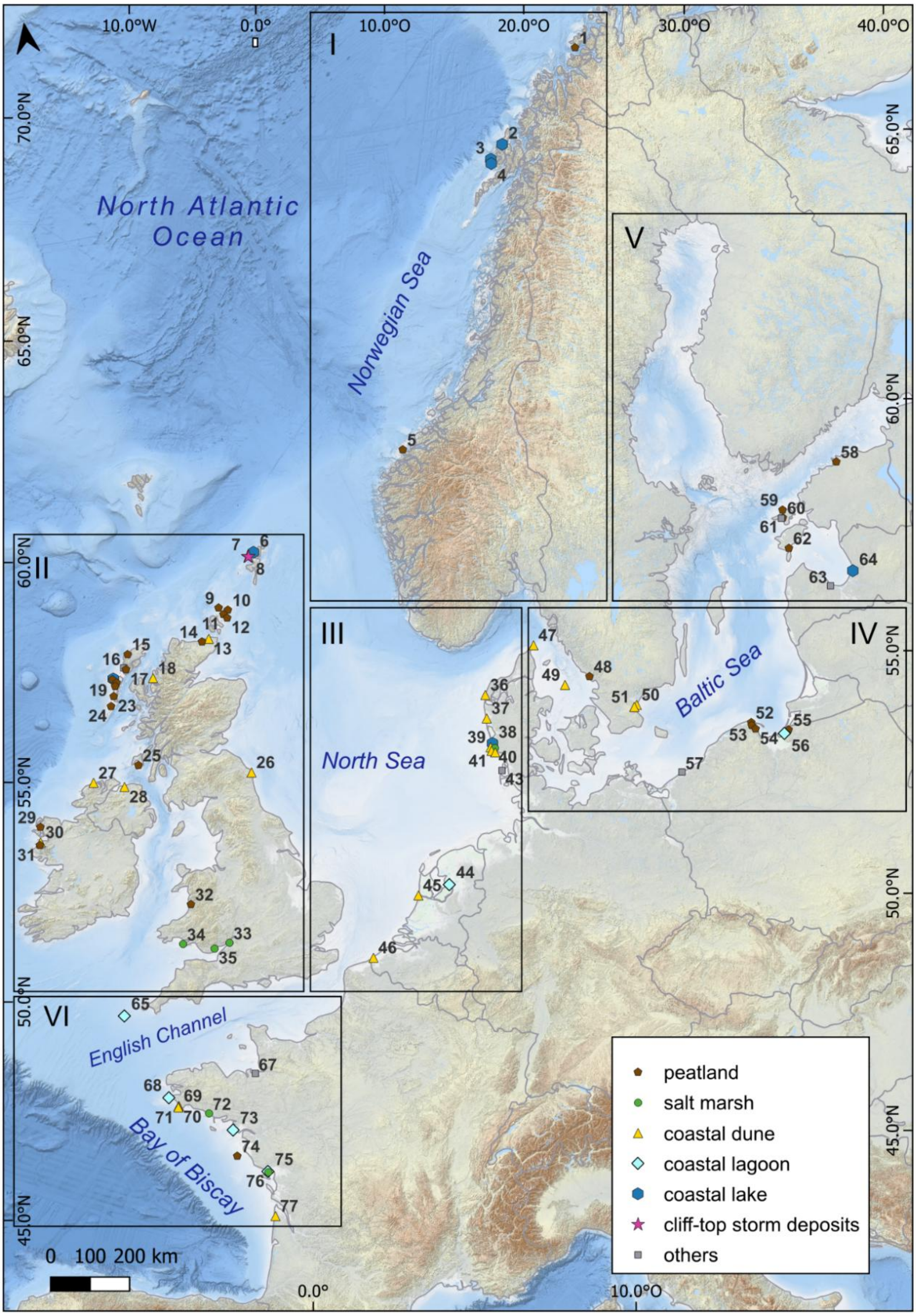

Figure 3. Map of the distribution of different sedimentary storm archives in north-west Europe. The six different regions I – Norwegian Sea, II – British Isles, III – North Sea, IV – Skagerrak/West Baltic Sea, V – East Baltic Sea and VI – English Channel/Bay of Biscay are indicated with black rectangles.

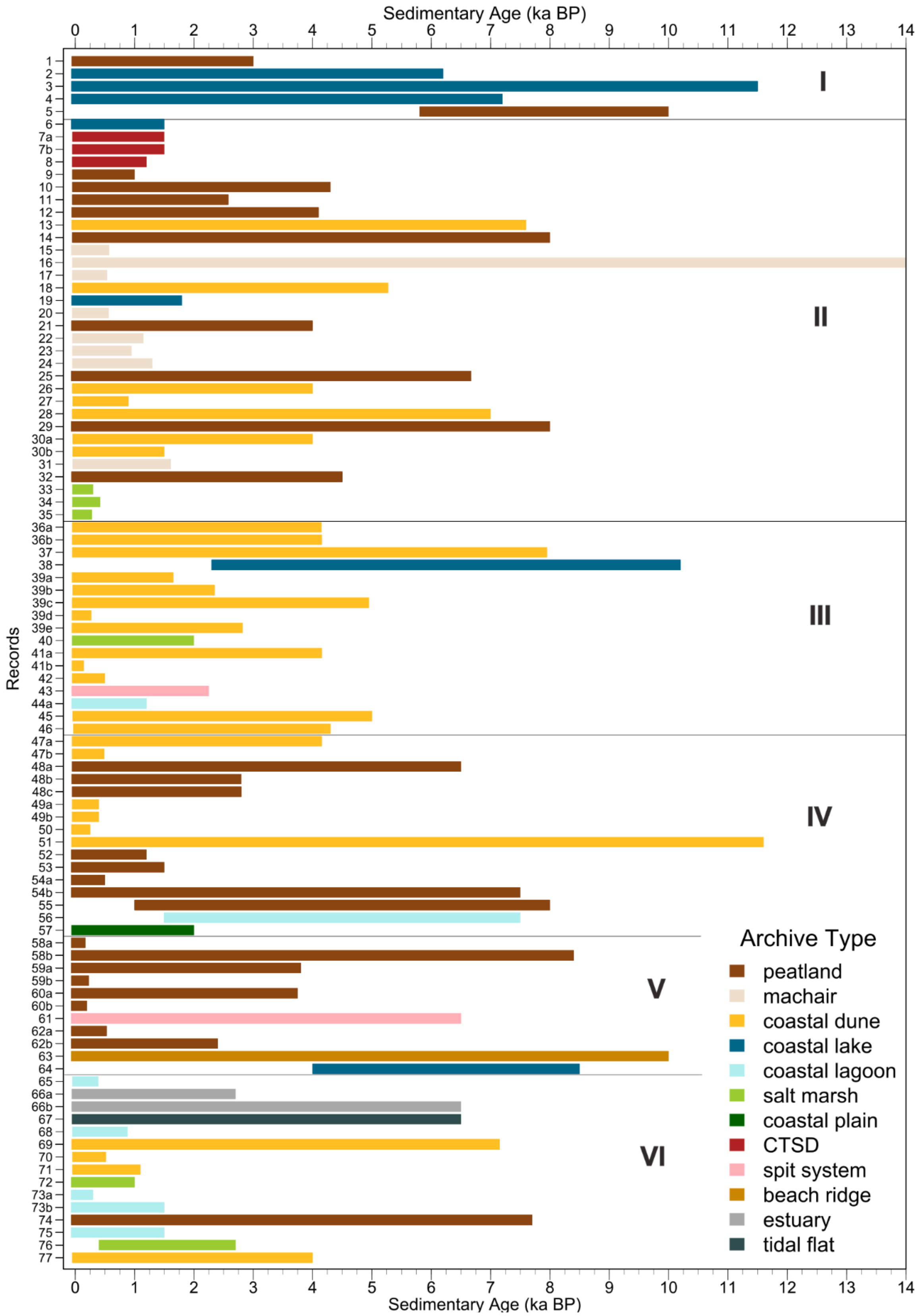

Figure 4. Overview of time spans covered by the various coastal storm archives in north-west Europe. For a key to numbers see Table S1.

The large gap along the Norwegian coast south of the 68°N is striking. There is only one coastal archive at 62°N, however, it contains sediment ages solely for the early and middle Holocene (10–5.8 ka BP) as a function of relative sea-level fall since the mid-Holocene due to glacial isostatic adjustment (GIA) (Bondevik et al., 2019). Furthermore, the east coast of the British Isles as well as the southern part of Ireland are almost unstudied, showing only one coastal record (Wilson et al., 2001). The coastline of Germany, which has access to both, the North Sea and the Baltic Sea, also represents a larger spatial gap, with only one study on storm deposits on Sylt Island (Lindhorst et al., 2010). In addition, there is not a single coastal archive in the northern part of the Baltic Sea along the east coast of Sweden and the coasts of Finland, as these areas also experience relative sea-level fall exposing more or less resistant rocky coastlines (Leszczyńska et al., 2025).

