



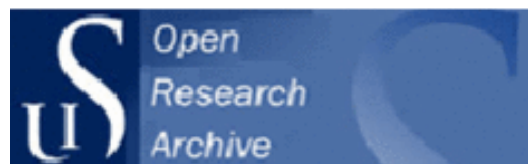
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Maritime Site Protection and the Fetch Method: an example from Rogaland, Norway

Marianne Nitter, Endre Elvestad, Lotte Selsing

Abstract

Predictions of future requirements for the protection of maritime archaeological sites are made using the fetch method which has been developed to evaluate the quality of landing-places and navigable channels. The very useful method may explain why archaeological sites along the coast are rare in some areas, but numerous in others. Many of them are vulnerable to destruction by the effects of climate change, especially rising sea-levels, based on the IPCC scenarios. The objective fetch method can be used worldwide to predict where new finds of sites close to sea-level can be expected, and also to predict a site's vulnerability.

Key words: fetch method, threatened maritime archaeological sites, landing-place, navigable channels, climate-change scenarios, rising sea-level.

Until recently, the Norwegian Cultural Heritage Act has been directed towards archaeological sites on land. There has been little focus on maritime archaeological sites along the coast and in the sea, even though they are protected by the same law as other cultural monuments (Norwegian Cultural Heritage Act sections 4 and 14). The archaeological sites below sea-level are managed by Norwegian universities and maritime museums. The Directorate for Cultural Heritage (*Riksantikvaren*) has concentrated the protection of coastal culture on buildings and the surrounding cultural landscape (Selsing *et al.*, 2005: 6).

Registration of maritime archaeological sites in Norway started much later than the registration of monuments on land (Elvestad, 2000; 2005a; 2005b; Elvestad *et al.*, 2009: 132). No overview of the types, age or the locations of maritime archaeological sites exists. In the national database of cultural monuments (*Askeladden*) very few maritime monuments are recorded; in 2008 there were no mooring or sailing marks, and only six quays and four landing-places. One reason for this is that marine archaeologists mainly concentrate on underwater projects.

Knowledge of the old landing-places, the function they had in the past and their importance is limited, while at the same time these sites are vulnerable (Nymo and Nævestad, 2006). Maritime archaeological sites are threatened because the beach-zone is being altered by increased boat-traffic which generates rapid waves with high erosive power, by an increasingly condensed urban population, and by building and recreational use of the beach-zone. The effects of these will be amplified in the future because of climate change and the rising sea-level.

Protection of maritime archaeological sites in areas related to landing-places and the main navigable channels in Rogaland is here elucidated from an interdisciplinary perspective combining marine archaeology, climatology and quaternary geology (Fig. 1). The aim is to create a base for evaluating the consequences of a rising sea-level. Local navigable channels and routes used by local fishing boats are therefore not included either in sheltered waters close to the coast or in open waters out to the fishing banks or deep-sea fishing. Data and analyses related to climate and climate space are used (Nitter, 2008; Nitter, 2009) as well as sedimentation rates in selected areas and sea-level changes. The results from these three fields of study are synthesised in the discussion with conclusions and recommendations for the protection of maritime archaeological sites associated with landing-places.

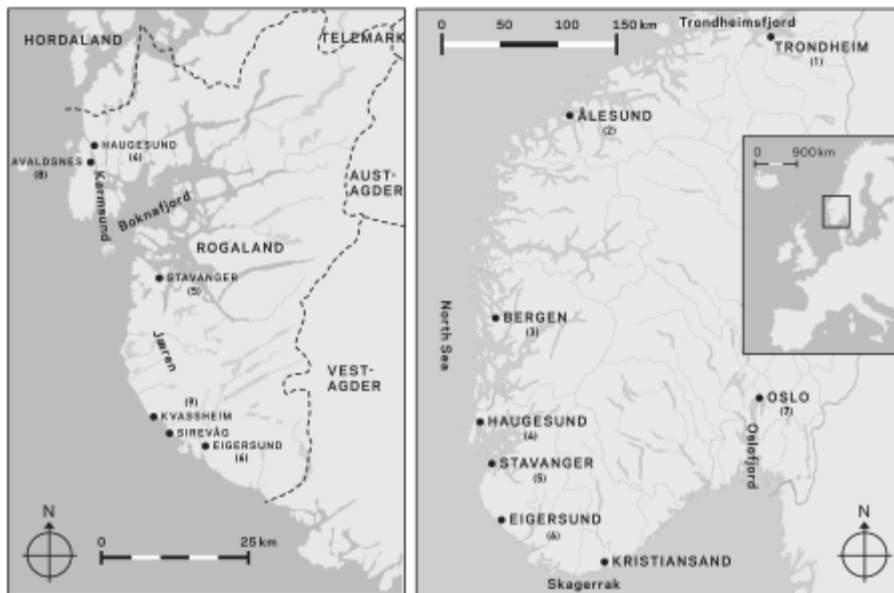


Figure 1.

Location of Rogaland in South Norway and the places mentioned in the text. (Drawn by Martin Blystad)

The example of Rogaland

Natural conditions such as coastal topography, type of coast and beach displacement were important for the choice of navigable channels and landing-places, as were conditions related to climate, currents and waves. Changes in the natural environment also provoked change in the usage of areas close to the coast.

Harbours and landing-places

Harbours are usually places that are protected from wind and waves, and where vessels can anchor or make fast. A good harbour should have an easy seaward approach, be relatively free of skerries and sunken rocks, the sea-floor ought to be good for anchoring and fresh water must be available. Different types of seamarks may show the route into the harbour, quays and buildings and fixed moorings may have been available to make it easier to handle cargo and take on supplies. The term anchoring-place is often used for simple harbours without built structures, but with good natural anchoring conditions and protection from wind and waves. Our understanding of what constitutes a harbour is affected by traditions of sailing ships, and more recently of motor ships, and it has probably excluded many landing-places.

A landing-place is any spot where a ship or boat can come close enough to land to allow the people on board to disembark safely. That may mean beaching the boat, or anchoring the boat and rowing or wading ashore. To prevent a definition from excluding specific types of harbours or landing-places in Norwegian the term *anløpsplass* is used as a place where ships and boats call in (Ulriksen, 1998: 13). It is often translated as landing-place, but the characteristics of a good landing-place are different from the characteristics of a good harbour. It is an advantage to be protected against wind and waves, but even more important are the landing conditions; a low beach relatively free of stones. A well-functioning harbour is

more dependent on protection than the landing-place because vessels were designed to surf on the waves of relatively high seas to land safely on the beach.

