FORSKNINGSGSRAPPORTER

FRÅN

HUSÖ BIOLOGISKA STATION

No 153 (2019)

Henna Rinne, Charlotta Björklund, Jyrki Hämäläinen,

Maija Häggblom, Sonja Salovius-Laurén

Mapping Marine Natura 2000 habitats in Åland

Final report

(Kartering av marina Natura 2000 habitat på Åland - Slutrapport)

EUROPEISKA UNIONEN
Europeiska
havs- och fiskerifonden

I publikationsserien **Forskningsrapporter från Husö biologiska station** rapporteras forskning utförd i anknytning till Husö biologiska station. Serien utgör en fortsättning på serierna **Husö biologiska station Meddelanden** och **Forskningsrapporter till Ålands landskapsstyrelse**. Utgivare är Husö biologiska station, Åbo Akademi. Författarna svarar själva för innehållet. Förfrågningar angående serien riktas till stationen under adress: Bergövägen 713, AX-22220 Emkarby; telefon: 018-37310; telefax: 018-37244; e-post huso@abo.fi. (Även: Åbo Akademi, Miljö- och marinbiologi, BioCity, Artillerigatan 6, 20520 Åbo).

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Redaktör/Editor: Tony Cederberg

ISBN 978-952-12-3797-3

ISSN 0787-5460

Pärmbilder / cover photos: Charlotta Björklund

Forskningsrapporter från Husö biologiska station. No 153 (2019): 1-36. ISSN 0787-5460 ISBN 978-952-12-3797-3

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Abstract

In 2016-2018 marine geological and biological surveys were carried out in the Åland Islands, in a project financed by the European Maritime and Fisheries Fund and the Government of Åland. During the project, special emphasis was set to mapping sandbanks (1110) and reefs (1170) as defined in the Habitats Directive, as well as esker islands (1610) and boreal Baltic islets and small islands (1620), including their underwater parts. The geological surveys covered five study areas in the eastern archipelago, including also Lumparn, while biological sampling covered larger areas from the southern coast (Eckerö) to Kökar and further to northeastern Vårdö.

The surveys revealed eelgrass (Zostera marina) meadows in association with the esker islands, along the esker formation that runs in a SE-NW direction from eastern Kökar all the way to Vårdö. There were also sandbanks along the esker formation. Rocky reefs and Boreal Baltic islets and small islands are very common habitats in the Åland archipelago, and they were found to be especially representative in the northeastern part of the surveyed area. In the southeast, the bladderwrack (Fucus vesiculosus) occurred rather seldom on the rocky bottoms, indicating a poor status of the species in the area. Parts of the southern archipelago had diverse red algal communities, but further studies are needed to clarify their distribution. In northern Lumparn, abundant domes formed by biogenic gas were found during the geological surveys. The shallow nearshore areas of Lumparn were often sandy with eelgrass meadows.

Based on the results, areas of particular interest due to high nature values and/or rare geological features are presented in the report.

Sammanfattning

Marina geologiska och biologiska undersökningar utfördes i åländska havsområden 2016-2018 inom ett projekt finansierat av Europeiska havs- och fiskerifonden och Ålands landskapsregering. Under projektets gång betonades speciellt vikten av karteringar av sandbankar (1110), rev (1170), rullstensåsöar (1610) och boreala skär och småöar (1620) inklusive deras undervattensdelar, som definieras i habitatdirektivet. De geologiska undersökningarna täckte fem områden i östra Ålands skärgård, Lumparn medräknad, medan de biologiska provtagningarna gjordes över större områden från Eckerö söderut till Kökar och vidare mot nordöstra Vårdö.

Resultaten visar förekomster av ålgräs ängar (Zostera marina) i anslutning till åsöarna längs med åsformationen som sträcker sig från Kökar mot Vårdö i SÖ-NV riktning. Sandbankar påträffades också längs med åsformationen. Undervattensrev och boreala skär och småöar är väldigt vanliga habitat i den åländska skärgården, och de var speciellt representativa i nordöstra delarna av de karterade områdena. På hårda bottnar i sydost var förekomsterna av blåstång (Fucus vesiculosus) rätt sparsamma, vilket indikerar att artens status i området är dålig. Delar av den södra skärgården hade mångformiga rödalgssamhällen, men tilläggsinventeringar krävs för att få tillförlitligare information om deras utbredning. I samband med de geologiska karteringarna i norra Lumparn påträffades rikligt med s.k. upphöjda domer i sedimentet som formats av biogen gas. De grunda kustnära områdena i Lumparn var ofta sandiga och förekomster av ålgräs var vanliga.

Områden av speciellt intresse baserat på naturvärden och/eller sällsynta geologiska formationer, har presenterats i rapporten utgående från projektets resultat.

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1 Introduction

The Habitats Directive (Council Directive 92/43/EEC), together with the Birds Directive, is the cornerstone of the Europe’s nature conservation policy. The aim of the Habitats Directive is to protect the species and habitats that are listed in its annexes (Annex I for habitats, Annexes II and IV for species). Habitats listed in the Annex I of the Habitats Directive are hereafter referred to as Natura 2000 habitats. 69 Natura 2000 habitats occur in Finland. Out of these, seven are marine habitats, occurring either completely under water or including parts that are under water:

- Sandbanks (1110)
- Estuaries (1130)
- Lagoons (1150)
- Large shallow inlets and bays (1160)
- Reefs (1170)
- Esker islands (1610), including also their underwater parts
- Boreal Baltic islets and small islands (1620), including also their underwater parts

It is also possible, that structures made by leaking gas occur in the Finnish marine are, but such areas have not been found.

In order to protect the Natura 2000 habitats sufficiently, and to evaluate their status, we need to know where they occur. Knowledge on their occurrence and status is needed especially, when the progress made with the implementation of the Habitats Directive, and the status of the habitats are evaluated and reported to the European Commission every six years. In addition, knowledge on the occurrence of the habitats is needed in many other management tasks related to the protection of the environment, e.g. when evaluating the environmental impacts of different human activities. The knowledge is also essential as a background information for coastal and maritime spatial planning.

Prior to this project, the underwater marine areas around Åland Islands have been largely unmapped. The few geological studies have focused mainly on cable route surveys. In 2010-2011 some systematic biological surveys were carried out in the eastern Åland (Kumlinge-Enklinge area) and in selected areas in the western and southwestern Åland as a part of the EU Central Baltic Interreg financed NANNUT - project. In addition, some bays were visited in northern Åland and in the Kökar area (SE Åland) during the project (KIVILUOTO 2013). In the NANNUT -project, data was mainly gathered using drop-video, but also some scuba-dive transects were done. In addition to the NANNUT -project, marine vegetation data have been collected by Åbo Akademi University, Husö Biological Station in various projects, mainly in co-operation with the Government of Åland (Husö projects / Husö Specialarbeten). Mainly scuba-diving has been used when gathering the data. The data from these projects are mainly concentrated to shallow bays with soft-bottom vegetation (e.g. PUNTILA 2007, SNICKARS 2008, NYSTRÖM 2009, EVELEENS MAARSE 2013), but there are also some data from the more open, rocky areas. The data from rocky shores have been mainly gathered to develop and carry out status classification based on macrophytes and macroalgae, as required by the Water Framework Directive (SCHEININ & SÖDERSTRÖM 2005, SÖDERSTRÖM 2008, KAUPPI 2011, HOLGERSSON 2013, SAARINEN 2015).

The aim of this project ”Mapping Marine Natura 2000 habitats in Åland”, financed by the **European Maritime and Fisheries Fund (EMFF)** and the operative program of **the Government of Åland**, was to increase knowledge on the distribution of the marine Natura 2000 habitats in the marine areas around the Åland Island. As there were more existing information from the shallow bays, and they can also be delineated based on the shape of the shoreline, it was decided that the project will mainly concentrate on habitats that often occur completely underwater; Reefs and Sandbanks. Furthermore, the project aimed to map the distribution of the underwater parts of the Esker islands, and Boreal Baltic islets and small islands that due to similar sediment types and shapes largely correspond to reefs and sandbanks, despite their connection to islands. One of the aims was also to find out whether there are Submarine structures made by leaking gas in the Lumparn area. Existing data were utilized in the project, to ensure cost-effectivity of the surveys.

The definitions of the Natura 2000 habitats can be found in the Interpretation Manual of European Union Habitats (ANONYMOUS 2013) and adapted to Finnish conditions in AIRAKSINEN & KARTTUNEN (2001). According to the European definition

- **Sandbanks** are elevated, elongated, rounded or irregular topographic features, permanently submerged and predominantly surrounded by deeper water. They consist mainly of sandy sediments, but larger grain sizes, including boulders and cobbles, or smaller grain sizes including mud may also be present on a sandbank. Banks where sandy sediments occur in a layer over hard substrata are classed as sandbanks if the associated biota are dependent on the sand rather than on the underlying hard substrata. The water depth is seldom more than 20 m below chart datum. Sandbanks can, however, extend beneath 20 m below chart datum.
- **Reefs** can be either biogenic concretions or of geogenic origin. They are hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone. Reefs may support a zonation of benthic communities of algae and animal species as well as concretions and corallogenic concretions.
- **Submarine structures made by leaking gases** are submarine structures consisting of sandstone slabs, pavements, and pillars up to 4 m high, formed by aggregation of carbonate cement resulting from microbial oxidation of gas emissions, mainly methane. The formations are interspersed with gas vents that intermittently release gas. Bubbling reefs and carbonate structures within pockmarks are types of leaking gas areas.
- **Esker islands**, including also their underwater parts, are glaciofluvial islands consisting mainly of relatively well sorted sand, gravel or less commonly of till. They may also have scattered stones and boulders. The vegetation of esker islands is influenced by the brackish water environment and often by the ongoing land upheaval, which causes a succession of different

vegetation types. Several rare vegetation types (heaths, sands and gravel shores) and -threatened species occur.

- **Boreal Baltic islets and small islands** are groups of skerries, islets or single small islands, mainly in the outer archipelago or offshore areas. Composed of Precambrian, metamorphic bedrock, till or sediment. The vegetation of boreal Baltic islets and small islands is influenced by the brackish water environment, the ongoing land upheaval (in areas with intense land upheaval) and the climatic conditions. The vegetation types are influenced by wind, dry weather, salt and many hours of sunlight. Land-upheaval causes a succession of different vegetation types. Bare bedrock is common. A lot of small islands have no trees. The vegetation is usually very sparse and consists often of mosaic-like pioneer vegetation communities. On some islands the species diversity is increased by nitrogenous excrement from birds. Many of the plants are xerophytic and lichens are common. Temporary or permanent rockpools are common and these are inhabited by a variety of aquatic plant and animal species. Boreal Baltic islets and small islands are important nesting sites for birds and resting sites for seals. The surrounding sublittoral vegetation is also included in the habitat.

In addition to above-mentioned documents, there is a more specific national guide for mapping the Natura 2000 Habitats (FINNISH ENVIRONMENT INSTITUTE & METSÄHALLITUS, 2016), giving more detailed guidance for delineating the habitats. However, there is still ongoing discussion on what is considered a sandbank, especially related to sandy areas connected to sandy shores with typical vegetation to sandbanks (e.g. *Zostera* meadows), and elevated sandy areas with no vegetation (typical e.g. in Bothnian Bay).

The project was carried out in co-operation between Åbo Akademi, Geological Survey of Finland and the Government of Åland. The following people participated in the project:

Åbo Akademi: Sonja Salovius-Laurén (project lead), Henna Rinne (planning of biological inventories, GIS work, species distribution modelling, reporting), Charlotta Björklund (head of biological surveys 2017-2018, data analysis), Pauliina Saarman (biological surveys 2017), Cecilia Edbom-Blomstrand (biological surveys 2017), Ella Pippingskiöld (biological surveys 2018) and Ella von Weissenberg (biological surveys 2018).