There is a quite strong spatial clustering of specific archive types. Peat bog and peatland archives are the predominant type for the East Baltic Sea, whereas for the Bay of Biscay/English Channel no peatland studies exist at all (Figure 4). Coastal dunes were mostly studied in the North Sea region, especially on the west coast of Denmark and in the Skagerrak region along the coasts of eastern Denmark and southern Sweden. Salt marshes or machairs are used as coastal archive mostly on the British Isles, some salt marshes were studied in France as well. The Norwegian Sea subregion is characterised by coastal lake archives. However, the Norwegian coastal lake studies use the ASI instead of washover sediments as storm indicator as the lakes are located too far from the coastline (Sjögren, 2009; Nielsen et al., 2016b, 2024).

The various coastal storm archives in north-west Europe cover a median age of 2.3 ka BP, with a majority covering parts of the late Holocene (Figure 4). Over 25 records cover less than 1 ka, only 22 studies extend into the middle Holocene and eight studies reach back to the early Holocene. The oldest sediment archive from a machair in Scotland (Outer Hebrides) dates back to the Pleistocene at 14 ka BP (Gilbertson et al., 1999).

3.5. Proxies and laboratory analyses used in north-west European storm deposits

The proxy data used in palaeotempestology studies in north-west Europe are mostly lithology-related (facies description, mineralogical sediment structure, grain-size distribution), physical properties (bulk density, magnetic susceptibility), and chemical data (µXRF counts, loss-on-ignition (LOI), total organic carbon (TOC)). In some cases, also microfossils, such as foraminifers, diatoms or ostracods, were investigated (Table 1).

Table 1. Laboratory analyses and proxies used in the different sedimentary storm archives (table structure modified after Melles et al., 2022).

ID	Location	Archive type	Country	References	Dating					Sedimentology			Physical properties			Bulk chemistry			Microfossils				Others
					Radiocarbon	Luminescence	Radionuclids	Others	Age model	Lithology	Sediment structures Microtexture	Grain size	Bulk density	CT-Scan	Magnetic susceptibility	TC, TIC, TOC, TN, TS	XRF elements	Ash content	Pollen	Diatoms	Foraminifera	Ostracods (O), Bivalves (B), Gastropods (G)	
63	Apsuciems	beach ridge sequences	LVA	Kalińska et al., 2024		x			x		SEM												
13	Dunnet Bay	coastal dune	GBR	McIlvenny et al., 2013	x	x			x	x		x				LOI							pH
18	Opinan	coastal dune	GBR	Wilson et al., 2002	x																		
26	Northumber-land	coastal dune	GBR	Wilson et al., 2001	x	x				x		x				LOI			x				
27	Horn Head	coastal dune	IRL	Wilson and Braley, 1997	x							x				LOI							pH
28	Northern Ireland	coastal dune	GBR	Wilson et al., 2004	x	x				x													
30a, 30b	Carrownisky	coastal dune	IRL	Delaney and Devoy, 1995; Devoy et al., 1996	x					x		x											
36a	Lodbjerg	coastal dune	DNK	Clemmensen et al., 2001b	x	x						x											
36b	Lodbjerg	coastal dune	DNK	Clemmensen et al., 2009	x	x						x											
37	Ulfborg	coastal dune	DNK	Dalsgaard and Odgaard, 2001	x	x				x	x	x				x			x				pH
39a	Vejers	coastal dune	DNK	Clemmensen et al., 1996	x					x													
39b	Vejers	coastal dune	DNK	Clemmensen et al., 2001a	x	x				x													
39c	Vejers	coastal dune	DNK	Clemmensen et al., 2006	x	x																	
39d, 41a, 47a	Vejers, Hvidbjerg, Skagen Odde	coastal dune	DNK	Clemmensen et al., 2009	x	x						x											

39e, 41b, 49a	Vejers, Hvidbjerg, Anholt	coastal dune	DNK	Clemmensen and Murray, 2006		x																	
42	Skallingen Spit	coastal dune	DNK	Aagard et al., 2007		x						x											
45	Bergen	coastal dune	NLD	Jelgersma et al., 1995	x					x												S, G	
47b	Skagen Odde	coastal dune	DNK	Clemmensen et al., 2015		x				x													
49b	Anholt	coastal dune	DNK	Clemmensen et al., 2007		x						x											
50, 51	Åhus, Vittskövle	coastal dune	SWE	Kalińska-Nartiša et al., 2017	x	x																	
69	Audierne Bay	coastal dune	FRA	Van Vliet-Lanoë et al., 2014a	x				x	x		x											
70	Pointe de la Torche	coastal dune	FRA	Haslett and Bryant, 2007	x																x		
71	Porz Carn	coastal dune	FRA	Haslett and Bryant, 2007	x																		
77	Médoc	coastal dune	FRA	Clarke et al., 2002		x																	
46	De Panne	coastal dune	BEL	Ceunynck, 1985	x					x									x				
2	Latjønna	coastal lake	NOR	Nielsen et al., 2016b	x				x			x	x		x	LOI	x						
3	Trehynnvatnet	coastal lake	NOR	Nielsen et al., 2016c	x		Cs, Ra		x	x	SEM	x	x	X	x	LOI	x						
4	Nøkktjønna	coastal lake	NOR	Nielsen et al., 2024	x		Pb, Cs, Ra		x	x	x	x	x	X	x	LOI	x						
6	Loch Flugarth	coastal lake	GBR	Hess et al., 2024	x		Cs	x	x	x	TS	x	x	X	x	x	x						
19	Loch Hosta	coastal lake	GBR	Orme et al., 2016b	x		Pb, CS, Ra		x							LOI, C/N	x						
38	Filsø	coastal lake	DNK	Goslin et al., 2018; Goslin et al., 2019	x	x			x	x		x				LOI	x	x					plant macrofossils
64	Lake Lilaste	coastal lake	LVA	Kalińska-Nartiša et al., 2018	x						SEM	x			x	LOI				x			
57	Rogowo	coastal plain	POL	Piotrowski et al., 2017	x							x				LOI	x			x		O, M	ICP-OES
7a	Grind of the Navir, Eshaness	CTSD	GBR	Hansom and Hall, 2009	x			L, C															

7b	Grind of the Navir, Eshaness	CTSD	GBR	Sommerville et al., 2003		x																	
8	Villians of Hamnavoe	CTSD	GBR	Hall et al., 2006; Hansom and Hall, 2009		x		L, C															
66a, 66b	Seine	estuary	FRA	Sorrel et al., 2009; Sorrel et al., 2012	x			PM	x	x													
44	Schokland	lagoon	NLD	van den Biggelaar et al., 2014	x					x	x	x				x					x	O, B	
65	Big Pool - St. Agnes	lagoon	GBR	Haslett and Bryant, 2007		x																	
68	Baie des Trépassé	lagoon	FRA	Haslett and Bryant, 2007	x																		
73a	Traicts du Croisic	lagoon	FRA	Pouzet et al., 2019			Pb, Cs					x		x	x		x						
73b	Traicts du Croisic	lagoon	FRA	Pouzet and Maanan, 2020	x		Pb, Cs		x	x					x	x	x						
75	Belle Henriette	lagoon	FRA	Maanan et al., 2022	x		Pb, Cs			x	x	x		x			x						
14, 17, 20, 22, 23, 24	Crip Riof, Horgabost, Balranald, Nunton Benbecula, Kildonan, Borve	machairs	GBR	Dawson et al., 2004	x							x								x			
15	Shebster	machairs	GBR	Stewart et al., 2017	x			T	x							LOI	x						
16	Uist	machairs	GBR	Gilbertson et al., 1999	x	x				x	TS												
31	Silver Strand	machairs	IRL	Delaney and Devoy, 1995	x					x		x											
1	Sørøya	peatland	NOR	Sjögren, 2009	x				x			x				LOI, C, N, S			x		x		
5	Longva	peatland	NOR	Bondevik et al., 2019	x				x							LOI			x				
9, 11	Quoygrew (Westray),	peatland	GBR	Sommerville et al., 2003		x																	