Sea-bed topography can also play a role because underwater barriers can calm the waves and make it possible to land safely in bad weather. A good landing-place has often been improved over time. Stones were removed from the beach, often at more than one spot allowing several vessels to land at once, and from under the water as far as was possible and necessary for vessels to float freely. On the shore there are often remains of boathouses. This kind of landing-place was common in the Iron Age (2440–970 BP, 550 BC–AD1030) and the Middle Ages (970–370 BP, AD1030–1535) (chronology, see Selsing, [2010](#): 24, table 4). Both written sources and archaeological finds confirm that it was possible to draw up even quite large vessels (for example *Landsloven* and *Byloven* from the 13th century, Falk, [1917](#): 37; Olsen and Crumlin-Pedersen, [1969](#): 132). This was common in western and northern Norway until recently. For example, smaller trading vessels were pulled up on land after ending the season or between trips (Kiil, [1993](#): 158–60).

A typical landing-place in the Iron Age and early Middle Ages was a shallow bay with one or more narrow entrances, or a beach where a vessel was easy to pull on land. Many Viking Age places of commerce were located in lagoons, which are well known on Gotland, east of the Swedish east coast, and on the south-west coast of Norway (Simonsen, [1969](#): 46; Lundström, [1971](#): 42; Nylén, [1973](#): 32; G. Lillehammer, [1988](#)). At the same time, in Denmark there was a tendency to locate landing-places at sites with a sandy bottom, rather than gyttja, for ease of carrying cargo between the vessel and the beach (Ulriksen, [1998](#): 115). Recent landing-places and navigable channels are relatively simple to map because of the many sources, such as charts and descriptions of sailing routes from the latter part of the 16th century until today (Elvestad, [2001b](#): 8). The landing-places mentioned in these sources are quite deep and protected from wind and high waves by the surrounding land. Landing-places in the Iron Age and the Middle Ages were of another character, at least in Rogaland, and they can be difficult to identify because the evidence is often only located on the shore.

Ship technology and navigable channels

The criteria for a good landing-place are dependent on vessel technology. Rowing vessels in the Iron Age and the Middle Ages did not draw much water and many could be manoeuvred with oars in shallow and narrow waters or into shallow and narrow harbours and landing-places (Elvestad *et al.*, [2009](#): 135–6). Oars were used as the method of propulsion until sail was introduced in the 9th century (Andersen and Andersen, [1989](#); Crumlin-Pedersen, [1997](#): 190). When sail took over it was more difficult to manoeuvre vessels in narrow stretches of water and probably both navigable channels and landing-places with a broader seaward approach were preferred.

Rowed navigable channels and landing-places from the Iron Age and early Middle Ages can be located using the principle of the present as a key to the past. Since the types of rowing boats and the method of propulsion have not changed, preferred fairways in the Iron Age and early Middle Ages may have been in protected waters, through sounds and narrow fiords avoiding the open sea if possible, as they are today.

A land-register from 1665 shows that some farms in Norway had reduced taxes because they were located on the ‘Alfar vey’ (*allfarvei*, the public road) (Myhre, [1959](#); Ætt og Heim, [1976](#) and later volumes; Elvestad, [2001a](#): 13). These farms had expenses connected to travellers

who stopped for food and lodging. Remarkably these farms are located in other areas than the main navigable channels of the same era (Elvestad *et al.*, 2009: 136–7). The *allfarvei* farms were usually not located at good harbours or anchoring sites from more recent times, because the authorities were rowed in vessels that landed on the beach. For rowing boats, the *allfarvei* farms had suitable landing-places in shallow bays where farm boathouses were often situated. Burial mounds, heaps of stones and standing stones are often located at the landing-places of *allfarvei* farms.

The location of *allfarvei* farms along ancient navigable channels may have been intentional (Elvestad *et al.*, 2009: 137). The geographical pattern and the distance between them indicate that it should be possible to row from one to the next before resting or changing the shift of rowers. Several alternative routes can be drawn between the *allfarvei* farms. The shortest route was probably dependent on the weather. Some of the *allfarvei* farms were located at the entrance to fiords or sounds, or where an open distance would be crossed. In summary, the *allfarvei* farms indicate a very old pattern of traffic, when the navigable channels used were better suited for rowed rather than sailed vessels.

Constructed marks

Marks in the Iron Age coastal landscape related to seafarers include symbolic expressions such as monumental graves, mounds, cairns or standing stones (Fig. 2), and monumental buildings such as halls or boathouses. They also include practical navigational aids or seamarks, such as cairns or beacons, and structures at the landing-places such as slipways, piers or boathouses (see Elvestad *et al.*, 2009: 138–42). In Norway, the cairns are simple constructions of stones with varying appearance depending on their function (Odden, 1998). They are still common in the mountain areas today, where some of them may date back to prehistoric times (Fønnebø, 1988: 77).



Figure 2.

Cairn on an Iron Age grave mound overlooking the sailing route, Låder, Rennesøy, Rogaland. (Endre Elvestad)

Already in the late-19th century, Bronze Age burial mounds in Denmark were identified as a possible indicator of traffic routes on land because they are located in rows (Müller, 1904: 55). This pattern of burial mounds is also identified in Rogaland from the Bronze Age to the Late Iron Age with a close relationship between visible mounds and very old landing-places. Many of them are located along traffic routes both on land and at sea, at road forks or where traffic moves from water to land. At Jæren in Rogaland there is a close relationship between

burial mounds and large cemeteries on the coast and very old landing-places, for example, the Iron Age cemetery at Kvasshem (Elvestad *et al.*, 2009: 140, fig. 8 and 169, fig. 25). This kind of landing-place was probably not only for the farmer's local use but also for the public and the authorities. Their importance disappeared in the late Viking Age and early Middle Ages when ships were no longer pulled up on the beach but were anchored. The North Sea coast south of Boknafjord, along Jæren to Sirevåg, which is formed of unconsolidated sediments, has a bad reputation because it is unsheltered, dangerous because of difficult current conditions and has no good harbours. Safe navigation was therefore especially important here.

The marks often had several practical, mythical and religious meanings (Elvestad *et al.* 2009: 137–8). Landscapes with burial mounds were, when they were in use, loaded with symbols which indicated a transition from one state to another (Rudebeck, 2001: 97–8). In this way the traffic routes associated with both sea and land could be associated with travelling from one world to another, from life to death and life after death, a journey to ancestors and cosmological places. The burial customs of the late Iron Age could have been a dramatisation of myths which link both the deceased and the family to a divine origin (Opedal, 1998: 91–2). This content was sealed in a monumental grave which very often was located at a highly visible site along important traffic routes. The graves were demonstrations of power, strategically placed where people travelled and served perhaps to signal supremacy through impressive monuments in the landscape to potential enemies from other areas. By locating graves at strategic places, where many people passed or rested, they gave signals and information to many other people.

Even if water and journeys may mediate transitions from one state to another, this does not explain why some monumental and rich graves are located at specific places and on certain traffic routes. When the graves appear monumental, they are monumental within the surrounding landscape and to specific directions in the landscape. This is particularly clear where the graves are located on promontories or hills visible from navigable channels. If the graves only had meaning for the family living on the farm this would not have been necessary. The location of the graves demonstrates that they were of importance for both the family of the deceased and for travellers who passed by. It is likely that the number and size of graves, and probably also the material value of their contents, can be related to the importance of the navigable channels and landing-places; the more important the navigable channel, the more powerful the symbolic expressions.

