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# VISIBILITY ANALYSIS OF MEDIEVAL AND EARLY MODERN PERIOD FIRE BEACON SITES IN TURKU ARCHIPELAGO, SOUTHWESTERN FINLAND

Abstract

A defense and guarding system consisting of fire beacon networks was commonly used in Scandinavian coastal areas from the Late Iron Age until the Early Modern period. A chain-like system of signal fire stations was established in locations strategically important for defense and activated if the threat of an enemy attack concretized. Historical sources evidence that the same defense system was also utilized in the archipelago and coastline of southern Finland. Also, certain place names are considered to reflect ancient warning fire activities. Using GIS-based analyses, we examine whether these place names in the Turku archipelago can be distinguished from other locations based on their visibility and topography. In addition, we investigate how visible other potential signal fire stations and certain sailing routes are from the sites selected for the analysis, and the possibility of them having an interactive connection based on visual observation.

Keywords: fire beacons, GIS, visibility analysis, place names, Archipelago Sea

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## INTRODUCTION

The iconic work “A Description of the Northern Peoples” of the Swedish scholar Olaus Magnus, printed in 1555, has an interesting woodcut in its section about Finland (Fig. 1). It depicts a key element related to the ancient coastal defense system: three high hills with warning fires flaming on their tops can be seen behind armed soldiers manned to repel the landing of an enemy ship approaching from the sea near the coastline. A chain-like system of warning fire stations was established at high points of the terrain in places strategically important for defense, especially along well-known sea routes. Presumably fire beacon sites should have had good visibility to the environment and stood clearly out in the landscape, so that either the fire or smoke signals sent from the other beacon stations of the warning fire network would have been able to be unmistakably noticed. Ancient defensive systems based on fire beacon signalling are widespread around the world (e.g., Hill & Sharp 1997; Baker & Brookes 2015; Iturrizaga 2019), and many authors attest the active use of early signal fire systems and beacon sites in Scandinavia (e.g., Gulowsen 1909; Engqvist 1968; Johnson 1979; Kjellson 1994; Westerdahl 1995). The woodcut in question supports the assumption that a defensive signal fire system based on visual observation actively operated also in the Finnish coastline during the Middle Ages.

However, fire beacon sites are a slightly problematic subject of research for archaeology. Investigating the phenomenon with archaeological methods and techniques is complicated because of the difficulty to detect and identify archaeological remains that would incontestably point to the maintaining of a signal fire station at a certain location in the remote past. For this reason, we examine potential historical fire beacon sites in the Turku archipelago making use of place names and historical sources.

For southwestern Finland the topic of locating historical fire beacon sites by place name has been discussed earlier (Voionmaa 1925; Havia 1981; Sjöstrand 1992), but in this article we also employ spatial and geographical information system (GIS) methods to study the visibility of potential fire beacon stations and observation posts in the archipelago and coastal landscape. GIS-based visibility modelling has been recognized to be a useful tool for investigating and understanding the function and meaning of sites and phenomena that are difficult to discern and measure using conventional archaeological field methods (e.g., Wheatley 1995; Seppälä 2003; Earley-Spadoni 2015; Kantner & Hobgood 2016; Link & Fassbinder 2021; Mauro & Durastante 2022).

We test if the sites selected solely based on place names stand out from the landscape in terms of their location and visibility, and the probability of these sites to have been part of a medieval and Early Modern period defence and warning system in the Turku archipelago. We hypothesize that the sites included in this system differ from other locations in the landscape in terms of their suitability for the observation of incoming enemy ships and the transmission of signals from one site to another. Although some of the Iron Age and medieval hill forts situated at the present mainland and coastline of southwestern Finland may have been part of this same defence and guarding arrangement, we limit our research area to cover only the Turku archipelago, which refers to the western part of the Archipelago Sea between the former municipality of Särkisalo in the southeast and Kustavi municipality in the north (Fig. 2.) Likewise, despite the fact that the coastal defence and signal fire system that was active during the Middle Ages in the Baltic Sea region is a continuation of a system used in the Viking Age (ca. 800 – 1050 CE) in connection with the Scandinavian military levy -organization (e.g., Orrman 1990; Larrea 2021), in this article we restrict the temporal examination of the phenomenon to a period from the Middle Ages to the Early Modern

*Figure 1. A woodcut from the Historia de Gentibus Septentrionalibus, chapter X: De ignibus montanis tempore hostile (Olaus Magnus 1555).*

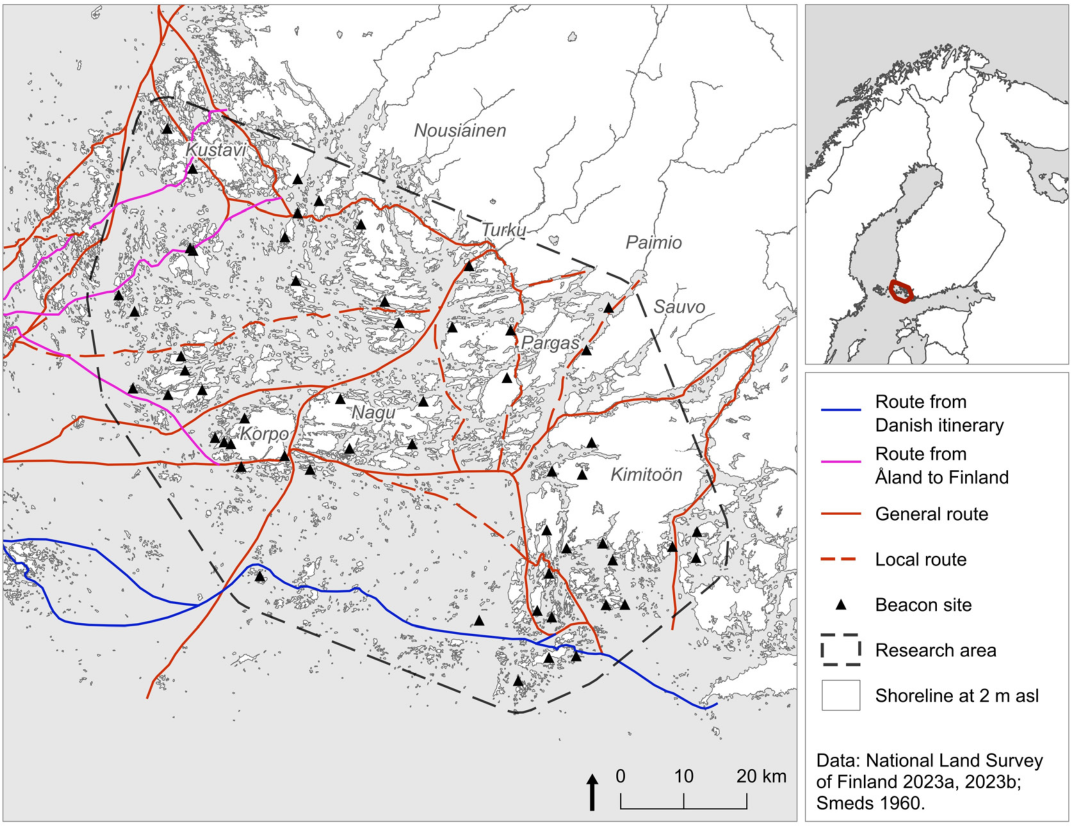


*Figure 2. Study area with fire beacon sites selected for the study and the map of archipelago's medieval sailing routes as presented in the Atlas över Skärgårds-Finland (Smeds 1960).*

Era since part of our place name dataset is in Swedish. The Swedish speaking population settled permanently in the Turku archipelago only around late 12th or early 13th century (Orrman 1990), hence the sites identified with Swedish place names cannot be undisputedly linked to prehistory.

## SCANDINAVIAN ORGANIZATION FOR COASTAL DEFENSE

In the Baltic Sea region, the period from the Viking Age to the 13th century was marked by considerable instability and conflicts in political power relations, which evoked feelings of insecurity among population, especially in coastal areas, and created the need for a guarding system based on a warning fire signalling (Orrman 1990). The turbulent times also contributed to the introduction and operation of the *leiðangr*, the Scandinavian military levy -organization for defending and strengthening the political power of the rulers and securing the vital trading activities in the area. Participation in the *leiðangr* coastal fleet organization was compulsory for all free men. Its guarding and protection mission consisted of three main elements (Skoglund 2003), of which most important was the levy -system based on ships being mustered from various administrative districts in Scandinavian countries to protect coastal settlements from seaborne attacks. The second was the signalling network consisting of several beacon sites, and the third underwater fortifications positioned to prevent the movement of enemy ships in strategically important shipping lanes near the coast and their possible attempts to land. The coastal defence system of the Scandinavian military levy operated under kings' command and was active from the Viking Age until the Middle Ages (e.g., Larrea 2021).

Based on historical sources and references, Voionmaa (1912; 1925) is of the opinion that the *leiðangr* was operative also in southwestern Finland during the Middle Ages, at least in its Swedish-speaking coastal regions. Similarly, Jokipii (2002: 81) states that the *leiðangr* has been proven to have extended into Finland Proper, because the Black Book of the Turku Cathedral in 1380 mentions the Taivassalo fleet or boat company (*Theuesala snäkiolagh*) in the archipelago, and the 'boat company ting' held at Nummenkylä in the parish of Nousiainen in the mainland area inhabited by Finnish-speaking population.