	Sandhill (Orkney)																						
10	Sanday, Orkney	peatland	GBR	Sommerville et al., 2007		x																	
12	Stronsay, Orkney	peatland	GBR	Tisdall et al., 2013	x	x					TS	x				LOI			x				
21	Struban Bog	peatland	GBR	Orme et al., 2016a	x				x							LOI							
25	Laphroaig bog	peatland	GBR	Kylander et al., 2020	x				x			x	x				x	x					
29	Roycarter bog	peatland	IRL	Sjöström et al., 2024	x				x			x	x			LOI	x	x					FTIR-ATR, pXRD, pH
32	Cors Fochno	peatland	GBR	Orme et al., 2015	x				x							LOI	x						
48a	Undarsmosse	peatland	SWE	De Jong et al., 2006	x				x			x	x			x		x	x				
48b	Undarsmosse	peatland	SWE	De Jong et al., 2007																			
48c	Undarsmosse	peatland	SWE	Mellström et al., 2015	x				x	x		x							x				
52, 54a	Słone Łąki, Mechelińskie Łąki	peatland	POL	Moskalewicz et al., 2020	x		Pb, Cs, Bi		x			x				LOI				x			
53	Puck Lagoon	peatland	POL	Uścinowicz et al., 2020	x				x	x									x	x		$\delta^{13}C$, ^{18}O	ICP-OES
54b	Mechelińskie Łąki	peatland	POL	Leszczyńska et al., 2022; 2024	x	x	Pb,Cs		x	x	TS	x				LOI	x			x			
58a, 59a, 60a, 62a	Juminda, Hiiuma N, Hiiuma SW, Saaremaa	peatland	EST	Vandel et al., 2019	x				x			x				LOI							
58b, 59b, 60b, 62b	Juminda, Hiiuma N, Hiiuma SW, Saaremaa	peatland	EST	Vaasma et al., 2024	x				x		x	x				LOI							
55, 56	Łaki Rozanskie, Vistual Lagoon	peatland / lagoon	POL	Uścinowicz et al., 2022	x				x	x									x	x		S, $\delta^{13}C$	

33	Oldbury-on-Severn	salt marsh	GBR	Haslett and Bryant, 2007	x																x		
34	Llangennith	salt marsh	GBR	Haslett and Bryant, 2007	x						x												
35	Rumney	salt marsh	GBR	Haslett and Bryant, 2007	x																		
40	Ho Bugt	salt marsh	DEN	Szkornik et al., 2008	x	x				x		x								x			
72	Petite Mer de Gâvres	salt marsh	FRA	Pouzet and Maanan, 2020	x		Pb, Cs		x	x		x		x	x	x	x						
74	Island of Yeu	salt marsh	FRA	Pouzet et al., 2018	x					x	x	x				LOI	x						
76	Pertuis Charentais	salt marsh	FRA	Poirier et al., 2017	x				x	x													
43	Sylt	spit system	DEU	Lindhorst et al., 2010	x							x											
61	Tihu	spit system	EST	Suursaar et al., 2022		x						x											
67	Mont-Saint-Michel Bay	tidal flat	FRA	Billeaud et al., 2009	x					x	x												

B = Bivalves, Bi = ^{214}Bi dating, C = Colour, Cs = ^{137}Cs dating, D = Diatoms, F = Foraminifera, G = Gastropods, L = Lichenometry, LOI = Loss-on-ignition, M = Mollusks, O = Ostracods, P = Pollen, Pb = ^{210}Pb dating, PM = Paleomagnetic, Ra = ^{226}Radon dating, S = Shells, SEM = scanning electron microscope analysis, T = Tephra dating, TS = Thin sections

For chronologies, luminescence dating is more often used for coastal dunes, while radiocarbon dating is more frequently applied in peat-dominated and lacustrine environments (Figure 5). However, there are exceptions where dune-based studies rely on radiocarbon (Delaney and Devoy, 1995; Jelgersma et al., 1995; Clemmensen et al., 1996; Wilson and Braley, 1997; van Vliet-Lanoë et al., 2014b) and luminescence dating is applied in peat environments (Sommerville et al., 2003, 2007; Tisdall et al., 2013; Leszczyńska et al., 2024) or a coastal lake (Goslin et al., 2018, 2019). Some studies in lakes and coastal lagoons use ^{210}Pb and/or ^{137}Cs in addition to radiocarbon for the topmost stratigraphic section (Nielsen et al., 2016b; Orme et al., 2016; Pouzet et al., 2019; Moskalewicz et al., 2020, 2022; Pouzet and Maanan, 2020a; Leszczyńska et al., 2022, 2024; Maanan et al., 2022; Hess et al., 2024). Other dating methods include tephrochronology (Stewart et al., 2017) and lichenometry (Hall et al., 2006; Hansom and Hall, 2009). Sorrel et al. (2009) also used palaeomagnetic dating for the Seine estuary in France.

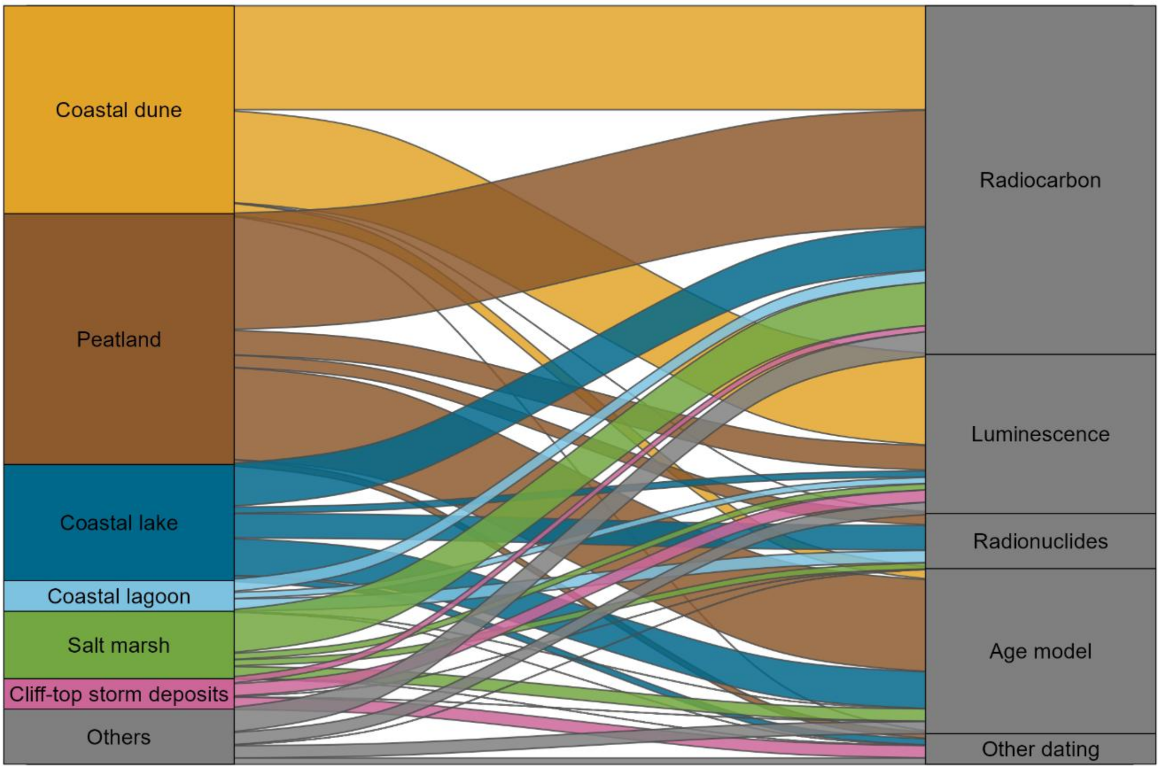

Figure 5. Alluvial diagram of the different dating methods (right) used for each archive class (left). The width of the links indicates the frequency of the individual dating method applied.

The grain-size distribution is the most important proxy for palaeostorm reconstruction and was analysed by 38 studies (Figure 6). The lithology, which gives a detailed overview of the different facies and sediments within the archive was only investigated in 30 studies and the mineralogical sediment structure or microstructure of individual sediment layers, such as thin sections was studied by 15 studies. For aeolian processes the grain size of larger than 200 µm or 350 µm is regarded as an indicator of a severe storm. Sometimes this value is reduced to >180 µm (Orme et al., 2016) or >150 µm (Kylander et al., 2020; Sjöström et al., 2024). For washover deposits there is no general grain size, as it very much depends on the site-specific availability of sediment along the barrier. Nevertheless, medium to coarse sand fractions sprinkled with gravels or pebbles and a finingupward trend together with a sharp, sometimes erosional basal boundary are common signatures of washover deposits (Goslin and Clemmensen, 2017).