Landing-places and visible remains

Different types of landing-places (for example, for local transport and fishing, military purposes, trade or transshipment of goods) leave different types of archaeological material. Where vessels were pulled on land, traces may be found on land close to sea-level.

The different methods of mooring leave different traces, such as anchors or solid arrangements on land (Crumlin-Pedersen, 1997: 144; Elvestad *et al.*, 2009: 142–3). It is often difficult to identify constructed moorings at landing-places: erosion might cause destruction and therefore they may be mistaken as a natural part of the landscape (Fig. 3). As a result they are probably under represented.



Figure 3.

A mooring stone at Lahammar, Avaldsnes, exemplifies the difficulty of identifying maritime archaeological sites in south Norway. (from Elvestad *et al.*, 2009: 144, fig. 12)

Anchors have been used since at least the Bronze Age, but it seems reasonable that they became common for mooring when the vessels became so big that it was impractical to pull them on land or when there were not enough crew. This probably occurred during the Viking Age when heavily loaded trading ships had only a small crew. During the Viking Age the use of landing-places changed from pulling vessels up on land to the use of basins and bays, as indicated by the details in the Norse Law about the organisation of harbours and mooring. Both written sources and archaeological finds indicate that, in addition to anchors, ships could be moored to trees, stones or wooden poles. From the 16th century iron rings were used (Rode, 1941: 14, 214 and 224).

Activities at landing-places left specific distribution patterns of objects and rubbish related to the vessels and the activity around them. Preparation of food, eating and sleeping happened both on board the vessels and on land in the early Middle Ages. Remnants of these activities include fireplaces, cooking stones, cleared areas for tents and garbage (Elvestad *et al.*, 2009: 146–7). The accumulation of cultural layers is dependent on the intensity of activities over time. At transshipping or trading places, ballast and trading goods are usually found, including rubbish and broken or lost objects. In some cases ballast was dumped at landing-places close to the transshipping place (Elvestad *et al.*, 2009: 147). The remnants of pottery found at many landing-places give good opportunities for precise dating of the stratigraphy.

Nature and landscape

The topography around a landing-place determines exposure to wind, waves and currents. The exposure of unconsolidated sediment along parts of the North Sea coast results in continuous changes of the coast at Jæren, for example. The unconsolidated sediments are reworked by rivers, wind, waves and sea currents during heavy weather conditions.

The vertical beach displacement since the last Ice Age is well-known for South Norway (for example, Hafsten, 1983; Kaland, 1984; Kleppe, 1985; Prøsch-Danielsen, 2006). In the Iron Age and early Middle Ages in south-west Norway, beach displacement was $\frac{1}{2}$ –2 metres vertically. The coastal palaeogeography at Jæren has been reconstructed for two phases by Bang-Andersen (1986: 63, figs 4 and 5). Beach displacement and the resultant changes in

sedimentation processes entailed changes in harbour conditions along the coast. In many places the cultural layers formed in the marine environment in areas with landing-places have been raised by about ½–1 m since the Viking Age. They are located close to the level where the activity of waves and currents is most intense and are therefore often at risk of being destroyed by sea action, as well as human factors such as development and boat traffic.

Erosion and transport of sediments

Little is known about how erosion from water, wind and ice influenced the archaeological remains on the beach and in shallow water compared to those located on watercourses (Bang-Andersen, 1990: 215–6; Indrelid, 1994; Bang-Andersen, 2006; Nymo and Nævestad, 2006: 77–82; Indrelid, 2009). In exposed areas, waves cause erosion depending on their size. At the outer, unprotected coast, or in the long fiords, wave action can be seen at depths of more than 20 m. This implies poor conservation for maritime sites because the waves may wash away the sealing sediments that protect them from oxidation, and which are required to preserve organic material and other remains in context. In less exposed areas, protective sediments may be undisturbed and, where the waves are low, the sealing sediments may survive even in shallow depths.

Landing-places are located in the beach-zone where the sedimentation environment is very complex. Conditions change based on beach displacement, waves, tide, wind, currents and drainage from land. Erosion and the breakdown of landing-places are therefore complicated processes. Also, erosion will vary in proportion to the sea-bed topography close to the landing-places, which is difficult to observe (see for example Mathisen and Prestmo, 1999). Erosion may ruin archaeological maritime sites because stratigraphy, find-distribution and context are disturbed. This is especially important at shallow landing-places from the Iron Age and the Middle Ages, where archaeological evidence is the only sources of knowledge about them.

Seaweed and other marine plants and animals can reduce erosion and the transport of sediments. The same is true of the vegetation cover along the coast, because it keeps mineral and soil particles in place, which reduces erosion and soil and sand drift (Bahnsen, 1973; Selsing and Mejdahl, 1994; Prøsch-Danielsen and Selsing, 2009). Sand-drift has affected conditions associated with the landing-places, especially along the Jæren coast.

Sedimentation

Information concerning sedimentation and stratigraphy at landing-places is sparse (Bill and Clausen, 1999). The sediments from Middle Age landing-places in Bergen and Oslo were mostly fine inorganic particles, rich in organic material from anthropogenic rubbish, mixed with natural sediments (Krzywinski and Kaland, 1984). Sedimentation conditions probably varied dependent on the proximity of the settlement to the beach, human activities and variations in natural conditions. Preservation conditions have therefore changed over time and natural processes have destroyed organic material unless it was sealed beneath protective sediments. The conditions described at constructions related to landing-places outside towns are comparable with those in many coastal Middle Age towns, with a mixture of terrestrial and marine, natural and anthropogenic sediments. This type of site requires an interdisciplinary approach to disclose the processes that formed the deposits (Heimdahl *et al.*, 2005).

Unfortunately, only a few investigations have focused on the destruction of cultural layers at landing-places. At the landing-place of Avaldsnes, analysis indicates quite a high rate of sedimentation during the Middle Ages (*c.*30 mm per 10 years, Simonsen, 1978). This is slightly lower than the minimum rates of sedimentation of the anthropogenic sediments in more recent times in Vågen, close to Bryggen in central Bergen, where the upper sediments may already have been lost (50.7 and 43.5 mm per 10 years, Mathisen and Prestmo, 1999). The average yearly rate of sedimentation at Bryggen is 23 mm in the period 1170–1198 AD and 14 mm in the period 1198–1248 AD for the layers of rubbish (Hansen, 2003: 87). The composition and depth of the early deposits of rubbish ('unit 7') at Bryggen indicate that, if the accumulation of sediments was not fast and/or intensive, the organic components would have been washed away by the sea (Krzywinski and Kaland, 1984; Hansen, 2003: 83, 85–7).