From the beginning of the Middle Ages, when the three Nordic kingdoms were gradually forming within the politically, culturally, and economically hectic Baltic Sea region, detailed regulations on coastal guarding were recorded in Swedish Medieval provincial laws, and a zonal guard service system was stipulated.[1] The system was activated if the threat of enemy attacks in the area concretized. Of the different guard services, the village guard (*byvård*) was local, the coast guard (*strandvård*) was provincial, and the outer guard or signal fire guard (*bötesvård*) was a nationally organized task operating under the command of the king during the Middle Ages (e.g., Modeer 1937). The reactivated signal fire guard system on the Swedish east coast was used in defence against Russia as late as 1719 and 1721 (Dahlström 1944: 89). Since Finland was part of the Sweden at the time, the outer guard system could very well have extended at least to the archipelago and coastal area of southwestern Finland. In any case, according to historical sources (Nagu Sockens Beskrifning 1735: 24) warning fires were lit in Turku archipelago in Nagu parish in 1714, when the Russians had passed Hankoniemi while sailing west. In 1710, the residents of Sauvo parish were obliged to prepare warning fires at three new fire beacon sites to alarm people in case a Russian fleet approached Sauvo bay (Alifrosti 1990: 89). In Åland, signal fires are known to have been used for the last time in 1809 (Drejer 1947).

## ANCIENT SAILING ROUTES IN THE TURKU ARCHIPELAGO

Due to the rocky shores and islets of the archipelago and coast of southwestern Finland, sailing and landing in the area is quite challenging. Therefore, marine traffic has always had to travel along certain routes known in advance. The sailing routes in the area probably date back to early prehistoric times, but it wasn't until the end of the Iron Age that the main routes in the Baltic Sea became commonly used as the intensity of trade grew and maritime technology and ships developed further. The so-called Danish itinerary of the 13th century describes, for the first time, an early medieval sailing route from Scania via the east coast of Sweden, the Åland Sea, and the southwestern coast of Finland to Estonia (e.g., Gallen 1993). The manuscript mentions several harbours and landing places along the route, of which Aspø (Aspö), Refholm (Revholm), Malmø (Malmö), Iurima (Jurmo), and Ørsund (Hitis) are in the Turku archipelago. Other important medieval, or even older, shipping lanes in the area include the route from the Åland Sea along the coast of Finland Proper to the Bothnian Sea, the Uusikaupunki route from Lemland in Åland via Enklinge to Kalanti area, and the route from Utö to Turku, which went via Korpoström between Korpo and the main island of Nagu, through Vandrocksund and Omenaistenaukko to Airisto and finally to the Aura River estuary (Fig. 2). In addition to these, there have always been several local sailing routes in Turku archipelago, mostly known and used by people who lived and fished there.

Supposedly, to navigate safely in the labyrinthine archipelago, enemy ships that tried to invade the area would have had to use the same generally known sea routes as the ships that moved peacefully in the area. Consequently, visibility to important sailing routes would have been one of the most important criteria for the placement of the fire beacon sites. Voionmaa (1925), Dreijer (1947), Niitemaa (1964), and Havia (1981) also believe that signal fire stations in the Archipelago Sea area were likely related to ancient sailing routes and natural harbours known to seafarers since primordial times.

*Figure 3. View from Nagu Prostvik Kasberget (64 m asl) to the northwest in the direction of the Airisto shipping lane. A potential fire beacon site by the place name (Kasberget, 'beaconfire hill' in English). Photo: S. Saunaluoma 2023.*

## BEACON SITE AND SIGNAL FIRE CONSTRUCTION

Voiomaa (1925: 7) states that fire beacon sites in southwestern Finland typically locate on top of high hills, from which 'there are extraordinarily ample views toward open sea and the seaways' (Fig. 3). It would be assumed that in the past fire beacon sites had to be reasonably easily accessible, especially when it comes to transporting firewood. In addition to the actual beacon sites, the signal fire network may have also included observation points, from which activities and traffic at sea were merely detected and monitored.

According to the Scandinavian provincial laws, among free men of full age, those 'with good eyesight, good hearing and healthy legs, and who were fit for fight' were obliged to serve as signal fire guards (Skoglund 2003: 61). The law stipulated that warning fires had to be lit when a certain minimum number of approaching enemy ships was detected, so guards also had to be able to identify different types of ships and make the right decisions. Harsh punishments followed if the guard lit the warning fire on the wrong grounds or did not do it when necessary.

Nagu Sockens Beskrifning (1735: 23) mentions that the fire beacons of the Nagu area in the southwestern part of Turku archipelago were built of pine wood and tar casks in the shape of a teepee-like hut, while in Sweden, according to Modin's (1908) ethnographic example, fire beacons were built of tree trunks in a conical shape around a strong pine trunk or equivalent central post (Fig. 4). The walls of beacon construction could have been sealed with smaller branches and sometimes with moss or similar material to make them snow- and watertight. The wood had to be resinous, such as dry pine, so that it would burn intensely, and the flames would rise as high as possible. When a column of smoke was needed, the burning material could for example be moistened. The height of the fire

*Figure 4. Reconstruction of a medieval fire beacon structure at Vårdberget, Fituna, Nynäshamn, southeastern Sweden. Photo: Karl Macklin 2017, CC BY-SA 4.0, via Wikimedia Commons.*

beacon construction was usually approximately 10–12 meters and the diameter of its lower part was on average 5 meters. An empty space was left inside for kindling material, such as casks of tar. The beacon construction could even have had a small 'doorway' serving also as an overnight accommodation or weather protection for the guard.

## PLACE NAMES

Place names are one of the key factors in locating historical fire beacon sites, since potential signal fire stations have today very little, or no physical remains of burned materials or structures left. Many place names still in use in the archipelago and in the coast of southern Finland are considered to be referring to historical guarding or fire signalling places. Such are place names that contain as one part the Swedish words *böte*, *böt* (Voionmaa 1925; Modeer 1937), *vård, var, vål, vakt* (Modin 1908; Modeer 1937), or *kas, kaas, kase, kasa* (Modin 1908; Voionmaa 1925). In the same category belong place names that are formed from the Finnish root word *vartia* (Voionmaa 1925), as in Vartiovuori and Vartsala. Some related words, *pyöt, pyyt,* and *kaasi,* seem to be Finnish versions of the originally Swedish expressions and presumably allude to old warning fire stations.

For this study, place names indicating fire beacon sites were collected from the National Land Survey of Finland's Geographic names dataset (2023a). About 30 000 placenames located in our study area were filtered with the above-mentioned root words associated with old fire signalling stations. This resulted in 446 place names, which were manually inspected and narrowed down to a sample of 56 placenames that could reliably be linked with fire beacon sites (see Supplementary material 1 online). Other place names possibly indicating defence activities, such as words alluding to castles (*linna, slot*), words ambiguous in terms of their meaning (*valkia*) and more general words related to fire (*bränd, kokko, kokon*) were omitted from the analysis, as these names may derive from sources other than signalling fire activity .

Nevertheless, it must be recognized that over the centuries, place names have changed, become distorted in their spelling, or completely fallen out of use, so the etymological information has at least partially been lost. For example, in the 18th-century map (Special Charta över Porkala fjärd 1751) from the Porkkala archipelago in southern Finland, a word '*wårdkase*' and a drawing of a high hill with a cone-like structure on the top is marked on a location in Kirkkonummi where, on the present-day National Land Survey's topographic map is a place called Järsö Kasberget, a potential fire beacon site. However, at two other *wårdkase* locations marked on the same historical map any nominative references to fire signalling no longer exist in the latest versions of topographic maps. Therefore, the dataset collected for this study must be considered a sample of possible fire beacon sites.

## ANALYSIS OF TOPOGRAPHY AND VISIBILITY OF POTENTIAL FIRE BEACON SITES

### *Methods and datasets*

The hypothesis of this study is that in selecting locations for fire beacon sites in the coastal defence system, the most important features were visibility to sea and visibility to other beacon sites, and as such the presumed beacon sites should be distinguishable from other locations based on these features. The sites' relationship to areas of settlement is another equally important aspect of the coastal defence system, but was omitted from this study, as our focus is on the attributes of individual beacon sites as well as the internal functionality of the beacon fire system.

To test our hypothesis, a two-part analysis was conducted. First, the characteristics of possible fire beacon sites identified via place names were evaluated through topographical, spatial, and visibility-based variables (Fig. 5). This analysis was executed with statistical tools in reference to several stratified sample datasets, as proposed by Fisher et al. (1997). The objective of this part was to examine whether the fire beacon sites are located on statistically distinct features in the landscape and optimally placed in terms of visibility to the sea and sailing routes. The second part of the analysis focuses on networks of intervisibility formed by the beacon sites. Comparison networks are created from other hilltops of the area to test whether the beacon sites form a more optimal network of visibility.

Datasets were prepared with QGIS v3.34.6 and the GDAL, GRASS and SAGA modules included therein. Operations related to visibility were performed with QGIS Visibility Analysis plugin (v1.9; Čučković 2021). Statistical analyses are performed using R Statistical Software (v4.4.0; R Core Team 2021) and packages rstatix (Kassambara 2020), FactoMineR (Husson et al. 2024) and factoextra (Kassambra & Mundt 2020), effsize (Torciano 2020) and vegan (Oksanen et al. 2024), with some visualizations with package ggplot 2 (Wickham et al. 2024).