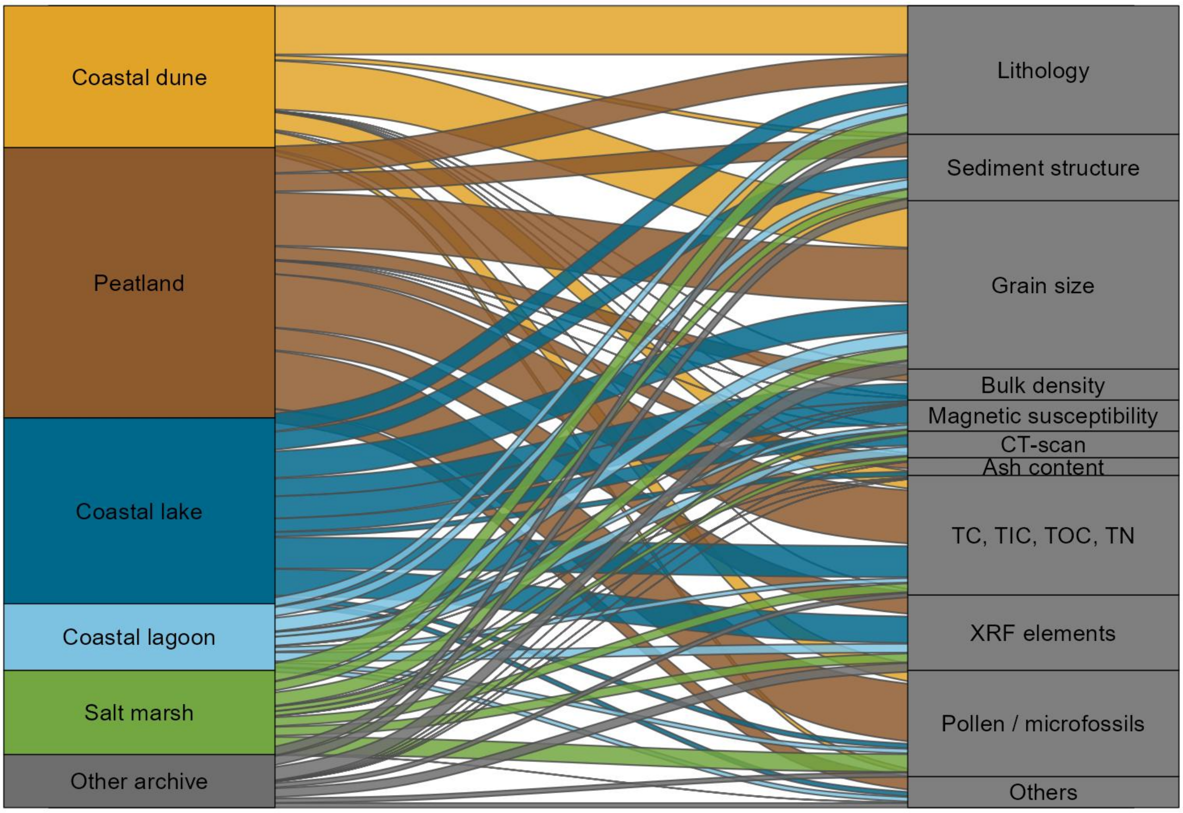

Figure 6. Alluvial diagram of the different proxies (right) used for each archive class (left). The width of the links indicates the frequency of the individual proxy applied.

The physical properties (CT-scan and magnetic susceptibility) were only applied in a salt marsh, coastal lakes and lagoons to identify lamination and other sediment structures. The bulk density was analysed in four coastal lake studies (Nielsen et al., 2016a, 2016b, 2024; Hess et al., 2024) and in three peat bog studies (De Jong et al., 2006, 2007; Kylander et al., 2020; Sjöström et al., 2024). In another study, powder X-ray diffraction (pXRD) was used to quantify the mineral composition of the crystalline phases of the sediments (Sjöström et al., 2024).

LOI is a widely applied method for calculating the organic matter, which usually reflects the TOC, measured by 28 studies (sometimes in combination with inorganic carbon, nitrogen and/or sulfur). LOI is more commonly used in peat bog/peatland and coastal lake/lagoon studies compared to salt marshes (n=1) (Pouzet et al., 2018) or coastal dunes (n=4) (Wilson and Braley, 1997; Dalsgaard and Odgaard, 2001; Wilson et al., 2001; McIlvenny et al., 2013). The µXRF analysis was carried out in 17 studies, for almost all (6 out of 7) coastal lake studies, as well as in peatland studies (n=5), coastal lagoons (n=3), salt marshes (n=2) and a coastal plain (n=1). Most studies used an ITRAX device with a downcore resolution between 200 µm (Orme et al., 2015, 16b; Nielsen et al., 2026b) and 1 mm (Nielsen et al., 2016a, 2016c; Goslin et al., 2018). Besides, WD-XRF (Kylander et al., 2020), EMMA-XRF (Sjöström et al., 2024) and a handheld ED-XRF (Leszczyńska et al., 2022) were used with lower resolutions.

In north-west Europe, there are only three studies using foraminifera as indicators for storm deposits (Haslett and Bryant, 2007; Sjögren, 2009; van den Biggelaar et al., 2014). Diatoms are a more common proxy (n=16), predominantly applied in salt marshes (Dawson et al., 2004; Szkornik et al., 2008), peatland and machairs (Dawson et al., 2004; Moskalewicz et al., 2020; Uścinowicz et al., 2020, 2022; Leszczyńska et al., 2022) and in isolated cases on a coastal plain (Piotrowski et al., 2017), coastal lagoon (Uścinowicz et al., 2022) and coastal lake (Kalińska-Nartiša et al., 2018). Seven sites are studied for pollen (Dalsgaard and Odgaard, 2001; Wilson et al., 2001; De Jong et al., 2006, 2007; Sjögren, 2009; Tisdall et al., 2013; Mellström et al., 2015; Bondevik et al., 2019). Stable isotopes, such as oxygen or hydrogen, frequently used in palaeostorm studies from the north-west Atlantic to identify hurricanes which have commonly a depletion in heavy oxygen, are not used in north-west Europe.

In summary, a fewer number of different proxies are applied for coastal dunes compared to coastal lakes, lagoons and peat bogs. In general, there is a trend towards a wider spectrum of different proxies in more recent studies (Leszczyńska et al., 2022, 2024; Hess et al., 2024; Nielsen et al., 2024).

4. Challenges of European palaeotempestology research

The most important criteria defining the quality of a palaeostorm record include: (I) Length of the record, (II) reliability of the age model and chronological resolution, (III) precision and accuracy with which to identify the sedimentary storm signature and filter out other local signals, (IV) geomorphic stability of the archive, and (V) the preservation potential of the storm signature.

4.1. Length of the record

In north-west Europe, the longest palaeostorm records are established in machairs, coastal lakes, and peatlands, where coastal environments and relative sea levels have been nearly stable across millennial time scales. Records extending into the phase of rapid eustatic sea-level rise before around 6 ka BP are therefore rare, and only occur at near-field sites where GIA kept up with the eustatic component (e.g., Bondevik et al., 2019) resulting in relative sea-level fall across the Holocene (Creel et al., 2022), or where aeolian sands are used as a proxy for storminess in peat bogs and machairs (e.g., Gilbertson et al., 1999). However, also without substantial GIA, coastal lakes or peatland have the potential to contain washover deposits from storm events reaching far into the mid-Holocene (e.g., Kalińska-Nartiša et al., 2018; Pouzet et al., 2018; Leszczyńska et al., 2022, 2024). Coastal dunes can also reach far into the mid-Holocene (e.g., Kalińska-Nartiša et al., 2018), however, their temporal resolution of storm periods is low and with high uncertainty due to age-dating uncertainties and the fact that phases of dune stability are investigated and dune mobility due to higher storminess is difficult to prove. Coastal lagoons and salt marshes, prevalent in the southern UK and Bay of Biscay area with a eustasy-dominated sea-level history, tend to provide shorter records. The same applies to CTSD, which reflect the shortest storm records on rather centennial timescales.

4.2. Reliability and resolution of the age model

Due to these age-dating challenges CTSD have the lowest chronological reliability and resolution, followed by coastal dunes. Coastal lagoons, lakes, salt marshes and peatland records have in common that they are sampled by sedimentary cores. If a consistent stratigraphy is available without hiatuses, these coastal archives have the best chronological resolution. The sedimentation rate is crucial; however, most studies do not give any identification of sedimentation rates (mm per year) or temporal resolution (years per cm) for the archive they use. Sedimentation rates should reach >0.2 mm/year to have a suitable temporal resolution. In general, age-depth models containing more than one proxy are more reliable (Sabatier et al., 2022). Coastal lake and lagoon records often combine radiocarbon dating with radionuclide (^{210}Pb, ^{137}Cs) dating (Figure 5), which enables to link individual known storms during recent decades (e.g., Orme et al., 2016b; Nielsen et al., 2016c; Pouzet et al., 2019; Pouzet and Maanan, 2022; Hess et al., 2024; Nielsen et al., 2024).

4.3. Clarity of the storm signal

A further important criterion for defining the quality of a palaeostorm record is the possibility to identify the sedimentary storm signature and filter out other local signals. To ensure correct attribution of storm layers, competing processes and alternative sediment sources – including tsunamis, which may create a range of similar sedimentary signatures (Sharrocks et al., 2025) – must therefore be identified and excluded (Pleskot et al., 2023). To fulfill this criterion a multi-proxy approach should be chosen in order to consider all sedimentary processes.

