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ABSTRACT

Many parts of Europe are today facing a wide range of societal and environmental challenges that demand a high degree of resilience and adaptability. Archaeology has an important role to play by providing novel perspectives on how people have been living with, and adapting to, change in dynamic environments over considerable time. This paper adopts a trans-chronological perspective on human-environment interaction in the Syltholm Fjord on the Danish island of Lolland. The area provides extraordinary archives of long-term data on the environment and human activity in a dynamic and changing landscape. The fjord, which has been inhabited for several millennia, has been prone to regular flooding. We focus on three topics: (1) Habitation and subsistence, (2) Ritual behaviour and burial, and (3) Responses to dynamic environmental challenges and opportunities. From these topics, we identify a set of key-insights related to how to be resilient through disruptive societal and environmental changes.

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Long-term human-landscape interaction; landscape dynamics; resilience and change; prehistoric human behaviour; present-day challenges; Femern project

Introduction

Environmental and climate change, political and economic stability and food security have been major concerns to past as well as contemporary societies. It is increasingly realised in academic research that interdisciplinary research from an archaeological perspective may not only yield detailed insights into past human responses to specific sets of challenges and opportunities, but can also provide inspiration to tackle modern-day problems such as climate change and the biodiversity crisis (eg Davis, 2020; Jackson et al., 2018; Kerr et al., 2022; Shepherd et al., 2022; Tubi et al., 2022). Resilience theory is one of the key concepts in such discussions. This is defined by Redman and Kinzig (2003) as 'an expanding body of ideas that attempts to provide explanations for the source and role of change in adaptive systems, particularly the kinds of change that are transforming'. These authors also advocate a more prominent and

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active role of archaeologists, who are able to provide a long durée perspective on the preconditions and consequences of human actions in the past (Redman & Kinzig, 2003). Davis (2020) even states that contemporary issues concerning environmental change are unlikely to be solved without an understanding of resilience theory and the contributions made by archaeological research. However, disentangling 'human-induced' and 'natural' landscape change can be highly complex (cf. Carleton & Collard, 2020; Oldfield & Dearing, 2003), and both environmental and anthropogenic processes need to be unravelled. Indeed, it has been argued that 'climate change is a cultural, as much as it is an environmental, problem' (Kerr et al., 2022, p. 5). Furthermore, Kerr et al. (2022, p. 9) argue that archaeology and history can bring a valuable contribution to fostering community engagement and participation by helping in creating new, powerful and localised narratives. If successful, these narratives have the potential to venture from the local to the glocal, thus connecting local, national, and global perspectives on climate change and its future implications. In consequence, this means that different scientific disciplines need to be interlinked in a way that results and perspectives from different scientific streams (eg archaeology, history, sociology, biology, etc.) inform the final interpretations. This, in consequence, implies that methods need to be found to integrate diverging types and 'qualities' of data in one analysis, and, hence, working towards real 'interdisciplinary' studies (*sensu* Meier, 2012, p. 509):

> Combined research involving more than one discipline is useful when our interest in the past invokes a complex, close-to-holistic image of it, rather than one which requires unidisciplinary details. So far it is mainly multidisciplinary research with a number of disciplines working on what they believe to be the same topic, each of them more or less acknowledging the results of the others.

Tubi et al. (2022) note that historical antecedents are often used uncritically, assuming that past societal impacts and responses are directly analogous to contemporary ones. More critical and reflective perspectives are necessary to increase awareness on the boundaries, pitfalls and benefits of this approach. We corroborate this observation and aim to apply such a reflective approach in this paper, in which we present a case-study of the Danish prehistoric Sylteholm Fjord, situated on the southern coast of the island of Lolland (Figure 1).

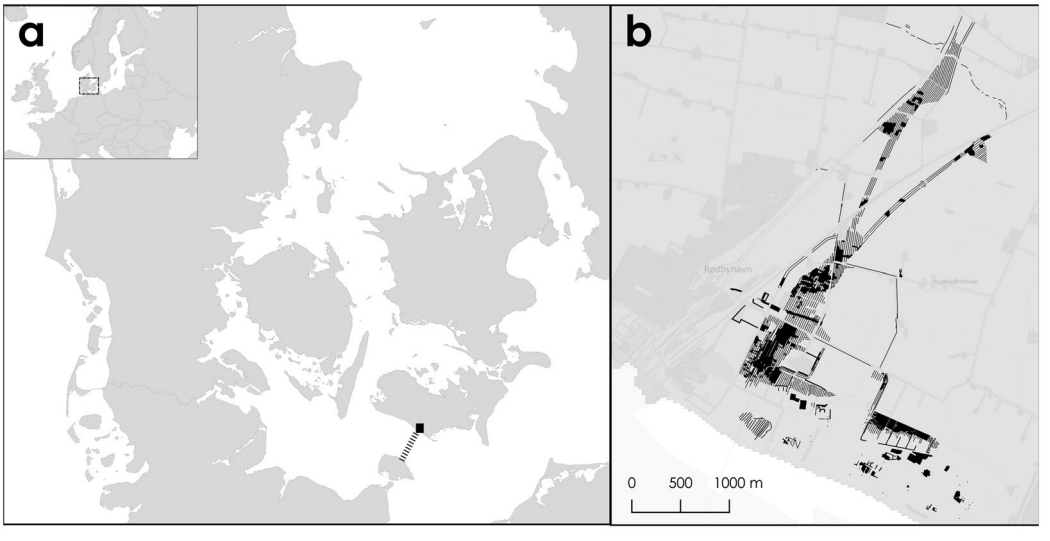

Figure 1. (a) Location of the Femern project study area in Denmark (black rectangle, small inset) and the future Fehmarnbelt tunnel (hatched strokes, large map). b) Overview of all excavation trenches from the Femern project (black polygons). Image: Museum Lolland-Falster. Background maps: © EuroGeographics for the administrative boundaries and the Danish Agency for Data Supply and Infrastructure.

Exceptionally large-scale archaeological investigations have been conducted at the west coast of Lolland (from 2012 to 2022; total surface of the study area 368 ha, with ca. 57 ha totally excavated) in the framework of the construction of the Fehmarnbelt Tunnel, which will form a landfast connection between Eastern Denmark and the European mainland (for an overview see contributions in Groß & Rothstein, 2023). The research has yielded unprecedented insights into long-term environmental processes, human habitation and exploitation of the former Sylthom Fjord and its surrounding areas. The investigated sites have become known for their excellent preservation conditions for organic materials, with an emphasis on Stone Age remains (mainly from the Mesolithic-Neolithic transition, ca. 5000–3000 cal BCE), but various Bronze Age, Iron Age, and medieval finds are also represented. The find assemblages yield an extensive body of archaeological materials, containing eg flint, pottery, amber, bone, plant remains, and worked wood. The archaeological features and structures include pits, postholes, activity areas, refuse zones, burials, depositions, and stationary wooden fishing structures from the Mesolithic period onwards. As such, they offer a unique opportunity to study human adaptations to environmental change on time scales spanning several millennia, as well as to identify both deliberate and unforeseen consequences of specific human actions. In this paper, we adopt a long-term approach by combining selected archaeological, historical and contemporary sources spanning the period from the Mesolithic to the present day.

This paper explores human behaviour at the Sylthom Fjord from an adaptive point of view (*sensu* Human Behavioural Ecology, eg Bird & O'Connell, 2006), in particular regarding the variation of human behaviour within the context of environmental change. We aim for connecting the prehistoric and historic data with past and current decision-making. Our approach is materialised by addressing three selected themes, explained in further detail below:

1. Habitation and subsistence
2. Ritual behaviour and burial
3. Responses to dynamic environmental challenges and opportunities

The patterns and shifts derived from these themes, using a methodology unfolded in more detail in Section 3.2, are used to answer our central research question: Which insights can long-term interactions between people and their environment in the Sylthom Fjord provide to modern-day society? These insights will be gained through exploring aspects of human resilience in relation to an ever-changing landscape. Likewise, we aim at providing perspectives for how previous human choices (indirectly) influenced later developments. The latter includes unexpected side effects of human actions, and the opening up of (either foreseen or unforeseen) new opportunities.

