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RESEARCH

A Diachronic Triangular Perspective on Landscapes: a Conceptual Tool for Research and Management Applied to Wadden Sea Salt Marshes

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Abstract
Strong disciplinary academic fragmentation and sectoral division in policies lead to problems regarding the management of landscapes. As a result, there is a focus on the preservation and development of either cultural or natural landscapes. We argue that framing landscapes as "natural" or "cultural" will not help sustainable management. The goal of this paper is to show that even what is referred to as nature, virtually always features an intricate combination of physical geography, biology, and cultural history. It provides an analytical framework that visualizes the three forces at play in physical landscapes. Therefore, we introduce a diachronic triangular approach to study and manage landscapes from a holistic point of view, allowing an exchange of different perspectives. To test this approach, we have applied our model to a diachronic case study on Wadden Sea salt marshes. That area has been influenced by physical-geographical, biological, and cultural landscape forces, which are still visible in the landscape to a large extent. By placing different landscape zones in the triangular concept for different time periods, we can identify and visualize these driving forces through time for this specific landscape. These all play their specific roles in the appearance of the landscape over time in a close mutual interconnection. More importantly, we show that the diverse and complex interplay between these forces makes the current-day landscape what it is. We therefore conclude that the diachronic triangular approach provides a conceptual tool to define and operationalize landscape management in the Wadden Sea area. We welcome similar approaches in other landscapes to assess the usefulness of the diachronic triangular landscape approach.

Keywords Sustainable landscape management · Heritage · Ecology · Geology · Culture

Introduction

In landscape management, there is a gap between physical-geographical, biological, and cultural(−historical) approaches, because of the strong disciplinary academic fragmentation and sectoral division in policies (Walsh et al. 2020). This leads to serious problems regarding the management of heritage and the readability of our landscapes, because policies often have single aims, not taking into account the broader context within the physical landscape (Burbridge 2020; Kolen and Renes 2015). For instance, in many large-scale nature development areas in North-western Europe, soil and groundwater conditions have been altered aiming to (re-)create optimal baseline conditions for flora and fauna. Physical-geographical conditions are mimicked in areas where they do not occur naturally. In addition, cultural historical and archeological traces are (unintentionally) removed to make place for higher biodiversity, namely, plants and animals. Although this is with the best intentions, in line with EU Natura 2000 goals, and in some cases, due to lack of knowledge, while we are gaining some

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aspects of the landscape, we run the risk to lose other aspects (Höchtl et al. 2005).

There is a strong focus on the preservation and development of either cultural or natural sites. This is exemplified by UNESCO, which separates natural from cultural heritage sites. In the World Heritage Convention (1972), both types of heritage are defined, but they are treated as separate. In practice, this means that sites can either be awarded cultural or natural heritage. Although mixed sites are defined, in which both the cultural and natural are combined, they are relatively rare (Leitão 2017). Physical-geographical features are formally regarded as part of natural heritage, albeit generally treated as substrate only for the habitat of threatened species of animals and plants. In many landscapes however, ongoing sediment dynamics justify a more prominent and visible position for physical processes as a landscape builder. Such dynamics often create new or substantially different base conditions impacting natural and cultural use of the landscape. In 2015, UNESCO introduced Global Geoparks to also recognize the international importance of geodiversity, confirming that preservation and protection of the landscape rests on three pillars: cultural, natural, and geological heritage. However, it could be argued, that although geoparks formally focus on geological sites of significance, in fact the management of such areas is focused on social cohesion, shared identities and economic development, i.e. the cultural aspects of the region.

We argue that framing or positioning certain environments as "natural" or "cultural" will not help in managing landscapes in a sustainable way. Therefore, with this paper, we aim to (1) introduce a new approach in landscape management and (2) test this approach in a case study. We propose a diachronic triangular approach that can serve as a tool to study, and manage landscapes from a holistic point of view, allowing for an exchange of opposing worldviews and perspectives, or as put by Walsh et al. (2020): contrasting landscape imaginaries.

To do so, we have chosen the Wadden Sea salt-marsh landscape as a case study. Salt marshes are vegetated ecosystems clearly distinguishable ecologically from the adjacent intertidal flats (Van Regteren et al. 2020). The diverse history of the landscape, with strong and varying influences of biological, physical-geographical, and cultural processes makes the case study area an ideal location to test the triangular approach over a long period. The elucidation may help to evaluate ongoing discussions on the conservation and restoration of this coastal landscape in particular and sustainable landscape management more generally.

Landscapes and Concepts of Naturalness

At the core of this paper lies a complex terminology on the relation between natural and cultural-historical values. Conceptually, one should not forget that what people consider nature or even wilderness today, acquired this image to a considerable degree because of human (cultural) appreciation and designation as such (Cronon 1996).

Within the physical-geographical disciplines, there is no generally accepted geological or geomorphological subdivision with respect to the "naturalness" of landscapes. In soil science, however, specific manmade soils are distinguished. In nationally (e.g., De Bakker and Schelling 1989) and internationally accepted soil classifications (FAO 2015; Soil Survey Staff 2014), "anthrosols" are defined for soils that show distinctive signs of human influence. Such soils could be formed as human-transported or as human-altered material (Soil Survey Staff 2014). In the former, people are regarded as a geogenetic or geological factor. In the latter, people are regarded as a pedogenetic factor, by indirectly influencing soil properties to such an extent that the soil significantly deviates from the natural situation. This mostly occurs via a change in land use for prolonged periods. Although some subtypes of anthrosols can be described, a detailed subdivision into different levels of cultural influence is not quantified or divided into ordinal classifications. Human influences are also recognized and acknowledged within the physical-geographical discipline. Influences of people on meandering river systems (Gregory 2006; Hijma et al. 2009), sedimentary processes along sandy shorelines (Wang et al. 2018), or the formation of drift sands (Heidinga 2010; Koster 2009, 2010; Pierik 2017) are just a few examples. Human influences are acknowledged, but generally, this does not mean the resulting landform is classified as "cultural": they are generally referred to as an outcome of a physical-geographical process, whether this has a human cause or not. It is acknowledged that the formation of coastal landscape elements such as dunes, salt marshes, and peatlands strongly depends on the interaction of water, wind, sediment availability, and what are referred to as "bioengineering plants," resulting in the concept of biogeomorphology (Corenblit et al. 2011). Once the biogeomorphological units have emerged, they create habitats for many characteristic plant and animal species, referred to as biodiversity.

From an ecological point of view, various systems have been suggested to classify naturalness (Anderson 1991; Machado 2004). Classic in this respect is the work by Arthur Tansley, who, from a plant ecological perspective, introduced the notion of *semi-natural landscapes* (Saris and Van der Maarel 2018). According to Tansley (1949), the concept is necessary since there are a great many cases intermediate between what he considered the two extremes culture and nature. In the Netherlands, the concept of semi-natural landscapes is commonly associated with the ecologist Victor Westhoff, who dealt with the issue of various grades of naturalness throughout his long career. The background of his concept emerged when he realized that nature reserves such as heathland could only be maintained by continuation of the land use that formed it, hence needed management. By leaving it to "nature" (i.e., doing nothing), the heath would develop into woodland. Westhoff (1943) coined the concept in 1943 in an unknown Dutch journal and never published it in a refereed journal (Saris and Van der Maarel 2018). A subdivision in natural, semi-natural, and cultural landscapes is now commonly accepted and applied in (plant) ecology (e.g., García-Feced et al. 2015; Peet and Roberts 2013; Stevens et al. 2016). In natural landscapes, both the original flora and the vegetation are not (or extremely limited) affected by humans. In semi-natural landscapes, the "original" flora is still present, but the view of the vegetation (e.g., from open woodland to heathland with the same plant species) has undergone changes through cultural activities and new species may have been introduced. In cultural landscapes, both the flora and the vegetation are mostly determined by people.

More or less the opposite of naturalness is hemeroby (Greek *hemeros* = cultivated). The concept of hemeroby was originally developed for measuring human impact on flora and vegetation but was later modified to be applicable on a landscape level (Jalas 1955; Sukopp 1972; Walz and Stein 2014; Saris and Van der Maarel 2018). It uses seven classes reaching from aheremobic (no human impact) to metahemerobic (excessively strong human impacts). Thus, while taking a different starting point, both naturalness-categories and hemeroby scales take one of the classic extremes "nature-culture" as a reference point. In addition, both are firmly rooted in plant ecology and are measured from a vegetation and management perspective.

Instead of starting from a vegetation, the abiotic subsurface or a cultural point of view, one could also use the landscape as a starting point. However, the meaning of the term landscape differs between discourses and disciplines (Atha et al. 2019). In addition, its variation throughout time and place is complex (see, for example, Olwig 2002; Davidovic 2018; Egberts 2018; Renes 2018). Though historically by definition associated with people and culture, one can now commonly come across the term "natural landscape," which would historically be a *contradictio in terminis*, and can be led back to German naturalist Alexander von Humboldt (Kwa 2005). Numerous types of landscapes have since been defined, reaching from aforementioned natural landscapes via cultural landscapes to urban landscapes, sometimes even resulting in elaborate and complex landscape typologies (Kolen 2005).

All of these approaches have a strong essentialist or positivist character, implying that the landscape can either be defined by a limited number of characteristics considered to be "essential," or categorized by its physical, and to a considerable degree measurable, components (Gailing 2012; Kolen 2005; Weber and Kühne 2019).