Ideally, recent storm events or historically well-known storm deposits should be used as modern analogues (Chaumillon et al., 2017; Sabatier et al., 2022; Leszczyńska et al., 2025), in order to identify the storm event as precise as possible. However, it is not absolutely necessary, provided that all competing local hydrodynamic and sedimentary processes are sufficiently considered. To better understand the archive itself, several cores and/or sampling locations should be studied within their bathymetric and topographic context in order to filter out micro-scale effects and conditions (Chaumillon et al., 2017).

A further challenge lies in distinguishing whether storm deposits represent single storm events or are the cumulative result of multiple events during a short period of time (Goslin and Clemmensen, 2017). This question becomes particularly relevant when dealing with long-term sedimentary records covering millennial timescales. If a sediment record reflects both individual or multiple storm events, it becomes crucial to determine the point at which the record shifts from event-scale to a multi-event deposition (Chaumillon et al., 2017). Along the coasts of north-west Europe, the relatively high frequency of storm events complicates this differentiation. In particular, washover deposits may become indistinguishable if successive storm events occur in rapid succession, preventing the formation of background sediment layers that would otherwise separate individual events (Minamidate and Goto, 2024; Leszczyńska et al., 2025). Simultaneously, a rapid succession of storm events may cause erosion and the recovery of the coast and the archive is impaired. However, in the case of beach-ridge systems recent studies have shown that the coasts can substantially recover within a few months to years (Monecke et al., 2015; Quix et al., 2025).

In other depositional sediment archives, intense precipitation events, aeolian processes, volcanic fallout, lake-borne sediment collapse or high tides may deposit coarse material, potentially mimicking or disturbing the overwash signal (Oliva et al., 2017; Sabatier et al., 2022). Also, bioturbation, reworking or erosion may disturb the storm signal. Ombrotrophic peat bogs and peatlands, whose storm signals are characterised by aeolian input rather than overwash processes, tend to record periods of higher storminess rather than individual events. This makes it difficult to fulfill the overarching goal of palaeotempestology i.e., to investigate the recurrence patterns of the most severe storm events not recorded in the instrumental data period.

To identify the storm signal, a wide spectrum of proxy data is crucial. The analysis of the present dataset of original studies identifies grain-size distribution and characteristics as the most important proxy data, as well as geochemical proxies, such as from µXRF or TOC. For peatbog studies based on the aeolian signal the grain-size distribution and the ASI are useful tools. Magnetic susceptibility, colour information and density data are additional valuable information; however, they are not absolutely necessary for the interpretation (Sabatier et al., 2022). Even though rarely applied in north-west European coastal archives compared to the western Atlantic (Oliva et al., 2017, 2018), microfossils such as foraminifera, diatoms and ostracods can provide valuable information about storm signals. However, foraminifera are relatively rare in extratropical high-energy coastal areas of north-west Europe with low carbonate availability and have limited preservation potential in the abundant low-pH environments (Hippensteel et al., 2013; Hawkes, 2020). Additionally, microfossil analyses are time-consuming approaches that require specific expertise and experience. Besides, stable isotopes are not much analysed in north-west European archives. The reason could be that stable isotopes in other regions are often studied in tree rings, speleothems, or calcareous microfossils (Oliva et al., 2017) which have not been used as palaeotempestological archives in the present area of interest. Another promising proxy are CT-scans and their analyses, which are only applied in coastal lakes (Nielsen et al., 2016c, 2024; Hess et al., 2024) and coastal lagoons (Pouzet et al., 2019; Pouzet and Manaan, 2020; Manaan et al., 2022) so far. This approach can provide specific information about the sedimentation process such as flow direction and becomes more and more relevant particularly for washover deposits (Biguenet et al., 2022), but it could also be applied for aeolian sedimentary archives, such as ombrotrophic peat bogs, where it helps to quantify aeolian influx (Nielsen et al., 2024).

4.4. Geomorphic stability of the sedimentary archive

Coastal environments experience multiple sedimentary processes and are among the most dynamic geomorphic systems. Their capacity to preserve storm and surge signals depends fundamentally on the geomorphic stability of the sedimentary archive and on the dominant transport processes involved (Table 2). Geomorphic stability refers here to (i) the persistence of the morphological features (e.g., barrier systems) and thresholds for storm signal occurrence, and (ii) geomorphic stability of the source environments.

Table 2. Comparison of coastal archive types from north-west Europe in terms of geomorphic stability and storm-signal reliability.

Archive type	Geomorphic stability	Storm signal detection	Main risks of disturbance / uncertainties
Coastal dunes	*Low to medium*: dunes themselves are highly dynamic and prone to migration or stabilisation by vegetation	*Low to medium*: enhanced sand mobility may indicate stormy periods, but attribution to single events is rare	Human dune stabilisation; vegetation changes; low temporal resolution; wind-dominated reworking
Peatlands	*High*: stable stratigraphy and environment	*Medium*: only indirect minerogenic inputs from storms; do not record storm surges	Multiple potential sediment sources; long transport pathways; RSL control on sand availability; risk of misinterpreting atmospheric dust or local erosion as storm signals
Coastal lakes	*Medium to high*: dependent on barrier crest height, width, sediment budget, high sensitivity to RSL rise, basin morphology is relatively stable, but inlets/outlets may shift; sensitive to catchment changes	*Medium to high* due to direct overwash signal	Terrestrial flooding from heavy rainfall; catchment erosion; inflow-channel migration; anthropogenic modification; difficulty distinguishing storm-driven vs. fluvial inputs
Coastal lagoons	*Medium to high*: depends on inlet dynamics, lagoon flushing rate, and sediment trapping efficiency	*Medium*: can store storm-induced sand layers, but signals often attenuated or mixed	Inlet opening/closure cycles; terrestrial inflow; lagoon circulation changes; human alteration (dredging, artificial openings)
Salt marshes	*Medium to high*: relatively stable accreting environments, but sensitive to RSL rise and creek migration	*Medium to high*: can record washover layers, high-water sediment pulses, or sudden minerogenic input	Creek migration; bioturbation; anthropogenic channelisation; high riverine sediment loads; mixing of storm and non-storm high water events
Cliff-top storm deposits	*Low to medium*: strongly dependent on cliff erosion rates, retreat and surface instability for long timescales; relatively stable for short timescales	*High* for individual extreme storm events: coarse clasts deposited well above normal wave run-up	Erosion and reworking by subsequent storms; loss of older deposits due to cliff retreat; difficult long-term preservation; dating challenges
Tidal flats / Estuaries	*Low to medium*: strong tidal dynamics; sediment remobilization; and changing bathymetry	*Medium*: storm layers possible but often diffuse and overprinted by daily tidal processes	Fluvial flooding mimicking storm layers; strong reworking; shifting deposition centers; bioturbation; channel migration; changes in tidal range

Barrier systems underlie continuous alterations in the height, width and overall morphology over time. These changes influence the threshold conditions required for overwash events and thus determine whether storm signals are preserved in the back-barrier archives (Goslin and Clemmensen, 2017; Leszczyńska et al., 2022). The formation and preservation of washover deposits further depend on hydrodynamic factors similar to those of marginal marine environments, including RSL, tidal cycle (e.g., spring tides), nearshore bathymetry, and the angle and energy of incoming waves (Goslin and Clemmensen, 2017). Because both barrier crest height and storm surge height can vary over time, there is uncertainty in the relationship between overwash frequency and storminess. For instance, an apparent increase in storm deposits in recent sediments may result from lowered overwash threshold due to rising RSL rather than from more frequent or intense storms. Additionally, not all extreme storm events produce severe coastal flooding, and the controlling mechanisms behind this variability remain insufficiently understood (Leszczyńska et al., 2025).

In contrast, aeolian archives, such as coastal peatlands, are less affected by short-term coastal geomorphic changes, as they are usually located further inland. However, RSL variations can substantially influence sediment availability and dune mobility, since rising RSL reduces the width of exposed beach surfaces and thereby limits the supply of minerogenic material for aeolian transport. Conversely, colder periods with slightly lower sea-levels and reduced vegetation cover, such as the Little Ice Age, enhanced sediment supply along exposed shorelines (Clarke and Rendell, 2009; Cunningham et al., 2011). Although aeolian archives can record storm-driven increases in sand mobilisation, they generally do not capture storm surges directly. Consequently, environmental changes recorded in such archives often reflect broader regional dynamics rather than individual storm surge events, making it more challenging to assess geomorphic stability or isolate storm signals.