For comparison, the rate of sedimentation was calculated for natural marine gyttja and freshwater gyttja without any known anthropogenic elements, mainly from basins close to the coast in South Norway, preferably isolated basins (Elvestad *et al.*, 2009: 150–1, table 1). The calculation shows a variation in the rate of natural sedimentation from 1 mm to more than 10 mm per 10 years and with an average of about 4–5 mm per 10 years. This shows, as expected, that the rate of sedimentation close to the coast is many times higher where the sediments are dominated by anthropogenic material than during natural sedimentation alone.

The fetch method

Wind conditions are one of the main factors governing current and waves. With wind direction changing constantly, this may result in a disorderly and chaotic wave pattern, especially in open sea. The following definitions are used for waves: 'wave-height' is the difference in height between the bottom and the top of the wave; 'significant wave-height' is defined as the average height of the highest one third of the waves.

Three factors are important when calculating wave-height: the fetch – the distance the wind blows over the sea (at a specific site the fetch of the wind will vary in relation to wind direction); the wind strength, both prevailing wind and gusts; and duration – how long the wind blows. Wave-height, as a function of the fetch, strength and duration of the wind, can be expressed by a mathematical formula (Grøen and Dorrenstein, 1976; Elvestad *et al.*, 2009: 154, fig. 19). Significant wave-height is calculated using a manual wave forecasting diagram (see WMO, 1998:44, fig. 4.1) with the following parameters:

- Horizontal axis: wind duration (hours)
- Vertical axis: significant wave height (m)
- Diagonal lines from left to right with intervals of 2.5 or 5 m/s: wind speed (m/s)
- Lines crossing the wind speed-lines at different intervals: the fetch (km)

The relation between wind speed and wind duration at open sea can be illustrated by two examples where the wind speed is 7.5 m/s and 30 m/s. The two wind speed lines follow each other. This illustrates that after six hours the significant wave-height had increased to 1 m and 8 m, respectively. The highest possible wave-height with these wind speeds is reached after 96 hours. This is termed the maximum significant wave-height and the values are 1.4 m and 21 m, respectively. The fetch, however, is an additional factor, which limits the wave-height considerably. Follow the wind speed line from left to right with a fetch of 6 km in both examples until the lines cross the 6 km fetch. The horizontal and vertical axis show that after

1.5 hours the maximum significant wave-height is 0.45 m when the wind speed is 7.5 m/s. The maximum significant wave-height is 2.2 m after 0.7 hours when the wind speed is 30 m/s.

The presentation of the fetch method used here has some weaknesses and limitations. The formula is valid for open sea, but the sites analysed are inside the skerries. Thus the formula is used for a topography for which it was not developed. The real values for maximum significant wave-height will be considerably lower because the wave-height is reduced by friction and spreading within the skerries. The topographical conditions both above and below sea-level play a significant role in how wave-energy, and therefore wave-height, are reduced at a fixed point (WMO, 1998). Maximum significant wave-height therefore must be seen as a trend and in analyses the difference between the values is most important.

Many habitats and activities are vulnerable to wave-action. Increased probability of extreme wave-height is a central question in relation to future climate changes. Therefore, wave-models applicable to large geographical areas, such as the North Atlantic, have been developed (Reistad 2001, Debernard *et al.* 2002, Swail *et al.* 2005). A numerical model for smaller areas, such as fiords, has also been developed (Rohweder *et al.* 2011). However, it is demanding, requiring detailed wind data from the area under consideration (for example Kvamme & Reistad 2006), and a field specialist to develop the model. Kvamme & Reistad (2006) have developed an analysis of risk and vulnerability for the beaches in the municipality of Bergen as a tool for planning. They used a weighted version of the fetch method and calculated the maximum significant wave-height along parts of the archipelago. This method can be used for fiord areas along the entire Norwegian coast. Such calculations and data simulations are also time consuming and require both expertise and computer power.

Our method can be used widely, even in the field, to calculate a specific location's vulnerability to wave-action, to search for maritime archaeological sites for example. We emphasize the simplicity of our method, our aim being that an archaeologist should not need to consult specialists to evaluate the potential of a site as a landing-place; it should be possible to make one's own calculation without delving into the complicated physical-mathematical background of the fetch. We emphasize that the fetch method is reliable in the form used here.

Avaldsnes was used to test the fetch method (Fig. 4). Two prehistoric landing-places with traces of piers were chosen (A and B, Fig. 5). The fetch was calculated for the wind directions which cause waves at both landing-places. The wind sectors were roughly estimated and delimited by topography in such a way that the entire wind sector represents approximately the same fetch. The two landing-places were both vulnerable to easterly wind, which is frequent from November to February (Table 1) (see also Elvestad *et al.*, 2009: 155–6, fig. 20 and table 2). However, the results from points A and B show that shifting a landing-place by a few tens of metres changed the wave climate considerably because the sites were then vulnerable to different wind directions. This indicates that detailed local knowledge was required in the choice of landing-place (Elvestad *et al.*, 2009: 153–8).

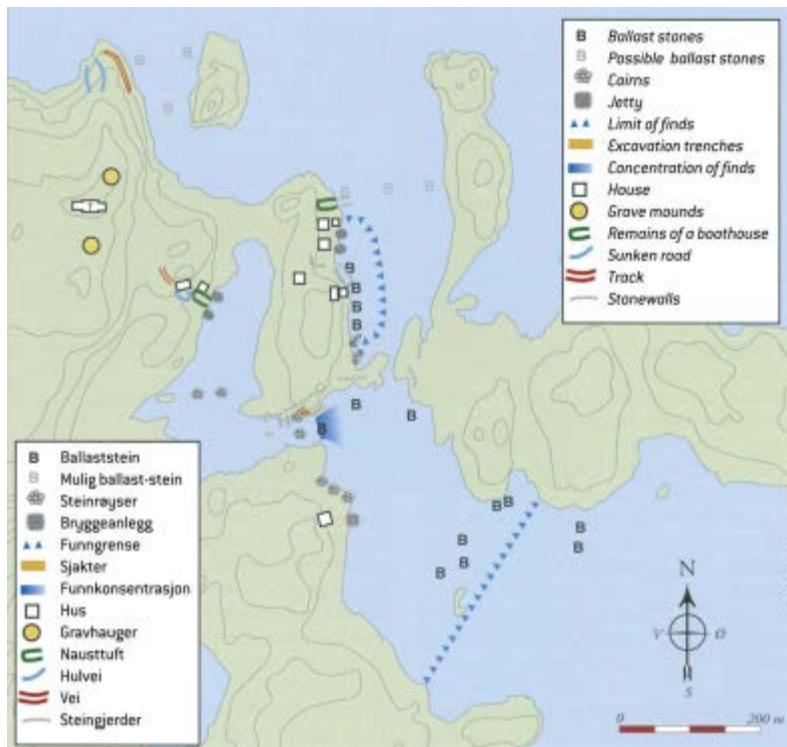


Figure 4.