These approaches all have in common that they leave little room for varying perspectives, and the evolution of perspectives over time, and suggest that it is indeed possible to come up with a single fixed description of a landscape. The opposing view, constructivism, is that the human perception on, and the ideas about landscapes (and nature), define what landscape actually is (Cosgrove and Daniels 1988; Gailing 2012; Greider and Garkovich 1994; Kolen 2005; Kühne 2019). Attitudes toward nature and culture and thinking about landscapes have changed profoundly over the course of time (Lowenthal 2005). Moreover, the attitudes may vary considerably depending on the individual or organization involved. Swart et al. (2001) describe three approaches of valuation of nature in conservation and restoration. The wilderness approach, according to them consisting of true nature with no or low human influence; the Arcadian approach, which refers to semi-natural landscapes with low-intensity land use; and the functional approach where geological and biological factors are fully adapted to the current high-intensity human land use and only act as service to human needs. Buijs (2009) explored the variety of images of nature existing with the general public and roughly defined five images. The wilderness and functional images overlapped with the images by Swart et al. (2001). The esthetic image is closely related to the Arcadian approach, but combines the semi-natural aspects with beauty and landscape diversity particularly being valued. In the autonomy image, "real" nature should be self-organizing and self-sufficient, independent of human influences, and is not restricted to nature reserves but can be found anywhere (see also: Schama 1995). Lastly, in the inclusive image, people are seen to be part of nature, meaning that the distinction between culture and nature does not exist at all. As a result, Buijs defines the wilderness and autonomy images to be similar to the contrast between nature and culture, whereas the inclusive, esthetic, and functional images do not show a (strong) nature-culture divide. So, this strengthens the notion that also from a perception point of view, the framing or positioning of certain environments as natural or cultural is much more complex and therefore not very useful.

Proposing the Diachronic Triangular Landscape Approach

In this paper, we introduce a triangulated model (Fig. 1) to overcome the monodisciplinarity of academic and management approaches in sustainable landscape management. Next to cultural processes, we reach a triangular form by dividing natural processes in abiotic and biotic components. First, because the physical-geographical background determines biological conditions to a large extent, and secondly, because in nature management or restoration, the soil and hydrological conditions are often only seen as a substrate or background condition for plants and animals (see above). They are often not regarded as also being a result of, in this case, abiotic natural processes. In nature development areas, this regularly results in manmade abiotic conditions that are

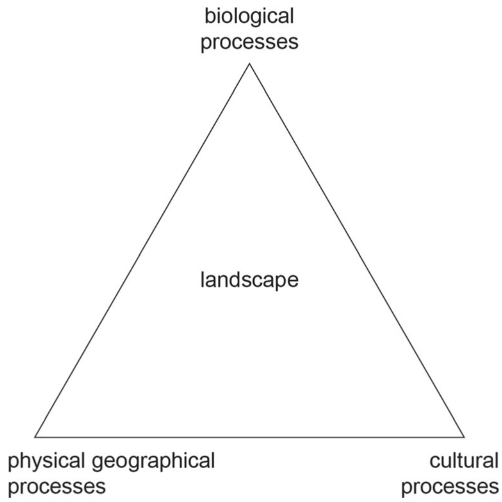

Fig. 1 The diachronic triangular landscape model

not representative for the original physical-geographical processes that have created the natural landscape. To raise awareness as a starting point to integrate all landscape forces, it is vital to visualize physical geography as a separate landscape builder and this has been acknowledged explicitly for various types of "cultural landscapes" previously indeed (Farina 2000; Lugeri et al. 2011). A triangle approach comparable to ours is proposed by Smeenge (2020), in his dissertation, who integrates the components to visualize the relations between various landscape related disciplines, and introduces the concept of "historical landscape ecology" in the center of the triangle, as an integrated form of landscape analysis.

We position the landscape itself within the triangle, as the ever-present realm in which it all happens, rather than focusing on either culture, biology, or physical geography. Throughout space and diachronically, the landscape has been formed by all three factors in varying levels of importance, and varying levels of interaction (see also Smeenge 2020). We adopt the triangular approach to serve as a tool in the assessment, interpretation, and management of landscapes, as well as a tool to visualize opposing (complementary?) perspectives. By marking a certain area within the triangle, the relative influences of the three factors at any time and place can be indicated (see also "Methodology" and "Diachronic development of salt marshes and their position in the landscape triangle"). This also explains why we opt for "cultural" rather than cultural-historical here. At any given moment in time, cultural processes play a role, which conceptually can also be zero. It only becomes historical in hindsight.

Case Study: Implications and Applications for Wadden Sea Salt-Marsh Landscapes

To operationalize the concept, we apply the diachronic triangular landscape approach to the Wadden Sea area. From a present-day as well as from a historical perspective, this landscape should be regarded as the result of physical-geographical, biological, and cultural processes, in varying ratios, and depending to a considerable degree on the eye of the beholder. As a result, the area shows a rich variety of, and a strong connection between, natural (physical-geographical and biological) and cultural-historical heritage values.

This is explicitly acknowledged in the Wadden Sea Quality Status Report (Esselink et al. 2017, p. 34), which states that "artificial salt marshes are part of the cultural history of the Wadden landscape. When aiming at increasing naturalness in these marshes, considering this in the overall framework of the Wadden Sea Plan is recommended." As both the cultural and natural values are equally being acknowledged, this appears to be promising and does justice to the complex development of the area through time. However, the recommendation potentially suggests a conflict of interest as it may be interpreted a separation between either cultural or natural values. The presumed nature-culture dichotomy in this area has recently been discussed in a new volume dealing with the cultural history of the Wadden Sea area. Rösner (2018) argues that we have come a long way in getting (parts of) the Wadden Sea area protected. In his view, the cultural aspects of the Wadden Sea area should be restricted to the areas on the landward of the seawalls as much as possible, resulting in not only a thematic separation between cultural and natural values but also a physical segregation between presumed natural and cultural landscapes on both sides of the main seawalls. Renes (2018, p. 58), on the contrary, proposes to define the entire Wadden Sea area as a (maritime) cultural landscape, since human activities have influenced the landscape for a long period, changing an "extremely soft, flexible and permeable land-water interface" into a landscape with barriers that acted as connections at the same time. The concept of the maritime cultural landscape however (Westerdahl 1992), works for the tidal sea, the harbors and the fishing grounds, but does not necessarily include agricultural use of the coastal area. An alternative for this concept, *avant la lettre*, is proposed by Smit who speaks of the agricultural-maritime structure for the island of Terschelling (1971).

The concepts listed in the theoretical section all have to some extent be applied to the Wadden Sea area. In many discourses, the area is currently praised for its dynamic physical-geographical processes and exceptional natural values, while often acknowledging that great parts of the area are significantly influenced by human activities at the same time (e.g., Egberts 2018; Prokosch 1990; Reise 2013). This appreciation of natural values in the Wadden Sea is justified and understandable. In fact, the hemeroby classes of the Wadden Sea are rated amongst the most natural in the whole of Europe (Paracchini and Capitani 2011).

From a visitors' perception point of view, there also seems to be a strong focus on the naturalness of the Wadden Sea area. It is regarded by many as a natural landscape, in which virtually all aspects of modern-day human life (technology, tourism, fisheries, etc.) are considered potential threats (Fischer and Hasse 2001). This image of the Wadden Sea area as a predominantly natural realm has, one might say, led to an active "deculturization" of the area in the political and public discourses. In 2016, for example, the Wadden Sea was elected by the general public to be the "most beautiful natural area" in the Netherlands (Programma naar een Rijke Waddenzee 2016).

The outstanding natural values resulted in (parts of the) Wadden Sea area being inscribed as UNESCO World Heritage Nature in 2009. The criteria applied to the Wadden Sea area emphasize the importance of various physical-geographical processes and the biodiversity in the area (criteria VIII–X, World Heritage Centre 2019). More specifically, UNESCO (2009) acknowledged the direct link between physical-geographical and biological factors as "The Wadden Sea includes some of the last remaining natural large-scale intertidal ecosystems where natural processes continue to function largely undisturbed. Its geological and geomorphological features are closely entwined with biophysical processes and provide an invaluable record of the ongoing dynamic adaptation of coastal environments to global change." Although UNESCO clearly attributes both physical-geographical and biological factors to the concept of nature, they are not presented as equal. The physical geography is mostly presented in a supporting role of the biodiversity in the area.

However, no statement is made on cultural-historical values within the World Heritage Site area. This is striking, since cultural factors directly and indirectly and within and outside the area have greatly influenced the area, and its "natural processes," during the past two and a half millennia (i.e., Bazelmans et al. 2012; Renes 2018). This may be partly due to the political decision in delineating the Wadden Sea as World Heritage Site, which rather strictly only encompasses the areas not protected by seawalls. However, elements of UNESCO's definition of cultural landscapes are equally true for these areas outside the seawalls, stating that the term "embraces a diversity of manifestations of the interaction between humankind and its natural environment" (UNESCO World Heritage Centre 2019).

From a political perspective, the Wadden Sea UNESCO World Heritage Site aims to unify the three countries Denmark, Germany and the Netherlands bordering the Wadden Sea into a single natural entity, in a sense disregarding the historical development of different people influencing the area by diking and draining (Olwig 2005). In the Netherlands, this can partly be explained by strategic choices made by the government to explicitly designate certain areas as nature (Renes 2018). As a result, cultural-historical values are being ignored and the attention for integrating perspectives, concepts and methods that share the physical-geographical, biological, and cultural landscape forming processes is limited (Krauss 2005; Walsh 2018).