4.5. Preservation potential of the storm signal

Finally, the preservation potential of the storm signature must be considered. Good preservation is typically found in relatively protected or accreting environments, such as salt marshes, coastal lakes, beach ridges and restricted embayments (Chaumillon et al., 2017). Washover deposits in low-energy back-barrier environments are regarded as the most reliable coastal archives in terms of preservation potential as they do not experience any significant erosion (Chaumillon et al., 2017; Bregy et al., 2018). However, these archives are vulnerable to bioturbation and anthropogenic disturbances, such as infrastructure constructions, human dune modification and agricultural practices (Chaumillon et al., 2017; Oliva et al., 2017). Besides, CTSD have a very good preservation potential as well, as these deposits reflect high intensity storm events and due to their large size and they hardly experience any changes by post-depositional processes, except for stepwise landward transport or some degree of weathering across long time scales (Kelletat et al., 2020). Other subaerial deposits are more prone to erosion, such as coastal dunes which are easily eroded by marine flooding or storms. In this case, the vegetation cover plays a crucial role and might vary widely over longer timescales, which influences the preservation potential especially for coastal dunes.

Another important factor is the anthropogenic impact on the coastal environment and the sedimentary archive itself. Wide parts of the European coastline affected by human impacts due to coastal infrastructure but also by coastal protection such as dykes (e.g., Belgian, Dutch and German coasts).

5. Implications for future European palaeotempestology research

A supra-regional European understanding of past storm activities requires the integration of regional palaeotempestology studies and a comparison with other studies. Therefore, all available information on the location itself should be provided in the published study. This information includes material and the coastal archive type as well as the geological setting and sedimentary system. For a better comparison, information on the date and/or year of the sampling should be given. This is crucial for interpreting more recent storm events or periods from palaeostorm records. Furthermore, a comprehensive information on the geographical location and site description is required in the publication including the coordinates of the study site.

There is a challenge in establishing precise and reliable chronologies of storm-induced sediment deposition, and the application of Holocene storm chronologies to interpret both regional and supra-regional climate and oceanic patterns (Goslin and Clemmensen, 2017). This presents a further challenge, as sedimentary records often differ in temporal resolution and the periods they cover (s. Chap. 3.4). Therefore, it is essential to report sedimentation rates, temporal resolution, age uncertainties and the chronological framework used in each study to allow for meaningful comparisons. This enhances a more reliable age-depth model and also a better process understanding with respect to sedimentary characteristics. For future studies multiproxy analyses and multiple independent methods for chronology and sedimentary characteristics should be applied (Goslin and Clemmensen, 2017) considering the peculiarities of the individual archives as discussed here. Multiple dating methods, such as radiocarbon dating along with OSL dating, were applied mutually in some studies, particularly in studies using coastal dunes as sediment record, which requires a uniform time system. In literature, the specified time varies from e.g., '*Before Present*' (BP), *'Common Era/Before Common Era'* (CE/BCE), '*Before Christ/Anno Domini*' (BC/AD) or '*before 2000*' (b2k). This variation complicates a direct comparison between various regional studies. We suggest one common time reference. Since most of the studies investigated in this review cover less than 2000 years, we propose to use the CE/BCE time reference. Most importantly, original data should be provided to the community in a stable repository following the FAIR principles (Kinkade and Shepherd, 2022).

6. Conclusion

Here, we present the first comprehensive review of coastal sedimentary storm archives in north-west Europe based on studies from 1985 to May 2025. Storm signals are mainly inferred from peatland archives, coastal dunes, salt marshes, coastal lakes and lagoons, and cliff-top storm deposits, depending on the subregion. The region with the most sedimentary records is the British Isles, followed by the Bay of Biscay and English Channel. The most important dating methods are radiocarbon and luminescence dating. Since storm signals mostly consist of quartz and/or feldspar rich sand layers, luminescence dating becomes increasingly relevant for storm archives. Radionuclides can improve the age model, particularly for younger and shorter sedimentary ages. The most important proxies are grain size characteristics, elemental composition and organic matter content. In terms of the preservation potential, the application of a wide range of proxies for unambiguous storm signals and the potential for reliable and high-resolution chronological models, coastal lakes seem to be the most promising archives, along with machairs and peatlands, which may provide the longest records, even beyond the Holocene. Geomorphic stability of the archives very close to the coast often depend on stable RSL histories bound to areas of very moderate GIA and local tectonics.

Moreover, this study reveals potential spatial gaps for coastal palaeotempestology research that should be addressed in future studies, especially the coasts of southern Ireland, the Norwegian coast, and the coasts of the Netherlands and Germany. We found that studies on European sedimentary storm archives are diverse and a profound comparison of these studies is challenging. For future case studies, we therefore propose a standardised protocol as uniform as possible with information on site settings, such as coordinates, year of sampling, geological setting, archive type, temporal resolution and sedimentation rate. A reliable age-depth model and chronology is essential to derive recurrence patterns of palaeostorminess. For a better spatial understanding of past storm patterns across Europe, more regional sedimentary records are required for which comparability is enabled through overlapping spectra of proxies and openly accessible publication of original data. The intensities or magnitude of past storm surges is still poorly understood and should be further addressed in future studies. The growing number of publications on sedimentary storm records across Europe have shown that palaeotempestology research is in fact a discipline in Europe and becomes increasingly relevant.