Geological survey of Finland: Jyrki Hämäläinen (project lead), Anu Kaskela (GIS work), Henry Vallius (geological field surveys), Alexandra Nyman (geological field surveys, interpretation of acoustic profiles, map production), Kimmo Alvi (geological field surveys, interpretation of acoustic profiles, map production, reporting).

Government of Åland: Maija Häggblom (project planning, data user).

2 Material and methods

2.1 Collation of existing biological data

To get a complete picture of the existing biological data from the Åland marine area, the existing data was collated and stored into a common format (Excel-sheet) in the beginning of the project. The format used was the same that has been used in the Finnish Inventory Program for the Underwater Marine Environment VELMU, thus joining the data e.g. to VELMU data is possible, if needed. In order to be accepted, the data needed to include 1) coordinates, 2) plant and algal species recordings as percentage cover, 3) bottom substrate and 4) depth. Only data from the year 2000 onwards were considered. If not directly available, the point coordinates for each study point on a dive transect were calculated using the direction of the dive-transect and the distance from the shoreline.

2.2 The study areas for new surveys

The focus areas for marine geological mapping were located in the south-eastern Åland. The study areas were chosen based on preliminary modeling that identified areas as potential areas for sandbanks and reefs. There is very little existing geological information from this part of the archipelago and even the nautical charts do not cover the area in full. Three survey areas (fig. 1) covered the known esker formation east of Kökar, running in NW-SE direction. Lumparn was chosen for its special character as being an area with extensive gas discharge from bottom sediments. Prior surveys from Lumparn by the GTK have showed that large parts of the seabed is covered by domes, induced most likely by shallow gas. The geological surveys were carried out between July-September 2016, in June 2017 and in June 2018.

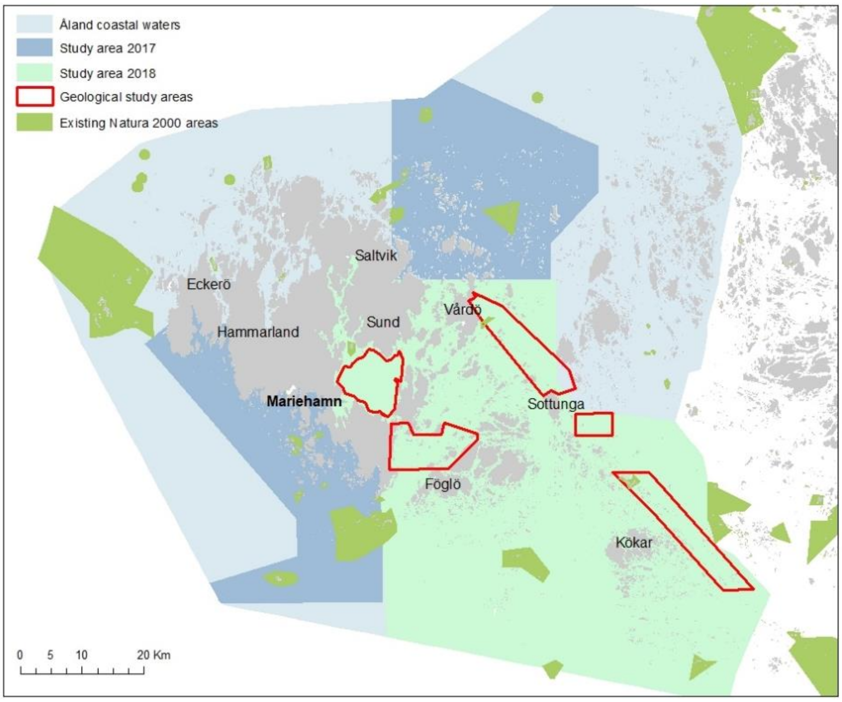

Figure 1. Map of the study areas.
Figur 1. Karta över studieområdet.

The focus areas for biological surveys (fig. 1) were chosen, as they had very little existing data and also high potential to host reefs and sandbanks. In 2017 mapping was first carried out in the southern / south-western Åland (Eckerö, Hammarland, south of Mariehamn) and later on in the summer in the north-eastern Åland (Saltvik, Sund, Vårdö). In 2018, the biological mapping efforts were put into south-eastern Åland. Special attention was paid to the areas where geological mapping (carried out in 2016) had revealed interesting features. In the Lumparn area, the surveys were carried out in co-operation with another project at Husö Biological Station. The actual inventories were carried out by Linn Engström, using the same methodologies (ENGSTRÖM 2018).

When planning the surveys, it was also agreed that the new mapping efforts should concentrate mainly outside the existing Natura 2000 areas, as one of the mapping purposes was to find suitable areas for expanding the existing Natura 2000 network.

2.3 Methods for geological surveys

The geological surveys were carried out using R/V Geomari and survey boat Gridi. Several different acoustic methods were used during the surveys (acoustic profiling, side scan sonar imaging and multibeam echosounding). Bottom samples were also obtained from the Lumparn study area (NYMAN 2018). Geological survey methods are described in more detail in Annex I of this report.

2.3 Methods for biological surveys

The methods used in the biological surveys of project follow the methods used in the VELMU program to a large extent (ANONYMOUS 2015). The surveys were carried out using drop-video and scuba-diving transects. Also, benthic fauna was sampled in the Lumparn area. All biological surveys were carried out between late June and early September 2017-2018.

2.3.1 Sampling design

Surveys were concentrated to areas < 25 m deep, as vegetation occurs mainly above 20 m depth.

The drop-video surveys were planned using stratified random sampling design, where sampling points were randomly located within five depth classes (0-5m, 5-10m, 10-15m, 15-20m, 20-25m) and 3 exposure classes (sheltered: < 10 000, moderately exposed: 10 000-50 000, exposed > 50 0000). More information on the depth and exposure data used is given in the “Environmental variables” -section. The stratification ensured that the sampling covered different kinds of environments (different depths and exposures) and thus the data obtained was suitable for carrying out species distribution modelling. The existing reef model covering the Åland coastal waters (KASKELA & RINNE 2018) was also considered in the sampling design: approximately half of the drop-video sites were on predicted reefs, and half of them outside the reefs. This was done to evaluate the functionality of the reef model in the coastal waters of Åland. Also, the areas with existing data were avoided.

In 2017, special attention was paid on finding eelgrass meadows (*Zostera marina*). To do that, approximately 100 drop-video points were placed to areas with high potential for finding *Zostera*, based on a *Zostera* distribution model, developed at the Finnish Environment Institute. Also, aerial photos were used to find potential sites for *Zostera* meadows.

In 2018 mainly similar techniques as in 2017 were used to place the drop-video points (stratified random sampling, approximately half of the point on predicted reefs). However, as one of the aims in 2018 was to validate the habitat maps produced by GTK (UW parts of esker islands, sandbanks and reefs), the habitat maps and geological data produced by GTK were also considered in the sampling design (see results for more information). Also, the *Zostera* model was used to some extent, as well as aerial photos from the study area. The Government of Åland also hoped for complementary biological surveys in the Föglö-Gripö area (earlier survey reported in SAHLIN & JOHANSSON 2015) and therefore some study points were specifically placed in that area.

The SCUBA-diving transects were also placed using stratified random sampling design, but since dive transects always start from the shoreline, only exposure was used as a stratifying factor. Furthermore, it was ensured, that the sampling design covered the “archipelago gradient” from the inner to outer archipelago (ANONYMOUS 2015).

The sampling design for benthic fauna in the Lumparn area was based on geological surveys that identified domes arising from the bottom sediment (see the “Results” -section). In 2017, ten stations were sampled (three replicates at each station), five from domes and five reference samples. As the depth variation in the 2017 data was high, in 2018 16 sites were sampled from 15-18 m depth (one site was the same as in 2017 to estimate inter-annual variation); eight sites on domes and eight reference sites.

2.3.2 Field methods

The drop-video surveys were carried out from a boat. After stopping the boat, a video-recorder equipped with lights was lowered with a cable near the seafloor and the seafloor was filmed for one minute (covering 20 m^2 on average). The videos were later analysed and recordings of substrate and species cover (%) were made from the whole area filmed (ANONYMOUS 2015).

The scuba-diving transects (100 m) were placed perpendicular to the shoreline. In all transects, recordings of species cover and substrate cover (%) were made from an area of 2 m^2 either at 10 m horizontal (along the seafloor) or 1 m vertical (in the water column) intervals along the transects. The species-specific cover (%) of macrophytes, macroalgae and sessile fauna, as well as substrate, were recorded on a scale from 0 - 100%. The substrate recordings were based on a 11-level classification used in VELMU (bedrock, boulders > 300 cm, boulders 120 - 300 cm, boulders 60 - 120 cm, stones 10 - 60 cm, stones 6 - 10 cm, gravel, sand, silt, clay and mud). Also, the depth of the study point was recorded.

In addition to “basic” mapping with dive-transects, special attention was paid to species that are considered as indicator species when evaluating the ecological status of the water bodies, in relation to the Water Framework Directive (HOLGERSSON 2013). If the species listed as an indicator species occurred at the site, its lower limit of occurrence was recorded. This was done to collect baseline information on the depth distribution of these species in different environments, to support their use as indicators.

Also, benthic fauna in the Lumparn Bay was sampled to study the fauna on the doming structures found in the area (NYMAN 2018) in relation to the fauna in the surrounding environment. The samples were taken using Ekman grab sampler. In 2017 the sampling was partly carried out from GTK's survey vessel Geomari, partly from Åbo Akademi's own boat and in 2018 solely from Åbo Akademi's boat. In total, eight stations were sampled in 2017 and 16 stations in 2018 (fig. 2). At each station, three samples were taken and put into separate buckets on the boat. When all three replicas from a specific station were on the boat, the replicas were one by one carefully sieved through a 0,5 mm sieve. The samples were placed into jars with 70% ethanol as preservative along with the information from that specific site and replica. The samples were later sorted in the laboratory under light microscope, species were identified and the individuals per species counted.

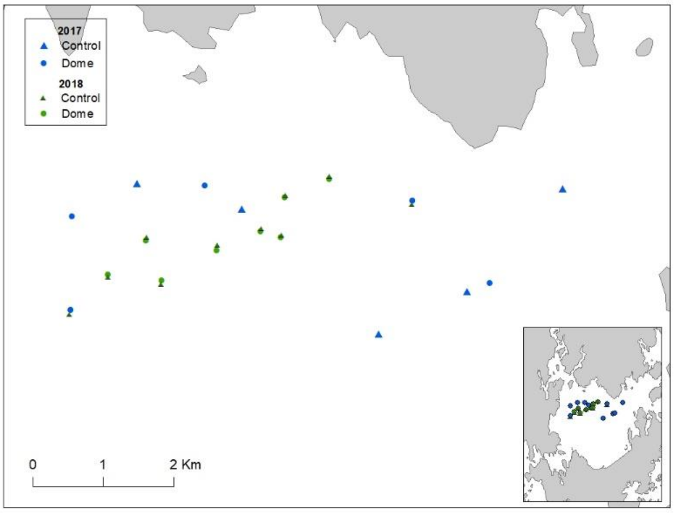

Figure 2. The sampling stations for benthic fauna in Lumparn Bay.
Figur 2. Stationer där bottenfauna i Lumparn samlats in.

2.4 Environmental data

The following data were used in the project, both in planning biological surveys and in the species distribution modelling.