Also, from an academic perspective, there appears to be a nature-culture dichotomy, in which the Wadden Sea area is placed on the natural side of this division (Egberts 2018). In our opinion, framing the Wadden Sea area as either cultural or natural landscape does not do justice to the rich variety in the area (and the way it developed by human action) on one hand, and runs the risk of excluding different perceptions of the same area on the other. A similar position was taken in by Egberts (2018), who argues that the nature-culture dichotomy as presently very prominent in the Wadden Sea area is counter-productive, and a landscape-based approach is needed. Egberts, however, proposes an "approach of the Wadden Sea area as one contiguous landscape in which both nature and culture have a place" whereas we take the argument a step further: at any given moment in time, the landscape is what it is because all factors play their interconnected roles in a highly complex manner, or as Krauss (2005) puts it: "bio-geological processes and human efforts are inextricably intertwined."

Demarcation of the Study Area: The Wadden Sea, where and when

It is vital to properly discuss what is actually meant by the "Wadden Sea" by different disciplines and in different discourses. Various scholars, people in governance, as well as inhabitants and tourists have different ideas of what the Wadden Sea encompasses, and this can even vary depending on the situation. Nonetheless, there seems to be a general habit of distinguishing something one might call a Wadden Sea sensu stricto and a Wadden Sea sensu *lato* (e.g., the Wadden Sea area). The former is the tidal sea, which is more or less what is now the UNESCO World Heritage Site and should be regarded as mostly an administrative unit which is largely restricted to the uninhabited parts outside the main seawalls (Renes 2018; Rösner 2018). This landscape could also be regarded as the sea itself and the area directly affected by the sea, roughly up to storm tide water level. This landscape is largely separated from the landscape of the mainland coasts and the islands by embankments, which used to be salt marsh before seawalls were constructed.

The Wadden Sea area in its wider sense should be regarded from a physical-geographical, biological, and cultural-historical landscape perspective and has, consequently, not a strict boundary. In addition to the aforementioned Wadden Sea sensu stricto areas, it includes the inhabited islands and the landward side of the main seawalls that are physical geographically unmistakably shaped by the sea. This area, or parts of it, is known under various names as "Waddenland" (Egberts and Schroor 2018), "Terpen- en Wierdenland" (Betten 2018; Nieuwhof et al. 2018), "Frisian coastal area"

(Kegler 2013), or simply "Wadden Sea Region" (Vollmer et al. 2001). In some of these cases, even the adjacent higher sandy Pleistocene landscapes are included, although they have only been indirectly influenced by the sea. Throughout this paper, we use "Wadden sea area." We will restrict ourselves to the Holocene marine deposits, both inside and outside the present-day seawalls, including (inter)tidal flats, dunes, and salt marshes. We will specifically target the, already quite diverse, salt marshes in the area (Fig. 2).

Methodology

The diachronic triangular model will be tested using the salt-marsh landscape in the Wadden Sea. We have identified six different salt-marsh landscape zones, according to the current-day geographical defined boundaries following Esselink (2000). We applied this classification system in a schematic cross section through the present-day landscape in the northern Netherlands (Fig. 3), in which we regard the landscape zones to be geographically fixed. The zones are (1) the (terp) salt marshes that existed before the construction of permanent seawalls; (2) the inland polders that developed as a result of active stimulation of accretion and subsequent diking and embankments; (3) the summer polders on the seaward side of the present mainland; (4) the present mainland salt-marsh area on the seaward side of the summer dikes; (5) the back-barrier island salt marshes; and (6) the green beaches on the North Sea side of the barrier islands. As stated above ("Proposing the diachronic triangular landscape approach"), the position of these areas in the landscape triangle can be indicated by estimating the relative influence of the three driving forces. By doing so for different stages (time periods), the major changes the different zones underwent are made explicit (Fig. 4). Basically, all filled-in triangles ("Diachronic development of salt marshes and their position in the landscape triangle") can be easily understood when compared to Figs. 3 and 4.

Although the salt-marsh types defined by Esselink et al. (2017) do not fully cover all salt-marsh types currently present for the Wadden Sea area (leaving out Halligen in Germany and recently de-embanked summer polders, for example), we consider the zones to be sufficiently representative for the purpose of this paper. Esselink et al. (2017) have defined different salt-marsh types based on morphology, in which not the geographic location, but the salt marsh building factors are dominant. These salt-marsh types are therefore not geographically fixed, although the nomenclature sometimes suggests otherwise. We, nevertheless, have used this typology to characterize the salt-marsh zones during certain conditions and in certain stages. They are described in Table 1.

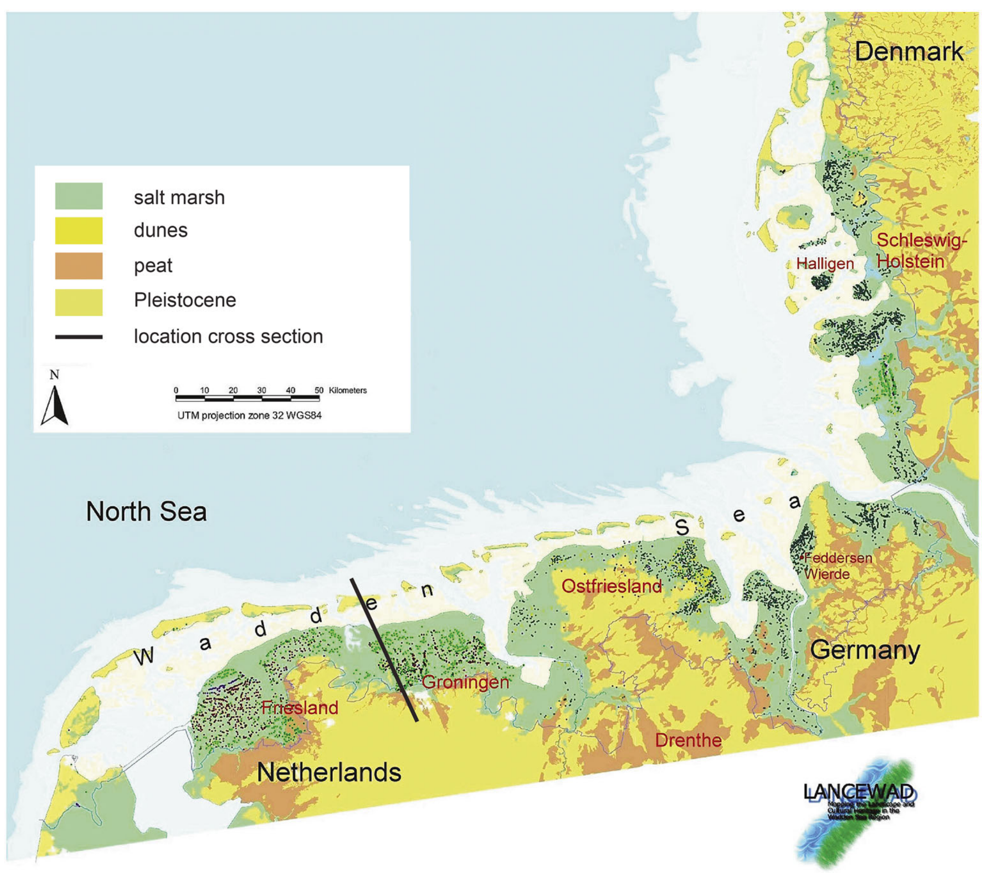

Fig. 2 Salt-marsh areas in the Wadden Sea area. The black line indicates the direction and approximate length of the cross section in Fig. 3. A similar line could be positioned at multiple places on this map (Source: Vollmer et al. 2001)

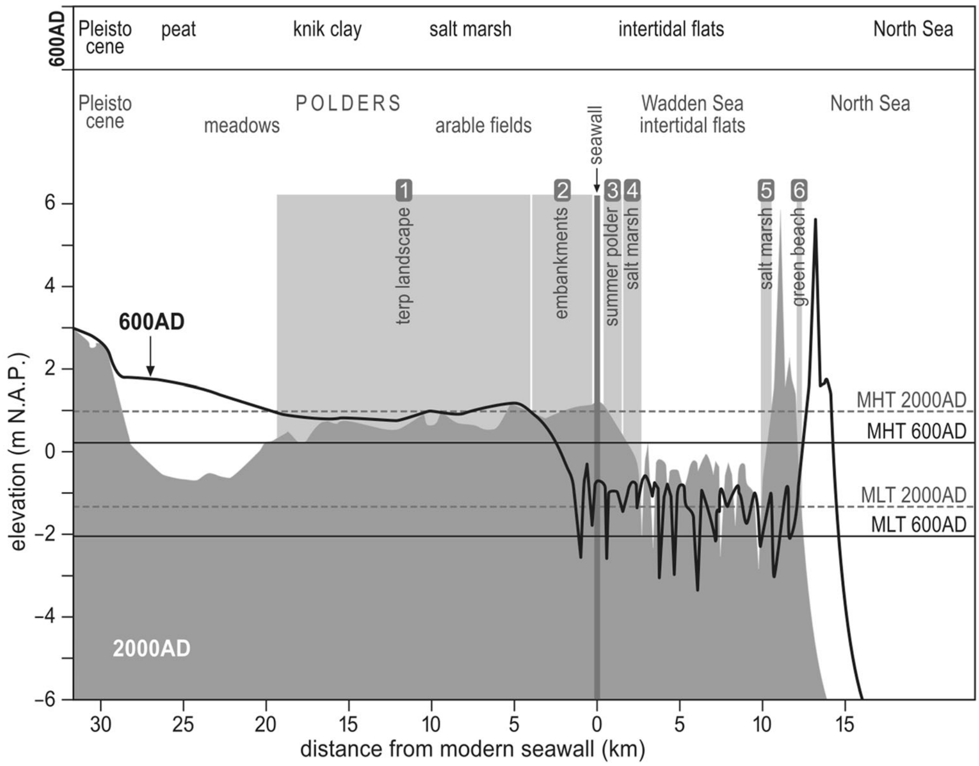

Fig. 3 Cross section through the Dutch Wadden Sea area in the northern Netherlands from the Pleistocene hinterland to the North Sea beach for AD 600 and 2000 with the former (thick line) and present soil elevation (dark gray physical geography) and the six geographically defined salt-marsh zones indicated as light gray blocks on top of the dark gray physical geography inside and outside the present seawall as discussed in this paper. See Fig. 2 for an example of a location where this cross section could be located (adapted after Esselink 2000)

Representative examples are shown in Fig. 5. For this paper, however, this typology should be expanded with the former salt-marsh landscapes on the inward side of the seawall, which include both the former terp landscape as well as the embanked polders. Based on the morphological salt-marsh types, each of the landscape zones (Fig. 3) was classified and described and positioned within the triangular model for a set of representative time periods or stages.