### *Elevation maps*

The basis of the topographical and visibility analysis was the National Land Survey's Elevation model 10 m dataset (2023b). This digital elevation map (DEM) was resampled to a spatial resolution of 25 metres, and all subsequent raster datasets derived from the DEM were in this resolution. To account for the change in sea level and shoreline displacement in the archipelago, sea level in the DEM was modified to 2 metres above sea level, which roughly corresponds to sea level in our study area in the 15th to 16th century (Vuorela et. al 2009: 89–95).

Digital elevation models typically represent the bare ground surface. The archipelago area was not, however, devoid of vegetation in the medieval and Early Modern periods, even though the scale of forest cover during that timeframe is not known. To explore the effects of forests on the visibility of the fire beacon sites, an additional elevation map with an estimation of average forest height was created.

A map of forest and non-forested areas was aggregated from 18th 19th century maps digitized in the Landscape history dataset by the

Provincial Museum of Southwestern Finland (2018). Fields, meadows, grasslands, and house plots included in the data were classified as non-forested areas and other features as forest. Areas of missing data were supplemented with CORINE Land Cover (CLC) data (SYKE 2018), where fields and other low-vegetation areas were classified as non-forested and the rest as forest. Forested areas were then divided into 5-metre-tall forests present at rocky areas and 15-metre-tall forests present elsewhere, based on the CLC dataset's level 4 classes. The tree height values for the two general types of forest were estimated based on a present-day dataset of average tree height (Luke 2021).

The vegetation map was then draped over the 25-metre elevation map by summing the two rasters together. During the analysis, forests from areas within 1000 metres of each beacon site were removed, with the assumption that any trees hindering visibility near fire beacon sites would have been cut down.

Relative elevation of beacon sites was approached with a topographical position index (TPI) calculated with the module of the same name in SAGA GIS. TPI is a measure of a point's height in relation to its neighbourhood and is

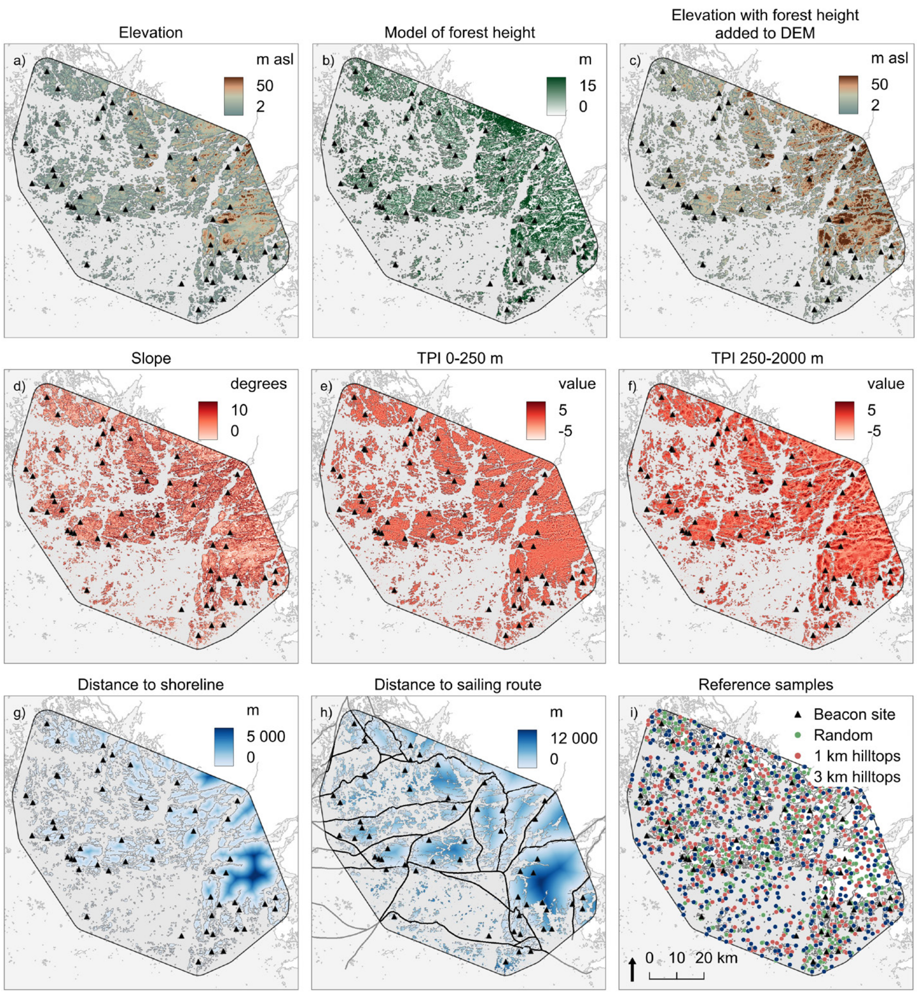


*Figure 5.a-f) Elevation and d-e) distance-based variables analysed in the study, and i) reference samples used in the first part of the analysis. Model of forest height (b) is an intermediary dataset used to produce the forest-covered DEM.*

widely used to describe and classify landscapes (Tagil & Jenness 2008; Mihu-Pintilie & Nicu 2019; Nicu et al. 2019). TPI is reliant on the size of the neighbourhood to which the height of the cell is compared to. In this study two TPI datasets were created with neighbourhood radii of 0–250 metres and 250–2000 metres, the first representing small topographical features within the landscape, and the latter a wider estimation of the archipelago landscape.

### *Reference data*

The analysis was performed by comparing fire beacon sites to three sets of reference sites. The first dataset was formed from a random sample (n=464) of land area over 2 m asl. The second and third datasets were stratified samples of other hills in the study area, as fire beacon sites are typically situated on elevated landforms (see Fig. 6). Therefore, samples of other elevated landforms in the landscape were established to provide a comparable baseline for the analysis.

The two datasets of reference hills were extracted by classifying topographical variation of the study area with GRASS GIS tool r.geomorphons. The geomorphons approach utilizes image analysis methodology to auto-segment the landscape into 498 patterns that correspond to different landform types (Stepinski & Jasiewicz 2011; Jasiewicz & Stepinski 2013). The r.geomorphons tool simplifies the patterns to the 10 most common geomorphons that can be used to describe the landscape: flat, peak, ridge, shoulder, spur, slope, hollow, footslope, valley and pit (Stepinski & Jasiewicz 2011; Grass Development Team 2023).

A set of five geomorphon maps were generated with search radii of 1000, 2000, 2500, 3000 and 4000 metres. These were evaluated visually, and the search radius of 3000 metres (120 cells) was chosen as the best representation of the local geomorphology. Values representing peaks (2) were extracted from the geomorphon map and turned into polygons. Then a point dataset consisting of the centres of each peak polygon was created (n=27682). Points within 1000 metres of the beacon sites were omitted from the dataset, to ensure that the datasets are distinct populations.

The peaks were sampled to the highest points in a 1-kilometre and 3-kilometre grid pattern, from which more manageable sample sizes were drawn at random (n=428 and n=465). The reference datasets are hence referred to as the random sample, 1 km peak sample and 3 km peak sample. It is to be expected that the 3 km peak sites are more elevated than the 1 km peaks because of the larger sampling radius, and as such the analysis focuses more on differences between the beacon sites and the 3 km peaks.

### *Data sampling format and location*

The Land Survey's place name dataset (2023a) is in a vector point format. These points are likely not situated in the exact location of the landscape feature the place name refers to and are certainly not in optimal locations for fire beacons. Some of the selected place names are situated slightly off from the hilltops, and some refer to a feature next to the hill, a bay, for example. To correct this, the points used for the analyses were selected as the highest elevation on the DEM within 150 metres of the place name point. The distance between the place name and the point selected to represent the site varies between 5 and 148 metres and is on average 69 metres. The same procedure was also executed for the reference datasets.

### *Sailing routes*

Data for medieval sailing routes is based on the map presented in the *Atlas över Skärgårds-Finland* (Smeds 1960). The route map, digitized in Fig. 2, is quite general in resolution, as routes go through numerous small islets in the archipelago. Consequently, the routes were corrected to be as accurate as possible, buffered to be 500 metres wide, and cut with the shoreline at 2 m asl. The resulting sailing route dataset is at most 500 metres wide and narrows down in straits.

### *Visibility range*

The theoretical maximum distance an object is visible to the naked eye is quantifiable from the maximum angular resolution of the human eye, which is 1 arcminute (0.000291 radians) (Yanoff

& Duker 2009: 54) and the size of the object being observed. In the case of observing incoming ships, the critical object size is the width of the ship and its sails. In this study a conservative value of 6 metres is used to represent the average width of a typical ship in the Baltic Sea during the timeframe in question (Litwin 1998: 91–95; Belasus 2019: 178–179; Eriksson 2021; Tanner 2020; Tammet et al. 2023; Tevali 2023). A 6-metre-wide object is visible to the naked eye at a maximum distance of 20.6 kilometres. Height of the target being observed was set to 3 metres, as it was assumed that to detect the incoming ship, some amount of the sail or, in the case of rowed ships, the top portion of hull had to be over the horizon or obstructions in the line of sight, i.e. landmasses or vegetation.

It is recognized that the sizes of ships varied and generally increased with time, but uniform values were chosen for simplicity. The identification of incoming ships as hostile entities was also likely partly based on the number and speed of the vessels (e.g., Skoglund 2003: 61). The range of visibility is also affected by the effects of the atmosphere, weather conditions, time of day, the amount of light, the contrast between the object and its background, as well as the eyesight of the observer (Mauro & Durastante 2022). Effects of the curvature of the Earth and atmospheric refraction with a value of 0.13 are included in the analysis parameters.