Theoretical framework: humans and environmental change in past societies

To be resilient and adaptable in the face of a constantly changing world means possessing abilities to deal with and accept loss, transformation, and uncertainty (Holtorf, 2018). These abilities are crucial both in preparing for risks (risk-preparedness) and recovering after a crisis (post-disaster recovery). Needless to say, this is more urgent than ever, in the midst of human-induced climate and biodiversity crises of unprecedented scales (Heritage et al., 2023; Wollentz et al., 2023). Jackson et al. (2018) claim that the long-term perspectives offered by historical disciplines provide important human-scale data about climate adaptation over long time scales, but still are largely lacking in global change research and scenario planning. Pre-modern societies differ from modern societies, and as such comparisons between periods need to be made cautiously (Tubi et al., 2022). Nevertheless, the completed experiments they represent can offer evidence of the consequences of environmental change, the challenges of uncertainty, and socio-cultural limits to adaptation (eg Costanza et al., 2007; Davis, 2020; Jackson et al., 2018).

The basis for tracing vital connections between past and present challenges lies in the realisation that current life does not mark a distinct break to life in (pre)historic Denmark, or any other region, in the sense that completely new rules would apply. Contrary, the trajectories shaping modern society can be traced over long time horizons, but have accelerated and intensified during the last few decades. As argued by Shepherd et al. (2022, p. 48),

> Naming and entering a new epoch like the Anthropocene, there is the danger that this comes to be regarded as a break in the timeline of history, such that we enter a new world characterised by new rules. In fact, just the opposite appears to be the case. Arguably, the last few decades have witnessed not a break, but an acceleration and intensification of many of the forces and dynamics that created the modern/colonial world.

Dearing (2006) notes that previous work on human-environment interactions has often focused on either the destructive impact of humans on their environment, or on the impact of 'natural forces' on societies: resource (over)exploitation versus climate/environmental determinism.

In extreme cases, the term 'collapse' has frequently been used to describe the destruction or abandonment of individual sites, the end of archaeological and historical cultures, systems, and empires, and in grand narratives of human history and theories of social change (Diamond, 1997; Middleton, 2012). In recent years this discourse of 'apocalyptic' scenarios, which has been criticised for being ill-defined, leaning too heavily on environmental processes and placing too little emphasis on social processes, has largely been replaced by a focus on adaptive strategies and resilience, either socially or environmentally (eg Butzer & Endfield, 2012; Middleton, 2012; Redman & Kinzig, 2003; B. Walker et al., 2004). A relevant related concept is complexity theory, which suggests that human activities and environmental change should be viewed together as a co-evolutionary and adaptive process (Dearing, 2006; Holling, 2001). It includes the emergence of multiple actors - political systems, hierarchical organisation, social connections, environmental conditions – and their dynamic interplay (Davis, 2020). The fact that human-environment interactions can be, and often are, bi-directional, still appears to be an underdeveloped aspect in current research. In this context, an important role is assigned to decision-making, and how this is mitigated by internal and external factors (eg Ribeiro, 2022).

From the above, it follows that for a proper understanding of resilience and adaptation in the past, high-resolution interdisciplinary research designs are of the utmost importance (for recent examples, see eg Mjærum, 2022; Out et al., 2021; Van Beek, Quik, & Van der Linden, 2023; Weinelt et al., 2021). One of the key challenges in such studies is establishing causal links between different (environmental and human) processes (eg Carleton & Collard, 2020; Davis, 2020). This requires empirical association, temporal priority of the independent variable, and accuracy by accounting for confounding variables (Davis, 2020; see also Contreras, 2016). Implementing a cause-and-effect perspective can inform us about relations between prehistoric actors more adequately.

In this paper, we aim for a balanced approach, starting off from the archaeological datasets, while referring to the high-resolution data from the Sylthom Fjord to highlight the intricate, intertwined interplay between environmental and human processes. Rather than attempting to write a full, exhaustive landscape biography we place a particular focus on selected periods and themes (see also Section 3.2) – with special attention for potential links with modern-day societal challenges.

Materials and methods

Study area

The prehistoric Sylthom Fjord provides extraordinary archives of long-term data on the environment and human activity in a changing landscape. Located on the southern coast of

modern-day Lolland, Denmark (Figure 1), it was deglaciated after the Weichselian, approximately 17 000 years ago. For thousands of years the later fjord was a dryland terrain, characterised by relatively flat, melt-out till (Houmark-Nielsen et al., 2012). During the Holocene, however, the coastal environment was marked by an eustatic sea-level rise level, resulting in an overall increase of water levels by about 30 m (Bennike et al., 2023). In the first half of the Holocene, sea-level rise was relatively fast and could probably have been perceived within a human lifetime. Around 7500 cal. BCE, the Syltholm area transformed from a dryland area into a freshwater marsh and afterwards a brackish wetland. Around 6600 cal. BCE, a marine fjord system was formed, protected by coastal spit formations (stretches of beach projecting out to the sea) and with a relative sea-level of c. 13 m below the current level. The initially brackish water became fully marine in the second half of the Holocene, from ca. 4000 cal. BCE onwards. After 4000 cal BCE the sea level rise became more gradual and rose only from circa 1.5 m below to the current sea level, resulting in a generally low sedimentation rate in the area (Bennike & Jessen, 2023; Bennike et al., 2023). Due to the low sedimentation rate, the local environment was generally stable in the Neolithic, making it an attractive place for human habitation and resource exploitation. The area became more dynamic again around ca. 3000 cal. BCE, which resulted in an increased deposition rate of minerogenic sediments like sand and gravel (Bennike & Jessen, 2023, p. 39). These sediments were potentially eroded from the spits and re-deposited, so that the spits were opened in different places, resulting in a reduction of their protective effect.

During the late Mesolithic and Neolithic, the dryland areas around the fjord were characterised by dense broad-leaved woodland dominated by oak (*Quercus* sp.), lime (*Tilia* sp.), elm (*Ulmus* sp.), and alder (*Alnus* sp.). The vegetation remained relatively dense until the mid/late Bronze Age (1000 BCE), when a more open, agricultural landscape developed that remained relatively stable until today (Bennike & Jessen, 2023; Enevold, 2013; Jessen et al., 2018).

The low-lying areas in the inner Danish waters, including those of Lolland, have regularly been exposed to storm floods. This typically happens when upwelled water from the Baltic Sea, after periods of strong westerly winds, drains out through the Great Belt and Øresund. Since the late 16th century CE, several storm surges and floods have been recorded along the coastline of Lolland (Aakjær & Buch, 2022, Munksgaard, 2022). In 1872 CE, a major flood, generated by storms that pushed large quantities of water into the Baltic Sea, ravaged the Danish, Swedish and eastern German coasts, causing widespread destruction. Lolland was heavily affected as the water in some places rose more than 3 m above mean sea-level. In response to the catastrophe, a 63 km long and 4 m high dyke, the 'Lollandsdige', was finished in 1878. After the construction of the dyke, the Syltholm Fjord was reclaimed as land and used for agricultural purposes (Ejdorf, 2002; Munksgaard, 2022).