In the following sections, we will first provide a short overview of the major physical-geographical and ecological processes of salt marshes to get an idea of the spatial and temporal variation between different salt-marsh environments. Then, we will focus on the salt-marsh landscapes in different periods to show the diachronic perspective of the triangular landscape approach. We provide insight into the most important aspects of the interdependency of the physical-geographical, biological, and cultural landscape components and their relative importance in different periods. More comprehensive diachronic developments of salt marshes are well described elsewhere (e.g., Bazelmans et al. 2012; Nieuwhof and Schepers 2016; Nieuwhof et al. 2019). Although we describe the different periods in seemingly separated stages, the shifts from one stage to another generally occurred gradually; in practice, several stages were often found next to one another.

Major Physical and Ecological Processes Associated with Salt Marshes

A salt marsh and its surroundings feature zonation (Fig. 6) and a halosere succession. At the lowest elevations in a tidal sea environment, physical-geographical processes are highly dynamic, with relatively high sedimentation and erosion rates along tidal gullies as well as on the intertidal mudflats. This

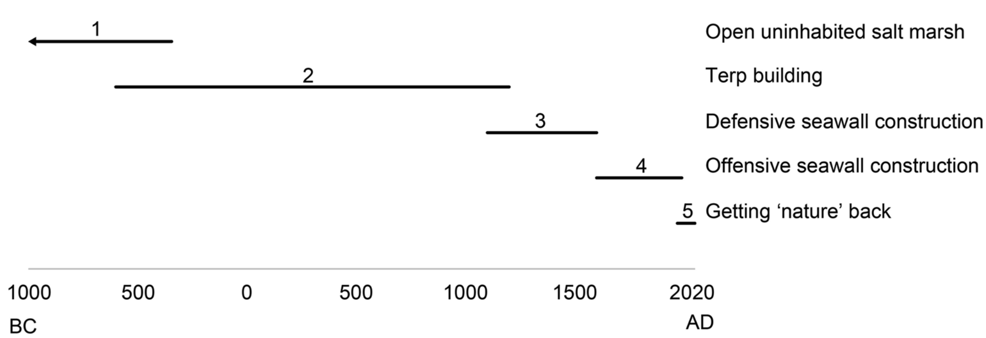

Fig. 4 Five stages to which the method is applied. Stage 1 starts ~5000 BC

Table 1 Morphological classification of salt-marsh types in the Wadden Sea adapted after Esselink et al. (2017)

Type	Characterization	Figure 5
Barrier-connected salt marsh	Sandy salt marsh in the lee of a dune ridge (restricted to the barrier islands)	a
Foreland type	Salt marsh mostly found on the mainland and largely created by active stimulation of accretion	b
Hallig salt marsh	Salt marsh that developed on the historic mainland and which are only protected by a summer dike	c
Summer polder	Salt marsh on the seaward side of the seawalls that is only protected by a low summer dike. It is protected against flooding during the summer period. In the storm season, the sea may flood the polder occasionally	d
De-embanked (summer) polder	Summer polder of which the summer dikes have been reopened up for tidal influences	(d)
Green beach	Salt marsh on the seaward area of a dune ridge, and as such physical geographically part of the barrier-connected sandy salt marsh	e
Former salt-marsh landscapes	Former salt marshes, mainly on the mainland, now closed off to the sea by seawalls and used for intensive agricultural purposes mainly	f

means there is relatively little room for plants to play a substantial landscape-building role. In natural conditions without seawalls, the accommodation space for the seawater is large, resulting in a large volume of water entering the Wadden Sea during the flooding tide, the tidal prism. Along the edges of the tidal sea, where the physical-geographical processes on the intertidal mudflats covered with diatoms are less dynamic, a natural salt marsh forms when a mud or sand flat rises through vertical accretion. This process continues until it lies just below the mean high tide (MHT) so that it is submerged twice a day for several hours and is dry the rest of the time. Where this is the case, the intertidal mudflat will be colonized by the halophyte pioneer plants *Spartina anglica* and *Salicornia* spp. The zone where these plants grow is referred to as the pioneer zone. When the tide rises, the plants standing in the water impede the flow of water and augment the sedimentation of silt particles. Next, the low grass *Puccinellia maritima* may establish itself, promoting the trapping of sediment even further. This second zone, which lies just above MHT level and is not submerged at high water every tide, is referred to as

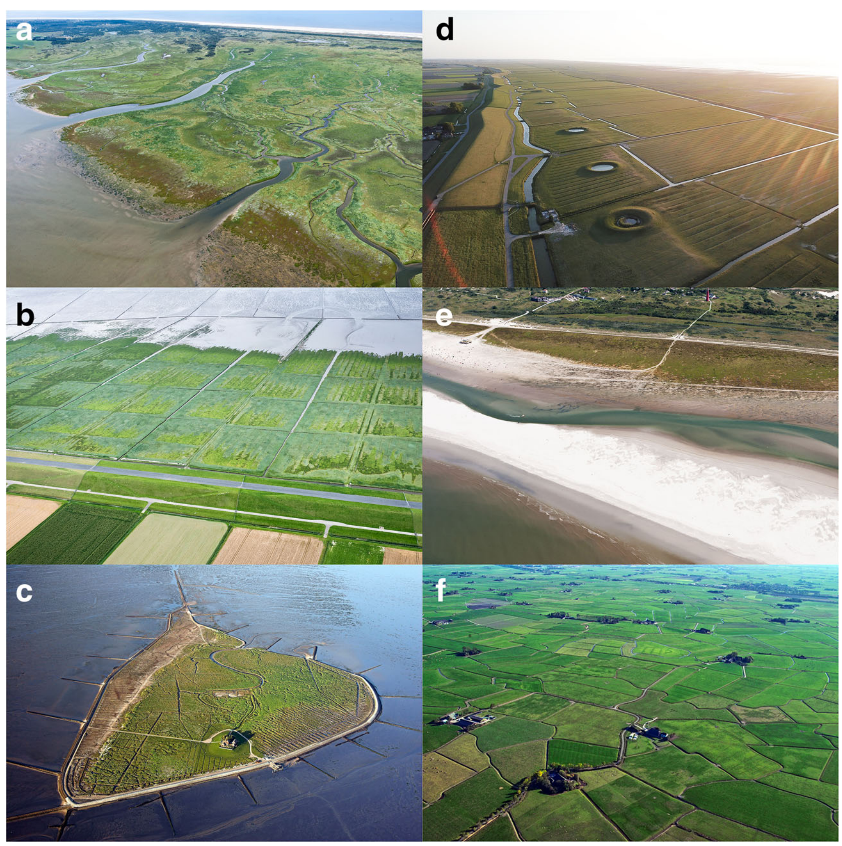

Fig. 5 Examples of the six characteristic salt-marsh types for the Wadden Sea area. **a** Barrier connected, **b** foreland salt marsh with embankment and seawall on the foreground, **c** Hallig, **d** embanked summerpolder between seawall and fresh water basins at the left, summerdike at the right, **e** green beach along dunes, and **f** rural area on former salt marsh now behind permanent sea walls. (Photos Rijkswaterstaat (**a**, **b**, **e**), Martin Stock (**c**), Sander Schuil (**d**), Paul Paris (**f**)). For descriptions, see Table 1

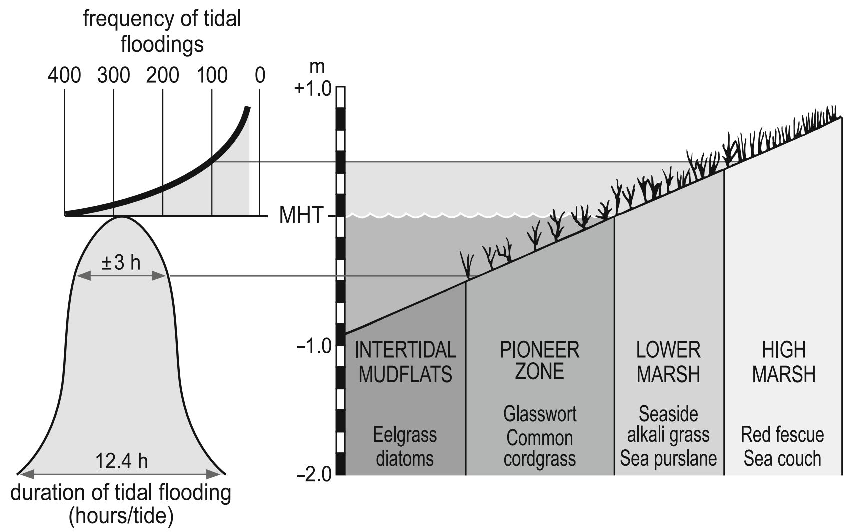

Fig. 6 Schematic structure of a salt marsh with elevation zones and characteristic plant species in relation to inundation duration and inundation frequency (adapted after De Vlas et al. 2013)

a lower salt marsh. The shrub *Atriplex portulacoides* is a typical species of this zone. As the salt marsh grows and becomes higher, it is flooded less and less often, and new plant species establish themselves until a high marsh with the medium grass *Festuca rubra* and tall grass *Elytrigia atherica* is formed, which is flooded less than one hundred times per year. Higher elevated areas are regularly flooded during spring tides, and irregularly during storm surges. As a result from relative sea-level rise and an abundance of sediments in the seawater vertical accretion continues. Hence, succession takes place from pioneer zone into lower marsh and from lower marsh into high marsh with an increase in vegetation height.