- Depth model (20 m resolution) covering the whole Finnish marine area, produced in the VELMU programme (Finnish Environment Institute). The slope was also derived from the depth model.
- Exposure model (originally 25 m resolution), calculated using the simplified wave exposure model (SWM) for the whole Finnish marine area (ISAEUS 2004). Also, depth attenuated exposure was calculated using the method presented in BEKKBY et al. 2008.
- Surface salinity model (20 m resolution) produced in the VELMU programme, covering the Finnish marine area. During this project, the model was updated with more comprehensive salinity data from Åland (obtained from Husö Biological Station), as the earlier version included

only very scattered data from Åland. The methods used in the development model can be found from the metadata of the model in the VELMU map service (http://paikkatieto.ymparisto.fi/velmu)

- Secchi depth layer (20 m resolution) produced in the VELMU programme, based on satellite data (MERIS). The methods used in the development model can be found from the metadata of the model in the VELMU map service (http://paikkatieto.ymparisto.fi/velmu)
- Interpolated layers on total phosphorus and nitrogen concentrations, covering the Finnish marine area (originally 100 m resolution). The interpolations were based on average summer values (June-August) from years 2003-2013. During this project, the interpolations were updated with more comprehensive data from Åland (obtained from Husö Biological Station), as the earlier versions included only very scattered data from Åland.
- Distance to sandy shore was calculated based on data on sandy shores from CORINE land cover 2012 http://www.syke.fi/avointieto, using Cost Distance function in ArcGIS and land as the "cost" layer.
- Reef model produced in the VELMU programme, covering the Finnish marine area (methods used to produce the model are presented in KASKELA & RINNE 2018).

2.5 Identifying Natura 2000 habitats

2.5.1 Natura 2000 habitats within the geological survey areas

The identification of the Natura 2000 habitats within the geological survey areas followed the same methodology to a large extent as presented in KASKELA & RINNE (2018). A major difference was that detailed geological maps were now available from the whole survey areas, thus the habitat maps produced within the geological survey areas are reliable across the surveyed areas. The more detailed methodology and data used in modelling are described in Annex 2 of this report.

In addition to work described in Annex 2, the submarine parts of the esker islands identified based on geological surveys were complemented with an analysis of aerial images (orthophotos, National Land Survey of Finland). This was done because the geological surveys did not always reach the shallowest areas close to the shoreline, and thus there were often gaps between the esker island and its submarine part. By comparing the aerial photos with the polygons of identified submarine continuations of esker islands, it was possible to fill in the gaps by digitizing in ArcMap.

To further verify the submarine continuations of esker islands and sandbanks, and to study their associated biota, dive and video data were collected from these areas in 2018.

2.5.2 Sandbanks outside the geological survey areas

In addition to the sandbanks that were identified within the geological survey areas, other potential sandbanks were identified within the area covered by biological survey using the national reef model

(KASKELA & RINNE 2018) and the biological survey data. Reefs (i.e. elevations identified using 300m search radius), that had > 1 surveyed site with sand on it, were regarded as a potential sandbanks.

There is ongoing discussion in Finland, whether sandy bottoms in connection to a sandy shore, and hosting e.g. *Zostera marina* communities, should be classified as sandbanks defined in the Habitats Directive. In the framework of this project, these kinds of areas were not delineated as sandbanks, but this may be done later, if needed.

2.5.3 Evaluation of the reef model functionality

Outside the geological survey areas, no new model on reefs was produced. Instead, the functionality of the reef model produced in the work carried out for the whole Finnish marine area, here referred to as "the national model" (KASKELA & RINNE 2018, fig. 4), was evaluated within the project study areas. The evaluation also included the reefs in connection to islands, i.e. the underwater parts of the Boreal Baltic islets and small islands. Here, they are together referred to as the reef model, as they are based on the same analysis (KASKELA & RINNE 2018). Approximately half of the drop-video sites surveyed were located on modelled reefs, and half of them outside.

During the project, the reef model was evaluated using two approaches.

1) Within the geological survey areas, the national model was compared to a model made using more detailed data (Annex 2) to evaluate the differences between the two.
2) Based on biological survey data, the occurrence of hard substrate and typical reef communities both on reefs and outside the reefs were assessed to evaluate how well the model has captured the hard-bottom communities. This was done separately for different depth zones (5 m interval) to evaluate the functionality of the model in different depths and also to get an idea of the depth distribution of the reefs within the study area.

The identification of typical reef communities was based on HELCOM HUB classification of underwater biotopes (HELCOM 2013). The classification takes into account the underlying substrate as well as the dominating species/community occurring at the study point. In the analysis, the following HUB level 5 and 6 communities, identified based on survey data, were regarded as typical to reefs:

- C Perennial algae
- C1 *Fucus* spp.
- C2 Non-filamentous corticated red algae
- C3 Foliose red algae
- C5 Filamentous algae
- S Annual algae
- S1 Filamentous annual algae
- S2 Chorda filum and/or *Halosiphon tomentosus*

- R Soft crustose algae
- E Epibenthic bivalves
- E1 *Mytilidae*

In addition, description of communities occurring on hard bottom across the study areas were produced, based on HELCOM HUB-classes (levels 5 to 6), identified based on survey data.

2.3.4 Boreal Baltic islets and small islands – a new model

Parallel to the project, in 2018-2019, Finnish national work on identifying the Boreal Baltic islets and small island was ongoing, related to the Habitat Directives reporting 2019. The work was mainly carried out at Metsähallitus Parks and Wildlife Finland (Matti Sahla, Maija Mussaari). The Åland mapping project (Henna Rinne) was also involved in defining the criteria used to identify the islands and especially in defining the criteria for delineating the submarine parts of the islands.

The description of the new data on the underwater parts of the Boreal Baltic islets and small island is shortly described here. The maximum size of 4 hectares was used to select islands, located within the outer or middle archipelago areas (as defined in work related to the Water Framework Directive). CORINE Land Cover data 2018 were used to identify tree cover. If the extent of the tree cover was > 10%, the island was excluded. In addition, the islands were checked manually using aerial photos. However, islands 2-4 ha in size and islands located in the Åland middle archipelago, have not yet been manually checked, thus it is possible that the material still contains islands that have e.g. “too much” forest or are otherwise unsuitable to be included in the habitat. Considering the underwater parts of the Boreal Baltic islets and small islands, a 100 m buffer was applied around each island to delineate the underwater parts. Further enquiries on the data should be addressed to Metsähallitus (Matti Sahla).

2.6 Species distribution modelling

Species distribution models covering the Åland coastal waters were built for key species and for selected communities used in the evaluation of the threat status / the red list of habitats (KONTULA & RAUNIO 2018). The models were built using Boosted Regression Trees (BRT, HASTIE et al. 2001), using the gbm package in R (R CORE TEAM 2017). In each model, the data was divided to a train dataset (80% of the total data) that was used to build the model and to a test dataset (20%) that was used to test the model. The distribution of the following species / communities were modelled.

- *Zostera marina* (eelgrass, hereafter *Zostera*)
- *Fucus vesiculosus* (bladder wrack, hereafter *Fucus*)
- *Furcellaria lumbricalis* (clawed fork weed)
- *Chara aspera* (rough stonewort)
- *Mytilus edulis* (blue mussel, hereafter *Mytilus*)
- Red algal communities (excluding *Hildenbradia rubra*)
- *Chara* spp. (excluding *C. aspera*) – resembling charophytes in sheltered areas

The models were run using presence/absence of the species as a response variable and the following environmental variables as explanatory variables: depth, slope, exposure, depth attenuated exposure, salinity, Secchi depth, distance to sand as well as total concentrations of nitrogen and phosphorus. The environmental layers are described in more detail above, in section "Environmental data". Different thresholds for presence/absence were used for different species, depending on whether the aim was to model denser occurrences of the species or simply presence. The thresholds per species are presented in table 1. In the vegetation models, a random set of 1400 absence points was used in the deep areas (> 20 m depth) to balance the model, as very little actual data exists from these areas and it is evident from VELMU data, that the species do not occur > 20 m depths. In the *Mytilus* model, 500 random absence points were used in areas > 40 m deep (no observations of > 20% *Mytilus* coverage in > 40 m deep waters in VELMU data). In addition to environmental layers, a layer describing hard vs. soft bottom (1: 250 000 scale, available from http://hakku.gtk.fi) was used as a predictor in the *Mytilus* model.

3 Results

3.1 Existing vegetation data

The data was collated to a common format mainly from Husö Biological Station reports and their related datasets (SCHEININ & SÖDERSTRÖM 2005, PUNTILA 2007, SÖDERSTRÖM 2008, NYSTRÖM 2009, KAUPPI 2011, EVELEENS MAARSE 2013, HOLGERSSON 2013, SAARINEN 2015), and from one PhD study (SNICKARS 2008). The data from NYSTRÖM (2009) lacked exact coordinates of the dive-transects, and thus, the data was stored separately (different sheet of the Excel-file). The data from the NANNUT project was also included into the dataset (KIVILUOTO 2013) as well as one study by external consults for the Government of Åland (SAHLIN & JOHANSSON 2015). On the contrary to VELMU data, In Åland the main part of the existing dive transects were 50 m long, thus, especially on gently sloping shores, the lower limit of vegetation was often not reached. There were many studies where several transects were drawn e.g. across a whole bay/lagoon, with the aim of mapping the vegetation in the whole bay (e.g. SNICKARS 2008, EVELEENS MAARSE 2013). The area used to document the vegetation cover was often 0.5 m x 0.5 m quadrat, thus it is much smaller than used in e.g. the VELMU surveys ($4m^2$). It should also be noted that none of the studies (except for SAHLIN & JOHANSSON 2015) reported the cover of sessile animals, e.g. *Mytilus*. Thus, the absence of animals from the data does not necessarily indicate their absence from the survey sites.

The data collation resulted in over 6300 rows of vegetation data, out of which approximately 5800 points were dive-transect data (partly done by snorkelling) and 500 points were collected using drop-video (NANNUT-project data). The distribution of the data is presented in fig. 3.

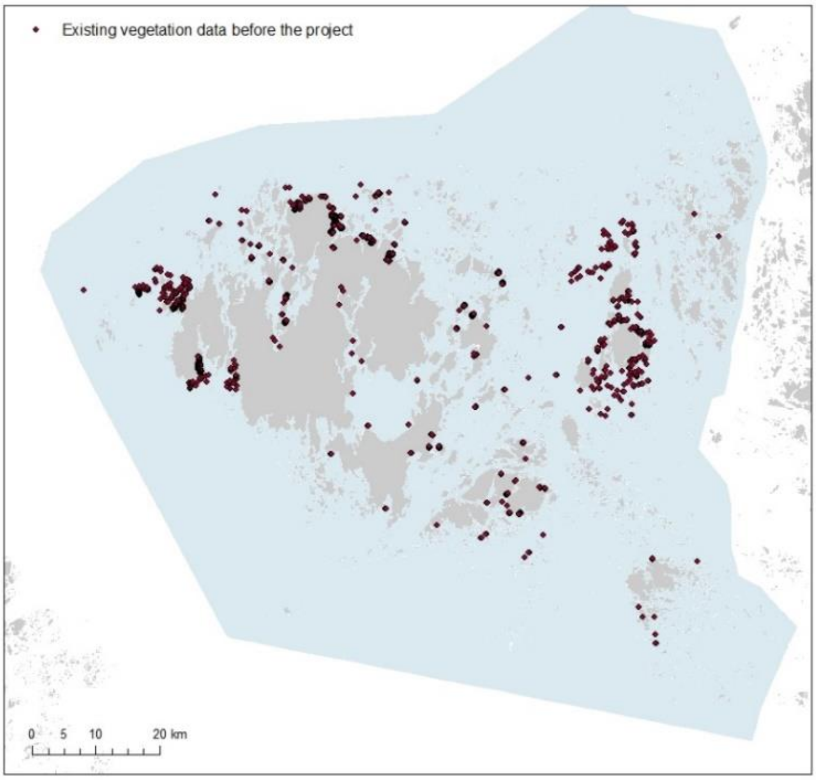

Figure 3. Existing data from Åland (2000-2015) that was collated into a common data format in the beginning of the project.
Figur 3. Befintliga data från åländska havsområden (2000–2015) som sammanställdes i ett gemensamt dataformat i början av projektet.