Methodology

Within the framework of the current paper, it is neither feasible nor desirable to present an exhaustive overview of the enormous wealth of environmental, archaeological and historical data available for the Syltholm Fjord area (Groß & Rothstein, 2023). Instead, we define three key themes that play a pivotal role in the interactions between people and their environment over long time scales. Each of the selected themes is addressed by a customised approach. These themes emphasise different time periods in the area's biography, meaning that certain time periods will be more exhaustively covered than others. Hence, we do not approach a full, diachronic biography of the area. On a similar note, it should be mentioned that, despite the exceptionally large area that was excavated (see Section 1), significant parts of the study area have remained uninvestigated. Instead of aiming for 'completeness' we choose to present a selection of relevant material for the key themes, frequently providing references to underlying sources. These consist of environmental (see also Section 3.1) and archaeological data obtained from the extensive development-led excavations during the Femern project (see Groß & Rothstein,

2023), ethnographic studies and archival material at Museum Lolland-Falster. For the latter, we particularly focus on insights into human responses to the major flooding event in 1872 and recent storm floods.

We address resilience in the following three themes:

1. *Habitation and subsistence* – we highlight general observable changes in habitation patterns and the main developments in human subsistence in the Sylthom Fjord over time. Bioarchaeological data are obtained from analyses and screenings of samples. Due to the nature of the available archives, some sites and samples are more precisely dated than others. We also highlight early modern and modern-day patterns through the use of historical sources.
2. *Ritual behaviour and burial* – we address long-term trends in the suggested intentional artefact depositions in wetland and dryland contexts (cf. Sørensen, 2020) and changes in burial customs in the Sylthom Fjord.
3. *Responses to dynamic environmental challenges and opportunities* – we examine human responses to flooding events in the Sylthom Fjord by assessing the consequences of the 1872 catastrophe and its 'afterlife' in folklore, oral history, and artistic engagement, while also looking further back in time.

Results

Habitation and subsistence

Habitation patterns

The first evidence of human activity in the study area belongs to the Ahrensburgian culture and dates to 9800–9320 cal. BCE (Figure 2). Starting in the Late Mesolithic (around 5000 cal. BCE) there is an increasing human activity that peaks during the Middle Neolithic (ca. 3500 to 3100 cal. BCE), when the fjord became a central area for activities (Måge, 2019; Måge et al., 2023). During the Middle Neolithic and onwards, the construction of several stationary fishing structures can be interpreted as a sign of more sedentary settlement around the fjord, as people regularly maintained and replaced these structures and used them over several generations (cf., Koivisto et al., 2024; Stafseth & Groß, 2023). Artefact depositions and numerous constructions in watery contexts (see Section 4.2.1) suggest long-term human activity around the fjord as well. While the overall find assemblages in the fjord are dominated by Late Mesolithic and Neolithic remains, Bronze Age settlement features are documented as well (see Måge et al., 2023). In general, habitation continuity on a site level is difficult to prove, as short occupation hiatuses (eg one or a few generations) are highly difficult to pinpoint archaeologically. The available archaeological data do show clear spatial shifts of habitation clusters over time, when looking at the entire excavated area. In the Iron Age (ca. 500 cal. BCE - cal. 800 CE), occupation and activities moved away from the coast - but not to significantly higher ground, which could be explained by the sea-level rise. A withdrawal from the immediate coast might be found in the need for more protected locations (cf. Måge et al., 2023), possibly against the background of increased social or political instability (eg Holst et al., 2018; Randsborg, 1995). This is indicated by the establishment of a defensive structure of so-called Caesar's lilies (small adjacent holes with centrally placed stakes/spears), as a barrier oriented towards the coast (Figure 2, Iron Age). Their location in a lower part of the landscape furthermore, underlines dryland conditions during their construction (Figure 3). A more comprehensive analysis of the Iron Age material is still to be carried out, and it is likely that more fine-grained details about the habitation structure and shifts will be observed in the near future. In post-medieval times, the coast has only been sporadically used until 1912, when a new coastal harbour, Rødbyhavn, was built directly at the shore of the Baltic Sea.

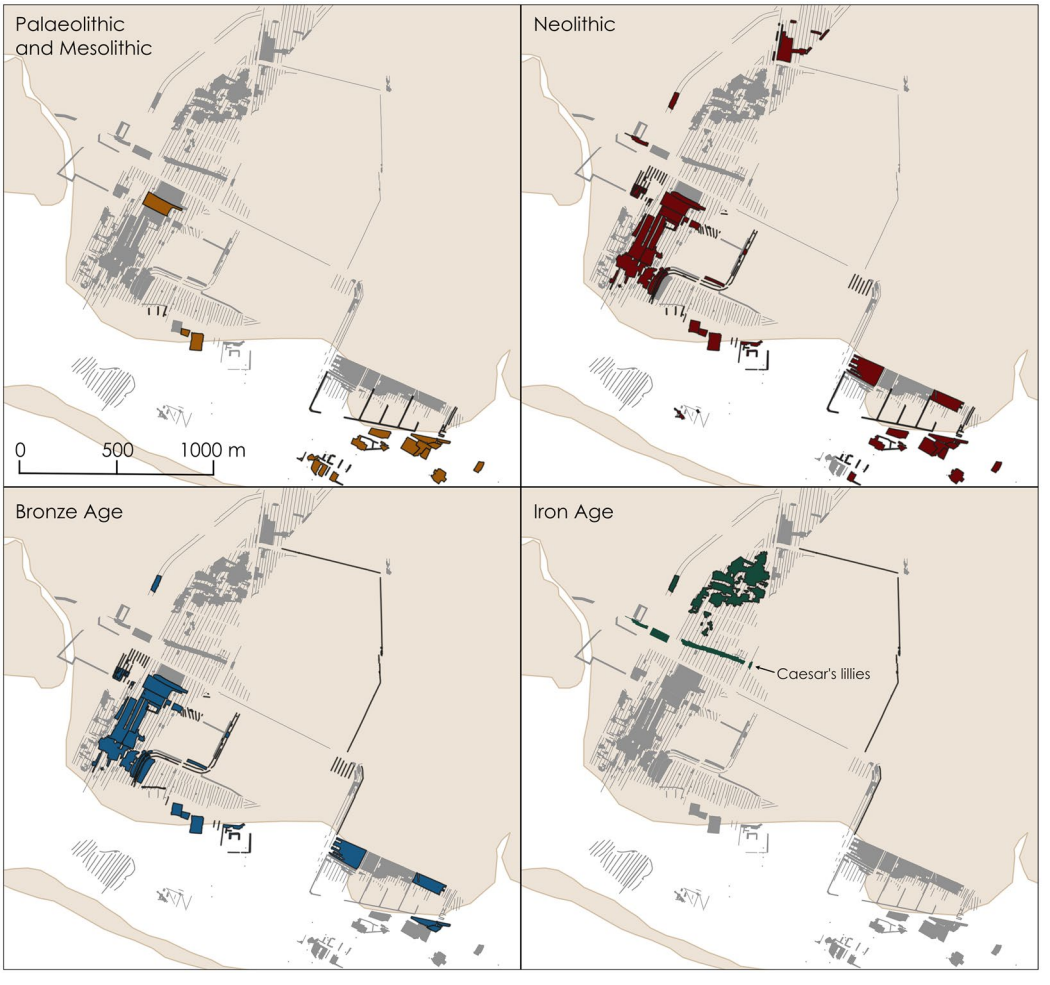

Figure 2. Overview of the excavation area with a chronological subdivision of relevant features from the different excavations. Note that the sites are colour-coded if a substantial or relevant archaeological assemblage has been recovered at the sites (each colour showing a different period). Image: Museum Lolland-Falster (background map: the coastline around 1776; Videnskabernes Kort).