Although the zonation is mainly vertical, there is also a substantial degree of geographical variation, which is caused by the interaction between physical-geographical and biological processes as described above. The sea and creeks are sediment sources. When sediment is transported onto the marsh, the coarse particles are deposited where the velocity of sea current or tidal stream is reduced by the vegetation. Consequently, this fraction is deposited along the salt-marsh edge and creeks, thus creating sandy levees, slightly higher in elevation than their more clayey hinterland environment (Townsend et al. 2011). Further from the sediment sources, fine particles are deposited to become clayey depressions (Hughes 2012). These physical-geographical differences are found at the local scale of a salt marsh. At the multiple landscape-scale gradient from the sea to the elevated Pleistocene sandy hinterland (Fig. 3), sandy salt-marsh ridges are found near the sea. Where sea storm floodwater meets the somewhat acid fresh water from the hinterland, the sediment is deposited as a heavy decalcified marine clay. Due to clay ripening (a pedogenetic soil process), the soil subsides leaving a relatively low, poorly drained wet area. The salt marsh expands through horizontal accretion as long as the sediment input balances out the relative sea-level rise, otherwise, the salt-marsh edge will erode (Townsend et al. 2011).

The mainland marsh is bordered by the higher elevated Pleistocene hinterland that produces fresh seepage water. This results in a zone with tall reedbeds with *Phragmites australis* and adjacent to the hinterland forest with *Salix* spp. and *Alnus glutinosa*. On barrier islands, the salt marsh is bordered by dunes from which fresh water exfiltrates and where reed beds occur.

As will become evident below, most of these processes will be affected when cultural processes become more prominent, but will only fully disappear following permanent embankment.

Diachronic Development of Salt Marshes and their Position in the Landscape Triangle

Stage 1: Open uninhabited salt marsh (ca. 5000 BC–600 BC)

In the first stage, approximately from 5000 BC to 600 BC, salt marshes were fully open to the sea and flooded regularly. Frequency was daily on the lowest parts and in the higher parts only occurred with spring tide or during winter storms ("Major physical and ecological processes associated with salt marshes"). In relative tranquil conditions, clay accretion occurred, whereas in stormy conditions, sands were deposited. Not only the water level and meteorological state determined sedimentation conditions but also the vegetation cover that reduced flow velocities and hence increasing accretion levels (Townsend et al. 2011; Masselink 2017).

Generally speaking, the tidal basins of the Wadden Sea, including the salt marshes, received enough sediment during the past 7000 years to sustain the intertidal flat and salt-marsh system, but did not receive enough to fill the basin completely (Van der Molen and Van Dijck 2000). Before human settlement on the marshes (Stage 2), human impact on this landscape must have been very small to negligible (Fig. 7). Pollen diagrams from the Northern-Netherlands coastal area testify to human presence in the area at this early stage indeed, but these generally focus on the peat and sand deposits. Little to nothing is known about the prehistoric appearance of the salt-marsh landscape, partly explained by the problematic formation of the palynological record in coastal clay sediments (Van Zeist 1955; Van Duinen and Van Zeist 1961; Cleveringa 1978). However, during this period, large parts of the mainland marshes must have been suitable for human activities and incidental bronze age finds do occur in the area (Vos and Knol 2015), showing that the cultural component is limited, but not to be ignored completely.

Nonetheless, based upon general knowledge of halosere salt-marsh zonation and physical geography, a rather detailed image of the marsh' appearance can be estimated. The marsh must have been an open landscape, with large spatial variation in vegetation successional stages ("Major physical and ecological processes associated with salt marshes"). Ongoing seaward growth, largely stimulated by accretion during spring tides and storms stimulated this system. Natural, free-flowing tidal meandering creeks interspersed the marshes (Hughes 2012). Biogeomorphology (Corenblit et al. 2011; Townsend et al. 2011) therefore plays an important role in the marsh formation, in which biological landscape formation in the high salt marsh (zone 1, Fig. 3) was more dominant. The direct influence of physical-geographical processes was more important in the other geographical zones (2–6), hence the position of these zones along the physical-geographical-biological axis in Fig. 7. Zones 2–4 were actually no salt marshes yet, but rather intertidal flats. They were hence dominated by tidal processes, justifying their extreme bottom left position within the landscape triangle. For substantial parts of the salt marshes, this phase of very limited but not absent human involvement was restricted to the lowest zones.

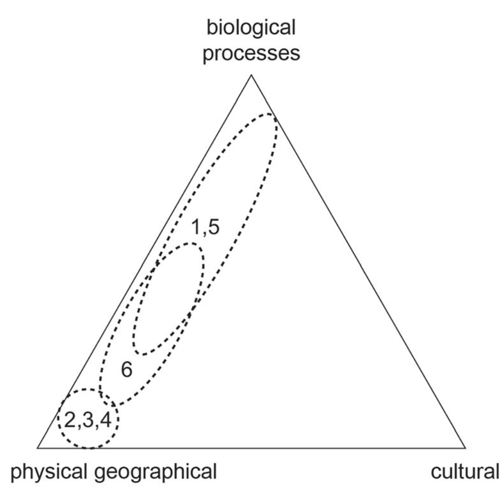

Fig. 7 The relative position of the salt-marsh zones for stage 1 (ca. 5000–600 BC). Numbers refer to the landscape zones as defined in "Methodology" and Fig. 3

Stage 2: Terp building (600 BC–AD 1200)

The first manmade mounds (regionally called "terp," "wierde," or "warft") were built to prevent flooding in homesteads (Bazelmans et al. 2012; Nieuwhof et al. 2019). They were constructed on the slightly higher sandy salt-marsh ridges along the edge of the salt marsh, the border of estuaries, and the tidal creeks (Fig. 2). Due to ongoing sea-level rise, the elevation of the salt marsh was raised naturally by accretion and at the same time, inhabitants raised their terps using surrounding material available (generally a combination of clay sods, dung and household waste). Accretion, erosion and creek formation thus continued alongside habitation in the area (Stouthamer et al. 2020; Nieuwhof et al. 2019; Fig. 8). Human settlement "followed" the seawards growth of the marsh in what has been defined as a "tandem development" of the cultural and natural landscape (Delvigne 2010).

Terp building itself hardly influenced sea dynamics, as the terps only locally formed an obstruction for high floods. Flood levels were limited, since the accommodation space was large. In this period, livestock and arable crops were introduced, directly increasing the biodiversity. The biodiversity on the community level, rather than the species level however, will have been greater than natural conditions due to a wide variety of human activities, resulting in combinations of organisms lacking a modern analogue. Different parts of the marsh were used for grazing, hay land, arable farming, and cutting sods. People were actively modifying the hydrology of the landscape already (Lascaris and De Kraker 2013). To improve the drainage of the surrounding lands, local straight ditches connecting to tidal creeks were dug. Due to lowered groundwater tables and increased numbers of livestock, some soil compaction and land subsidence occurred, with a slight increase in flooding frequencies and clay deposition at local levels. With increasing thickness of the clay layer, also autocompaction took place (Bartholdy et al. 2010). Burning was common practice, stimulating vegetation to rejuvenate for grazing purposes, which from an ecological perspective means that succession was reset. These human land use and modifications of the landscape affected physical-geographical processes and flora and fauna in a wide area surrounding the terps (Vos 2015; Schepers et al. 2013). Yet at the same time, the physical-geographical and biological processes generally associated with salt marshes, as well as the classical species associated continued to exist. The landscape featured high variation in land use superimposed on the large-scale gradient from the sea toward the Pleistocene hinterland. As such, the "terps salt marsh" (zone 1) can be placed at the very center of the landscape triangle (Fig. 9). The salt marshes on the islands (zones 5 and 6) were probably considerably less affected by human activity. It is not completely clear how far the human impact reached from the terps on the mainland salt marsh, and to what extent salt-marsh areas comparable to the stage 1

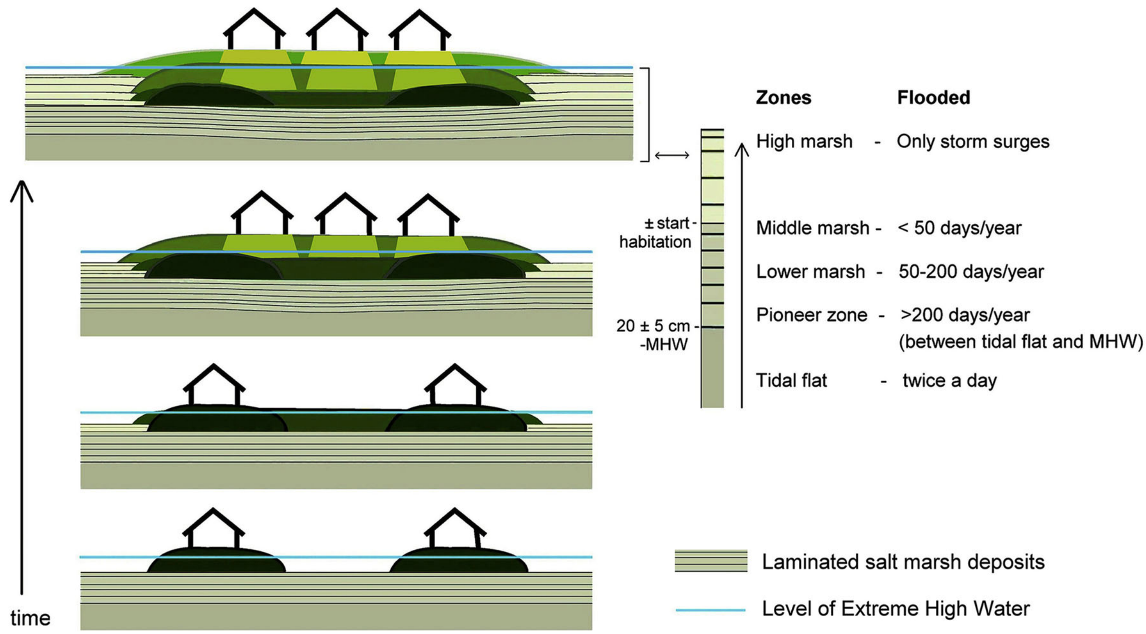

Fig. 8 Accretion and terp building continued alongside each other (Nieuwhof et al. 2019)

marshes remained (Schepers et al. 2018). In this period, the landscape zones 2, 3, and 4 were still not high enough to be classified as salt marshes.