Estimations on the maximum distance over which smoke signals could be transmitted from one beacon site to another are varied, and experiments and observations suggest values that range from 15-21 km (Ødegaard 2023: 18) up to 100-200 km (Iturrizaga 2019: 46). One study has found that distances of 5-10 km were most efficient in the system examined (Čučković 2015: 471). It is evident that the distances between sites in a beacon fire system are related to local topography, climate conditions as well as the objectives of the system.

In the 1980s, the functionality of a beacon system was experimentally tested in Finland Proper in the Salo area by burning car tires and cell plastic at a few places identified as historical fire beacon sites (Luoto & Huttunen 1987). It was found that the direct observation of fire was uncertain or impossible during daylight hours, especially when the distance was more than 4 km. The column of smoke, however, could be seen well at distances of 4–8 kilometres, and when the terrain or vegetation did not hinder visibility, even at 17 kilometres. Naturally, the smoke column of the warning fire must rise as high as possible, so that it surmounts the tops of trees and visibility to the next guard post is guaranteed. In addition, the position of the observers, the direction and strength of the wind, as well as the air pressure, humidity, and temperature affect the visibility of the column of smoke. In this study the signalling range of the beacon fire system was explored with values of 10, 20 and 30 km.

### *Variables*

Topographical, spatial, and visibility-based features of potential fire beacon sites were referenced against the random point sample and the samples of other hills in the study area. Topographical variables were sampled from raster datasets as the highest value within a 100-metre radius of the sites. Distance from sites to the shoreline at 2 m asl, and distance to sailing routes were sampled as the average within 100 metres of the sites.

Individual viewsheds were generated for each fire beacon and reference site with the QGIS Visibility Analysis Plugin. Height of the observer is set to 1.6 metres and height of the target to 3 metres in the viewshed analysis, and 5 and 30 metres in the intervisibility analysis. Variables related to visibility were calculated from the viewshed datasets by segmenting them into several classes. The surface area of each class was converted from number of cells to square kilometres.

### *Statistical tests*

The differences between beacon sites and reference datasets were examined with both a univariate and a multivariate test. First a test of normality was performed with Shapiro-Wilk tests for each variable. According to the test, some of the variables are not normally distributed. Based on this observation a non-parametric statistical hypothesis test was chosen for the analysis. The univariate method of choice was the Wilcoxon rank-sum test, which is used to determine whether two independent samples are from populations with the same or similar distributions (Hogg et al. 2015: 381–389).

The Wilcoxon test was performed in pairs, comparing each pair of the four sample groups in the analysis: beacon sites, random sites, and two reference hill sites. The null hypothesis (H0) is that the samples have the same distributions, while the alternative hypothesis (Ha) is that, based on distributions, the samples are from different populations. If the p-value of the test is less than 0.05, the null hypothesis can be rejected.

To evaluate if beacon sites and reference datasets are distinct from each other in a multivariate space, a Permutational Multivariate Analysis of Variance (PerMANOVA) was conducted. PerMANOVA, suitable for non-parametric datasets, first calculates a distance matrix using the distance measure of choice, in this case the Bray-Curtis measure. The test statistic F-ratio is calculated from the distance matrix, and from this the p-value determining the significance of differences between groups (Anderson 2001; 2005). The PerMANOVA analysis was conducted with the Adonis function in the vegan package in R (Oksanen et al. 2024) with 999 permutations for each analysis. Under a true null hypothesis in PerMANOVA, observations are interchangeable, but the results are sensitive to heterogeneity of the data. As such the test and p-values produced should be interpreted with caution (Anderson 2001: 37).

Two separate multivariate analyses were conducted for part 1 and part 2 of the analysis, because the difference in sampling method resulted in noncompatible reference datasets.

## RESULTS

### *Topographical variables*

Potential fire beacon sites are located at heights between 4 and 67 metres above sea level, with an average of 35.9 metres (Fig. 6). The 3 km peak dataset is similar with a mean of 36.1 metres. In comparison, the random sample and 1 km peak sample are on average at elevations of 20–25 m asl. Beacon sites and 3 km hills are evidently both situated on similarly elevated places. This is supported by the statistical test, which finds no significant difference between the beacon sites and 3 km peaks (p=0.899, Table 1).

In terms of both small and large topographical features identified with the topographical position index (TPI) datasets, fire beacon sites are higher than their surroundings, with means of 6.33 and 4.19 compared to means of 3.48 and 1.88 of the random sample and 4.45 and 2.59 of the 1 km hill sample, with the difference being significant at p<0.001. However, when compared to the 3 km peaks, the beacon sites tend to have higher TPI values only in terms of the small landscape features (p=0.004).

The average slope angle of sites was calculated to identify if fire beacon sites are located near cliffs, where visibility is less greatly reduced by vegetation compared to more uniform terrain. The data seems to confirm this, as there is a statistically significant difference among each of the group pairs tested (p<0.02). Potential fire beacon sites are slightly more often located near steep gradients than the reference hill datasets, though the effect size (0.11) indicates that the difference is not great.

### *Variables of distance*

The distance to sea from the fire beacon sites varies between 25 metres (the size of the raster cell) and 1890 metres, with an average of 260 metres and a median of 173 metres. The only statistical significance occurs when comparing fire beacon sites to the 1 km peaks (p=0.033).

In relation to sailing routes, beacon sites are located on average at a distance of 2768 metres, whereas with the reference samples the average is over 3000 metres. The difference between beacon sites and the other samples is, however, statistically significant only when compared to the 3 km peaks (p=0.034). Indeed, it would seem that in terms of topography, beacon sites greatly resemble the highest hilltops of the landscape but are crucially situated closer to the routes possibly used by hostile attackers.

It must also be noted that this examination does not consider the variation within the beacon sites dataset; if beacon sites presumably were organized into a chain connecting the outermost sites to settlement areas on larger islands and inland, naturally some sites might be further away from sea routes than others.

### *Viewshed analysis*

Viewsheds generated for each site were developed into three variables: total visibility to sea within 0–20 km, visibility to sailing routes, and an index of visibility range, which is the percentage of the

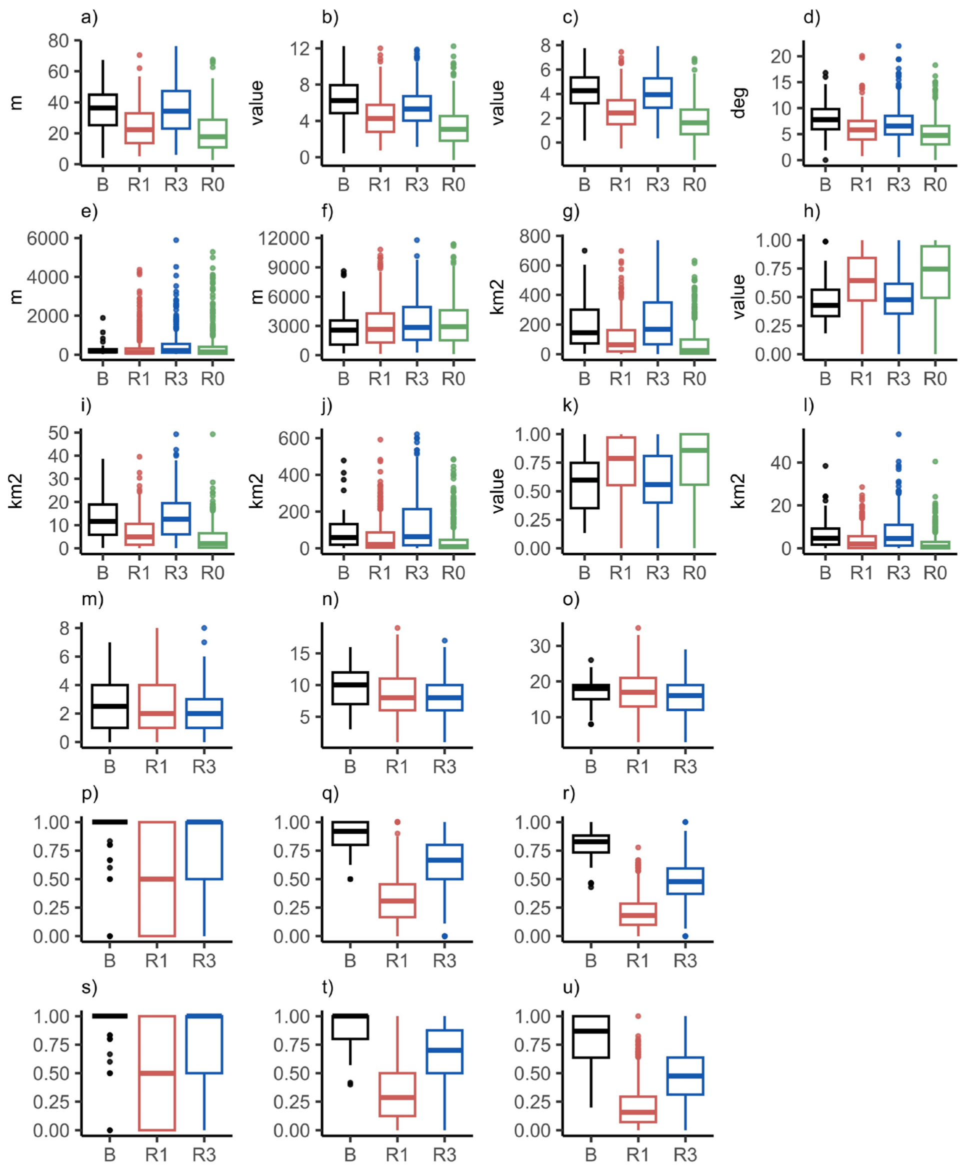


*Figure 6. Box plot of variables with bare DEM (a-i) and forest DEM (j-l): a) elevation b) TPI 0-250 m, c) TPI 250-2000 m, d) Slope, e) Distance to sea, f) Distance to route, g) Visible sea, h) Visibility range index, i) Visible route, j) Visible sea, forest DEM, k) Visibility range index, forest DEM l) Visible route, forest DEM. Intervisibility variables with forest DEM and target height of 30 m (m-u): number of other sites at m) 0-10 km, n) 0-20 km, o) 0-30 km, Connection success, incoming at p) 0-10 km, q) 0-20 km, r) 0-30 km, and outgoing at s) 0-10 km, t) 0-20 km, u) 0-30 km. B = beacon sites, R0 = random sample, R1= 1 km peaks sample and R3 = 3 km peaks sample.*