The proximity to the water has been a key factor for people ever since the Sylthom Fjord developed, as it provided not only a basis for subsistence, but also infrastructural and strategic advantages. The area is the only location in eastern Denmark from where continental Europe, which is only 18km away, has been visible since the Neolithic. The short travel over the Baltic had a significant impact on exchange of goods and ideas already in the Neolithic (cf. Jensen & Sørensen, 2023). This strategic location can be interpreted as a reason for the continuous or repeated occupation in the area during the Stone and Bronze Age. While the evidence of fishing activities increased in both periods (Koivisto et al., 2024), preserved layers of sandy sediments indicate storm or erosional activity (Bennike & Jessen, 2023) and thus underline the exposedness of the fjord. The increased storm activity can potentially be related to more unstable weather conditions during the Holocene Thermal Optimum, as identified on the Danish west coast (cf. Goslin et al., 2019). The closeness to the sea with established trade routes to the continent (eg Rasmussen, 2014) is potentially another reason for the habitation in the area during the Iron Age, while the need for fortification of the settlements arose.

The protection from the sea by the establishment of dykes in the late 19th century CE led to improved drainage and an increase of land, reflecting a shifting balance in the interaction

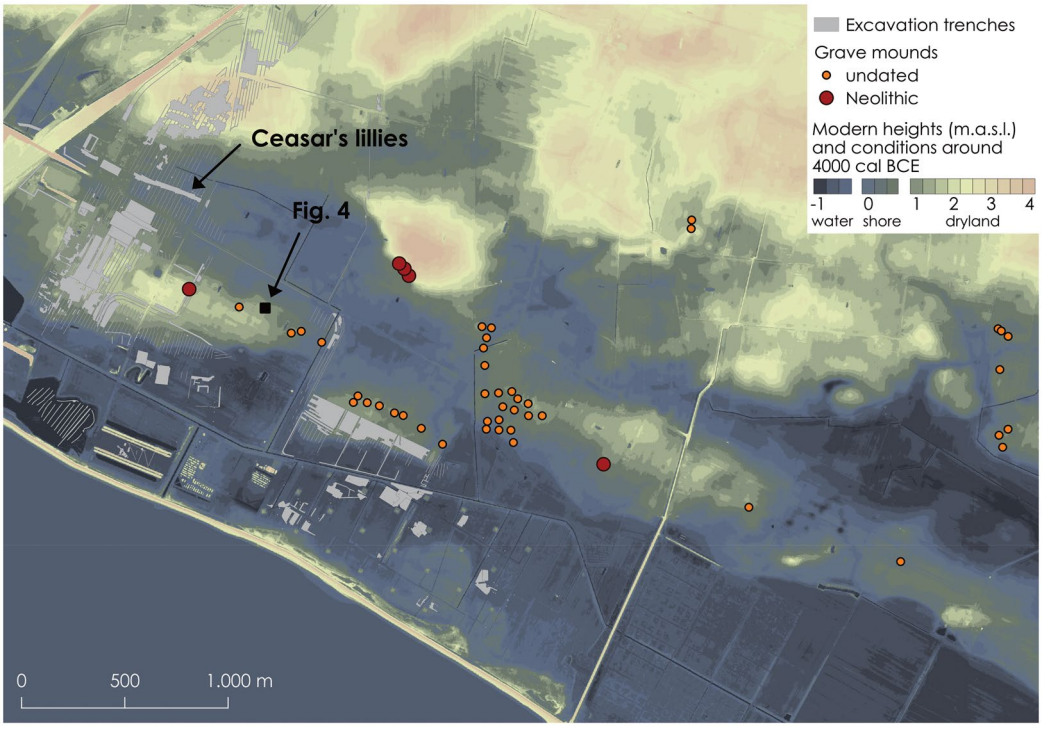

Figure 3. Location of grave mounds in the area of the Sylthom Fjord. The different shades of green colours (above 0 m.a.s.l.) approximately represent the Neolithic shore and dryland areas. Image: Museum Lolland-Falster (background map: CC BY 4.0 Danish Agency for Data Supply and Infrastructure).

between humans and their environment. Yet, embankment also had partly unforeseen consequences, such as an increase in flooding magnitude (see Section 4.3.2). The need for exchange became a crucial factor in the globalised economy, which led to the founding of Rødbyhavn town. From the mid-20th century, summer houses have been built in the area as a consequence of the new holiday culture of the modern welfare society. The coastal location in scenic surroundings has been attractive for modern vacationers, and the area has become characterised by temporary and recreational inhabitation. Later on, in 1986–1988, a holiday and amusement water park was built just west of Rødbyhavn, expressing the commodification of the coastal landscape as a source of relaxation, entertainment and wellness in a structural setting. Finally, economic decisions mark the latest massive impact on the area with the decision to establish a landfast connection between Lolland and Germany (https://femern.com/history/; 19 February 2025).

Subsistence

Thanks to the exceptional preservation of material deposited in the prehistoric Sylthom Fjord where activities concentrated during the Stone Age, there is much direct and indirect subsistence-related evidence for the Late Mesolithic and Neolithic. While bones of domestic animals are not dated before ca. 4000 BCE (Groß et al., 2024; Måge et al., 2023), remains of milk in Late Mesolithic Ertebølle pots highlight exchanged and/or imported animal products in an earlier stage (Lucquin et al., 2023). Besides domesticated animals and hunted mammals, fish was of great importance. The fishing-related equipment and structures preserved at sites – some still *in situ* during the excavations – included wooden fish weirs and artefacts (Chaudesaigues-Clausen, 2023; Koivisto et al., 2024; Stafseth & Groß, 2023). Fishing retained its

importance in subsistence and diet long after the introduction of farming in southern Lolland, throughout the Neolithic and into the Bronze Age (Koivisto et al., 2024) up until historic times (eg Holm, 2003; Nellemann, 2000).

Data from multiple sites provide insights into the diversity of exploited plants. Carbonised hazelnut shell fragments indicate the exploitation of this food source from the Mesolithic onwards, also after the introduction of crop plants. Attested potential food plants from dry terrain include sloe or bird cherry (*Prunus* sp.), hawthorn (*Crataegus* sp.), crab apple/wild pear (*Malus* sp./*Pyrus* sp.), blackberry (*Rubus fruticosus*), and raspberry (*Rubus idaeus*). The fjord and beach, with brackish water zones and possibly also freshwater zones behind the beach, may have offered a wealth of food sources, eg seeds of yellow water-lily (*Nuphar lutea*) (Karg, 2012). The presence of barley (*Hordeum vulgare* var. *nudum*) and emmer wheat (*Triticum turgidum* ssp. *dicoccum*) is documented from 3520 to 3350 cal. BCE onwards (Måge et al., 2023). Barley is the dominant crop at multiple sites dating from the Neolithic to the Iron Age, which can be explained by its relatively good tolerance for brackish conditions (Out, 2008). Flax is found at three sites broadly dated between the Neolithic and Iron Age (Stevnsvig, 2022).

The construction of the 'Lollandsdige' after the storm surge of 1872 (Section 4.3.2) generated new agricultural land (ca. 7500 hectares) behind this dyke. At the same time, the construction of a sugar factory in Holeby in 1872 led to the introduction of a new crop, the sugar beet (*Beta vulgaris* ssp. *vulgaris*). Sugar production is still a central element in the economy of Lolland, even though, since 2016 several farmers started growing quinoa (*Chenopodium quinoa*). In recent years, some of the agricultural areas have been changed into plantation forests, wind turbine parks and solar parks (Munksgaard, 2022, see Section 5.3). Prior to the construction of the Fehmarnbelt tunnel, several properties in and around the building site were expropriated by the state, some of them to be demolished. Thus, once again, the habitation patterns of the area have been changing.