Map of archaeological sites recorded in the sea and on land around the landing-places at Avaldsnes, south-west Norway. (from Opedal *et al.*, [1999](#): 109, fig. 6)

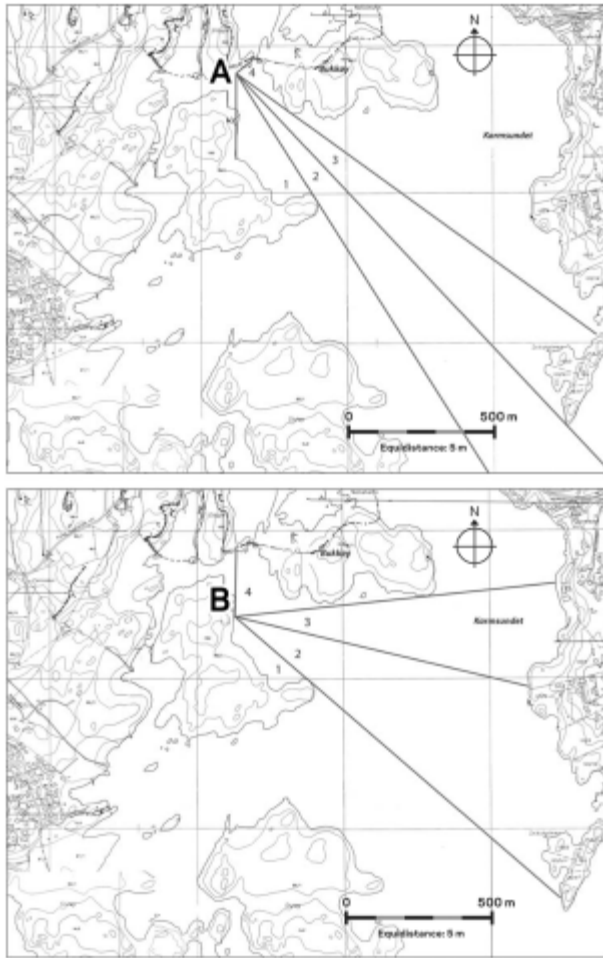


Figure 5.

Four chosen wind sectors for the two Middle Age landing-places A and B at Avaldsnes. The wind sectors represent the same fetch. Maximum significant wave-height is calculated for each wind sector. (Elvestad *et al.*, 2009: 158, fig. 22) (see Table 1)

Table 1. Calculated fetch and maximum significant wave height for wind sectors 1–4 at points A and B, two Middle Age landing-places at Avaldsnes, marked in Fig. 5. (Elvestad *et al.*, 2009: 159 table 4)

Wind sector	Fetch (m)	Maximum significant wave-height (m)
<i>Point A:</i>		
Sector 1: wind from S/SSE	200–400	0.2–0.3
Sector 2: wind from SSE/SE	4000	1.8
Sector 3: wind from SE	1100–1400	1.1
Sector 4: wind from SE by NE	100–200	0.1–0.2
<i>Point B:</i>		
Sector 1: wind from S/SE	100–300	0.1–0.25
Sector 2: wind from SE by E	900–1200	0.9–1.1
Sector 3: wind from E	900–1100	0.9–1.0
Sector 4: wind from E/NE by N	200–300	0.15–0.25

The fetch method and climate space

The fetch method was introduced to evaluate the quality and location of navigable channels and landing-places related to climate variables such as wind (speed, direction and duration), topography, vegetation and fetch (Elvestad *et al.*, 2009: 153–63). The main wind directions are calculated from the wind statistics for a specific area. The wind conditions on the coast change from day to day, and also throughout the year (Elvestad *et al.*, 2009: 156, fig. 21 and table 3; see also Nitter, 1999). The wind has a tendency to follow the large elements in the landscape (Utaaker, 1991), and on the coast and in the inner fiord districts both a local strengthening and limitation of the wind may occur. Because large parts of the Norwegian coast are unsheltered from the dominant wind directions, the choice of landing-places and navigable channels was important (Ramberg, 2005). The wave climate is particularly important for good landing-places and is dependent on the wind climate and the topography in a given area (for example Oke, 1978; WMO, 1998).

The concept of climate space is a tool to map the factors which are determined by the wave and wind climate at a site (Nitter, 2008; 2009). Different weather phenomena exist within different limited areas, the climate spaces, defined by an area limited by topography and vegetation, where the climate is homogeneous with regard to a specific climate parameter such as temperature, precipitation, wind-direction or speed. A climate space may be defined within four different levels: macro, meso, local and micro, because different weather phenomena occur at different levels horizontally as well as vertically. Different time-scales are used for the four levels (Nitter, 2009: 121, table 1).

This work focuses on the conditions inside the skerries. The fetch method helps to explain why archaeological sites along the coast are rare in some places, but numerous in others. The landing-places in the Middle Age towns of northern Europe are well known, which is not the case for areas outside the old towns. The fetch method can help to predict where the good landing-places and navigable channels were located. During the 16th century, both pilots and the location of farms indicate that the main navigable channel around Jæren had a more westerly location (through the Karmsund) than in earlier periods, when it followed a more protected easterly route. This was confirmed by the objective fetch method (Elvestad *et al.*, 2009: 159–63).

Landing-places and climate space

The height of waves is greatest in climate space on a macro level and smallest on a micro level. Landing-places and navigable channels can be in different levels of climate space because the fetch can change. The navigable channels and landing-places inside the skerries are related to climate space on meso, local and micro levels. For a specific site, such as a landing-place, the climate space changes character with changing wind direction, and therefore the optimal site will move depending on wind conditions. For climate space related to navigable channels, the focus is the site on the route for which the height of the wave is to be calculated. The fetch is calculated for every relevant wind direction and when the fetch changes from one site to another a new calculation must be made because the different navigable channels are vulnerable to different wind directions (see examples in Elvestad *et al.*, 2009: 157–63).

Western Norway forms a single climate space on a macro level and, as waves are a consequence of wind, Western Norway is also one big climate space on a macro level with regard to waves. The fetch method used in the North Sea and the Skagerrak shows that the maximum significant waves are higher than 10 m and winds from the south, west and north (180°–270°–360°) cause waves up to 15 m because the fetch is up to 600 km.

Climate space on a meso level can be a fiord or a fiord basin. The fetch is, however, the most important criterion for grouping dependent on wind direction, which means that a specific fiord can be in different levels of climate space (Elvestad *et al.*, 2009: 162–3). Therefore, the yearly cycle in south-western Norway means the fiords' climate spaces can be studied at a meso level, with maximum significant wave-height at 2.6–10 m, and more rarely at local or micro levels with a maximum significant wave-height.