On the mainland salt marshes, the increasingly higher salt-marsh ridges on the seaside prevented natural drainage of the salt marsh in the hinterland, which resulted in wetter conditions by fresh water seepage from the hinterland, and accumulation of peat at the edge of the sandy Pleistocene areas. In addition, the drainage and subsequent exploitation of the peatlands meant a higher input of (fresh) flooding water from the hinterland, causing a higher need to effectively drain the area. Moreover, agriculture including drainage caused subsidence and consequently erosion. This was particularly true in the Western Wadden Sea area, where the peat hinterland was

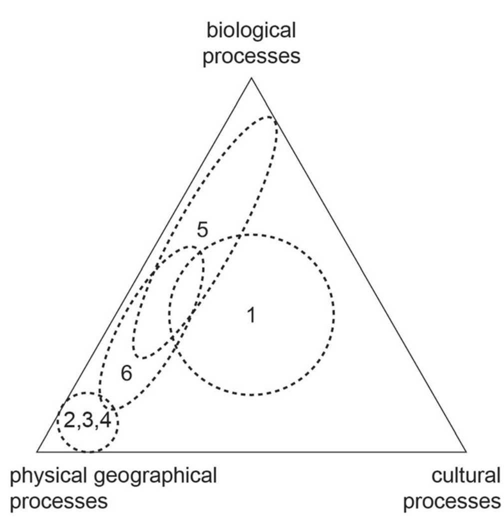

Fig. 9 The relative position of the salt-marsh zones for stage 2 (600 BC–AD 1200)

gradually changed into an intertidal area (Vos et al. 2011). As a result, the tidal prism increased ("Methodology"), deepening and widening the Wadden Sea inlets between the islands Texel and Vlieland, and subsequently stimulating the development of the Zuiderzee in the high middle ages.

Stage 3: Defensive seawall construction (1100–1600)

Although several small summer dikes are known from Roman times already (Bazelmans et al. 1999; Haarnagel 1979), more permanent seawalls were constructed from the eleventh century onwards on the mainland (Jensen 2019). This triggered major differences in the agricultural economy, most notably the expansion of dairy farming and of crop cultivation, not in the least because of the possibility to grow winter crops now. Combined reclamation and drainage of the peat area in the hinterland and sea-level rise from the sea side increased the risk of flooding of the coastal region and increased the accommodation space during high floods.

This problem could not be solved by small local summer dikes, but asked for protection along the entire coastline. The first protection along the entire coastline was not more than a summer dike, somewhat higher than 1.5 m, and breached occasionally. It is likely that building of seawalls coincided with the period that the levels of decreasing peat surface and increasing mean high tide of the sea met (Noordhoff 2011). During the twelfth century, Cistercian monks introduced a locally unknown organization skill which might have enabled them to build seawalls extensively, which also protected the land against the winter flood and reclaim the unprotected salt marsh (Bakker 1989). Where in stage 2 all land was more or less subject to the same sedimentation regime, the seawall building dramatically heterogenized the coastal marsh region, decreasing the influence of physical-geographical and biological processes and increasing cultural influences on the land side of the sea walls (zone 1). The flooding frequency after diking decreased to virtually zero, ground and surface water became fresh and vertical accretion stopped, meaning that the soil surface did no longer keep pace with relative sea-level rise. Increased drainage caused relative soil subsidence, with on its turn caused less favorable groundwater conditions. When seawalls were established in larger areas, the accommodation space on the sea side of the seawalls decreased resulting in an increased tidal amplitude and higher storm flood levels at these dike bodies (Meijles et al. 2018; Jensen 2019), resulting in indirect cultural influence outside the seawalls (zone 2).

The marshes outside the seawalls were still actively used and exploited in the summer months. The coast of Schleswig-Holstein (Germany) has been eroded because of increased storm surges and higher energy conditions, showing the indirect effects of cultural use. Parts of the former mainland maintained and exist nowadays as Halligen. The present Halligen consist, however, of recent material. The former remnants eroded at the western side and accreted fresh deposits at the eastern side until they became stabilized in their present position by summer dikes (König 1976).

The construction of permanent seawalls obviously had a profound impact on the sediment dynamics and ecology on their landward sides, but heavily impacted the seaward side as well. The interaction of a fresh water hinterland with the marine Wadden Sea environment was stopped, thus destroying the gradient toward brackish and fresh marshes with their characteristic plants and animals. After seawall building, the now former salt marsh could no longer receive sediment and vertical accretion stopped, whereas autocompaction continued. Fish migration systems were strongly affected, whereas coastal birds could continue to fly over the seawalls toward high tide roosting sites, substantially altering the wildlife composition in the area. The high marsh cannot longer shift toward the hinterland and is drowned by sea-level rise. This process is referred to as coastal squeeze (Pontee 2013).

For the landscape triangle, we would thus have to distinguish various (former) salt-marsh zones (Fig. 10). The cultural component became very dominant at the landward side of the seawall. At the same time, the number of cultural activities on the open marsh no longer included crop growing and (permanent) habitation and was mainly restricted to livestock grazing, hay making and, probably, cutting of sods, thus resulting in a relative deculturization as opposed to the terps marsh. On the island marshes, extensive grazing meant that zone 5 showed a higher degree of cultural influence.

Stage 4: Offensive seawall construction and seawards expansion: building the dichotomy (1600–1969)

In this stage, the seaward salt marshes continued to grow vertically and horizontally and stepwise people would expand

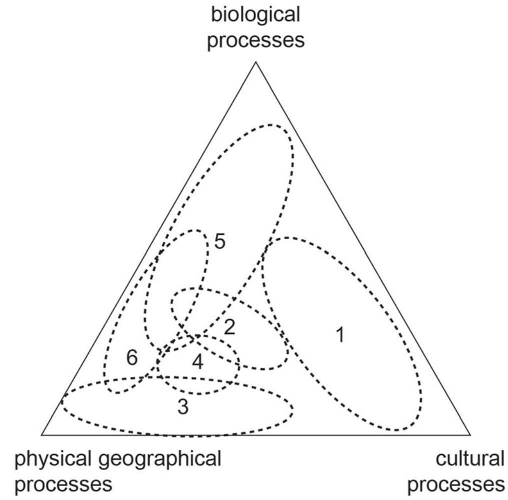

Fig. 10 The relative position of the salt-marsh zones for stage 3 (1100–1600)

their land by building new seawalls. Farmers were no longer passively waiting for the marsh to accrete high enough to allow the construction of new seawalls, but started actively managing the marsh to stimulate its expansion (Dijkema et al. 2001; Klinkhamer 1987; Fig. 11).

Land use became more intensive and included active drainage systems. Farmers were actively encouraged by the right of outwards expansion in the Netherlands, a legal framework that made farmers to own the newly acquired land after embanking. By establishing brushwood groins (semi-permeable dams), people actively used physical-geographical processes, by which sea current velocities were reduced, resulting in increased vertical accretion rates on the intertidal flats. As an effect of drainage measures, the lower fringe of both pioneer and low-marsh zone could descend vertically by 0.2 m, thus accelerating the horizontal accretion of salt marshes. The accretion rates were such, that within decades the intertidal flats rose above mean sea level, turning the area into "man-made" salt marshes with sedimentation fields and a dense system of drains (Esselink et al. 2017). In current management and in academic literature, both the terms "artificial" and man-made are well-established for these particular salt-marsh areas. For the scope of this paper, however, it is relevant to point out that it is not an accurate description of their formation history. We prefer to refer to them as anthropogenically stimulated salt marshes. This means, that the cultural use of the land had a significant effect on physical-geographical conditions. Nevertheless, the plant species involved in the zones from pioneer to high marsh were the same as indicated in Fig. 6. The vast majority established spontaneously, which is represented by zones 3 and 4 become more centered in the triangular diagram (Fig. 12).