Ritual behaviour and burial

Deposition patterns

Depositions in the prehistoric fjord were made in shallow water near the beach, close to burials and settlements. The archaeological materials found in the northern shore zone (site complex 5, see Måge et al., 2023) indicate waste disposal but also contain finds that suggest *structured* or *intended depositions* (Sørensen, 2020, 2023). Artefacts (eg antler axes, shafts as well as decorated wood and antler) and mandibles of selected animal species in shallow, shore-near areas indicate continued depositional practices from the Late Mesolithic to the Early Neolithic (ca. 4700–3600 cal. BCE; Sørensen, 2019). The deposited, clustered objects were placed among unclustered, discarded artefacts, like chewed birch tar (eg Jensen et al., 2019), fishing implements and tools (eg Chaudesaigues-Clausen, 2023; Jensen & Sørensen, 2023; Koivisto et al., 2024), which all can be interpreted as relics of everyday life. According to Sørensen (2023), the fjord area can therefore be interpreted as a landscape in which ritual and daily life were intertwined, and the activities that accompanied them may also have been interwoven (cf. Brück, 1999).

From the Middle Neolithic onwards, structured depositions in the fjord area diminished. Based on radiocarbon dates (Måge et al., 2023), the period of water depositions ended before the apparent peak of human activity in the Middle Neolithic around 3300–3100 cal. BCE. In later prehistory, habitation shifted towards inland areas (Section 4.1.1), which is corroborated by a significant decrease in later prehistoric finds in the Sylthom Fjord. The current data indicate that as people shifted their everyday activities and livelihoods to more dryland locations, ritual behaviour followed along. Votive depositions in the Southern Scandinavian Iron Age were predominantly done in wetlands, dryland sites, and lakes in the hinterland (cf. Hansen, 2006; Mortensen et al., 2020). During medieval times, churches and monasteries were founded, both

in towns and in the rural areas. These then became focal points of ritual behaviour and functioned as important landscape-structuring elements. As Jakobsen (2021, p. 2) writes: 'virtually all Danish men, women and children would, no matter where they lived, see the monasteries and their inhabitants on a regular basis'. These religious institutions also influenced the everyday-life of the people, as they owned a large part of the arable land (Jakobsen, 2021), such as manor houses in more recent times.

Burials

The oldest human archaeological remains from the Syltholm area consist of a few loose human bones retrieved from the beach of the fjord, dating to 3600–3500 cal. BCE. Other isolated human bones from later phases of the Neolithic, one of which is dated to ca. 2800 cal. BCE, have been recovered from the constantly waterlogged area as well (Måge et al., 2023). These finds are unlikely to reflect disturbed and redeposited materials from inhumation burials, but instead may point to specific types of ritual practices (cf. Ahola, 2019; Van Beek, Quik, Bergerbrant, et al., 2023) as only elements of the cranial skeleton were recovered. The earliest known 'formal' human burials in the study area consist of five Neolithic dolmens, dating to ca. 3300 cal. BCE; only one of these has survived to the present day. The dolmens were built at the highest points of the Sylthom Fjord landscape, only a few hundred metres away from the Neolithic waterfront (Figure 3). Between them wetlands were present, which made them distinctive landmarks, visible from afar and especially from the open water of the fjord. In addition, over 30 low earthen burial mounds are registered within a distance of less than a kilometre from the eastern excavated areas. One of these burial mounds has been excavated, revealing a stone packing only. The grave is not radiocarbon-dated. Based on comparable data from Lolland, we assume that most of the undated grave mounds have a Neolithic or Bronze Age origin. The (groups of) burial monuments must have been more or less 'stable', each individually representing fixed points in the landscape, and were probably used repeatedly (cf. Holtorf, 1998; Wollentz, 2012). Judging from their position, they may not only have been used for deposition of the dead, but also as naval navigational aid (cf. Davidson et al., 2010). The fact that ancient burial monuments in the Syltholm region may have remained meaningful and prompted 'responses' from later inhabitants (cf. Holtorf, 1998) is supported by the location of nearly 120 cooking pits, dated to 1100–900 cal. BCE, recorded in circles around one of the Neolithic dolmens (Figure 4, for location see Figure 3). A spatial relation between Neolithic, and potentially later, settlements and megalithic monuments, usually divided by a light topographical change or depression, is regularly documented in Neolithic Europe (eg Andersson et al., 2016; Scarre, 2018). Iron Age burials are not known from the Syltholm Fjord area but might be present in unexcavated areas nearby the Iron Age settlement features. After the introduction of Christianity at Lolland, cemeteries shifted to churchyards (cf. Roesdahl, 2004).

Responses to dynamic environmental challenges and opportunities

Floods during the Late Mesolithic/Neolithic

Overall, the sea level change in the southern part of Lolland predominantly was a slow and gradual process after 4500BCE (Section 3.1). However, the environment was occasionally influenced by short-lived, rapidly occurring flood events such as storm surges. During the Femern project, several layers containing coarse sediments could be observed in the excavation profiles in the fjord, indicating that storm floods occurred (Figure 5). As they occurred within the central fishing grounds, these may have had a sudden impact on people and their subsistence practices, as is exemplified by some fish weirs that were overturned and covered by sandy sediments (cf. Mortensen et al., 2015). Rapid events, including storm floods, may thus also have been socially relevant and required communal effort, when, for instance, the catch had to be hauled

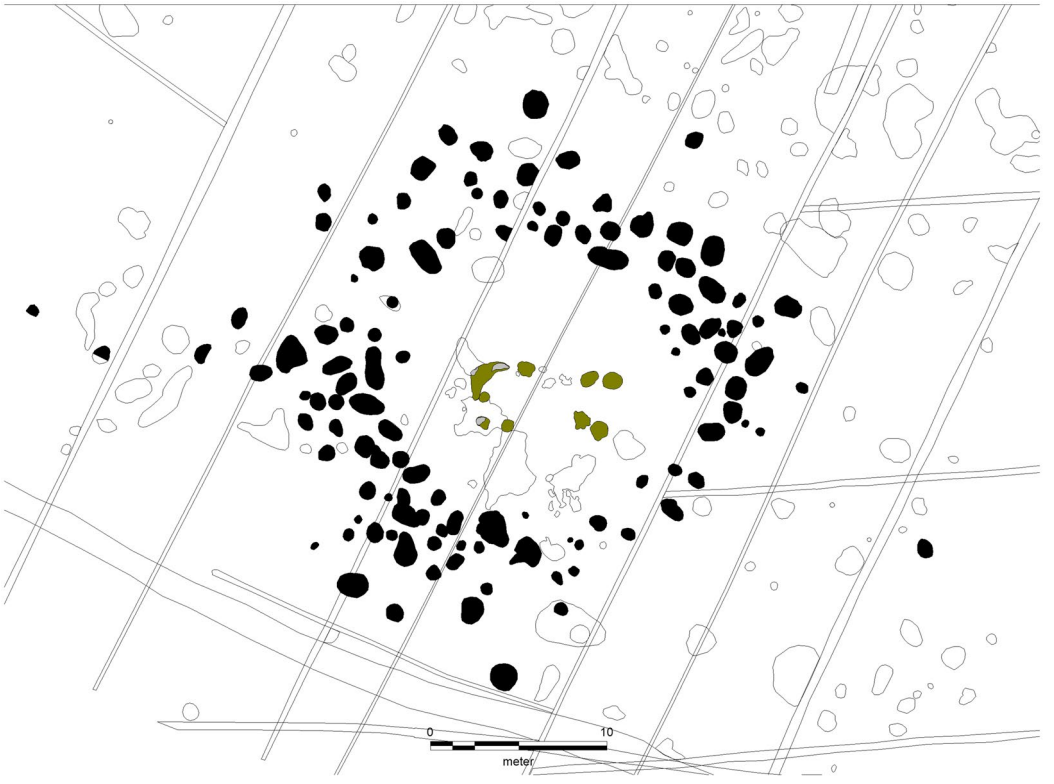

Figure 4. At site MLF00652, more than hundred Bronze Age cooking pits were registered around a Neolithic dolmen. The dolmen itself was not preserved. Black: Cooking pits, olive: Traces of megalithic stones, black lines: Other features. Image: Museum Lolland-Falster.