Climate space at the local level has a horizontal limit of 100 m to 20 km dependent on the small-scale topography. The day-to-day variations in the wind climate are linked to large weather systems, which cause changes in wind direction and speed, and the related local climatic conditions for wind and waves with maximum significant wave-height at 0.1–3.7 m. It is a challenge for people today to choose the safest landing-place or navigable channel (Nitter, 2003). All the islands in the Boknafjord basin contribute to form the setting for the climate spaces on local or micro levels. Climate space on a micro level has a horizontal extension of 1 cm to 1000 m with a maximum significant wave-height of 0.0 to 1.0 m. For example, a sound, a part of a fiord, a bay or one landing-place are climate spaces on a micro level.

Future climate variations

South-western Norway is located in the North Atlantic cyclonic circulation zone with the polar front, which greatly affects the variation of climate. Climate has changed over time, here exemplified by the past 1,000 years. The Middle Age Warm Period in the early Middle Ages was characterized by a higher frequency of anticyclonic circulation over South Norway, with 0.7–1.0 °C higher average summer temperatures than today. The Little Ice Age, on the other hand, was characterized by glacial advances and a decline in the forest limit in the mountain areas (Lamb, 1977; Grove, 1988; Selsing *et al.*, 1991: 227; Dahl and Nesje, 1994; Wishman, 1994; Gunnarsdóttir, 1999; Bjune *et al.*, 2005). The frequency of cyclonic circulation was high, with rough weather, storms and crop failure. For example, the winter 1821–1822 at Jæren was stormy, with many shipwrecks (Kastellet *et al.*, 1998: 58).

The climate change affected the traffic at sea, choices of navigable channels and landing-places, especially during extreme weather conditions. Information from diaries, archives and newspapers can be used to calculate the vulnerability of specific archaeological sites. The surface temperature of the Earth increased by 0.74°C over the past 100 years and scenarios indicate that before 2100 the global average temperature will increase by 1.1–6.4°C depending on greenhouse gas emissions (IPCC, 2007). Over the past 100 years in Norway, the increase in temperature and changes in the pattern of precipitation have differed from region to region and from season to season (Hanssen-Bauer and Førland, 1998; Hanssen-Bauer and Nordli, 1998; Hanssen-Bauer, 2005). Vulnerability to climate change is therefore different from region to region.

The prognoses for 2100 show that the yearly average temperature will increase by 2.5–3.5 °C and the climate will be wetter in Norway (Iversen *et al.*, 2000; Iversen *et al.*, 2002; Iversen

et al., 2005), with variability at the same level as the past 100 years. The highest increase in temperature will be in the north, in accordance with global results (IPCC, 2007).

Predictions indicate that the climate will probably be windier in Norway. The model calculations indicate an increase of 0–5% in wind speed towards 2050 and with more strong winds (Haugen *et al.*, 2008). Strong winds that today are expected once a year may occur as much as twice as often along the western part of the Norwegian coast in the period 2030–2050 (Iversen *et al.*, 2002). Towards 2100, all of Norway will probably get four more 24-hour periods with stronger wind than near gale annually (Iversen *et al.*, 2005). Statistically, there are no significant changes for waves and storm surge in the Norwegian waters. Small changes for wave-height and storm surge are predicted for the north and along the coast of the south-eastern part of the North Sea (Røed and Debernard, 2005). During a period of global warming the frequency of extreme wave-height and storms cannot be excluded (Røed and Debernard, 2008).

The increase in global average temperature will have consequences for the rise in global sea-levels. This will have consequences for Norwegian landing-places. The beach displacement indicates which areas will be most vulnerable to erosion when the sea-level rises in the coming years (Mäkinen *et al.*, 2005; Drange *et al.*, 2007). The global sea-level increased by 17 cm over the past 100 years and 1–2 mm per year over the past few years. The increase will accelerate over the next few decades towards the 22th century (IPCC, 2001; IPCC, 2007). Discounting isostatic uplift, the rise in sea-level along the Norwegian coast was 14 cm from 1891 to 1990 (Vestøl, 2006), caused by the expansion of water with higher temperatures and by melting ice and snow.

Model calculations show different scenarios for greenhouse-gas emission towards the close of the 21st century. One of these indicates a rise in sea-level of 55–110 cm compared to 2000 (Rahmstorf, 2007). This model was used to calculate changes in sea-level for Norwegian waters and 10 cm was added in the areas close to the Norwegian coast because of the current conditions (Drange *et al.*, 2007: 30). Because the isostatic uplift along the south and west Norwegian coast is smaller (5–13 cm) than in the inner Oslofjord and Trondheimsfjord (24 cm) the rise in sea-level will be higher in the south and west than in the Oslofjord and Trondheimsfjord (Drange *et al.*, 2007: 31, table 1). Vasskog *et al.* (2009: 4) calculated the rise in sea-level over the course of the 21st century to be about 70 cm along the south and west coast of South Norway and about 40 cm in the inner part of Oslofjord and Trondheimsfjord, with an uncertainty of minus 20 cm and plus 35 cm. Instanes (2007) criticized Rahmstorf's model (2007) as being too simple and that the results therefore are exaggerated, suggesting the rise in sea-level along the Norwegian coast will influence infrastructure and constructions only to a minor degree. This is, however, in contrast to ACIA (2005) who pointed to problems related to more open water that probably will result in more erosion caused by waves.

Preservation over the next 100 years

The causes of reworking of sediments through water action close to sea-level are complex. Construction work close to and in the sea have changed current conditions in many places (for example, Mathisen and Prestmo, 1999; Nymoene and Nævestad, 2006: Chapter 5). Changes in boat traffic since the 1970s have involved fast and radical changes in the sedimentation conditions close to land (Nymoene and Nævestad, 2006: Chapter 6.6). The frequency of the traffic has increased and the types of vessels have changed character, for example, supply boats, tugs and tankers that serve the oil industry are not suited to traffic in sheltered waters.

Vessels calling at port lead to an especially high risk of erosion, particularly because of propeller erosion (Magnusson, 1995). The use of anchors may also disturb sediments. These activities may damage old landing-places and other archaeological sites close to sea-level. For example, significant changes in the *in situ* upper cultural layers have been observed at the landing-places at Avaldsnes (Elvestad, 2001a).

The quality of the sediments is an important element in the whirling effect boats cause in harbours on arrival and departure from quay (The Norwegian Coastal Administration, 2002: 23). Sediments normally become resuspended when manoeuvring large vessels in harbours and must be a problem in many other places with shallow water. Waves spread from fast vessels and reach land with surprisingly high strength (The Norwegian Coastal Administration, 2002: 24). Strengthened by wind in combination with a long fetch, these waves result in the erosion of sediments in the coastal zone, the fiords and the narrow straits in West Norway. Waves, noise and risk are the effects of a moving vessel on the surroundings mentioned in the present regulations. It is also mentioned that waves that break on the coast may result in erosion and reworking of the sediments (The Norwegian Coastal Administration, 2002: 16, 20 and 25). However, the effects of erosion are not mentioned by the Norwegian Coastal Administration (2002) and respect for the environment has a low priority.