3.2 General description of the surveyed areas

3.2.1 SW Åland (Eckerö - Hammarudda)

South-west Åland, the area extending from SW Eckerö to Hammarudda (but excluding the inner parts of narrow inlets Kyrksundet and Gaveln/Marsund) was mapped during 28.6 - 7.7.2017. The water temperatures were still rather cold, and there were a lot of drifting filamentous algae. The vegetation had only just started growing.

The area is bordered by the Åland deep in the south and thus the coastal shallow area (<25m) is relatively narrow. The area is characterized by rocky shores, but often with sandy bottom under water. In some areas the sandy bottoms were connected to a sandy shore (e.g. Degersand and Hinder-Bengtsviken). The area is very exposed and at the time of the surveys, the water was also very clear. Typical species to the area were *Zostera* that often formed dense meadows (although often covered with filamentous algae) typically in 2-4 m depth, and *Stuckenia pectinata*. In addition, *Tolypella nidifica* occurred relatively often. Also, bare sandy bottoms with no vegetation were common. *Fucus* occurred throughout the SW and western coast, often in the shallower waters (max 2.8 m), in association with the rocky shores.

3.2.2 Southern coast (E Hammarudda - S Lemland)

The area extending from Hammarudda to south of Mariehamn was mapped during 10. - 28.7.2017. There were lot of sandy bottom also in this area, but they gradually changed towards more silty bottoms when moving eastward towards Mariehamn. Southeast of Mariehamn the visibility was poor, and the bottoms were silt/mud dominated. There were a lot of drifting filamentous algae. During the surveys, it was very windy which probably contributed to the poor visibility. The highly trafficked areas south of Mariehamn had very little *Fucus*. When moving south from Mariehamn towards more open areas the visibility was better, and the algal species diversity increased. South of Järsö, all the way to Lågskär there where beautiful red algal belts and reefs with blue mussel.

3.2.3 Southeastern Åland

The South East of Aland Island was mapped during 1.7. - 7.9.2018. The area ranged from the southeastern side of the main Åland Island to the eastern side of Kökar and continued north via Sottunga to the western side of Sandö at Vårdö (fig. 1). The area is famous for the esker formation (including esker islands) that runs from the eastern side of Kökar all the way to the western side of Sandö and Malören. In this area many of the islands consisted of cobble stone shores while the underwater coastline was very shallow and consisted of mainly gravel and sand. On esker islands, a lot of sea kale (*Crambe maritima)* occurred. The underwater part of the esker Islands was characterized by *Zostera* and *T. nidifica*. The sea floor in this area, although consisting mainly of gravel, sand and silt, had a large amount of blue mussel reefs also in more shallow areas. Outside the esker area, the islands had mainly rocky shores with a large amount of filamentous algae. *Fucus* belts where rare in this part of the Åland Island.

3.2.4 Lumparn

Lumparn bay is an ancient meteorite crater (LEHTINEN 1998), which is almost completely surrounded by land with rocky shores. The water depth is quite shallow, mostly around 20 m, and the bathymetry is flat. Almost all of the Lumparn seabed is a sedimentation area with a thick cover of recent mud. The biological surveys revealed that the nearshore areas (not included in the geological surveys) had also a lot of sandy areas with *Zostera* meadows, especially in the northern part, but also in the southern Lumparn. The biological sampling in the area was carried out in a parallel project (ENGSTRÖM 2018) in June-July 2018.

3.2.5 NE Åland (northern Vårdö, Sund and Saltvik)

The study area in the northeastern Åland was surveyed during 1.8. - 24.8. 2017. The area is mainly remote, and especially in its outer parts, characterized by small rocky islands. Overall, the area is very rocky and stony. The rocky shores have typical marks of the ice age with often large stones and boulders occurring on top of rocky bottoms. In over 10 m depth, the bottoms were mostly sand/silt.

Depth data was often misleading in the area, which made driving the boat more challenging. At the time of the surveys, there were a lot of cyanobacterial blooms and a lot of decaying cyanobacteria, especially north of Boxöfjärden. The most diverse areas were in the very exposed north (Kalskär / Rödskär / Flöjskär – and northwards), with rocky shores and a variation of rocky and sandy bottoms, often with large boulders under water. The area was characterized by *Fucus* zones, blue mussel reefs and red algal communities. The densest *Fucus* zones were found in 0.3 - 2 m depth.

The esker formation that starts east of Kökar extends all the way to the northeastern Åland. The islands associated with the formation (e.g. Sandö and Malören in Vårdö/Sund) differ from the surrounding rockier areas. The underwater parts of these islands have sandy bottoms with typical vegetation, e.g. *Zostera* and species rich Charophyte meadows. The area around Sandö was mapped 25. - 31.8.2017 and Malören in 28.8.2018.

3.3 The new data gathered during the project

The geological data gathered during the project are presented in Annex I of this report. The coverage of the biological data gathered is presented in fig. 4.

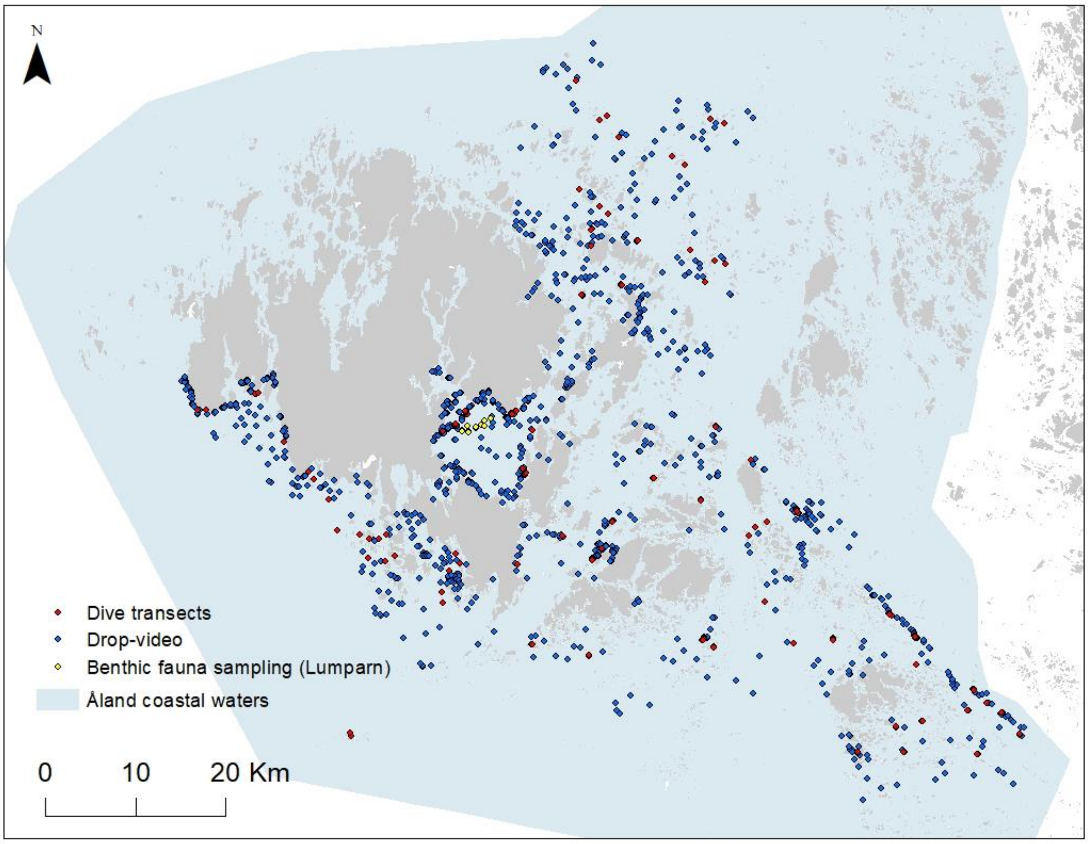

Figure 4. The data gathered during the project. The figure also includes data that was gathered in a parallel project (ENGSTRÖM 2018), as e.g. planning of the surveys and data collection were harmonized with this project.
Figur 4. Data insamlat under projektets gång. Figuren inkluderar också data som samlades in inom ett parallellt projekt (ENGSTRÖM 2018) eftersom planering och insamling av data gjordes i nära samarbete.

Altogether, 1799 biological sampling points were visited during the project (including dive-transects and drop-video). In 2017, the sampling covered 502 survey points on 27 dive-transects and 431 drop-video points. In 2018, 523 survey points on 42 dive-transect and 343 video-points were obtained. In addition, 24 benthic fauna sampling stations in the Lumparn area were visited, 8 in 2017 and 16 in 2018.

In general, the goals set for the surveys were reached. However, there were some areas that were included in the biological mapping plans, but were finally left outside the surveys, e.g. the open sea areas in southern Föglö and southern Kökar, as well as the northernmost part of the northeastern study area. Visiting these areas would have required very calm days that did not occur while the surveys were concentrated in the region.

3.4 The occurrence of Natura 2000 habitats

3.4.1 Sandbanks (1110)

The analysis carried out with the data gathered by GTK (bottom substrate + depth data) revealed that potential sandbanks were found associated with the Kökar esker formation (20 sandbanks altogether, Figure 5). However, out of these 20, three of these sandbanks were completely deeper than in 20 m, thus not fulfilling the criteria of sandbanks according to the Habitats Directive definition (AIRAKSINEN & KARTTUNEN 2001). Of the other sandbanks, the depth of the “top” of the sandbank varied from 2 m to 19.3 m. Often the distinction between the potential sandbanks and submarine continuations of esker islands was difficult, as many of the potential sandbanks occurred close to the esker islands. Here, the sandy/gravelly elevations with immediate connection to esker islands were classified as submarine continuations of esker islands, others as sandbanks.

12/20 modelled sandbanks were ground-truthed during the biological surveys. The ground-truthing data gathered revealed that all sandbanks had mainly sandy substrate. Only one relatively large sandbank southeast of Sandskär (Sottunga) had rock and stones in the central parts of the bank, *Mytilus* was the most common species to occur on sandbanks. *Zostera* occurred on one sandbank, southeast of Östra Partuvan (Kökar).

In addition to the identified sandbanks within the GTK’s case study areas, the biological surveys revealed many sandy areas with typical vegetation to sandbanks, e.g*. Zostera, Ruppia cirrhosa, S. pectinata, C. aspera* and *T. nidifica* (AIRAKSINEN & KARTTUNEN 2001). The methods used in biological sampling could not reliably identify whether these areas were elevated from their surroundings, as defined in the sandbank definition. The areas were often gently sloping and sometimes connected to a sandy shore.

All elevations identified with 300m radius (formerly classified as reefs) outside the GTK’s survey areas that were found to have > 1 point of sandy substrate, were in connection to an island. For example, in the Lumparn area, there were some islands, whose surroundings had sandy areas with *Zostera*, e.g. Röda kon and Knapgrundet in the western Lumparn, as well as Trollskär in the eastern Lumparn

(ENGSTRÖM 2018). However, due to their connection to an island, they were here not classified as sandbanks and their status regarding Natura 2000 habitats remains unclear, until the definition of a sandbank is further clarified.