before a storm front arrived or afterwards, when the catching facilities had to be repaired. Nevertheless, the continuous engagement of the coastal inhabitants with environmental challenges shows how resilient these communities and environments were. The tradition of reoccupation of the same weather-exposed area over a period of 3000 years indicates a persistence of location preferences, potentially as thresholds were never surpassed that would motivate people to abandon the area. While it has not yet been possible to see any effect of the storm events in the actual prehistoric settlements, for instance, as traces of flooded fields or houses, historic datasets clearly bear witness to the exposedness of Lolland's coast. As a consequence, traces of intense weather events are only preserved in the littoral areas, but here we find traces with fine and clear details. For instance, several footprints were found next to a fishweir (Figure 5). These footprints were filled with a coarse sandy sediment, after they had been imprinted in the organogenic sea-floor sediments. The fill-layer, that we interpret as a result of storms, is representing higher velocities in the water body. Moreover, finds of repeatedly repaired fish weirs (cf. Koivisto et al., 2024), show resilience not only with respect to the location and subsistence, but even down to single constructions.

Dyke constructions and the responses to the major flood in 1872

From historical records it is known that the low-lying coast of southern Lolland was flooded several times (Gram-Jensen, 1991). Examples of storm surges are recorded as far back as 1577 CE (Munksgaard, 2022). From the late 1700s onwards, several dykes and dams were constructed to protect the vulnerable shoreline. However, the early dykes were low, averaging around 2 m in height, and consequently short-lived. Hence, they were each time destroyed relatively soon

Figure 5. Excavation trench at site MLF00933-II. Some footprints are visible in front of and behind a segment of a Neolithic fish weir in the middle of the picture. Note the colour differences between the sediments in which the weir remains are embedded: The lighter sand layers represent flooding events, while the dark organogenic layers were deposited in stagnant water. Arrows = footprints,? = potential footprints. Image: Museum Lolland-Falster.

by the force of nature, resulting in repetitive flooding (Munksgaard, 2022). Nevertheless, the inhabitants of southern Lolland continued their protection efforts, as becomes clear from evidence of the regular maintenance and renewal of the smaller existing dykes. In general, construction of dykes may decrease the flooding frequency, but also trigger floods of higher magnitude in case of extreme events. The extreme storm surge of 1872, with hurricane winds and record-high water levels rising to more than 3 m above sea level, resulted in extensive damage (Figure 7(a–d)). The event did not only cause casualties but also had other disastrous consequences such as the loss of farms, livestock and ships, as well as decreased access to resources such as fresh water. The whole southern coast of Lolland was inundated, and even though the relatively low number of 28 people drowned on Lolland, the total damage amounted to ca. 94 mio €in modern currency (Aakjær & Buch, 2022). Studies of beach-ridge systems, as a source for understanding storm surge risks, demonstrate that the 1872 storm flood was the largest flooding that occurred in the last 4500 years, and an event with a likely return period of several thousands of years (Clemmensen et al., 2014). The dyke construction, the 'Lollandsdige', built in the wake of the 1872 storm surge, has been enhanced several times. As early as in 1904 it turned out that parts of the dyke were too low. Dyke improvements still take place nowadays and include the establishment of new breakwaters (Aakjær & Buch, 2022).

The dyke on Lolland fundamentally changed most of the island's southern coast. While the coastline before had been irregular, consisting of various fjords and islands, it was now drawn up as a rather straight line by the dyke, which at the same time formed a clear boundary between land and sea. New agricultural land was generated behind the dyke (4.1.2). Nowadays, the dyke also serves recreational purposes, for instance as a well-functioning cycle path, and it still protects the low-lying areas on South Lolland against rising water levels (Munksgaard, 2022).

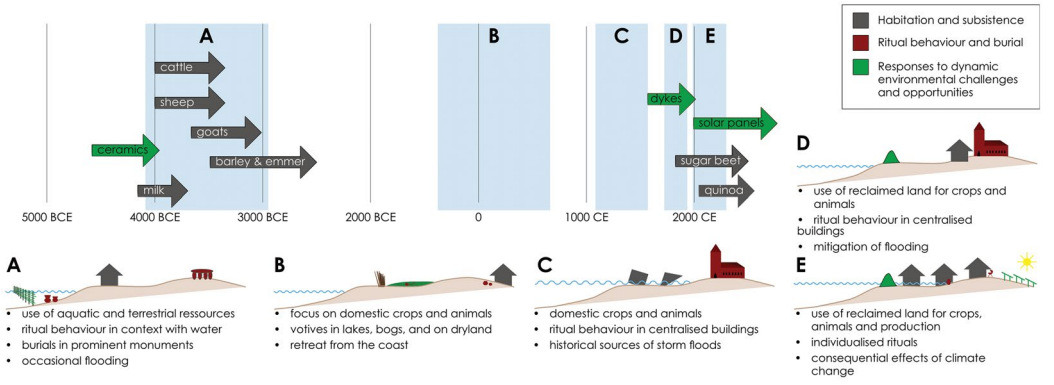

Figure 6. Lolland's changing landscapes from a chronological perspective. Arrows: Approximate times of selected imported wares and technologies on Lolland. Below: illustrations of different domains of daily life: (A) Neolithic: Activities with waterbound subsistence and deposition strategies, monuments as markers and spatial and ancestral relations. (B) Iron Age: Settlements not directly at the coast and a generally more inland-oriented deposition practise, (C) Middle Ages: Documentation of storm floods and centralisation of ritual activity. (D) 19th century: Attempts to control the environment, making use of gained land. (E) Recent times: Expansion in formerly safe areas, consequences of environmental and landscape change. More individualised ritual behaviour. The pictograms display changes in the discussed themes in this article.

At Lolland, the perception of storm floods is still deeply embedded in people's consciousness, and through generations, memorial groves, songs, oral history, literary narratives and poems have been instrumental in creating a culture of remembrance. The famous Danish novelist H.C. Andersen (1879) described the major flooding event in a poem just a few weeks after the catastrophe: 'The storm flew out with a message of death and horror', reflecting the force of nature that physically transformed the landscape and the image of a terrifying and traumatic event. The 'afterlife' of the collective memory is also displayed in artistic engagement such as paintings and drawings (e.g, Aakjær & Buch, 2022; Hallin et al., 2021). The storm flood left traces in the landscape in the form of a memorial garden near Gloslunde church with inscriptions of the names of all people who died in the flood, and a memorial for the damming of Rødby Fjord (cf. Aakjær & Buch, 2022; Figure 7(a)).

Discussion

The long-term patterns observed around the former Sylthom Fjord demonstrate an intertwined and ever-changing interaction between humans and their environment, which is reflected in different ways in geological, archaeological and historical records as well as in the landscape. The most important/significant trends found in this study are combined and visualised in Figure 6. Here, we reflect on key patterns, placing them in a wider context and attempting to connect them to present-day challenges. What insights can we get from Lolland's past for future opportunities?