The predictions for the rise in sea-level towards 2050 and 2100, along with the lack of knowledge about erosion in the zone close to the beach, present a problem for the protection of maritime archaeological sites. Predictions for transgression presented in Drange *et al.* (2007) are of the same magnitude as the regression seen since the Viking Age and will produce the opposite situation to the general regression in South Norway during the past 5500 years. A consequence will be a larger volume of water and therefore probably greater erosion in many places along the coast. Seven examples from South Norway illustrate the problems of a rising sea-level for the protection of threatened landing-places (see Elvestad *et al.*, 2009: 168–79 for further details) (Tables 2, 3).

Table 2. Predictions of threats to selected sites posed by climatic change in the 21st century

Site (number, see Fig. 1)	Prehistoric and historic setting and predictions for required protection	References
1) Trondheim Middle Age town, Middle Norway	At the mouth of Nidelv. Remains of poles, quay structures and jetties locate landing-places. Remains of wooden terraces and poles show a continuous development of harbours and jetties along the river. The fronts of the quays were moved further out into the river 1000–1150 AD. This site has the highest possible calculated storm surge in South Norway.	Christophersen, 1991; Christophersen and Nordeide, 1994: 84–97; Gundersen, 2000; Sandvik, 2006a; Elvestad <i>et al.</i> 2009: 176–7
2) Borgund Middle Age town, east of Ålesund, in	The landing-place with remnants of a pier, boathouses and storehouses has been filled in. The cultural monuments in the landing-place are especially exposed to wind and	Sørheim, 1990; Sørheim, 1997; Sørheim, 2004; Elvestad <i>et al.</i> 2009: 177, figs. 33–4

north-west South Norway	current from a very narrow wind sector from the west-south-west.	
3) UNESCO world heritage protected Bryggen in Bergen, west Norway	<p>The king's residence from c.1070, with the harbour in Vågen as the centre for trade. Vågen extends to the north-west and south-east for 1.4 km and is 14 m deep with an underwater barrier. The width of the bay has been halved since the 11th century. Many archaeological sites exist. Organic deposits show many signs of reworking. Fires destroyed the Middle Age town in every century. The burnt remains contributed to filling up the harbour and the town spread over the earlier harbour area sealing earlier cultural layers. The landing-places were moved seawards because of rubbish dumped in the harbour.</p>	<p>Herteig, <u>1959</u>; Herteig, <u>1969</u>; Krzywinski <i>et al.</i>, <u>1983</u>: 145; Krzywinski and Kaland, <u>1984</u>; Herteig, <u>1985</u>; Hjelle, <u>1986</u> figs. 21–2; Hansen <u>2003</u>: 168–9, figs. 21–2; Hansen, <u>2005</u>: 106, 108, 112–3, figs. 21–2, 207–8, figs. 55a–b, 211, figs. 56a–b, 214–5, figs. 57a–c and 216, fig. 58; Elvestad <i>et al.</i> <u>2009</u>: 174–6, figs. 31–2</p>
5) Stavanger Middle Age town, south- west Norway	<p>The harbour below Vågen was the main landing-place probably from the 12th and 13th century. North-north-westerly winds complicated manoeuvring in historical times. A small rotation in max. fetch (compare Table 1) towards the north (324–336°) reduced maximum significant wave-height from 4.2 to 2.4 m and a change in climate space from meso to local level.</p>	<p>A. Lillehammer, <u>1972</u>; Simonsen, <u>1972</u>; A. Lillehammer, <u>2000</u>; Dunlop and Sandvik, <u>2004</u>; Sandvik, <u>2006b</u>; Sandvik, <u>2006c</u>; Sandvik and Hafsaas, <u>2005</u>; Elvestad <i>et al.</i> <u>2009</u>: 173–4 fig. 30</p>
7) Gamlebyen Middle Age town, in Oslo, south-east Norway	<p>Located at Loelv, close to the fiord. Isostatic uplift is the main reason for the present day location, several hundred metres from the sea. Rubbish was dumped in the sea. Middle Age jetties and thick cultural layers exist in Oslo Harbour along with large quantities of rubbish from 17th and 18th century boat traffic. The islands in the fjord moderate the wave climate considerably for the wind directions that form waves. The archaeological sites are well protected from other wind directions than those mentioned in Table 3.</p>	<p>Hafsten, <u>1983</u>: 67 fig. 3; Schia, <u>1987</u>; Schia, <u>1988</u>; Schia, <u>1989</u>; Schia, <u>1991</u>; Schia and Wiberg, <u>1991</u>; Riksantikvaren, <u>2008</u>; Elvestad <i>et al.</i> <u>2009</u>: 176–7</p>
8) Avaldsnes, Karmsund,	<p>Many archaeological remains on land and in the sea. A Viking Age king's centre with large concentrations of</p>	<p>Simonsen, <u>1978</u>; A. Lillehammer <u>1989</u>; A. Lillehammer <u>1994</u>; Opedal <i>et al.</i>, <u>1999</u>; Elvestad and Opedal,</p>

south-west Norway objects in the sea, good conservation conditions, cultural activity increased in the 10th century and the infilling of the landing-places started in the 11th century. Two landing-places are vulnerable to changes in wind (see text).
 In a lagoon. One of few good landing-places along the Jæren coast, in use until 14th century. Close to an Iron Age cemetery, boat houses and burial mounds. The archaeological sites are protected from demolition by younger sediments if no physical encroachment is made by people. They are, however, threatened by erosion with higher sea level.

9) Øyren, Horr close to Kvasheim, Jæren, south-west Norway
 Simonsen 1969: 46; Rolfsen, 1974: 33; G. Lillehammer, 1988; G. Lillehammer, 1996; Elvestad *et al.* 2009: 140, fig. 8 and 168–9 fig. 25

Table 3. Predicted protection requirements due to a rising sea-level for selected landing-places in the Iron Ages and the Middle Ages in South Norway based on the IPCC Special Report on Emissions Scenarios A2 (<http://www.ipcc.ch/ipccreports/tar/wg1/029.htm>). (Sources 1. <http://www.vannstand.no>, The Norwegian Hydrographic Service; 2. Elvestad *et al.* 2009: 168–77; Other information is from Drange *et al.* 2007: 31, fig. 3 and table 1.)