Seepage of brackish water underneath the seawalls was counteracted by artificial fresh water input at the landward side of the seawall. Arable crops were grown on the relatively

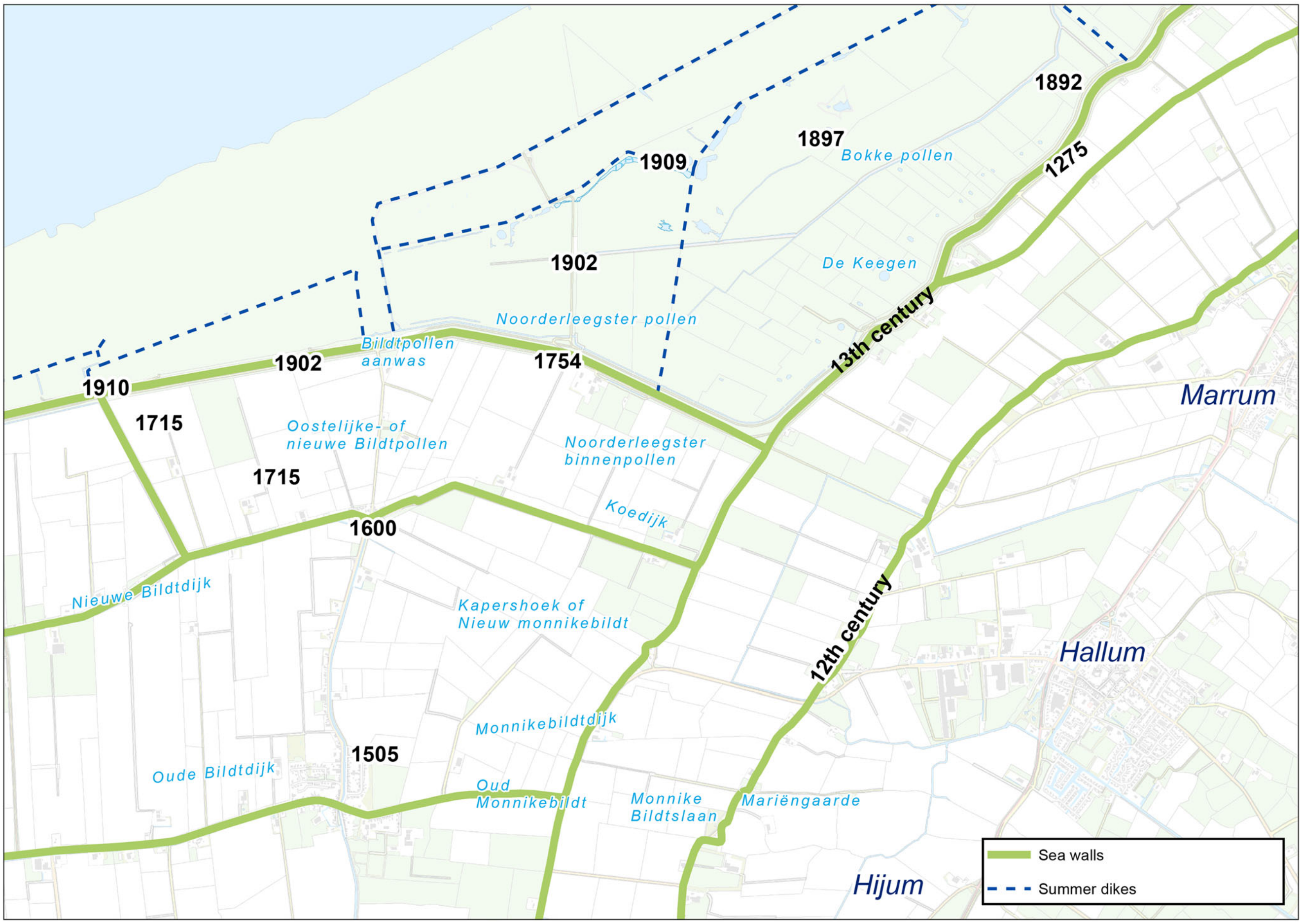

Fig. 11 Example of progressive embankments in the province of Fryslân (Northern Netherlands) (figure Jeroen Wiersma)

sandy salt-marsh ridges close to the seawall (zone 2). Further inland on the now former salt marshes (zone 1), clay soils, pastures, and meadows were established. The heaviest marine clay (furthest inland toward the elevated sandy landscapes) was mined locally for the brick industry, and the lower-lying remnants could afterwards only be exploited as wet grasslands.

The area of seaward salt marshes in the Netherlands Wadden Sea since 1600–1800 revealed a strong decline for mainland marshes as a result of successive embankments. The area of back-barrier island marshes was more dynamic. In the western Wadden Sea, they increased until 1800 because of the establishment of anthropogenically stimulated drift sand dikes to connect individual islands, e.g., on Texel and Ameland (The Netherlands). They decreased again after embankment. Further to the east, back-barrier marshes increased in the twentieth century after the establishment of drift sand dikes on Terschelling and Schiermonnikoog (The Netherlands), Skallingen (Denmark) but were not embanked (Dijkema 1987). The connected mainland barrier salt marshes of Eiderstedt (Germany) were never embanked. The seawalls along the mainland and barrier islands cut off the dynamics of tidal movement, sediment transport in the former salt marshes, now being polders. Summer dikes prevented sediment input and an accretion deficit whereas the sea level continued to rise, thus creating a sort of bathtub in front of the seawall. The drift sand dikes on the islands did allow salt-marsh development in its lee, but reduced the dynamics of

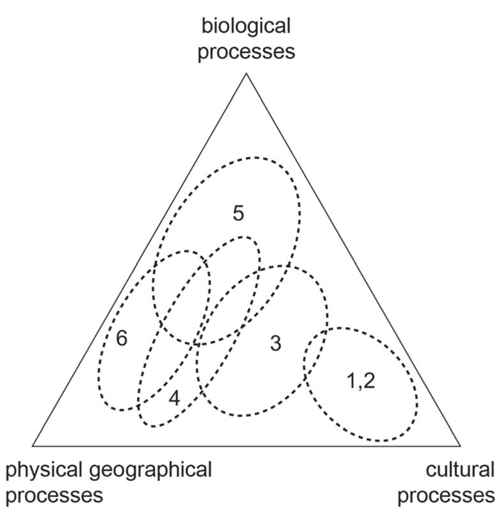

Fig. 12 The relative position of the salt-marsh zones for stage 4 (1600–1969)

water and wind, and wash overs during storm surges (Oost et al. 2012).

Through the centuries, the Wadden Sea basin, including the hinterland with its salt marshes, was changed by seawall construction, heightening and, in a later stage, shortening the coastline. The accommodation space was greatly reduced stepwise, meaning that the space for sediments to accrete reduced. The closures of the Zuiderzee (1932) and Lauwerszee (1969, see Buursma 2019) have dramatically decreased the respective tidal basins in the Wadden Sea in the Netherlands, which still influences the physical-geographical processes in the western part of the Dutch Wadden Sea (Oost 1995; Oost et al. 2012; Elias et al. 2012; Wang et al. 2018). As a result, in the tidal basin and the unembanked salt marshes, the combination of relative sea-level rise and land subsidence creates storage potential in the basin, leading to increased sea ingressions (Jensen 2019). The reduced accommodation space generates a net influx of sediments, due to a so-called sand-hungry basin (Van der Spek 1994). Sand nourishment outside of the Wadden Sea system along the Dutch western coastline causes an extra sedimentary influx (Elias et al. 2012). Elias et al. (2012) concluded therefore that during the past century, cultural activities inside and outside the Wadden Sea area have been more important than relative sea-level rise from a physical-geographical development point of view. That is a striking conflict with the notion that the Wadden Sea is the "largest tidal flats system in the world, where natural processes proceed undisturbed" (UNESCO 2009).

In the triangle, for the duration of this period, we position zone 2 in the same position as the (former) terp landscape (zone 1), consisting of polders permanently cut off from flooding and sedimentation. The present mainland salt marsh fully overlaps with zone 4, with new summer polders adjacent to the seawall (zone 3) (Fig. 12).

The salt-marsh area along the mainland coast decreased by embankments including summer polders. While embankments also took place on the barrier islands, salt-marsh areas locally increased as a result of the construction of drift sand dikes. Both activities reduced dynamics and local set-back of succession. Moreover, the mainland marshes were homogeneous. Opinions on sedimentation fields changed at the end of this stage: it became less economically feasible for new agricultural land, and reduction of intertidal flats was no longer accepted, being foraging grounds for migrating birds along the East Atlantic Flyway.

Stage 5: Getting "nature/natural processes" back in the landscape (1969–present)

Over the past centuries, embankment rates in the Wadden Sea by far exceeded the development of new salt marsh, despite the anthropogenically stimulated reclamation works (see stage 4). Consequently, the extent of the current mainland salt marshes is much smaller in comparison with any historic reference (Dijkema 1987). This development caused a call for salt-marsh restoration in the Wadden Sea area during the past decades.

In 1969, a government decision made that the primary function of the salt marshes shifted from (potential) agricultural grounds, to coastal protection and nature conservation, and changed from "reclamation works" into "salt-marsh works" (Dijkema et al. 2001; Klinkhamer 1987). Because of high-intensity land use by intensive livestock grazing in some countries the salt marsh featured a "green" of very short homogeneous vegetation without flowering plants. The idea was to make the salt marshes more natural by cessation of grazing, despite the major role of artificial constructions in stimulating the development of these mainland salt marshes (Stock 1993). Hence livestock grazing was strongly reduced resulting in succession to tall vegetation (Esselink et al. 2017).