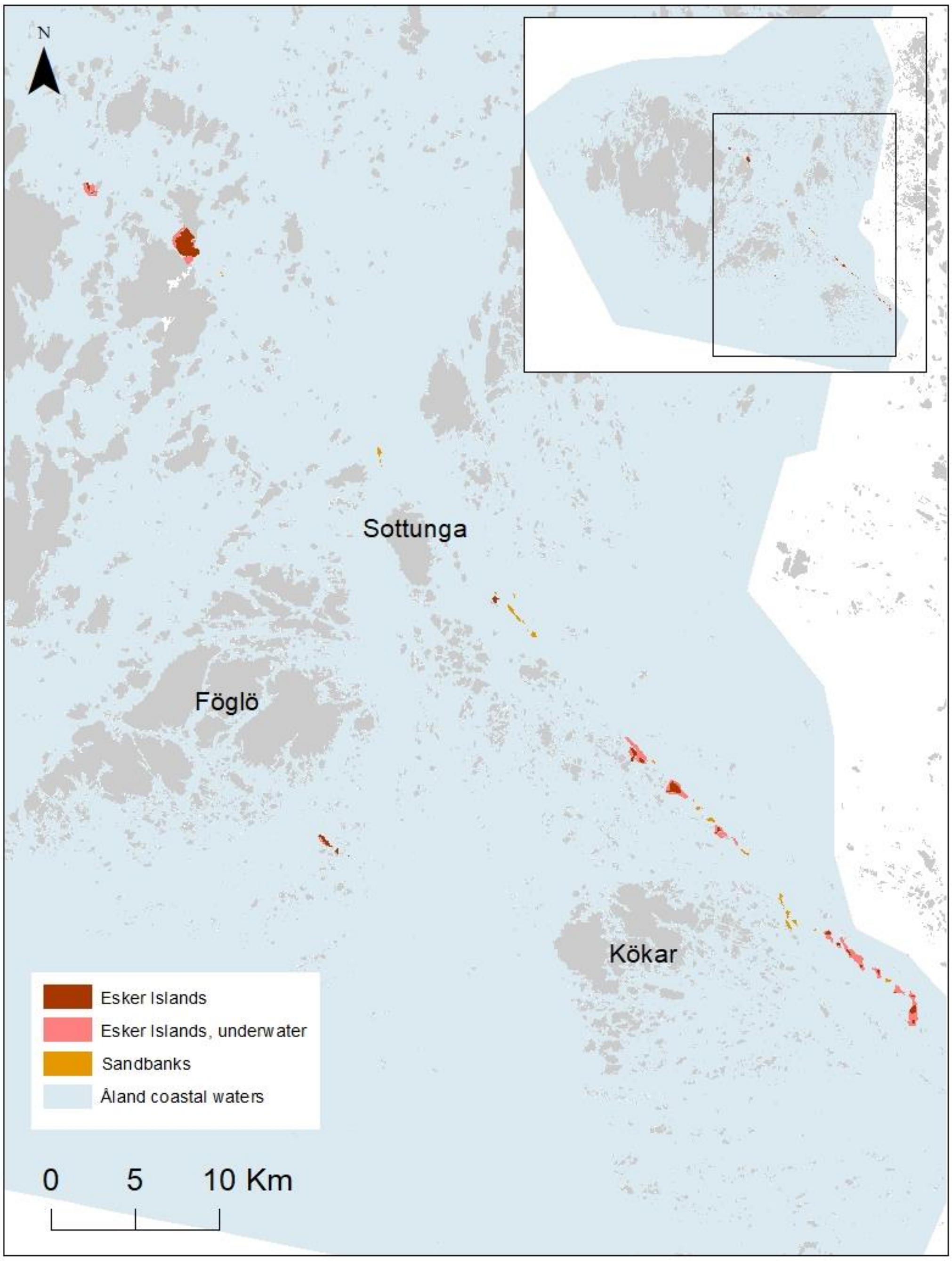

Figure 5. Sandbanks and esker islands (including their underwater parts) in eastern Åland.
Figur 5. Sandbankar och åsöar (samt delar av dem som fortsätter under havsytan) på östra Åland.

Also, some other sandy areas included in the biological surveys, outside GTK's survey areas, had particularly diverse or otherwise representative sandy bottom vegetation:

- Western Eckerö had some sites with high coverages of *Zostera*, where it occurred with *S. pectinata.* Here, the shore was often rocky, thus the sites were not connected to a sandy shore.
- Sandö area in Vårdö as well as Kökar esker area had representative sandy bottom vegetation and are covered in more detail in the next chapter on esker islands.

3.4.2 Baltic esker islands (1610)

The islands identified as esker islands were mainly part of the Kökar esker formation. The formation extends from eastern Kökar to Vårdö, with the southernmost island being Stora Revet (and a smaller island south of it) east of Kökar, and the northernmost island Malören. The island of Sandö included an esker formation (southern part of the island), but the whole island was not considered an esker island. In addition to the Kökar esker formation, a group of islands in southern Föglö were classified as esker islands: most of Stora Sandören, the northern part of Lilla Sandören and a small island east of Lilla Sandören (fig. 5). Altogether 18 esker islands were identified, and their size varied from 0.8 to 31 hectares, largest being Örlandet, north of Kökar.

Figure 6. Esker islands. Here Östra Partuvan, with sea kale (*Crambe maritima*). Photos: Charlotta Björklund.
Figur 6. Åsöar. Bilder från Östra Partuvan med strandkål (Crambe maritima). Fotografier: Charlotta Björklund.

The underwater parts of the esker islands had mostly sand and gravel and stones. The most typical communities occurring in the underwater parts of esker islands were *Zostera* meadows, including e.g. *T. nidifica, S. pectinata* as well as *Zannichellia palustris.* Also, *Fucus* and *Mytilus* occurred commonly is association with the esker islands.

As a whole, the area east and north of Kökar with its gravelly islands and rich surrounding underwater vegetation, presents a very unique area, both geologically and biologically (fig. 6). Also, the southern side of Sandön was unique, the underwater parts hosting shallow sandy bottoms and typical vegetation to sandy bottoms, such as *Zostera* and various species of charophytes. On the southern side of Sandön, one of the survey sites had fine sand with high coverage of *Chara connivens*. The western side hosted many species of Charophytes; *C. aspera, C. Baltica* and *C. globularis*, as well as *Zostera,* although the coverage of *Zostera* were not as high as on the eastern side.

The underwater parts of Malören were so far only surveyed from the southern side (one dive-transect). The sandy/gravelly bottom hosted typical species to relatively open sandy bottoms, *C. aspera, C. baltica, S. pectinata* and *Potamogeton perfoliatus*.

3.4.3 Reefs (1170) and Boreal Baltic islets and small islands (1620)

Both Reefs and Boreal Baltic islets and small islands are very common habitats throughout the archipelago area (fig. 7). During the project, there were no need to produce new models on these habitats for the Åland coastal waters, but instead, the functionality of the reef model (KASKELA & RINNE 2018), including the parts in connection to islands -- i.e. underwater parts of the Boreal Baltic islets and small islands) in the Åland waters was assessed.

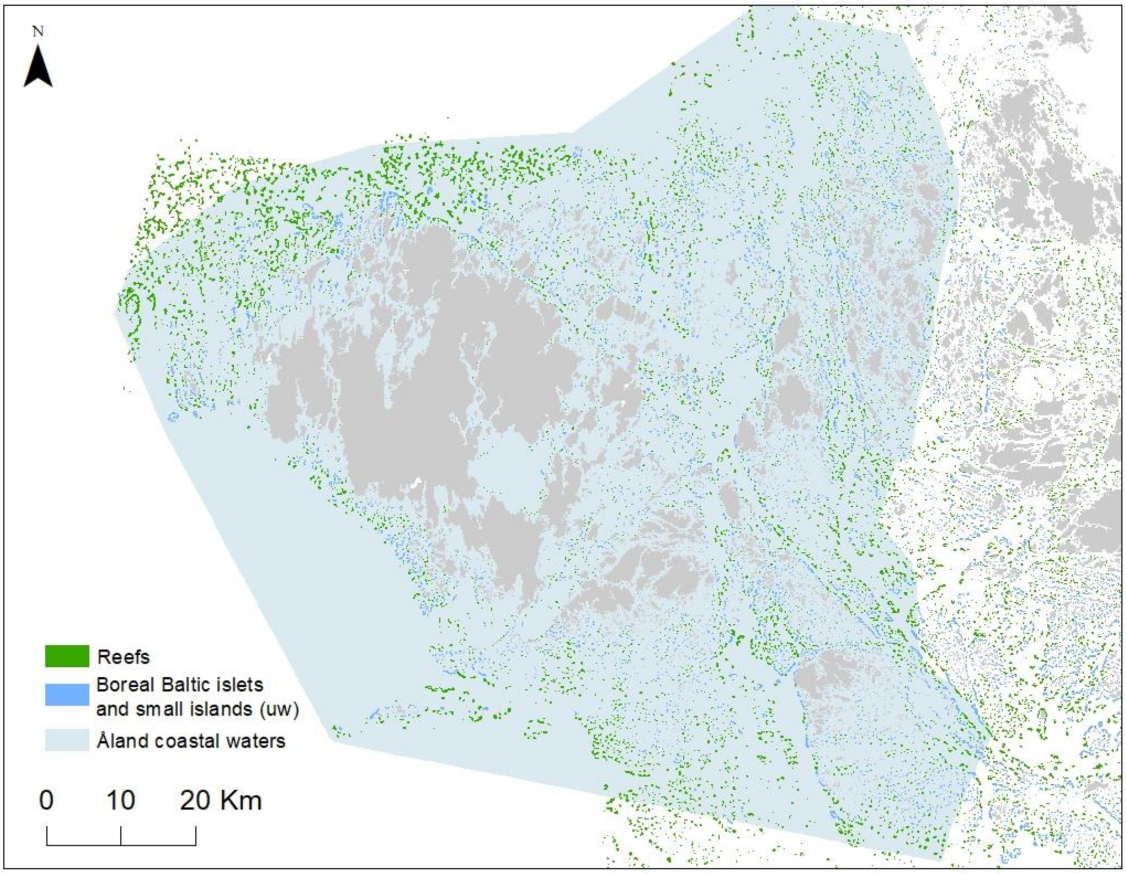

Figure 7. The Reefs (1170) and the underwater parts of Boreal Baltic Islets and small islands (1620) in Åland coastal waters based on the national reef model (KASKELA & RINNE 2018).
Figur 7. Boreala skär och småöar i Östersjön (1620) i kustvattnen kring Åland. Kartan baserar sig på rumslig modellering av rev på nationell nivå (KASKELA & RINNE 2018).

3.4.3.1 Comparison of the national reef model to the more detailed model

The model based on the more detailed depth and substrate data within the geological survey areas showed a higher number of reefs than the “national model” (541 vs. 481). However, the reefs in the more detailed model were in general smaller, as the total area of the reefs based on detailed data was approximately 65% of the total area of the coarser reefs (fig. 8). Out of the more detailed model, approximately 70% of the area overlapped with the national model, and it was mainly small reefs in the detailed model that did not appear in the national model causing the difference.

The results were somewhat expected, as it is natural that with more detailed depth data, finer variation in depth and smaller elevations are found. However, the analysis also shows that although the analysis based on the rougher data produces larger areas, they are often in the right locations. It is mainly the smaller scale features that are left out.