Site (see Fig. 1)	Average rise in sea level (cm) by 2050 ¹	Average rise in sea level (cm) by 2100 ¹	Highest/lowest observed sea level in cm (yr) ¹	Storm flood (cm) by 2100 from closest coastal city ²	Most vulnerable wind sectors ²	Max. significant wave height (cm) ²	Level climate space ²
1) Trondheim Middle Age town	7	41	419 (1971)/-37 (1980)	Trondheim (299)	WNW/N/NE	350	Local
2) Borgund Middle Age town	22	71	305 (1993)/-38 (1996)	Ålesund (262)	WSW, max. significant fetch 263–270°	450	Local
3) Bryggen in Bergen	23	73	241 (1990)/-42 (1980)	Bergen (235)	NNW	300	Local
5) Stavanger Middle Age town	26	78	184 (1994)/-17 (1996)	Stavanger (204)	NNW, max. significant fetch 322–324°	420	Meso
7) Oslo Middle Age town	7	41	261 (1914)/-47 (1999)	Oslo (231)	S/SW	120	Local

Site (see Fig. 1)	Average rise in sea level (cm) by 2050 ¹	Average rise in sea level (cm) by 2100 ¹	Highest/lowest observed sea level in cm (yr) ¹	Storm flood (cm) by 2100 from closest coastal city ²	Most vulnerable wind secotors ²	Max. significant wave height (cm) ²	Level climate space ²
8) Avaldsnes, Karmsund	27	80		Haugesund	SE/SSE	110–180	Local
9) Kvassheim, Jæren	27	80		Eigersund	SE/S/SW/W	2000	Macro

These predicted sea-level changes, along with the possible storm surge in 2100 are taken from Drange *et al.* (2007: 31, fig. 3 and table 1). A more recent report corrects the rise in sea-level by a few centimetres (Vasskog *et al.*, 2009). The fetch indicates from which direction a landing-place is most exposed to wind and current and therefore the directions from which it is difficult or impossible to use (Elvestad *et al.*, 2009: 153).

The submarine archaeology at Avaldsnes is especially threatened by a higher frequency of south-easterly wind, which will cause further erosion. Probably, the archaeological material will suffer oxidation and will be reworked out of context, thus reducing its value. This was confirmed by significant changes in the upper sediments, especially in the inner area of landing-places, but also in a narrow sound that separates the inner from the outer areas (Elvestad *et al.*, 2009: 132) (Fig. 6).



Figure 6.

Cultural layer in the Middle Age harbour at Avaldsnes, Karmøy, Rogaland. (Endre Elvestad)

The Iron Age and Middle Ages remains close to sea-level at the seven selected sites will be, in general, seriously exposed to erosion and destruction during the coming decades. Those below water will, with the rising sea-level, be deeper and wave and current conditions will determine the degree of erosion and destruction. More frequent storms cannot be excluded and will increase the erosion of maritime archaeological remains. The areas around the harbours in Stavanger, Bergen, Oslo and Trondheim will be flooded nearly daily at high tide

from 2050. The archaeological sites in the Middle Age towns are well protected against other wind directions than those mentioned in Table 2.

Artificial sealing

Many maritime archaeological remains are exposed to destruction not only in Norway but also in Sweden (Carlsson, 1987) and in other parts of the world, due to the reasons mentioned above. The prognoses outlined for 2050 and 2100 and the need for protection of landing-places and other archaeological sites close to the sea-level are obviously cause for concern.

When the protection of these archaeological sites fails, as it is assumed that it will, two diametrically opposite initiatives are possible: 1) excavation to move the cultural monument into storage and archives, or 2) protection *in situ*. As excavation of the myriad archaeological sites considered here will be difficult to carry out over the coming decades for financial reasons, protection *in situ* is proposed.

Preserving ship wrecks *in situ* has been the subject of several projects, for example the EU-project *MoSS* and the Norwegian Maritime Museum's project *Sikring av skipsfunn fra middelalder* (Preserving Middle Age ships). The protection of other archaeological sites has, in some cases, taken place naturally through the deposition of later sealing sediments or through fire layers (for example, Simonsen, 1969; Krzywinski *et al.*, 1983: 145). Artificial sealing of archaeological sites has been used on land recently in Norway (for example, Bårdseth, 2007). This method could be used to protect exposed remains at landing-places and in navigable channels. Relevant technology, methods and procedures have been developed in connection with polluted sea-bottom sediments in harbours to prevent them spreading, and to re-establish a natural flora and fauna. Some examples can illustrate procedures which could be used to protect remains exposed at landing-places.

Falconbridge Nikkelverk AS (2003) initiated efforts to prevent polluted sediments spreading in the quay area outside Kristiansand, on the south coast of Norway. This included initial investigation by divers, covering the unconsolidated sediments and follow-up checks being made by divers, along with video recording and long-term monitoring. By following the precautionary approach for maritime archaeological sites, this would entail preservation through sealing, combined with diver inspections (see also Gundersen *et al.*, 2005). The sealing sediments used must be clean and with a grain-size that prevents destruction of the archaeological remains; that means relatively fine sediments. It must also be easy to distinguish the sealing sediments from the cultural deposits. The thickness of sealing sediment applied will be dependent on depth, current and wave conditions. At Kristiansand, a 20–40 cm thick sealing sediment was recommended. A fortified cover may be appropriate in the areas most exposed to erosion. Geotechnical reinforcing nets with cover layers were used to prevent the sediment sliding in steep areas. At Kristiansand, 30–40 cm of coarse gravel or crushed stone was recommended.

Another project, *Ren Oslofjord* (Clean Oslofjord) successfully dredged and covered the polluted sea-bottom with clean sediments to great effect in Oslo Harbour (Bjærke, 2008: 1). In addition to covering the polluted sediments, an evaluation of effectiveness of the protection was conducted based on an evaluation of the speed of the current, erosion conditions and the reconsolidation qualities, taking into consideration that the added sediments must prevent resuspension and spreading of the protected sediment particles, and also that the sediments must sink rapidly.

Wave absorption may be used in some cases to protect archaeological sites exposed to erosion. The technology for wave absorbers was developed for sea wave-energy research for the oil industry. It is used to a limited degree in Japan (Brendmo, 2001). A wave absorber may be included in a construction that serves other purposes (Brendmo, 2001: 3). It may be suitable for protecting maritime and other beach-bound archaeological sites which would be affected by the rising sea and flooding.

Conclusions

Knowledge of the significance of navigable channels, landing-places, communication and trade in the Iron Age and the Middle Ages is limited in Norway. Recent investigations indicate that maritime archaeological sites are numerous, but many are suffering from destruction and threatened by erosion from rising sea-levels.

The fetch method is a very useful means of evaluating landing-places and navigable channels based on exposure to wind, currents and waves. It can be used to characterize them in objective and specific terms. The fetch method and climate space analysis were used as tools for finding the optimal conditions for old landing-places and navigable channels in different weather conditions, and also to predict scenarios for the future. This research may explain why boat houses, landing-places and slipways often are found close together. The fetch method can be used everywhere in time and space for landing-places and navigable channels.

Evaluation of the future needs for protection of selected landing-places was carried out. It is also relevant for other archaeological sites located close to the shore, especially many Stone Age sites. Those located 1–3 m above the present sea-level are at risk in view of predictions for the average rise in sea-level and possible storm surge in 2050 and 2100.

This work ought to result in new and revised strategies for protecting archaeological sites close to sea-level, and it is a good basis for a longer perspective than that generally used today. It is recommended that vulnerability analyses be conducted for the various types of the most exposed maritime archaeological sites, to point out areas of high risk and make proposals for protection, action and further monitoring.

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