*Table 1. Pairwise Wilcoxon rank sum test results of variables in a) analysis part 1 and b) part 2. The pair compared is the beacon sites to the 3 km peaks sample. Comparisons between beacon sites and random and 1 km peaks sample summarized as the p-value (p against R0/R1). The test statistic W is the sum of ranks of the smaller sample. The effect size was calculated as r=Z/√N, where z is the Z-score and N the number of observations (Fritz et al. 2012: 12). P-values of <0.05 are mildly significant, <0.01 significant and 0.001 highly significant. R values of 0.1 indicate small, 0.3 medium and 0.5 large effects.*

| **a) Variables** | | **W** | **p** | **Effect size (r)** | **p against R0/R1** |
|---|---|---|---|---|---|
| Elevation | | 13155 | 0.8994 | 0.01 | < 0.001 |
| TPI 0-250 m | | 16109 | 0.0037 | 0.13 | < 0.001 |
| TPI 250-2000 m | | 13693 | 0.5275 | 0.03 | < 0.001 |
| Slope mean | | 15586 | 0.0159 | 0.11 | < 0.001 |
| Distance to sea | | 11401 | 0.1283 | 0.07 | 0.11/0.03 |
| Distance to route | | 10758 | 0.0336 | 0.09 | 0.06/0.31 |
| Visible sea | | 12475 | 0.6089 | 0.02 | < 0.001 |
| Range index | | 11579 | 0.1759 | 0.06 | < 0.001 |
| Visible route | | 13212 | 0.8572 | 0.01 | < 0.001 |
| Visual sea, forest | | 12397 | 0.5586 | 0.03 | < 0.001 |
| Range index, forest | | 12283.5 | 0.4892 | 0.03 | < 0.001 |
| Visible route, forest | | 13053.5 | 0.9753 | 0 | < 0.001 |
| Forest index | | 12436 | 0.5835 | 0.02 | 0.11/0.45 |
| Forest route index | | 12868.5 | 0.8872 | 0.01 | 0.11/0.55 |
| **b) Variables** | **Target height** | **W** | **p** | **Effect size (r)** | **p against R1** |
| Sites at 0-10 km | | 38417 | 0.0035 | 0.09 | 0.203 |
| Sites at 0-20 km | | 41284 | < 0.001 | 0.12 | 0.0361 |
| Sites at 0-30 km | | 37326.5 | 0.0159 | 0.07 | 0.776 |
| Index 10 km incoming | 5 | 37268.5 | 0.0138 | 0.07 | < 0.001 |
| Index 20 km in. | 5 | 38483.5 | 0.00401 | 0.08 | < 0.001 |
| Index 30 km in. | 5 | 41120 | < 0.001 | 0.11 | < 0.001 |
| Index 10 km outgoing | 5 | 37622.5 | 0.00879 | 0.08 | < 0.001 |
| Index 20 km out. | 5 | 38132 | 0.00623 | 0.08 | < 0.001 |
| Index 30 km out. | 5 | 40701 | < 0.001 | 0.11 | < 0.001 |
| Index 10 km in. | 30 | 37555.5 | 0.0044 | 0.08 | < 0.001 |
| Index 20 km in. | 30 | 51499 | < 0.001 | 0.24 | < 0.001 |
| Index 30 km in. | 30 | 57966 | < 0.001 | 0.31 | < 0.001 |
| Index 10 km out. | 30 | 37005.5 | 0.008 | 0.08 | < 0.001 |
| Index 20 km out. | 30 | 48256.5 | < 0.001 | 0.2 | < 0.001 |
| Index 30 km out. | 30 | 53102 | < 0.001 | 0.26 | < 0.001 |

viewshed that is at the 10 km range. Values less than 0.5 indicate more visibility at the 10-20 km range and values over 0.5 mean that most of the visible sea area is concentrated in the close range. Visible land area was not analysed. The classes were calculated separately with the bare DEM and forested DEM. Four indices simulating the effect of vegetation on visibility were calculated by comparing the visible area with and without vegetation cover (Fig. 7).

On average a marine area of 201 $km^2$ can be seen from fire beacon sites and 223 $km^2$ from the 3 km peaks. For the random sample dataset, the average is 74.6 $km^2$. The average area of visible sailing route from both the fire beacon and reference sites is around 13 $km^2$, while for random points and 1 km peaks it is around 4.5 $km^2$. The results of the statistical tests reveal that in all visibility categories both fire beacon sites and the 3 km peak points are significantly different from the other reference samples (Table 1), but not from each other, with p-values in the latter comparisons ranging from 0.18 to 0.98.

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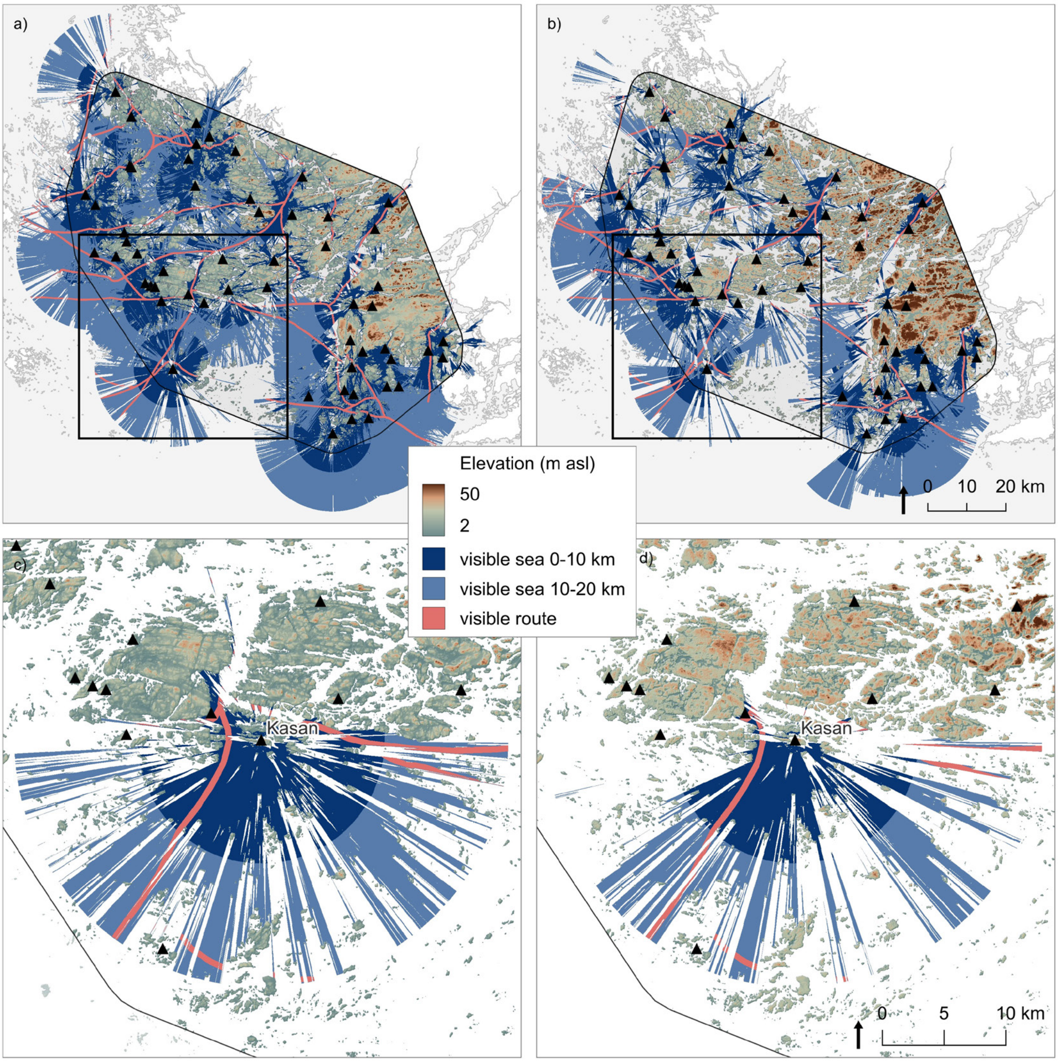


*Figure 7. Cumulative viewsheds of beacon sites and example of viewshed sampling in a) bare DEM and b) DEM with forest cover and example of the viewshed of Nauvo Kasan with the c) bare and d) forested DEM.*

around 4.5 km$^2$. The results of the statistical tests reveal that in all visibility categories both fire beacon sites and the 3 km peak points are significantly different from the other reference samples (Table 1), but not from each other, with p-values in the latter comparisons ranging from 0.18 to 0.98.