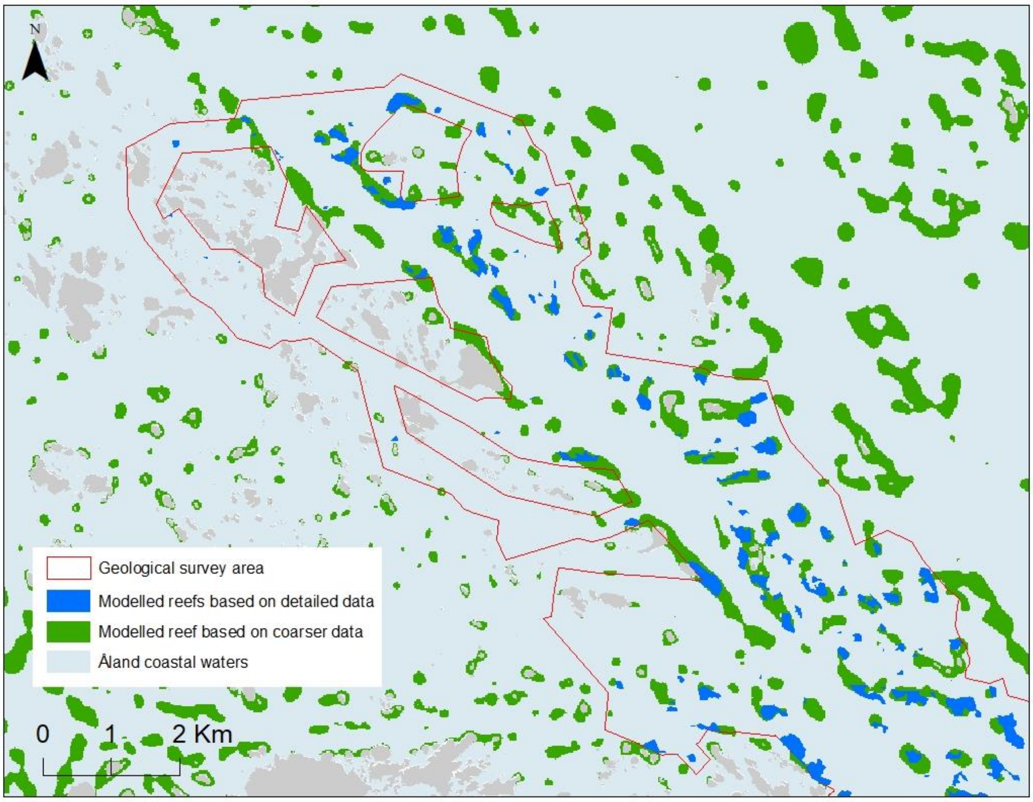

Figure 8. The comparison between the reef model based on coarser data (KASKELA & RINNE 2018) and the model based on more detailed data within the geological survey areas.
Figur 8. Jämförelser mellan revmodellen baserad på grövre data (KASKELA & RINNE 2018) och modellen som producerats med mera detaljerade data från de geologiska undersökningsområdena.

3.4.3.2 The functionality of the national reef model in Åland

The analysis on the amount of hard substrate on reefs and outside reefs, revealed that in all study areas, in the 0-5 m depth, 80-90% of reefs had hard substrate, indicating good functionality of the reef model in the shallow waters (fig. 9a). However, especially in the rocky northeastern area, hard substrate areas were often found also outside the modelled reefs (fig. 9b). These could be areas that are not elevated, and were therefore not recognized by the analysis, or could also be smaller elevations not identified due to coarser depth data. In the southwest, with generally more sandy bottoms, the model seemed to work well across the depth gradient, also in the deeper waters. However, in the deeper waters of the two other areas, the amount of hard substrate on modelled reefs was lower. This could be partly due the modelled reefs being larger than the actual reefs, as also identified when comparing the model to a more detailed model (above). It could also indicate that the lower parts of elevations often have softer substrate.

When looking at typical reef communities (fig. 9c, 9d), the vast majority of the modelled reefs had typical reef communities down to 15 m depth. In the deeper waters, especially in the northeastern area, the reliability of the model dropped, following also the general decrease in hard bottom. Again, in the northeastern area there were often reef communities found also outside of predicted reefs, indicating the general rocky character of the area, and that the area as a whole is largely dominated by rocky substrate and associated communities, especially in 0-5 m depth.

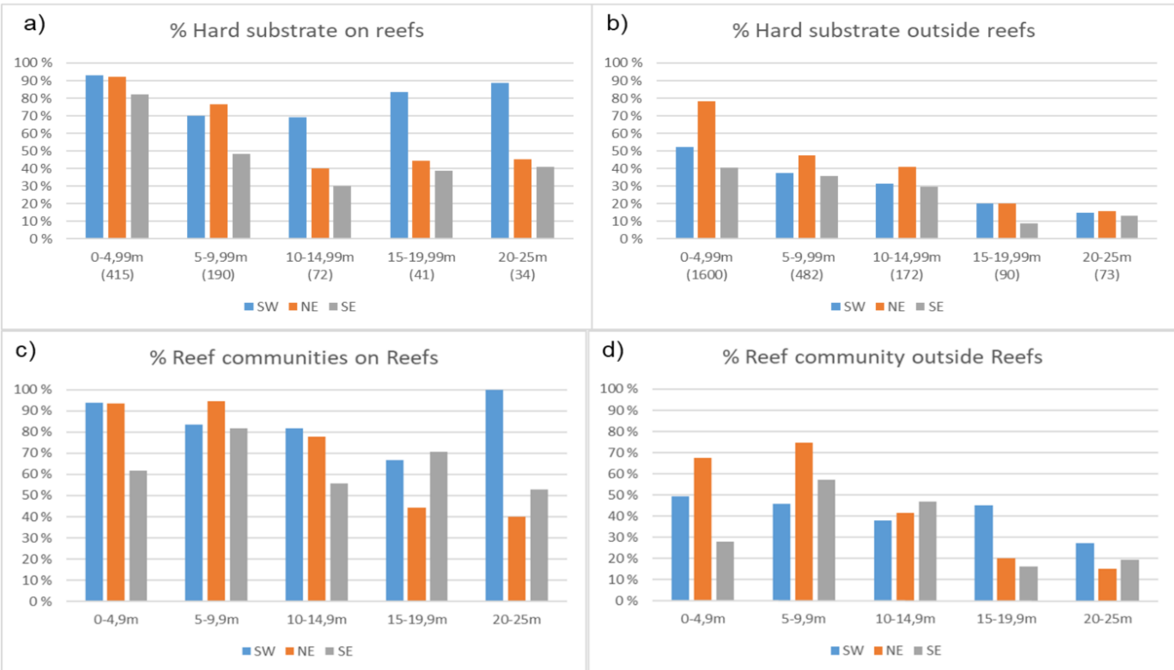

Figure 9. The analysis on the amount of hard substrate (rock, boulders, stones and gravel) and typical reef communities that occurred on reefs and outside reefs in different parts of the study area. The number in brackets refers to the number or survey points within the depth zone. The southwestern area (SW), and the northeastern area (NW) were both surveyed in 2017, and the southeastern area (SE) in 2018 (see fig. 1).
Figur 9. Analys över andelen hårt substrat (berg, flyttblock, sten och grus) och typiska revsamhällen som påträffades på reven och utanför dem i olika delar av undersökningsområdet. Numret inom parentes beskriver antalet undersökningspunkter från respektive djupintervall. Det sydvästra (SW) och nordvästra (NW) områdena undersöktes 2017, och det sydöstra (SE) området 2018 (se fig. 1).

The analysis looking into biological communities occurring on hard substrate across the study areas, revealed some differences between the areas (fig. 10). The shallowest zone (0-5 m) in the northeast, had a lot of *Fucus* dominated communities, but in general, relatively little red algae were found in the area, with the exception of soft crustose algae (mainly *Hildenbrandia rubra*). *Fucus* occurred less frequently in the southeast where it was often replaced by the filamentous annual algae. In the eastern areas, there were very little algae > 10 m depth, while in the southwest there were still perennial filamentous algae down to 20 m (not determined to species level in the data). Blue mussel communities clearly dominated in the deeper waters.

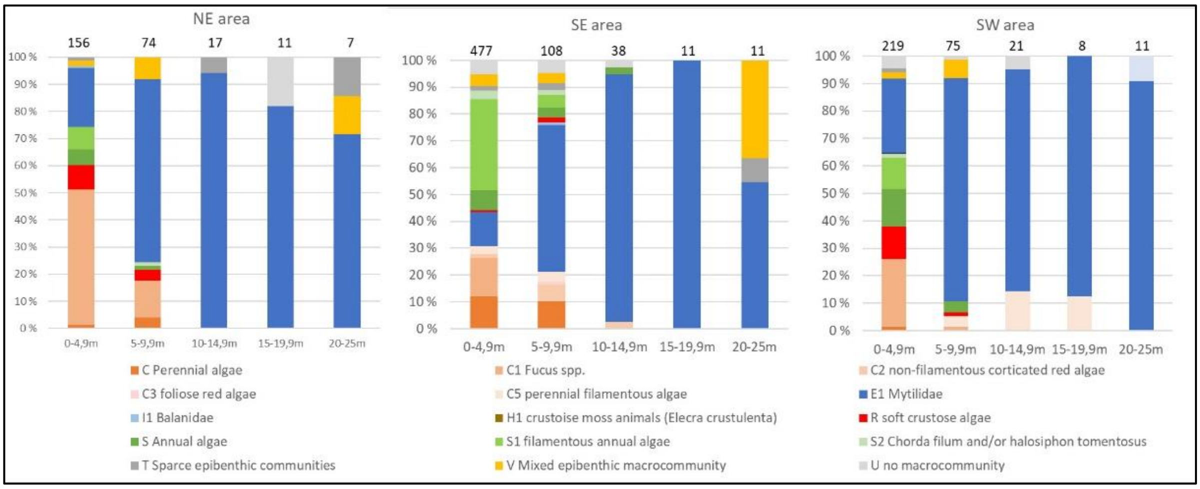

Figure 10. Communities occurring on rocky substrates in the study areas, northeast (NE), southeast (SE) and southwest (SW). The number on top of each bar represents the number of study sites that were used in the analysis in each depth zone.
Figur 10. Samhällen som förekommer på hårda bottnar i undersökningsområdet i nordost (NE), sydost (SE) och sydväst (SW). Siffran ovanför varje stapel beskriver antalet undersökningsplatser som användes vid analysen för respektive djupintervall.

3.4.4 Structures made by leaking gas (1180)

The Lumparn bay was of particular interest due to potential occurrence of structures made by leaking gas in the area. This Natura 2000 habitat has not been found previously in Finland. The results of the geological surveys carried out in the Lumparn area are more thoroughly presented in Nyman (2018) but are shortly presented here.

The geological surveys in Lumparn bay revealed thousands of dome-like structures that were especially abundant in the northern Lumparn (fig. 11). The domes were approximately 30 m in diameter on average, and generally 0.5 – 0.75 m high (NYMAN 2018). These kind of structures are rarely mentioned in the literature, but they likely result from gas occurring within the upper sediments, causing the sediment to dome upwards. It is also possible that the domes are precursors to pockmark formation, but this is unlikely, as no pockmarks were observed in the area.