In stage 5, the concept of coastal realignment involved the reintroduction of tidal influence to formerly reclaimed salt-marsh land, often referred to as "giving it back to nature." One aspect is to restore the physical-geographical effect of tidal forces. This is carried out through breaching of summer dikes. Since 1973, some eighteen coastal realignment projects have been implemented in the Wadden Sea area by permanently opening up inlets in summer dikes on reclaimed or anthropogenically stimulated salt marshes in Friesland (The Netherlands) and Lower Saxony (Germany) or remove them completely (Table 1). When the restored salt marsh results from salt-marsh works with intensive draining system, tidal forces are not strong enough to overrule the pattern of ditches and re-create meandering creeks. Hence, in some former embanked summer polders creeks are dug to enhance sediment input, strengthening the notion that physical geography may be viewed by some as the form, rather than the process. An experimentally de-embanked summer polder showed compensation of the accretion deficit, inception of creek levees, salinization, and establishment of salt-marsh vegetation after 10 years (Esselink et al. 2015). Tidal influence can be restored completely by the removal of the summer dike, or partly by interruption of the function of sluices, the installation of new sluices, culverts, or dams. In the latter situation, a strong interplay between physical-geographical and cultural landscape components is the result. Ecologically, parts of the former salt marsh are becoming "salt marshes" again after de-embankment, which contributes to an overall increase in salt-marsh area in the Dutch Wadden Sea area over the past decades (Elschot et al. 2020). At some coastal stretches in Lower Saxony, seawall reinforcement is partly dependent on clay from the salt marsh by digging deep clay pits. Nowadays, this demand for clay is combined with restoration aims and re-designing the anthropogenically stimulated salt marsh without vegetation management ("giving back to nature") after landscape engineering. The results are "meandering" creeks and spontaneously developing vegetation (Esselink et al. 2017).

The second aspect of giving salt marshes "back to nature" is stopping intensive livestock grazing that resulted in homogeneous short vegetation without flowering plants (see "Methodology"). However, the important conclusion is that no grazing brings only part of the possible biodiversity. When the aim is an enhancement of biodiversity, low-intensity livestock grazing is applied to control vegetation succession. Wherever appropriate, a maximum biodiversity may be obtained by the introduction of a large-scale mosaic of different management regimes including a regime of minimum intervention (Wanner et al. 2014; Van Klink et al. 2016). Then the logical consequence is a large landscape variation (Esselink et al. 2017). Nature conservation agencies do not maintain livestock, and the sheep, horses, or cattle are from local farmers in the hinterland. It is interesting to see how this approach comes close to the variety of land use in the stage 2 terp landscape with small-scale low-intensity farming, indicating that the aim of a high natural value (high biodiversity) requires active physical-geographical processes (tidal influence) and a strong cultural input (grazing by livestock).

At a broader scale, efforts aim to restore the connection between the fresh hinterland and the saline Wadden Sea salt marshes. However, what has to be taken into account, that the hinterland is relatively low in comparison with the sea level, which has risen since the seawalls were put in place. Hence, pumping engines are built on the seawall (e.g., Hallum) to bring large amounts of fresh water into the salt marsh to enhance brackish conditions, which is an essential cultural feature in achieving natural goals. Fish migration installations are installed at various places along the coast (Bult and Dekker 2007; Griffioen and Winter 2017), and some future plans exist for opening up these walls and recreate an interaction between the seaward and the landward side for recreational purposes (e.g., the Holwerd aan Zee project along the Dutch Wadden Sea coastline). In such a way, both nature and culture may benefit.

The impact of cultural activities is significantly lower on the barrier island salt marshes. Locally, previously actively maintained sand-drift dikes are planned to be removed to restore physical-geographical components by dynamics of wind and water. Nonetheless, or maybe because of that, these will continuously be affected by the human-induced distortion of the sediment dynamics in the Wadden Sea as a whole by reducing the accommodation space (compare stage 4). Livestock grazing continues in many areas.

In the landscape triangle, the hard border between the area inside and outside the seawall remains clearly visible, but some changes occur. When applying the triangular approach to this stage, a slightly larger overlap must be allowed between the seaward marshes (zones 3 and 4) and the landward polders (zones 1 and 2, Fig. 13) in comparison to the previous stage. Despite these movements "toward nature," the seaward salt marshes continue to have a substantial cultural appearance, both as a result of their systematic formation history, the active management of some of their anthropogenically stimulated components as part of the coastal defenses, and livestock grazing.

Discussion

There is a sense of urgency, that there is a need for more cooperation between, and integration of, various disciplines in the study and management of landscapes and human-environment relations, both in the Wadden Sea area and in a more general sense (Atha et al. 2019; Enemark et al. 2018; Davis 2020). We acknowledge the important notion that what a landscape has been, is, and can be, is for a large part determined by human perception, but also agree that we should be "wary of the trap of radical constructivism" (Kolen and Renes 2015). In planning and management of landscapes, all too constructivist approaches are not that easy to deal with (Fairclough 2012; Weber and Kühne 2019). With respect to the nature-culture dichotomy, Kolen (2016), argues that we do not need more theory and perspectives, but instead look for simple solutions in pragmatic and workable approaches.

The proposed landscape triangle is such an approach. It acknowledges the three driving landscape forces in shaping the Wadden Sea area: physical geography, biology, and culture. It shows that all these play their roles in the appearance of the landscape, but more importantly, it visualizes that the diverse and complex interplay between these makes the current-day landscape what it is. Through space and time, the interplay shifts and therefore, we propose to use the triangulated approach diachronically. This also explains why we define cultural processes, and not cultural-historical processes. Cultural, in our view, relates to all human activities, ranging

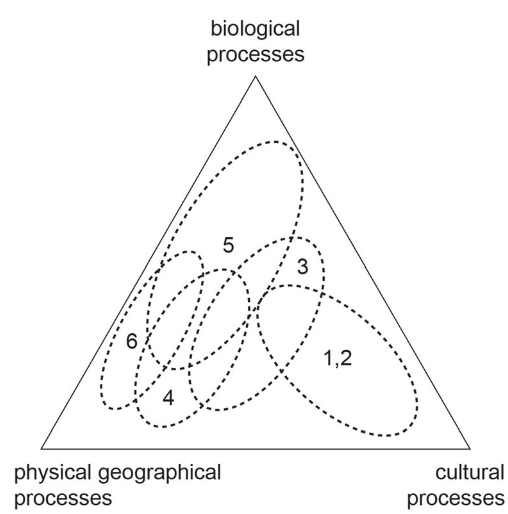

Fig. 13 The relative position of the salt-marsh zones for stage 5 (1969–present)

from tourism, to agriculture, to industry. We do, however, stress that physical remnants of cultural activities from the near and distant past are present throughout the area.

Importantly, the triangular approach is not designed to academically or objectively define a "desired" or "optimal" position for a specific landscape. It is thus, not strictly positivist. We would argue that the triangle actually facilitates a debate, or negotiation, on different perspectives and visions on the Wadden Sea area (Walsh 2018, 2020). We thus explicitly choose not to take a stand here in whether or not the cultural uses and history of the Wadden Sea deserve more appreciation (sensu Renes 2018), or if the number of cultural activities should be reduced to make room for a 'true national park' (sensu Jansen 2020). We do however, suggest to take the ecological, physical-geographical, and cultural history into account when making any plans for the future of (parts of) the area.

At the same time, in a more physical way, the triangle works to visualize, position, and analyze the interaction and importance of the different landscape forces physical geography, plants, animals, and humans for a specific location, or for the area in its entirety. Rising sea levels due to climate change are likely to affect the area substantially (Vermeersen et al. 2018). The triangle can help to operationalize landscape management in the wider Wadden Sea area, which could prove very useful given the challenges ahead (Reise 2017; De Vries 2019). An insight in developments through time is thereby of utmost importance, since "the baseline which different generations view as natural (for the Wadden Sea area) is shifting over time" (Lotze et al. 2005; Soga and Gaston 2018).

The triangular approach shows, that by taking the landscape as a starting point, none of the main factors is the a priori driving factor in thinking about the landscape. This is a noteworthy difference when compared to a division in, for example, natural and "semi-natural" landscapes, which seems to take nature as a starting point. A semi-natural landscape, however, implies still recognizable physical-geographical features, small-scale patterns of land use and characteristic plants and animals provided by for instance low-intensity farming (Bignal and McCracken 1996). In other words: it is a "complete" landscape in which none of the three processes dominates. Moreover, this approach allows more nuanced subdivisions, as has been shown by the slightly different positions of the pre-habitation salt marshes in stage 1, and the barrier island salt marshes in stage 5. It also encourages landscape managers to first fully grasp the different processes involved before taking decisions on management practices on one hand, and management aims on the other. So, using the triangular approach, it remains possible to decide to "apply pressure" from a specific angle.

We have shown that the location of a landscape within the triangle depends on time and space. One specific location may be differently positioned in the diagram in different periods. Similar landscapes on different geographical locations may be in different positions within the figure.

It must be stressed that the triangular approach is not meant to classify landscapes and we stress that we do not propose to discard of systems that do so. It is merely a concept showing the interrelation and inseparable connection between physical-geographical, biological, and cultural components within a landscape continuum, both throughout history and in current-day conditions. This means that, when valuing and managing the landscape in a sustainable fashion, all three factors should be acknowledged. It also shows, that when a landscape is valued as a natural or cultural landscape, it automatically means that other values are ignored.

Therefore, we advocate a landscape management approach that avoids a form of polarization that does not do justice to many centuries of interplay between physical-geographical, biological, and cultural forces in the area. This need not be a matter of making way for either nature or culture, but rather of embracing the particular richness of physical-geographical and biological phenomena resulting from their interaction with cultural influences or land use. We therefore propose to use the diachronic triangular approach of (heritage) landscapes can fulfill a crucial role in creating awareness and understanding of all factors that play a role in the landscape development. We welcome attempts to test the usefulness of the diachronic triangular landscape approach in other landscapes.

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Declarations

Conflict of Interest The authors declare no conflict of interest.

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