Beacon sites and 3 km peaks have an average visibility range index value of 0.46–0.49, indicating that the total visibility is split equally between the close and far ranges, whereas for the random and 1 km peaks visibility is concentrated in the long range (Fig. 6).

When using the elevation model modified with vegetation height, the average observable marine area for the fire beacon sites is reduced to 92.5 km$^2$ and a median of 57.9 km$^2$, and on average 6.8 km$^2$ of sailing routes is visible from the beacon sites and 3 km peak points. For beacon sites and all sample groups the viewshed area is reduced to around 30–40 % when vegetation cover is accounted for (Fig. 6). The statistical tests of viewshed size with the forest DEM show no differences between the beacon sites and 3 km peaks, indicating that the presence or absence of vegetation does not separate the beacon sites from the highest hills in the study area. This can be attributed to the naturally barren nature of hilltops in the archipelago area. Compared to the random and 1 km peak samples, the difference in viewshed size remains significant ($p<0.001$).

Based on the statistical tests, it can be concluded that fire beacon sites as well as the 3 km peaks are samples of locations distinct from the general landscape features and not randomly situated. However, when fire beacon sites are compared to the 3 km peaks, a sample of the highest hilltops in the landscape, the only statistically significant differences relate to the small relative elevation differences identified with the topographical position index ($p=0.004$), the steepest slope found near the sites ($p=0.016$) and distance to sailing routes ($p=0.034$). This indicates that the beacon sites in most ways

*Table 2. Results of PerMANOVA analysis comparing beacon sites to reference samples. Variation explained by the group factor (beacon or sample datapoint) is indicated by $R^2$. F is the ratio of external variance between groups to the internal variation inside groups. Df = degrees of freedom.*

| **Topographical, distance- and viewshed-based variables** | | | | | |
|---|---|---|---|---|---|
| Pair | Df | Sums of Squares | R2 | Pseudo-F | p (Pr(>F)) |
| beacon / random | 1 | 2.687 | 0.07295 | 42.81 | 0.001 |
| beacon / 1 km peaks | 1 | 1.1393 | 0.04019 | 21.48 | 0.001 |
| beacon / 3 km peaks | 1 | 0.053 | 0.00201 | 1.0587 | 0.354 |
| **Intervisibility variables, forest DEM, target height 5 m** | | | | | |
| beacon / 1 km peaks | 1 | 5.96 | 0.04267 | 52.333 | 0.001 |
| beacon / 3 km peaks | 1 | 0.586 | 0.005 | 5.9052 | 0.002 |
| **Intervisibility variables, forest DEM, target height 30 m** | | | | | |
| beacon / 1 km peaks | 1 | 5.812 | 0.05189 | 64.248 | 0.001 |
| beacon / 3 km peaks | 1 | 0.994 | 0.0195 | 23.348 | 0.001 |

resemble the highest hilltops, and dissimilarities arise only in certain details.

To further investigate this finding, the multivariate PerMANOVA analysis of topographical, distance- and viewshed-based variables comparing the beacon sites and the 3 km peaks dataset was employed. The analysis does not indicate a significant multivariate difference between the two groups (Pseudo-F=1.0587, $p=0.354$, $R^2=0.002$), and only 0.2% of total variance in the data is explained with the group factor (Table 2). This result further emphasises the general parallel nature of beacon sites and the most prominent hilltops of the environment. Beacon sites expectedly stand out in multivariate space when referenced against the random or 1 km peak samples.

### *Intervisibility*

The intervisibility of the fire beacon sites was explored by examining positive and negative connections of visibility between the sites at ranges of 10, 20 and 30 kilometres. Connections for each site were calculated as incoming and outgoing signals. We emphasize that there is no guarantee that the fire beacon sites identified by place names and analysed in this study are contemporaneous. Furthermore, the collected fire beacon site dataset likely does not contain all potential fire signal stations in the area. As such, the intervisibility network proposed here is a hypothetical model of possible connections between the sites.

Two reference datasets were used, each of which contained 20 sets of random samples drawn from the dataset of highest peaks identified with the geomorphons tool in a 1-kilometre and 3-kilometre grid. Each sample consists of 56 hilltops, and each reference dataset is an aggregate of all the sample datapoints (n=1120).

The intervisibility analysis was produced with the QGIS Visibility Analysis Plugin. Observer height is 1.6 metres, and target heights of 5 and 30 metres represent direct visibility to the light emitted from the fire and a minimum estimate of the height of the smoke column, respectively. Two separate intervisibility analyses were conducted with the vegetation-free DEM and the DEM modified with vegetation height, but statistical tests were examined only on the latter.

A connection success index was calculated from the number of sites visible at each visibility range. Connection success illustrates the proportion of sites within the selected visibility range that are visible from the observer site (Čučković 2015: 472). The index is a better indicator of a site's significance in the intervisibility network, especially when data is fragmentary, than looking solely at the number of successful connections.

The maximum number of sites with which communication via beacon fires could be executed, was calculated within 10, 20, and 30 kilometres. In both fire beacon and reference datasets one site is on average neighboured by 2.4–2.9 other sites within 10 kilometres, 8.3–9.5 sites within 20 kilometres and 16–17 sites within 30 kilometres. No statistically significant differences were identified with the Wilcoxon rank-sum test in the ranges of 10 and 30 kilometres between the fire beacon site dataset and the randomly generated samples. Within a 20-kilometre radius, fire beacon sites are slightly more clustered together when compared to the reference dataset, and this difference is statistically significant with a p-value less than 0.001 (Table 2).

Intervisibility networks generated at different ranges and target heights are presented in Figure 8. If it is assumed that the maximum range a fire signal could be communicated over is only 10 kilometres, the subsequent intervisibility network is a fragmentary map of isolated clusters of sites, although gaps in the system could easily be explained by missing data in the site dataset. If the maximum range is increased to 20 kilometres, a much more complete network is formed, both with 5 metre and 30 metre target heights, and notably each site has at least one successful connection to another site. With a 30-kilometre range, each site has multiple visual connections not only to sites nearby, but to sites across spans of sea and over islands. The actual maximum range the smoke column could be seen from is not clearly defined, but a distance of at least 20 kilometres seems plausible, if visibility is not hindered by obstructions.

Based on the connection success index, a 30-metre-high smoke column can be seen rising on average from 90 % of the fire beacon

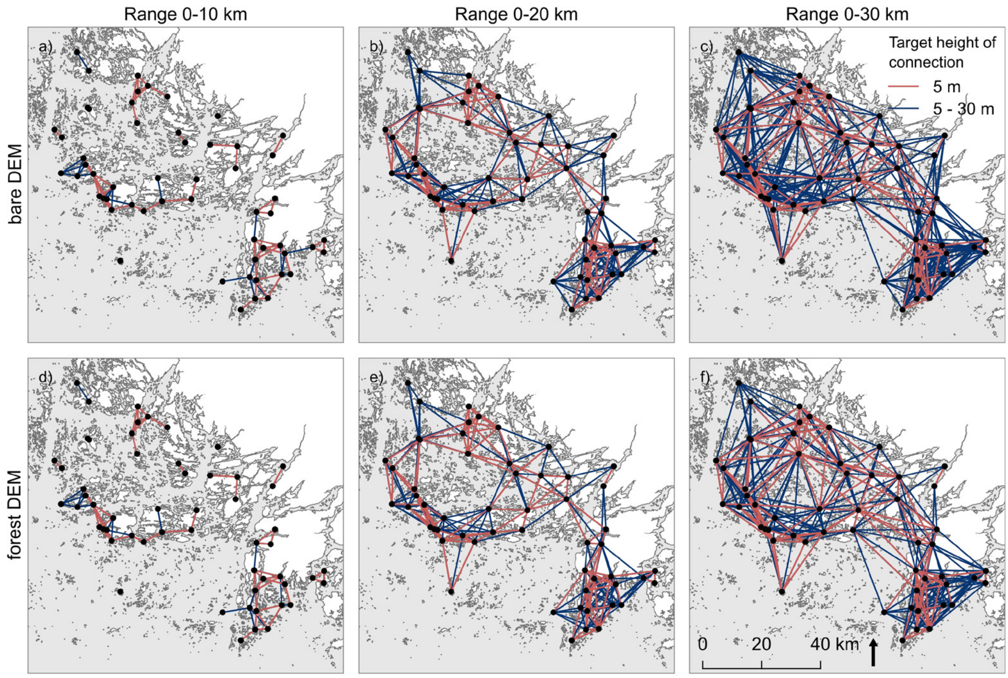


*Figure 8. Interconnectedness of beacon sites at ranges 10, 20 and 30 km with a-c) the original DEM, and d-e) the DEM with forest cover. Colour of the connections indicate whether the connection is possible with a 5-metre target, or if it requires a target height of 5-30 metres.*

sites within 10- and 20-kilometre ranges and 80 % within a 30-kilometre range of the fire beacon sites (Fig. 6). Vegetation does not seem to have a significant effect on the number of successful connections. For the reference datasets, connection success is much lower, mostly in the range of 30–60 %. Distribution of the connection success index is indeed significantly higher within the fire beacon site dataset compared to reference data in all visibility ranges.