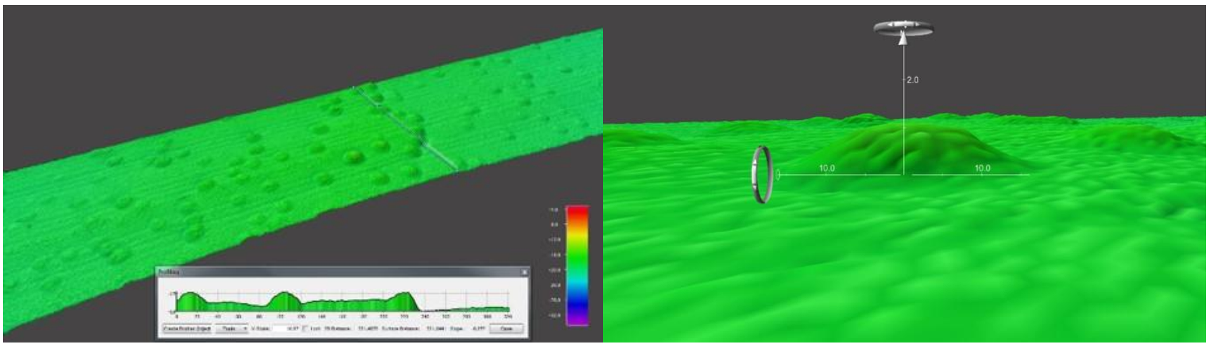

Figure 11. A multibeam image from the Lumparn bay, showing the dome-like structures (left) and their size (right). The images are based on GTK’s soundings.
Figur 11. Bilder från ett flerstråligt ekolod (multibeam) från Lumparns botten. Till vänster de dom-lika strukturerna på havsbottnen och till höger deras storlek. Bilderna baserar sig på GTKs mätningar.

The benthic faunal communities differed to some extent between the domes and the surrounding environments (control) both in 2017 and 2018 (fig. 12). In 2017, it was crustaceans (Ostracoda, *Corophium volutator*), gastropods (*Hydrobidae*), insect larvae (*Chironomidae*) and polychaete *Marenzelleria spp.* that contributed mostly to the dissimilarities between the domes and the surrounding environment. In 2017 the sampling depth varied from 7.7 m to 20 m and the variation in depth could also be seen in the faunal communities (fig. 12a: sampling station D in 7.7 m depth, stations 1 and 3, in 20 m and 19 m depth, respectively).

In 2018, the controls were taken right next to the domes (fig. 2), and there was less depth variation in the samples (15.1-18.2 m). The main taxa contributing to the difference between these groups were mainly the same as in 2017.

In general, there were more ostracods and *C. volutator* on/in domes and less *Marenzellaria spp.* and Hyrobiidae and chironomids on/in domes than in their surroundings.

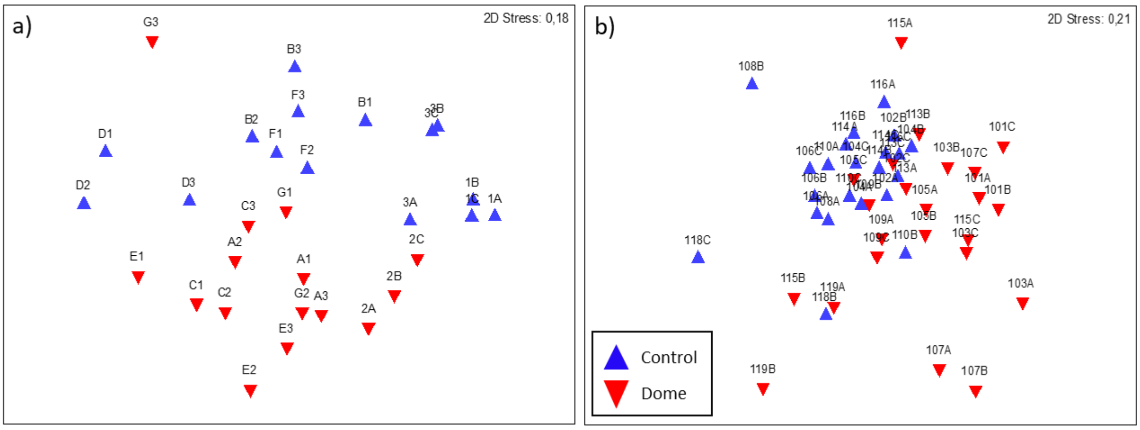

Figure 12. Non-metric multi-dimensional scaling (NMDS) of the benthic fauna sampled in 2017 (a) and in 2018 (b), including all three replicas at the sampling sites.
Figur 12. Icke-metrisk multi-dimensionell skalning (NMDS) av bentisk fauna insamlad 2017 (a) och 2018 (b). Alla tre replikat/provtagningsplatser finns med i figuren.

Despite the found doming structures and the differences in their associated fauna when comparing to the surrounding environment, the domes **do not** fulfill the definition of the submarine structures made by leaking gas (ANONYMOUS 2013, see also Introduction of this report). Although some acoustic chimneys were found in association with the domes (NYMAN 2018), it is probable, that the domes are not caused by leaking gas, but instead, gas is formed within the sediment (shallow gas). In addition, no slabs, pavements, or pillars were found, that are listed in the habitat definition as formations caused by leaking gas.

Although the domes do not fulfill the definition of the Natura 2000 habitat, they are unique geological formations. While pockmarks and other gas-related sedimentary structures have been found also from other Finnish marine areas (KOTILAINEN & HUTRI 2004), their occurrence has not been as extensive as in Lumparn.

3.5 Species occurrence

Bladder wrack - *Fucus vesiculosus*

Fucus vesiculosus, the key habitat-forming species of the rocky shores in the northern Baltic Sea, was found frequently especially in the northeastern archipelago (fig. 13). It was often observed also in earlier surveys along the northern coast. However, although there are a lot of suitable rocky areas for *Fucus* occurrence in the archipelago area east of Åland main island, *Fucus* was rarely found there. Also, the area south of Mariehamn had very little *Fucus*. The poor status of *Fucus* in the eastern/southeastern Åland is similar to the current situation in the adjacent outer Archipelago Sea (RINNE & SALOVIUS-LAURÉN, submitted manuscript). The few findings in the southeast and southern coasts are also reflected in the probability model that predicted higher probabilities mainly in the northern archipelago areas (fig. 13). However, if potential sites for *Fucus* occurrence were predicted or otherwise described instead, the areas would be much larger than shown in the probability map done based on current findings. The most important environmental variables for *Fucus* were exposure at seabed, depth and the slope of the shore (tab. 1).

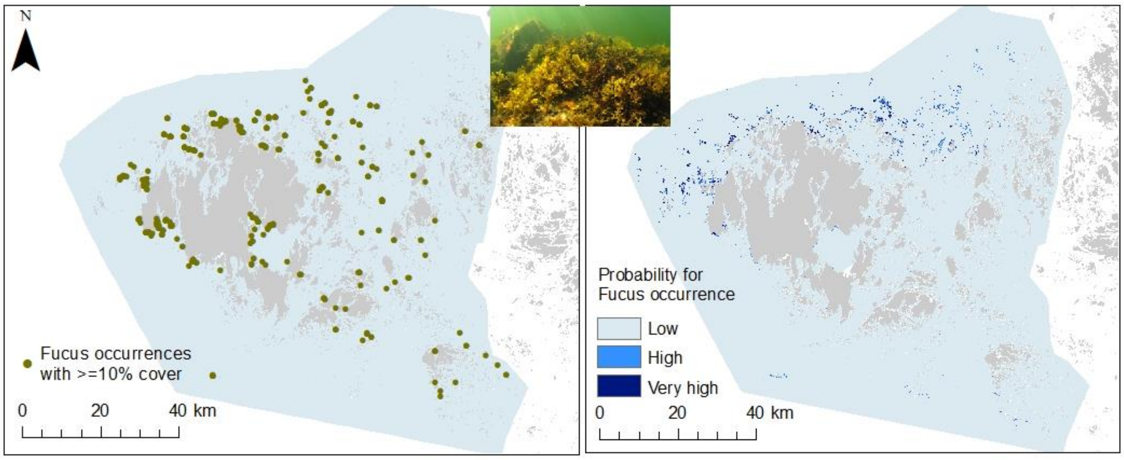

Figure 13. The occurrence of bladder wrack *Fucus vesiculosus* (left), including occurrences from the surveys in 2017-2018 and earlier surveys carried out by Husö biological station. The figure on the right shows the probability for *Fucus* presence within the Åland coastal waters. Photo: Metsähallitus Parks and Wildlife Finland.
Figur 13. Förekomster av blåstång Fucus vesiculosus (höger), baserat på inventeringar 2017–2018 samt på tidigare undersökningar gjorda av Husö biologiska station. Figuren till höger visar en rumslig modell över sannolika förekomster av Fucus inom de åländska havsområdena. Foto: Forststyrelsen.

Clawed fork weed - *Furcellaria lumbricalis*

Furcellaria lumbricalis occurs throughout the Åland coastal waters (fig. 14), sometimes even down to 13 m depth. The occurrences were mainly most frequent along the southern and northern coasts, in relatively exposed localities. According to the probability model, the most important variables for *F. lumbricalis* occurrence were exposure at seabed, slope of the shore, as well as depth (tab. 1).

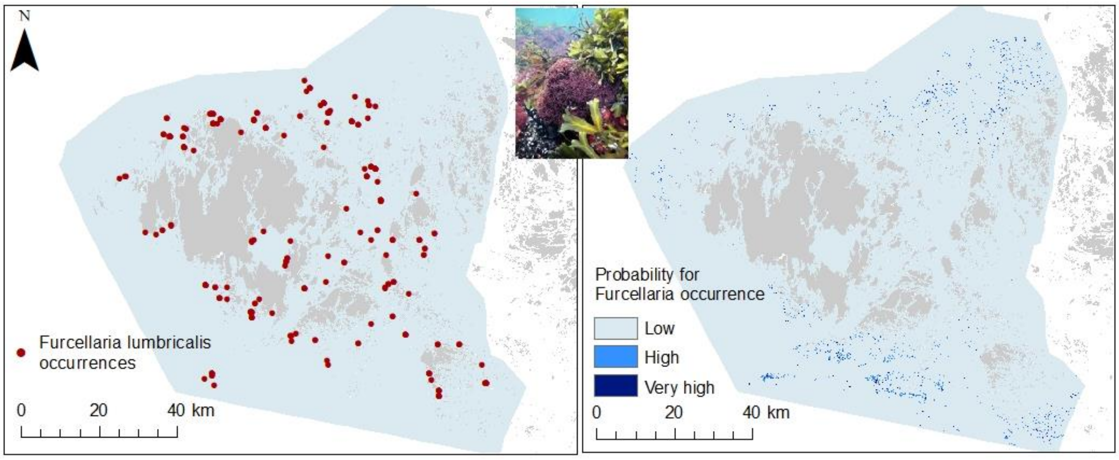

Figure 14. The occurrence of clawed fork weed *Furcellaria lumbricalis* (left), including occurrences from the surveys in 2017-2018 and earlier surveys carried out by Husö biological station. The figure on the right shows the probability for *Furcellaria* presence within the Åland coastal waters. Photo: Metsähallitus Parks and Wildlife Finland.
Figur 14. Förekomster av kräkel (= gaffeltång) Furcellaria lumbricalis (höger), baserat på inventeringar 2017–2018 samt på tidigare undersökningar gjorda av Husö biologiska station. Figuren till höger visar en rumslig modell över sannolika förekomster av F. lumbricalis inom de åländska havsområdena. Foto: Forststyrelsen.