Habitation and subsistence

The prehistoric coastal communities inhabiting the Sylthom Fjord exploited this flood-prone area for a period spanning several millennia. Neolithic groups on Lolland had a subsistence and settlement system that engulfed land and water simultaneously and showed a noteworthy resilience to external factors. Stationary fishing structures were constructed and maintained over centuries, despite the occurrence of several high-velocity events like storms or high-energy floods (cf. Johannsen, 2023; Koivisto et al., 2024). Prehistoric, historic and modern populations

on Lolland's coast have been living with and in relation to the surrounding landscape. Lolland's history shows a fascinating, dynamic and non-linear account of intertwined human land-use changes, human landscape modifications and environmental change. The mechanisms steering these processes are manifold and complex, but can be seen in constant relation to the changing coastline. External impulses for example, led to a new lifestyle incorporating agriculture in the Neolithic, while still relying to a large extent on aquatic resources as well as wild plants (McLaughlin et al., 2025). Some of the observed shifts may reflect changing societal needs, like shifts in settlement locations during the Iron Age, or new opportunities, as is also shown by the introduction of sugar beets in 1872 and quinoa in recent times.

Environmental changes may have triggered specific human responses, which in turn may have had (occasionally unexpected) side effects in different realms of society. A clear example is the storm flood of 1872, which led to the construction of the 'Lollandsdige'. This generated a significant monetary contribution from the government to Lolland's rural areas, significantly increasing the farming area of the island by ca. 10%, indirectly giving an impulse to tourism and instigating a remarkable 'culture of remembrance' (Section 5.3). While formerly to a large extent dependent on sugar beet production, currently the agricultural sector is changing again. Due to climate change, the growing conditions for sugar beets are deteriorating (wetter springs and shortened growing seasons). Therefore, large areas of the formerly productive arable soils are currently transformed into solar farms as another reaction to environmental change. As of yet, not all interrelations of environmental events and decision making can clearly be connected, pointing towards the need of more in-depth studies of habitation patterns at Lolland's coasts and in the hinterland.

Ritual behaviour and burial

González-Ruibal (2014) acknowledges that certain crafts, activities and practices in a dynamic/changing environment may have been performed over an extended period in order to resist change, and to maintain a form of stability and continuity. This can be one way of being resilient in the face of sudden environmental or social change or crisis: 'It is a visceral resistance that is played out in bodies, gestures, proxemics and the making and use of things' (González-Ruibal, 2014, p. 22). This may be exemplified through the suggested repeated depositional practices in the shallow water of the prehistoric fjord in the Late Mesolithic and early Neolithic (ca. 4700–3600 cal. BCE; Sørensen, 2019). These practices showcase a large degree of continuity during a period of major societal changes, namely the neolithisation process.

Monuments are working as landscape structuring elements; burial mounds are, for instance, intentional during the time of construction to mark the role of the deceased, and relational to other monuments and their placement in the landscape in the time following. Consequently, prehistoric burial monuments (eg megaliths and burial mounds) may have been used as a means of reforming the cultural landscape. Furthermore, they prompted specific responses from later communities, visible on Lolland in the form of Bronze Age cooking pits surrounding a Neolithic dolmen (Figure 4).

After the introduction of Christianity, a completely different landscape structuring appeared in large parts of Northern Europe (cf. Hållans Stenholm, 2012, p. 232; Roymans, 1995), both in ritual and burial, related to the Christian cosmology. 'Votive' depositions moved from lakes and bogs to centralised buildings (churches), where burials took place from now on. However, churches were often constructed in the proximity of already existing prehistoric graves, possibly enforcing a sense of 'ritual' continuity amidst major change. This can be exemplified by Kippinge church on Lolland's neighbour island Falster, which served since medieval times as one of Denmark's most prominent pilgrim churches. It was built in the vicinity of prehistoric barrows. The church was known for a holy spring on its compounds, which was maintained until c. 1790

(Trap, 1923). According to legend, the spring came to be where a recently completed parsonage sank into the ground (Weber-Andersen et al., 1951). Only in recent years, the spring has been renovated; hence, people re-established the link with the history of the place by figuratively installing a stable and continuous element, ie the constant flow of water.

From the sections above, it follows that past changes in landscapes always play a part when new changes are introduced. Tim Ingold evocatively phrased the pervasiveness of the past within the landscape in the following way:

> To perceive the landscape is therefore to carry out an act of remembrance, and remembering is not so much a matter of calling up an internal image, stored in the mind, as of engaging perceptually with an environment that is itself pregnant with the past. (Ingold, 2000, 189; see also Wollentz, 2020)

The maintenance or re-establishment of specific ritual practices and/or places in the landscape may be a mechanism to be resilient and adaptable in the face of potentially disruptive changes. It is indeed possible that ritual activities, and associated places in the landscape, may be one of the key methods to cope with change and (re-)establish a form of stability and continuity in a rapidly changing environment. It is particularly interesting that such types of activities tend to transgress the boundaries between what is commonly regarded as 'profane' and 'everyday' (cf. Bell, 1992). Indeed, our data shows they are intertwined, which is reflected in different ways through time (see Sections 4.2.1 and 4.2.2).

Responses to dynamic environmental challenges and opportunities

In the Western world, societal perceptions of the surroundings are usually based on static concepts. As a consequence, the understanding of responses to severe environmental events and challenges tends to be shaped from a *post quem*-perspective, mostly emphasising the successful overcoming of these. Even though the tendency to separate situations 'before' and 'after' change is understandable, reality is more complex. Change is constant in a dynamic world, whereas human reactions to changing conditions are hardly ever linear. Instead, they are permanently 'filtered through the complex lens of human culture' (Diaz & Trouet, 2014).

Most studies aimed at gauging the human impact of natural hazards and disasters (eg Athukorala & Resosudarmo, 2005; Diaz & Trouet, 2014; Rose et al., 2020) have understandably been framed within the social and geopolitical context of (pre-)modern state societies (and, for instance, discuss tsunami-related risk factors and damages to build environments). Such frameworks may be of little utility for understanding how prehistoric people experienced and dealt with similar events, but systematic investigations of how we might address these effects archaeologically are now being carried out (Nyland & Damlien, 2024; J. Walker et al., 2024). Important for this study is that long-term effects of environmental challenges are a relevant, yet variable, factor for society – including diversified coping mechanisms. On Simeulue Island in Indonesia, lessons of a tsunami event in 1907 were incorporated in lullabies and folk songs (Sutton et al., 2021). Located only 43 km from the epicentre of the earthquake that initiated the Indian Ocean tsunami in December 2004, songs and music turned out to be an efficient communication tool in disaster risk reduction, contributing to limiting the number of casualties on the island to seven (Syafwina, 2014).

The extreme flood event on Lolland in 1872 created a culture of remembrance as well which is not only embedded in the landscape by dykes and memorial groves, but also through arts, literary narratives, songs, and myths that have been transmitted through generations. Still, knowledge of a previous disaster does not necessarily foster disaster preparation (Sutton et al., 2021). This is clearly exemplified by recent events in the winter of 2023/2024, when the combination of a storm flood and extreme precipitation caused severe damage all over Lolland (Figure 7(e–g)). Due to the high water level in the Baltic Sea, the pumps of the drainage channels did no longer function properly, resulting in inundations of large areas of the island. The

Figure 7. (a,b) Before and after drawing of the 1872 storm flood on the east coast of Falster near Sølyst; (c) 'Falster under the hurricane on November 13th 1872', after an original sketch; (d) Memorial monument for the drainage of the Rødby Fjord and the storm flood in 1872. The horizontal line on the top of the stone marks the water level during the storm flood, 2.99 m from the base of the stone; (e) photograph of the beginning 2023/2024 storm flood on Falster. The water levels rose to c. 1 m more during the surge; (f,g): aftermath of the 2023/2024 storm surge on western Lolland (place and time: c: Handermelle 28 October 2023; b, d Lundehøje 21 October 2023). © a–c Museum Lolland-Falster (objects FMN00059F00002657; FMN00059F00002658; FMN00976X00008573) Photos: d Museum Lolland-Falster, e Bjørnar Tved Måge, f–g Bente Sonn.