With a 5-metre-high target, successful connections between the fire beacon sites are reduced to an average of 67–69% at the 10- and 20-kilometre ranges and further within the 30-kilometre radius to 54% with the vegetation-free DEM and 29% with the forested DEM. This suggests that, even though fire beacon sites are evidently located on hilltops, the hills are not high enough to rise above all treetops. Reference sites have on average only a 5–25% connection success with a 5-metre target height, depending on the presence of vegetation. The difference in connection success between fire beacon sites and reference sites with a 5-metre target height is statistically significant ($p<0.05$) in all ranges.

The PerMANOVA analysis of intervisibility of the beacon sites and the 3 km peaks dataset, conducted with the forested DEM, reveals a highly significant multivariate difference between the groups with 5- and 30-metre-tall target objects. However, only 0.5–2% of the variation in the data can be explained by sites membership in either the beacon site or sample dataset (Table 2). This indicates that a high amount of variation is explained either by internal differences within the groups, or the cause of the variation is not entirely captured in the analysis. Differences between beacon sites and 1 km peaks are also statistically significant and slightly more pronounced.

When compared to randomly sampled hills in the study area, the fire beacon sites appear to form a more functional network of visibility. This functionality is not a result of random variation of clustered sites, as fire beacon sites are not situated significantly closer to each other when compared to the random samples (Fig. 6: m-o).

## CONCLUSIONS

To substantiate the historical sources attesting to the active operation of the defense system based on fire beacon network in Turku archipelago, we conducted GIS-based analyses on a dataset of sites selected by place names alluding to ancient signalling fire activities. The hypothesis was that if the place names are indicators of beacon sites, their locations should positively correlate with high visibility to sea and to other beacon stations, assuming that the main purpose of the system was to identify sea-borne enemy ships and notify these observations to the mainland via a chain of beacon fires.

Our study demonstrates that place names indicating fire beacon sites typically point to steeply sloped hills that are prominent landscape features in comparison to their immediate surroundings and have impressive ranges of visibility. These characteristics clearly distinguish beacon sites from the surrounding landscape and other hills. The fire beacon sites even rival the highest hilltops in the study area in terms of their visibility. However, based on visibility and topography alone, beacon sites do not stand out as a superior dataset when compared to the highest peaks in the archipelago.

More significant differences lie in the connections of visibility between fire beacon sites, which indicate a strong probability that these sites are not randomly situated but rather deliberately placed in predefined positions. The interconnectedness of beacon sites is even greater than that of the most prominent hilltops of the landscape. The analysis suggests that the network of intervisibility contributed significantly to the selection of locations for fire beacon sites. It must be noted, however, that due to the currently lacking data for the fire beacon sites, the intervisibility network presented in this study remains hypothetical.

Since the fire beacon sites identified by place names in this study are not necessarily contemporaneous, further investigations based on the exploration of predictive modelling and geovisualization, as well as multidisciplinary field surveying would be needed. More rigorous modelling is required to fully understand the complexities of the whole fire signalling network. One refinement of the analysis would be the classification of potential beacon sites into groups, corresponding perhaps to their function as either lookout points or as intermediary points in the fire beacon chain. Another important aspect of beacon sites that was left outside the scope of this article and deserves further study is the signalling network's relationship with the settlement sites of the archipelago and coastal mainland.

In any case, our study augments the probability of the existence of various historical fire beacon sites in Turku archipelago as a part of wider defensive system operating in the coastal areas of Scandinavia and Finland during the Middle Ages and the Early Modern period. It also shows the utility of GIS-based analyses and modelling in bringing new perspectives to the research of unrecognized or overlooked archaeological phenomena.

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## REFERENCES

Alifrosti, K. 1990. Sauvon historia Ruotsin ajalla n. 1200–1808. In J. Luoto & K. Alifrosti (eds.) *Sauvon historia* 1: 71–345. Sauvon kunta, Salo.

Anderson, M.J. 2001. A new method for non-parametric multivariate analysis of variance. *Austral Ecology* 26: 32–46. https://doi.org/10.1111/j.1442-9993.2001.01070.pp.x

Anderson, M.J. 2005. *PERMANOVA: a FORTRAN computer program for permutational multivariate analysis of variance*. Department of Statistics, University of Auckland, New Zealand.

Baker, J. & Brookes, S. 2015. Signalling Intent: Beacons, Lookouts and Military Communications. In H. Clegg & G. Owen-Crocker (eds.) *Built Environment of Anglo-Saxon England*: 216–234. University of Liverpool Press.

Belasus, M. 2019. The ships that headed north – an archaeological perspective. – AmS-Skrifter 27: 175–186. https://doi.org/10.31265/ams-skrifter.v0i27.272
Čučković, Z. 2015. Exploring Intervisibility Networks: A Case Study from Bronze and Iron Age Istria (Croatia and Slovenia). In F. Giligny, F. Djindjian, L. Costa, P. Moscati & S. Robert (eds.) *CAA 2014 - 21st Century Archaeology : Proceedings of the 42nd Annual Conference on Computer Applications and Quantitative Methods in Archaeology*: 469–478. Paris: Archaeopress.
Čučković, Z. 2021. Quantum GIS plugin for visibility analysis. GitHub Pages. https://www.zoran-cuckovic.from.hr/QGIS-visibility-analysis/help_qgis3.html Read 16 May 2024.
Dahlström, S. 1944. Ledungsanstalter i Åbo län år 1450. *Acta Academiae Aboensis Humaniora* 15(3): 1–96.
Dreijer, M. 1947. Om Ålands fornborgar och bötesberg. *Åländsk Odling* 1947: 24–54.
Earley-Spadoni, T. 2015. Landscapes of warfare: Intervisibility analysis of Early Iron and Urartian fire beacon stations (Armenia). *Journal of Archaeological Science: Reports* 3: 22–30. https://doi.org/10.1016/j.jasrep.2015.05.008
Engqvist, S. 1968. Nya rön om gotländska vårdkasar. *Gotländskt Arkiv* 1968: 83–92.
Eriksson, N. 2021. The Bellevue Wreck: A Recent Survey of a Large Late Medieval Shipwreck in Dalarö Harbour, Sweden: A Possible Hulk? *International Journal of Nautical Archaeology* 50 (1): 116–129. https://doi.org/10.1080/10572414.2021.1945897
Fisher, P., Farrelly, C., Maddocks, A.& Ruggles, C. 1997. Spatial Analysis of Visible Areas from the Bronze Age Cairns of Mull. J*ournal of Archaeological Science* 24: 581–592. https://doi.org/10.1006/jasc.1996.0142
Fritz, C. O., Morris, P. E. & Richler, J. J. 2012. Effect Size Estimates: Current Use, Calculations, and Interpretation. *Journal of Experimental Psychology: General* 141 (1): 2–18. https://doi.org/10.1037/a0024338
Gallén, J. 1993. *Det 'Danska itinerariet'. Franciskans expansionsstrategi i Östersjön.* Red. och utg. av John Lind. Skrifter utg. av Svenska Litteratursällskapet i Finland nr. 579. Helsingfors.
Grass Development Team 2023. r.geomorphon. GIS 8.3.3dev Reference Manual. https://grass.osgeo.org/grass83/manuals/ Read 16 May 2024.
Gulowsen, J. 1909. De gamle Varder. *Historisk Tidsskrift* 4: 507–531.
Havia, T. 1981. *Varsinais-Suomen merellinen vartiointi- ja hälytysjärjestelmä esihistoriallisen ajan lopussa ja keskiajalla.* M.A. Thesis, History, University of Turku.
Hill, D. & Sharp, S. 1997. An Anglo-Saxon Beacon System. In A. Rumble & A. Mills (eds.) *Names, Places and People: An Onomastic Miscellany for John McNeal Dodgson*: 157–165. Stamford: Paul Watkins.
Hogg, R. V., Tanis, E. A. & Zimmerman, D. L. 2015. *Probability and Statistical Inference.* Ninth edition. Pearson.
Husson, F., Josse, J., Le, S. & Mazet, J. 2024. FactoMineR: Multivariate Exploratory Data Analysis and Data Mining. R Package version 2.11. https://CRAN.R-project.org/package=FactoMineR Read 28 April 2024.
Iturrizaga, L. 2019. Historical beacon fire lines as early warning systems for glacier lake outbursts in the Hindu Kush–Karakoram Mountains. *Natural Hazards* 99: 39–70. https://doi: 10.1007/s11069-019-03705-1
Jasiewicz, J. & Stepinski, T. 2013. Geomorphons – a pattern recognition approach to classification and mapping of landforms. *Geomorphology* 182: 147–156. https://doi.org/10.1016/j.geomorph.2012.11.005
Johnson, V. 1979. *Vårdkasar. Hälsingerunor.* Hudiksvall: Hälsinglands Fornminnessällskap.
Jokipii, M. 2002. Ledung -laitos – ristiretkien tekoväline. *Suomen Museo-Finskt Museum* 109: 47–96.
Kantner, J. & Hobgood, R. 2016. A GIS-based viewshed analysis of Chacoan tower kivas in the US Southwest: were they for seeing or to be seen? *Antiquity* 90(353): 1302–1317. https://doi.org/10.15184/aqy.2016.144
Kassambara A 2020. rstatix: Pipe-Friendly Framework for Basic Statistical Tests. R Package version 0.7.2. https://CRAN.R-project.org/package=rstatix Read 28 April 2024.
Kjellson, L. 1994. Om vårdkasarna, särskilt de i Östergötland och på Södertörn. *Meddelande / Armémuseum* 54: 35–64.
Larrea, B. E. 2021. Archaic martial traditions in high medieval Scandinavia: A glimpse