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ID	ID2	Name	Latitude	Longitude	Location	Country	Region	Region 2	Published year	References	Archive type	Archive class	Predominant process	Temporal resolution (yr/cm)	Sedimentation rates (mm/yr)	Sediment Ages kyr cal. BP (Beginning)	Sediment Ages kyr cal. BP (End)
1	1	Sørøya	70°29'N	22°10'E	Sørøya	Norway	Norwegian Sea	1	2009	Sjögren, 2009	coastal peat	peatland	ASI	38.0	0.26	3,000	-58
2	2	Latjønna	69°00'N	15°27'E	Andøya	Norway	Norwegian Sea	1	2016	Nielsen et al., 2016b	coastal lake	coastal lake	aeolian	36.0	0.28	6,200	-65
3	3	Trehynnvatnet	68°45'N	14°29'E	Vesterålen	Norway	Norwegian Sea	1	2016	Nielsen et al., 2016c	coastal lake	coastal lake	ASI	35.0	0.29	11,500	-65
4	4	Nøkktjønna	68°39'N	14°26'E	Vesterålen	Norway	Norwegian Sea	1	2024	Nielsen et al., 2024	coastal lake	coastal lake	ASI	200.0	0.05	7,200	-65
5	5	Longva	62°40'N	6°16'E	Western Norway	Norway	Norwegian Sea	1	2019	Bondevik et al., 2019	peat	peatland	overwash		0.00	10,000	5800
6	6	Loch Flugarth	60°36'N	1°20'W	Shetland Islands	UK	British Isles	2	2024	Hess et al., 2024	coastal lake	coastal lake	overwash	15-20	0.5 - 0.67	1,500	-68
7	7a	Grind of the Navir, Eshaness	60°30'N	1°36'W	Shetland Islands	UK	British Isles	2	2003	Sommerville et al., 2003	CTSD	CTSD	CTSD		0.00	250	-50
7	7b	Grind of the Navir, Eshaness	60°30'N	1°36'W	Shetland Islands	UK	British Isles	2	2006	Hall et al., 2006; Hansom & Hall, 2009	CTSD	CTSD	CTSD		0.00	1,500	-50
8	8	Villians of Hamnavoe	60°30'N	1°34'W	Shetland Islands	UK	British Isles	2	2006	Hall et al., 2006; Hansom & Hall, 2009	CTSD	CTSD	CTSD		0.00	1,200	-50
9	9	Quoygrew, Orkney	59°20'N	2°58'W	Orkney Islands	UK	British Isles	2	2003	Sommerville et al., 2003	peatland	peatland	aeolian	2.0	5.00	1,000	-50
10	10	Sanday, Orkney	59°17'N	2°33'W	Orkney Islands	UK	British Isles	2	2007	Sommerville et al., 2007	peatland	peatland	aeolian		0.00	4,300	-50
11	11	Sandhill, Orkney	59°11'N	2°45'W	Orkney Islands	UK	British Isles	2	2003	Sommerville et al., 2003	peatland	peatland	aeolian		0.00	1,150	-50
12	12	Stronsay	59°06'N	2°35'W	Orkney Islands	UK	British Isles	2	2013	Tisdall et al., 2013	coastal peat	peatland	marine + aeolian		0.00	4,100	-62
13	13	Dunnet Bay	58°37'N	3°24'W	Scotland	UK	British Isles	2	2013	McIlvenny et al., 2013	coastal dune	coastal dune	marine + aeolian	10.0	0.2 - 1	7,600	-62
14	14	Shebster	58°33'N	3°42'W	Scotland	UK	British Isles	2	2017	Stewart et al., 2017	peat bog	peatland	sea spray	13.3	0.75	8,000	-50
15	15	Crip, Riof	58°12'N	6°56'W	Outer Hebrides	UK	British Isles	2	2004	Dawson et al., 2004	machairs	peatland	aeolian		0.00	400	-65
16	16	Uist	57°53 N	7°04'W	Outer Hebrides	UK	British Isles	2	1999	Gilbertson et al., 1999	machairs	peatland	aeolian		0.00	14,000	-48
17	17	Horgabost	57°51'N	6°58'W	Outer Hebrides	UK	British Isles	2	2004	Dawson et al., 2004	machairs	peatland	aeolian		0.00	400	-50
18	18	Opinan	57°41'N	5°47'W	Scotland	UK	British Isles	2	2002	Wilson et al., 2002	coastal dune	coastal dune	aeolian		0.00	5,200	-50
19	19	Loch Hosta	57°37'N	7°29'W	Outer Hebrides	UK	British Isles	2	2016	Orme et al., 2016b	coastal lake	coastal lake	aeolian + overwash		0.00	1,800	-65
20	20	Balranald, North Uist	57°36'N	7°31'W	Outer Hebrides	UK	British Isles	2	2004	Dawson et al., 2004	machairs	peatland	aeolian		0.00	500	-50
21	21	Struban and Hilltop Bog	57°32'N	7°20'W	Outer Hebrides	UK	British Isles	2	2016	Orme et al., 2016a	peat bog	peatland	ASI	14.0	0.71	4,000	-65
22	22	Nunton, Benbecula	57°27'N	7°23'W	Outer Hebrides	UK	British Isles	2	2004	Dawson et al., 2004	machairs	peatland	aeolian		0.00	1,100	-50
23	23	Kildonan	57°13'N	7°25'W	Outer Hebrides	UK	British Isles	2	2004	Dawson et al., 2004	machairs	peatland	aeolian		0.00	950	-50
24	24	Borve	56°59'N	7°30'W	Outer Hebrides	UK	British Isles	2	2004	Dawson et al., 2004	machairs	peatland	aeolian		0.00	1,300	-50
25	25	Laphroaig bog	55°40'N	6°14'W	Scotland	UK	British Isles	2	2020	Kylander et al., 2020	peat bog	peatland	aeolian	17.0	0.59	6,670	-70
26	26	Northumberland	55°32'N	1°38'W	England	UK	British Isles	2	2001	Wilson et al., 2001	coastal dune	coastal dune	aeolian		0.00	4,000	-50
27	27	Horn Head	55°12'N	8°00'W	Donegal	Ireland	British Isles	2	1997	Wilson & Braley, 1997	coastal dune	coastal dune	aeolian		0.00	900	-45
28	28	Northern Ireland	55°09'N	6°45'W	Northern Ireland	UK	British Isles	2	2004	Wilson et al., 2004	coastal dune	coastal dune	aeolian		0.00	7,000	-50
29	29	Roycarter bog	54°05'N	9°57'W	Mayo	Ireland	British Isles	2	2024	Sjöström et al., 2024	peat bog	peatland	aeolian	21.0	0.47	8,000	-70
30	30a	Carrownisky	53°44'N	9°53'W	Mayo	Ireland	British Isles	2	1995	Delaney & Devoy, 1995	coastal dune	coastal dune	overwash		0.00	4,000	-44
30	30b	Carrownisky	53°44'N	9°53'W	Mayo	Ireland	British Isles	2	1996	Devoy et al., 1996	coastal dune	coastal dune	overwash		0.00	1,500	-44
31	31	Silver Strand	53°40'N	9°54'W	Mayo	Ireland	British Isles	2	1995	Delaney & Devoy, 1995	machairs	peatland	overwash		0.00	1,600	-44
32	32	Cors Fochno	52°30'N	4°01'W	Wales	UK	British Isles	2	2015	Orme et al., 2015	peat bog	peatland	ASI + sea spray		0.00	4,500	-50
33	33	Oldbury-on-Severn	51°37'N	2°34'W	England	UK	British Isles	2	2007	Haslett & Bryant, 2007	salt marsh	salt marsh	overwash		0.00	180	-64
34	34	Llangennith	51°35'N	4°17'W	Wales	UK	British Isles	2	2007	Haslett & Bryant, 2007	salt marsh	salt marsh	overwash		0.00	200	-50
35	35	Rumney	51°29'N	3°07'W	England	UK	British Isles	2	2007	Haslett & Bryant, 2007	salt marsh	salt marsh	marine		0.00	150	-50
36	36a	Lodbjerg	56°49'N	8°15'E	Thy	Denmark	North Sea	3	2001	Clemmensen et al., 2001b	coastal dune	coastal dune	aeolian		0.00	2,300	-50
36	36b	Lodbjerg	56°49'N	8°15'E	Thy	Denmark	North Sea	3	2009	Clemmensen et al., 2009	coastal dune	coastal dune	aeolian		0.00	2,300	-50
37	37	Ulfborg	56°17'N	8°09'E	West Jutland	Denmark	North Sea	3	2001	Dalsgaard & Odgaard, 2001	coastal dune	coastal dune	aeolian		0.00	7,950	-50
38	38	Filsø	55°42'N	8°13'E	West Jutland	Denmark	North Sea	3	2018	Goslin et al., 2018; 2019	coastal lake	coastal lake	ASI	40.0	0.25	10,200	2300
39	39a	Vejers	55°37'N	8°07'E	SW Jutland	Denmark	North Sea	3	1996	Clemmensen et al., 1996	coastal dune	coastal dune	aeolian		0.00	1,650	-55
39	39b	Vejers	55°37'N	8°07'E	SW Jutland	Denmark	North Sea	3	2001	Clemmensen et al., 2001a	coastal dune	coastal dune	aeolian		0.00	2,350	-45
39	39c	Vejers	55°37'N	8°07'E	SW Jutland	Denmark	North Sea	3	2006	Clemmensen et al., 2006	coastal dune	coastal dune	aeolian		0.00	4,950	-50
39	39d	Vejers	55°37'N	8°07'E	SW Jutland	Denmark	North Sea	3	2006	Clemmesen & Murray, 2006	coastal dune	coastal dune	aeolian		0.00	268	-55
39	39e	Vejers	55°37'N	8°07'E	SW Jutland	Denmark	North Sea	3	2009	Clemmensen et al., 2009	coastal dune	coastal dune	aeolian		0.00	2,820	-58
40	40	Ho Bugt	55°35'N	8°17'E	West Jutland	Denmark	North Sea	3	2008	Szkornik et al., 2008	salt marsh	salt marsh	aeolian		0.00	2,000	-55
41	41a	Hvidbjerg	55°32'N	8°08'E	Thy	Denmark	North Sea	3	2006	Clemmensen & Murray, 2006	coastal dune	coastal dune	aeolian		0.00	145	-55
41	41b	Hvidbjerg	55°32'N	8°08'E	Thy	Denmark	North Sea	3	2009	Clemmensen et al., 2009	coastal dune	coastal dune	aeolian		0.00	4,153	-55
42	42	Skallingen Spit	55°29'N	8°16'E	Skallingen Spit	Denmark	North Sea	3	2007	Aagard et al., 2007	coastal dune	coastal dune	overwash		0.00	500	-55
43	43	Sylt	55°03'N	8°25'E	Frisian Islands	Germany	North Sea	3	2010	Lindhorst et al., 2010	spit system	others	overwash		0.00	2,250	-59
44	44	Schokland	52°38'N	5°46'E	Flevoland	Netherlands	North Sea	3	2014	Van den Biggelaar et al., 2014; 2018	lagoon	coastal lagoon	marine		0.00	1,200	-63
45	45	Bergen	52°28'N	4°34'E	Holland	Netherlands	North Sea	3	1995	Jelgersma et al., 1995	coastal dune	coastal dune	overwash		0.00	5,000	-44
46	46	De Panne	51°08'N	2°42'E	South Belgium	Belgium	North Sea	3	1985	De Ceunynck, 1985	coastal dune	coastal dune	marine + aeolian		0.00	4,300	-34
47	47a	Skagen Odde	57°44'N	10°38'E	North Jutland	Denmark	West Baltic Sea / Skaggerak	4	2009	Clemmensen et al., 2009	coastal dune	coastal dune	aeolian		0.00	4,153	-55
47	47b	Skagen Odde	57°44'N	10°38'E	North Jutland	Denmark	West Baltic Sea / Skaggerak	4	2015	Clemmensen et al., 2015	coastal dune	coastal dune	aeolian		0.00	490	-55
48	48a	Undarsmosse	56°46 N	12°39 E	Halland	Sweden	West Baltic Sea / Skaggerak	4	2006	De Jong et al., 2006	peat bog	peatland	ASI		0.00	6,500	-55
48	48b	Undarsmosse	56°46 N	12°39 E	Halland	Sweden	West Baltic Sea / Skaggerak	4	2007	De Jong et al., 2007	peat bog	peatland	ASI	10.0	1.00	2,800	-55
48	48c	Undarsmosse	56°46 N	12°39 E	Halland	Sweden	West Baltic Sea / Skaggerak	4	2015	Mellström et al., 2015	peat bog	peatland	ASI		0.00	2,750	-64
49	49a	Anholt	56°42'N	11°35'E	Island Kattegat	Denmark	West Baltic Sea / Skaggerak	4	2006	Clemmensen & Murray, 2006	coastal dune	coastal dune	aeolian		0.00	400	-55