event reminded many of what happened 151 years earlier and led to a re-remembrance of the catastrophic storm surge, even though the water levels were significantly (> 1 m) lower in 2023/2024 than in 1872. Despite the lack of preparation before the storm surge of 2023/2024, the incident spurred debate on how to prevent similar devastation in the future. The combination of a continuously rising sea level with an expected increase in storm surges due to climate change will result in a higher risk of flooding and erosion along the coastline (Aakjær & Buch, 2022). This is a pressing issue, since many low-lying coastal areas in the western Baltic Sea are not protected by dykes. Consequently, extreme storm flood events are likely to result in extensive damage and risk of casualties (Aakjær & Buch, 2022). On the other hand, dykes may not always be able to protect against such events in the first place, and dyke breaches may even have more devastating effects than 'natural' flooding of unembanked areas. Hence, an important question of the debate prompted by the storm surge in 2023/2024 has been whether to prioritise further coastal protection or to simply withdraw from the coast and low-lying coastal areas (see eg Oppenheimer et al., 2019; Råd, 2023; Sønderriis, 2020).

Negotiating the impact of dynamic environmental challenges and adjusting to these is a process that can and will be seen in, for instance, the future reinforcement of the Lolland's dyke or the adaptation of better suited crops. Also, the national political goal to reach a completely fossil-free energy sector in 2040 (rgo.dk; 10 July 2024) is made visible by the large areas currently covered with solar panels. These are constant and distinctive reminders of climate change and the risk of living close to the sea, whilst simultaneously reflecting societal (re) actions to mitigate negative effects.

The complex relationship between change and continuity is also highlighted by the fact that the embanked and drained landscape, confined by the Lollandsdige, is now considered and administered as a cultural landscape worthy of preservation that requires special care and consideration in municipal planning (Nielsen & Pinholt, 2005; Pedersen, 2016). This perception of a relatively new and human-made landscape shows how the dyke and its drained hinterland, that were originally created for mere climate and agricultural reasons, have not only been accepted as historical landmarks, but even are cherished now as an important part of Lolland's cultural heritage and scenic value. With the French historian Pierre Nora's term, they have become sites of memory (Nora, 1984–1992). This suggests an underlying process of meaning making and of accepting the necessary; both can thus be seen as a strategy for coping with environmental and landscape change.

On the other hand, while the embanked landscape is now considered worthy of protection, not all changes are immediately accepted and understood as part of the area's development. Recently, the landscape-altering character of solar panels, similar to wind turbines, and their effect on the scenic value of the landscape, has spurred debate. This discussion connects to a greater societal change for the communities on Lolland, namely the transition from sugar beet farmers to sun collectors. It may be taken as an affective resistance to certain changes, while people are simultaneously adopting similar innovations in other parts of life (eg as seen through an increase of electric cars, private solar cells, and electric lawn mower robots).

Conclusions

Many parts of Europe are facing a wide range of similar societal and environmental problems of unprecedented scale. Much depends on how we face these challenges through joint strategies and agendas. Indeed, proactive cooperation across multiple sectors will be essential. In such a cooperation, archaeology and heritage studies may have an important role to play, for example, by providing novel perspectives on how people have been living with, and adapting to, change in a dynamic environment over considerable time horizons (Heritage et al., 2023; Holtorf, 2018; Wollentz et al., 2023). This can provide insights on how to mitigate the effects of the climate crisis, how to find ways to adapt to disruptive changes, and also how communities can induce

positive transformation by actively responding to environmental change. Being resilient through change is a perspective that certainly applies to Lolland, which is an economically rural but highly dynamic coastal area. Key insights that we have discerned through the unique long-term records and rich cultural history of Lolland are:

- **Complexity:** The relationships between human land-use changes, human landscape modifications and environmental change are non-linear and intertwined. Furthermore, the mechanisms that are steering processes of change are manifold and highly complex.
- **Dynamics and serendipity:** Environmental changes, most dramatically exemplified by the devastating storm flood of 1872, can trigger specific human responses, which in turn may have very unexpected side effects for society, affecting arts, subsistence economies, and ritual practices.
- **The past, present, and future:** We are living in landscapes shaped by past decisions. It is crucial that these past changes are taken into consideration, or even actively revoked or otherwise transformed, when changes are introduced. In one way or another, past landscape changes are constantly informing contemporary future-oriented landscape interventions. New, and often unexpected or unintended, forms of heritage and memory practices are created in this negotiation between the past, present, and future.
- **Continuity in the face of disruptive change:** The continued maintenance, or re-establishment of specific practices and/or places in the landscape, in the face of disruptive changes, may be one coping mechanism to be resilient and adaptable. This is most clearly indicated in our data by the activities pertaining to ritual behaviour and subsistence, suggesting that rituals and food may be key 'platforms' to cope with change.
- **Change is constant:** While there is a general tendency to separate change through thinking in terms of a 'before' and 'after', reality does not conform to such a linear logic. Landscapes will always change at social, political, and/or ecological levels, which requires a high degree of flexibility, adaptability and resilience. Thus, archaeology and cultural heritage are telling human stories of coping with, and learning from, change, over considerable time horizons. Such stories are becoming increasingly significant in a present and future where extreme climate events are becoming more widespread and common.
- **Opportunities:** Environmental change is not just a challenge that needs to be dealt with through mitigation strategies. It also creates new opportunities, that in turn foster coping strategies and can increase the resilience of local populations.

Spatial and chronological scales and precision are elements that play an important role for studies like this one, demanding a high level of source-criticism and abstraction. As such, complete landscape histories are difficult to achieve on a conceptual, narrative-based level. Nevertheless, future studies can add to this study and work towards a more holistic understanding of past, present, and future landscapes.

Lolland's changing landscape has become a valued cultural treasure that requires careful management in local planning. As an example: although the Lollandsdige was originally created to address climate challenges and support agriculture, it has since been appreciated as an important part of the island's cultural heritage and natural beauty, which can be seen as an unintended effect of the dike. This transformation shows how a relatively new, human-made landscape can evolve into something historically significant. It also reflects how local communities adapt to environmental change, turning practical solutions into symbols of identity and shared memory. Thus, even unintended effects can provide new economic opportunities and cultural potentials, for instance through the remembrance of ways to act and cope with devastating weather events. Nevertheless, the lack of preparation for the storm flood of 2023/2024 indicates that this potential has not yet been fully realised or socio-culturally embedded.

Unequivocally, additional questions arise in the face of climate change: which tangible and/or intangible elements of a landscape are significant to preserve or protect and which may we need to let go off? How can these elements be communicated to increase resilience and adaptability of local societies? And last but not least, what are the implications for archaeology and heritage management?

Questions such as these arise when working with cultural landscapes, where old and new, rupture and continuity, the past, present, and future, meet. Sometimes they must be weighed against each other, and it is the tension in these very interfaces that form an important part of the narratives that make archaeology and heritage meaningful for people. With this contribution, we set out to show that these narratives can provide insights of value for our present and future challenges, and that landscape studies as well as heritage management can benefit from an interdisciplinary deep-time perspective that spans a wider frame around landscapes and people, while acknowledging that change is the only constant.

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GW: writing – original draft, writing – review and editing
RvB: writing – original draft, writing – review and editing
CB: writing – original draft, writing – review and editing
SAD: writing – original draft, writing – review and editing
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WO: investigation, writing – original draft, writing – review and editing
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Data availability statement

All used data are referenced at appropriate locations in the paper. For this contribution, we did not incorporate any unpublished primary data.

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