of Viking Age warfare? *Viking* 84(1): 105–126. https://doi.org/10.5617/viking.9048
Link, R. & Fassbinder, J. 2021. Proving a Roman technical masterstroke: GIS-based viewshed and intervisibility analysis of the Bavarian part of the Rhaetian Limes. *Archaeological and Anthropological Sciences* 14, 25. https://doi.org/10.1007/s12520-021-01493-z
Litwin, J. 1998. Medieval Baltic Ships – Traditions and constructional aspects. Actes du VIe Congrès international d'Archéologie Médiévale 1996. *Actes des congrès de la Société d'Archéologie Médiévale* 6: 88–97.
Luonnonvarakeskus (Luke). 2021. Puuston keskipituus 2021 (dm). https://kartta.luke.fi/opendata/ Read 4 May 2024.
Luoto, J. & Huttunen, P. 1987. Tulitiedotus tutkimuksen kohteena. *Kotiseutu* 4: 194–198.
Mauro, C. & Durastante, F. 2022. Evaluating visibility at sea: Instrumental data and historical nautical records. Mount Etna from the Calabrian Ionian coast (Italy). *The Journal of Island and Coastal Archaeology* 17(1): 21–42. https://doi.org/10.1080/15564894.2020.1755394
Mihu-Pintilie A., Nicu I. C. 2019. GIS-based Landform Classification of Eneolithic Archaeological Sites in the Plateau-plain Transition Zone (NE Romania): Habitation Practices vs. Flood Hazard Perception. *Remote Sensing* 11(8): 915. https://doi.org/10.3390/rs11080915
Modin, E. 1908. Vårdkasar. *Fataburen: Kulturhistorisk tidskrift*: 54–58. Stockholm: Nordiska museets förlag.
Modeer, I. 1937. Forntida svensk försvarsberedskap. Saga och sed. *Kungl. Gustav Adolfs Akademiens Årsbok*: 66–77.
Nagu Sockens Beskrifning, författat av Johan G:vi Salonius: Anno 1735. Svenska litteratursällskapet i Finland. http://yksa.fi/200610/168145986153000 Read 24 May 2024.
National Land Survey of Finland 2023a. Geographic names dataset. https://www.maanmittauslaitos.fi/en/maps-and-spatial-data/datasets-and-interfaces/product-descriptions/geographic-names Read 24 January 2024.
Nicu, I. C., Mihu-Pintilie, A. & Williamson, J. 2019. GIS-Based and Statistical Approaches in Archaeological Predictive Modelling (NE Romania). *Sustainibility* 11 (21): 1–13. https://doi.org/10.3390/su11215969
Niitemaa, V. 1964: Suomen keskiaikaiset luonnonsatamat. *Turun historiallinen arkisto* XVII: 21–64.
Ødegaard, M. 2023. Bosetning, ressursgrunnlag og samfunnsorganisering i Kinn fra de eldste tider til høymiddelalderen. In Stige, M., Hauglid, K. & Nybø, K. N. (eds.) *Kinnakyrkja: lengst vest i havet. Institutet for sammenlignende kulturforskning. Serie B: Skrifter* (CLXXVII): 3–27.
Oksanen, J., Simpson, G. L., Blanchet, G. F., Kindt, R., Legendre, P., Minchin, P. R., O'Hara, R.B., Solymos, P., Stevens, M. H. H., Szoecs, E., Wagner, H., Barbout, M., Bedward, M., Bolker, B., Borcard, D., Carvalho, G., Chirico, M., Caceres, M. Durand, S., Evangelista, H. B. A., FitzJohn, R., Friendly, M., Furneaux, B., Hannigan, G., O.Hill, M., Lahti, L., McGlinn, D., Ouellette, M.-H., Cunha, E. R., Smith, T., Stier, A., Ter Braak, C. J.F. & Weedon, J. 2024. Vegan: Community Ecology Package. R Package Version 2.6-6.1. https://CRAN.R-project.org/package=vegan Read 25 May 2024.
Olaus Magnus 1555. Historia de gentibus septentrionalibus. K. Linnilä (ed.) *Suomalaiset Pohjoisten kansojen historiassa* 1. Helsinki: Tammi 2002.
Orrman, E. 1990. Den svenska bebyggelsens historia. In K. Zilliacus (ed.) *Finska skären:* 197–278. Helsinki: Konstsamfundet, 2. uppl.
Provincial Museum of Southwestern Finland 2018. Landscape History dataset. https://www.avoindata.fi/data/en_GB/dataset/maisemahistoria Read 12 September 2018.
R Core Team 2024. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/ Read 1 February 2024.
Seppälä, S.-L. 2003. Muinaislinna ja maisema – visuaalinen maisema-analyysi arkeologiassa esimerkkinä Rapolan muinaislinna. In Seppälä, S.-L., Nissinaho, A., Kankainen, T. & Vuorela, I. (eds.) *Sääksmäen Rapolan rautakautinen maisema ja elinkeinot Valkeakoskella.* Rapola-tutkimuksia 3: 9–75. Helsinki: Finnish Heritage Agency.

Sjöstrand, O. 1992. Böten, vårdar och kasar – eldsignalering vid våra kuster. *Skärgård* 15(2): 14–22.
Skoglund, F. 2003. *The Coastal Defence in Scandinavia: The Role and Composition of The Military Organization in The Viking and Early Middle Ages.* Ph.D. diss., Scottish Institute of Maritime Studies, University of St. Andrews.
Smeds, H. 1960. *Atlas över Skärgårds-Finland.* Nordenskiöld Samfundet i Finland. Helsingfors.
Special Charta över Porkala fjärd. Jonas Hahn 1751. Sjökarteverket, Finlands kust från Hangöudd till ryska gränsen, SE/KrA/0515/B/D/030 (1751), bildid: K0035412_00001.
Stepinski, T. & Jasiewicz, J. 2011. Geomorphons - a new approach to classification of landform. In T. Hengl, I. Evans, J. Wilson & M. Gould (eds.) *Proceedings of Geomorphometry* 2011: 109–112. Redlands, California.
Suomen ympäristökeskus (SYKE) 2018. Corine maanpeite 2018. https://ckan.ymparisto.fi/dataset/corine-maanpeite-2018 Read 2 March 2024.
Tagil, S. & Jenness, J. 2008. GIS-Based Automated Landform Classification and Topographic, Landcover and Geologic Attributes of Landforms Around the Yazoren Polje, Turkey. *Journal of Applied Sciences* 8: 910–921. https://doi.org/10.3923/jas.2008.910.921
Tamm, D. 2005. How Nordic are the old Nordic Laws? In How Nordic are the Nordic Medieval Laws? *Medieval Legal History* I: 6–22. Copenhagen: University of Copenhagen Press.
Tammet, M. Lätti, P. & Heikkilä, R. K. 2023. A 14th-century wreck discovered at Lootsi Street 8 in Tallinn. *Archaeological Fieldwork in Estonia* 2022: 115–128.
Tanner, P. 2020. *The Reconstruction and Analysis of Archaeological Boats and Ships.* Thesis for the degree of Doctor of Philosophy. University of Southampton. Faculty of Humanities. Archaeology.
Tevali, R. 2023. Wrecked trade: a medieval ship in the Gulf of Finland. *Estonian Journal of Archaeology* 27(1): 30–53. https://doi.org/10.3176/arch.2023.1.02
Torchiano, M. 2020. Effsize: Efficient Effect Size Computation. R Package Version 0.8.1. https://CRAN.R-project.org/package=effsize Read 23 April 2024.
Voionmaa, V. 1912. *Suomalaisia keskiajan tutkimuksia: veroja, laitoksia, virkamiehiä.* Helsinki: WSOY.
Voionmaa, V. 1925. *'Ledung'-laitoksen muistoja Lounais-Suomen rannikolla.* Historiallinen Aikakauskirja 34.
Vuorela, A., Penttinen, T., and Lahdenperä, A -M. 2009. Review of Bothnian Sea shore-level displacement data and use of a GIS tool to estimate isostatic uplift. Technical report. Helsinki: Posiva Oy. https://www.osti.gov/etdeweb/biblio/967484
Westerdahl, C. 1995. Försvar längs farlederna. Ledung, vårdkasar, farledsspärrar och borgar. In G. Flink (ed.) *Kung Valdemars segelled*: 95–101. Stockholm: Riksantikvarieämbetet - Streiffert Förlag.
Wheatley, D. 1995. Cumulative viewshed analysis: a GIS-based method for investigating intervisibility, and its archaeological application. In Lock G,. & Stancic, Z. (eds.) *Archaeology And Geographic Information Systems: A European Perspective*: 171–186. London: Taylor and Francis.
Wickham, H., Chang, W., Henry, L., Pedersen, T. L., Takahashi, K., Wilke, C., Woo, K. Yutani, H., Dunnington, D., van den Brand, T. 2024. Package 'ggplot2'. R Package Version 3.5.1. https://CRAN.R-project.org/package=ggplot2 Read 23 April 2024.
Yanoff, M. & Duker, J. 2009. *Ophthalmology.* Third Edition. Philadelphia: MOSBY Elsevier.

## NOTES

[1] The Hälsingalagen recorded in 1320 applied to Northern Sweden and parts of Finland's western coast (e.g., Tamm 2005).