49	49b	Anholt	56°42'N	11°35'E	Island Kattegat	Denmark	West Baltic Sea / Skaggerak	4	2007	Clemmensen et al., 2007	coastal dune	coastal dune	aeolian		0.00	400	-55
50	50	Åhus	55°53'N	14°15'E	Skåne	Sweden	West Baltic Sea / Skaggerak	4	2018	Kalińska-Nartiša et al., 2017	coastal dune	coastal dune	aeolian		0.00	250	-65
51	51	Vittskövle	55°51'N	14°08'E	Skåne	Sweden	West Baltic Sea / Skagerrak	4	2018	Kalińska-Nartiša et al., 2017	coastal dune	coastal dune	aeolian		0.00	11,600	-65
52	52	Słone Łąki	54°47'N	18°25'E	Gulf of Gdańsk	Poland	West Baltic Sea / Skaggerak	4	2020	Moskalewicz et al., 2020	coastal peat	peatland	overwash	27.0	0.37	1,200	-70
53	53	Puck Lagoon	54°43'N	18°24'E	Gulf of Gdańsk	Poland	West Baltic Sea / Skaggerak	4	2020	Uścinowicz et al., 2020	peatland	peatland	marine		0.00	1,500	-70
54	54a	Mechelińskie Łąki	54°37'N	18°30'E	Gulf of Gdańsk	Poland	West Baltic Sea / Skaggerak	4	2020	Moskalewicz et al., 2020	coastal peat	peatland	overwash	15.0	0.67	500	-70
54	54b	Mechelińskie Łąki	54°37'N	18°30'E	Gulf of Gdańsk	Poland	West Baltic Sea / Skaggerak	4	2022	Leszczyńska et al., 2022; 2024	coastal peat	peatland	overwash		0.00	7,500	-70
55	55	Łaki Rozanskie	54°22'N	19°42'E	Gulf of Gdańsk	Poland	West Baltic Sea / Skaggerak	4	2022	Uścinowicz et al., 2022	peat bog	peatland	marine	7.7	1.30	8,000	1000
56	56	Vistula Lagoon	54°19'N	19°30'E	Gulf of Gdańsk	Poland	West Baltic Sea / Skaggerak	4	2022	Uścinowicz et al., 2022	lagoon	coastal lagoon	marine	7.7	1.30	7,500	1500
57	57	Rogowo	54°09'N	15°18'E	Rogowo	Poland	West Baltic Sea / Skaggerak	4	2017	Piotrowski et al., 2017	coastal plain	others	overwash		0.00	2,000	-65
58	58a	Juminda	59°32'N	25°37'E	Hiiu	Estonia	East Baltic Sea	5	2019	Vandel et al., 2019	peat bog	peatland	ASI		0.00	170	-68
58	58b	Juminda	59°32'N	25°37'E	Hiiu	Estonia	East Baltic Sea	5	2024	Vaasmaa et al., 2024	peat bog	peatland	ASI		0.00	8,400	-70
59	59a	Hiiumaa N	59°02'N	22°37'E	Hiiu	Estonia	East Baltic Sea	5	2019	Vandel et al., 2019	peat bog	peatland	ASI		0.00	230	-68
59	59b	Hiiumaa N	59°02'N	22°37'E	Hiiu	Estonia	East Baltic Sea	5	2024	Vaasmaa et al., 2024	peat bog	peatland	ASI		0.00	3,800	-70
60	60a	Hiiumaa SW	58°52'N	22°30'E	Hiiu	Estonia	East Baltic Sea	5	2019	Vandel et al., 2019	peat bog	peatland	ASI		0.00	196	-70
60	60b	Hiiumaa SW	58°52'N	22°30'E	Hiiu	Estonia	East Baltic Sea	5	2024	Vaasmaa et al., 2024	peat bog	peatland	ASI		0.00	3,750	-70
61	61	Tihu	58°52'N	22°26'E	Hiiu	Estonia	East Baltic Sea	5	2022	Suursaar et al., 2022	spit system	others	aeolian		0.00	6,500	-70
62	62a	Saaremaa	58°11'N	22°15'E	Saare	Estonia	East Baltic Sea	5	2019	Vandel et al., 2019	peat bog	peatland	ASI		0.00	530	-68
62	62b	Saaremaa	58°11'N	22°15'E	Saare	Estonia	East Baltic Sea	5	2024	Vaasmaa et al., 2024	peat bog	peatland	ASI		0.00	2,400	-70
63	63	Apsuciems	57°3'N	23°16'E	Gulf of Riga	Latvia	East Baltic Sea	5	2024	Kalińska et al., 2024	beach ridge sequenc	others	overwash		0.00	10,000	-70
64	64	Lake Lilaste	57°10'N	24°21'E	Gulf of Riga	Latvia	East Baltic Sea	5	2018	Kalińska-Nartiša et al., 2018	coastal lake	coastal lake	overwash	8.0	1.25	8,500	4000
65	65	Big Pool - St. Agnes	49°53'N	6°20'W	Scilly Islands	UK	Bay of Biscay / English Channel	6	2007	Haslett & Bryant, 2007	lagoon	coastal lagoon	overwash		0.00	390	-50
66	66b	Seine estuary	49°25'N	0°05'E	Britanny	France	Bay of Biscay / English Channel	6	2012	Sorrel et al., 2012	estuary	others	marine		0.00	6,500	-58
66	66a	Seine estuary	49°25'N	0°05'E	Britanny	France	Bay of Biscay / English Channel	6	2009	Sorrel et al., 2009	estuary	others	marine		0.00	2,700	-58
67	67	Mont-Saint-Michel Bay	48°36'N	1°42'W	Britanny	France	Bay of Biscay / English Channel	6	2009	Billeaud et al., 2009	tidal flat	others	overwash		0.00	6,500	-55
68	68	Baie des Trépassé	48°02'N	4°41'W	Britanny	France	Bay of Biscay / English Channel	6	2007	Haslett & Bryant, 2007	lagoon	coastal lagoon	overwash		0.00	882	-50
69	69	Audierne Bay	47°51'N	4°20'W	Britanny	France	Bay of Biscay / English Channel	6	2014	Van Vliet-Lanoe et al., 2014a,b	coastal dune	coastal dune	overwash		0.00	7,150	-60
70	70	Pointe de la Torche	47°50'N	4°21'W	Britanny	France	Bay of Biscay / English Channel	6	2007	Haslett & Bryant, 2007	coastal dune	coastal dune	marine		0.00	520	-50
71	71	Porz Carn	47°49'N	4°21'W	Britanny	France	Bay of Biscay / English Channel	6	2007	Haslett & Bryant, 2007	coastal dune	coastal dune	marine		0.00	1,100	-50
72	72	Petite Mer de Gâvres	47°41'N	3°18'W	Britanny	France	Bay of Biscay / English Channel	6	2020	Pouzet & Maanan, 2020	salt marsh	salt marsh	overwash	8.3	1.20	1,000	-68
73	73a	Traicts du Croisic	47°18'N	2°29'W	Britanny	France	Bay of Biscay / English Channel	6	2019	Pouzet et al., 2019	lagoon	coastal lagoon	overwash	4.6	2.20	300	-68
73	73b	Traicts du Croisic	47°18'N	2°29'W	Britanny	France	Bay of Biscay / English Channel	6	2020	Pouzet & Maanan, 2020	lagoon	coastal lagoon	overwash		0.00	1,500	-68
74	74	Island of Yeu	46°42'N	2°21'W	Pays de la Loire	France	Bay of Biscay / English Channel	6	2018	Pouzet et al., 2018	marsh	peatland	overwash		0.00	7,700	-67
75	75	Belle Henriette	46°20'N	1°20'W	Pays de la Loire	France	Bay of Biscay / English Channel	6	2022	Maanan et al., 2022	lagoon	coastal lagoon	overwash		0.00	1,500	-70
76	76	Pertuis Charentais	46°19'N	1°19'W	Aquitaine Coast	France	Bay of Biscay / English Channel	6	2017	Poirier et al., 2017	salt marsh	salt marsh	overwash		0.00	2,700	400
77	77	Médoc	45°18'N	1°07'W	Aquitaine Coast	France	Bay of Biscay / English Channel	6	2002	Clarke et al., 2002	coastal dune	coastal dune	aeolian		0.00	4,000	-50