Red algal communities

Red algal communities were identified as being endangered when the status of marine habitats in Finland was recently evaluated (KONTULA & RAUNIO 2018). Here *H. rubra* that often grows as a soft "mat" on top of stones was not included, but the group included both perennial and annual red algae. Red algal communities with ≥ 10% coverage were found across the relatively open coastal/archipelago areas (fig. 15). The area south of Mariehamn and south of Lemland had particularly representative red algal communities that were rich in species and had high coverages. Also, according to the probability model on red algal occurrence, the open sea areas in the south have high probability for hosting red algal communities (fig. 15). A lot of these areas remain unmapped (areas far south of Föglö and Kökar), and they will hopefully be visited during the future mapping projects.

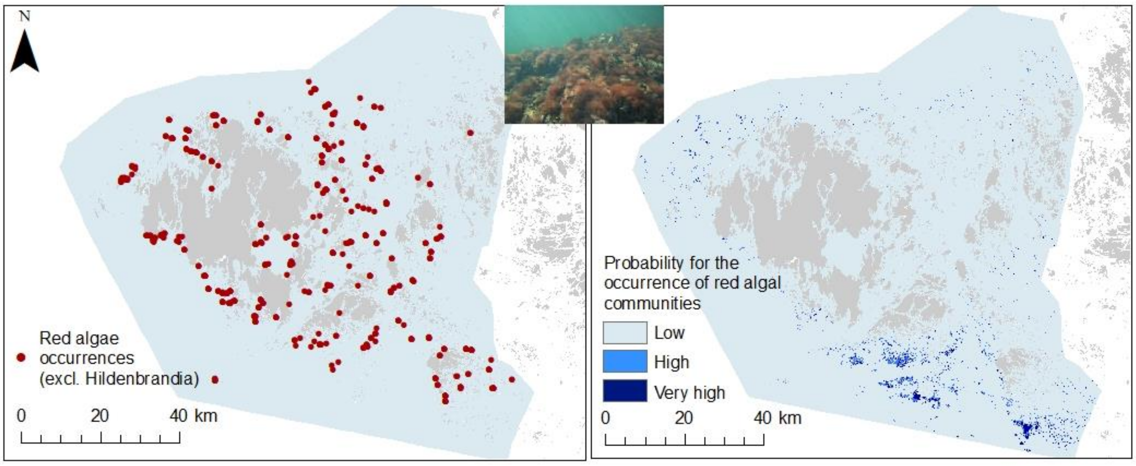

Figure 15. The occurrence of red algal communities with ≥ 10% coverage, excluding *Hildenbrandia rubra* (left), including occurrences from the surveys in 2017-2018 and earlier surveys carried out by Husö biological station. The figure on the right shows the probability of presence for red algal communities within the Åland coastal waters. Photo: Metsähallitus Parks and Wildlife Finland.

Figur 15. Förekomsten av rödalgssamhällen med ≥ 10% täckningsgrad, uteslutande Hildenbrandia rubra (vänster), baserat på inventeringar 2017–2018 samt på tidigare undersökningar gjorda av Husö biologiska station. Figuren till höger visar en rumslig modell över sannolika förekomster av rödalgs samhällen inom de åländska havsområdena. Foto: Forststyrelsen.

Table 1. The modelled species and communities, coverage thresholds used to indicate “presence” of the species in the model, as well as the most important environmental factors that contributed to the model. The sign after the contribution value indicates, whether the impact of the environmental factor was mainly positive (+) or negative (-), although the effects were never linear. The model AUC is the Area Under the ROC curve, which indicates the ability of the model to predict correctly.

Tabell 1. Arter och samhällen i de producerade rumsliga modellerna, och tröskelvärden som indikerar förekomst av arterna i modellen samt de viktigaste miljövariablerna som bidrog till modellen. Tecknet efter värdet som beskriver hur mycket miljövariabeln bidrar till modellen visar om miljövariabelns påverkan är huvudsakligen positiv (+) eller negativ (-), men effekterna var aldrig linjära. Modellens AUC är Arean Under ROC kurvan, som indikerar modellens förmåga att förutspå förekomst korrekt.

Species	Threshold used for ”presence”	Most important environmental factors	Contribution to the model (%)	Model AUC
Fucus vesiculosus	≥10%	Exposure at seabed	22.5 (+)	0.95
Bladder wrack		Depth	18.6 (-)	
Blåstång		Slope	11.6 (+)	
Furcellaria lumbricalis	>0%	Exposure at seabed	21.8 (+)	0.95
Clawed fork weed		Slope	19.0 (+)	
Kräkel		Depth	17.5 (-)	
Red algal communities	≥10%	Exposure at seabed	21.8 (+)	0.96
(excl. *Hildenbrandia*)		Slope	18.8 (+)	
Rödalgsamhällen		Depth	16.0 (-)	
Chara aspera	>0%	Depth	22.9 (-)	0.97
Rough stonewort		Exposure	13.6 (-)	
Borststräfse		Distance to sand	12.5 (-)	
Chara spp. (excl. C. aspera)	≥10%	Exposure	37.5 (-)	0.98
Stoneworts		Salinity	16.1 (-)	
Kransalger		Secchi depth	14.4 (-)	
Zostera marina	≥1%	Distance to sand	24.3 (-)	0.95
Eelgrass		Depth	20.3 (-)	
Ålgräs		Exposure	15.1 (+)	
Mytilus edulis	≥20%	Depth	23.4	0.92
Blue mussel		Slope	14.2	
Blåmussla		Exposure	10.7	

Rough stonewort - *Chara aspera*

Chara aspera occurs commonly on sandy shores, while other species in *Chara* spp. prefer softer substrate and sheltered habitats. During the surveys *C. aspera* was mostly found east of the Åland main island, in Föglö and in Vårdö (fig. 16). In addition, it has been often found in earlier surveys in the bays in northern Åland. There are some similarities in *C. aspera* occurrence patterns to *Zostera* (fig. 18) but it rarely occurred in the Kökar esker formation or in Lumparn. Generally, *C. aspera* seems to prefer slightly more sheltered localities than *Zostera.* Although *C. aspera* was rarely found along the southern coast of the Åland main island, *T. nidifica* that often occurs together with *C. aspera* was found in the area. According to the probability model, the main environmental factors that contributed to occurrence of *C. aspera* were depth, exposure and the distance to sandy shore (tab. 1).

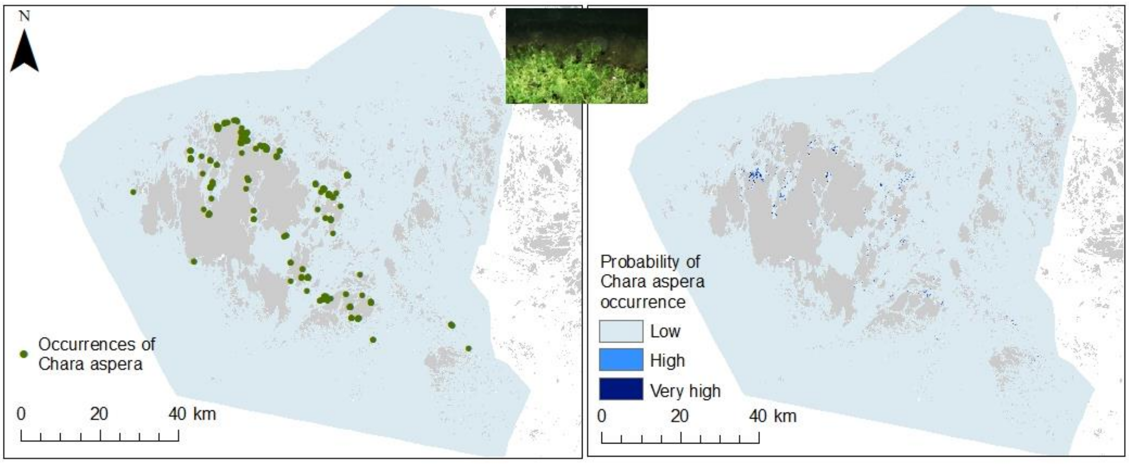

Figure 16. The occurrence of rough stonewort *Chara aspera*, including occurrences both from the surveys 2017-2018 and earlier surveys carried out at Husö biological station. The figure on the right shows the probability of presence for *C. aspera* within the Åland coastal waters. Photo: Metsähallitus Parks and Wildlife Finland.
Figur 16. Förekomster av borststräfse Chara aspera baserat på inventeringar 2017–2018 samt på tidigare undersökningar gjorda av Husö biologiska station. Figuren till höger visar en rumslig modell över sannolika förekomster av C. aspera inom de åländska havsområdena. Foto: Forststyrelsen.

***Chara* spp. (excluding *Chara aspera*)**

Chara spp. group included *Chara* species that occur mostly in sheltered bays with soft substrate. The group can be considered being equal to the class “Charophytes in the sheltered habitats” that was classified as being vulnerable in the red book of Finnish habitats (KONTULA & RAUNIO 2018). During the surveys in 2017-2018, charophytes were mainly found in Föglö area, as well as in Vårdö. The main part of the occurrences used in the modelling were from the earlier data, from the bays along the northern coast (fig. 17). The southern coast seems to largely lack charophytes that prefer more sheltered habitats.

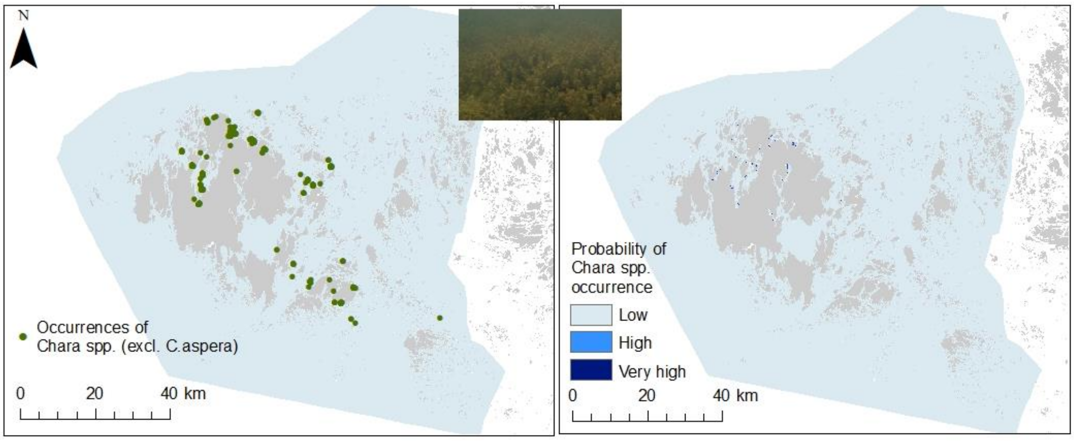

Figure 17. The occurrence of stoneworts (*Chara* spp.) communities, including occurrences both from the surveys 2017-2018 and earlier surveys carried out at Husö biological station. The figure on the right shows the probability of presence for *C. aspera* within the Åland coastal waters. Photo: Metsähallitus Parks and Wildlife Finland.
Figur 17. Förekomster av kransalgsamhällen (Chara spp.) baserat på inventeringar 2017–2018 samt på tidigare undersökningar gjorda av Husö biologiska station. Figuren till höger visar en modell över sannolika förekomster av Chara spp. inom de åländska havsområdena. Foto: Forststyrelsen.

Eelgrass - *Zostera marina*

Many previously unknown occurrences of *Zostera* were recorded during the project. In the southwest, *Zostera* was common from western Eckerö to western Hammarland (fig. 18). From there eastwards, *Zostera* was not found along the southern coast of the Åland main island, except for low coverages reported in Idskär, south of Nåtö / Mariehamn. *Zostera* was also very common in near shore areas of Lumparn bay, in western Föglö and along the esker formation both northeast of Kökar and around Sandö (Vårdö).

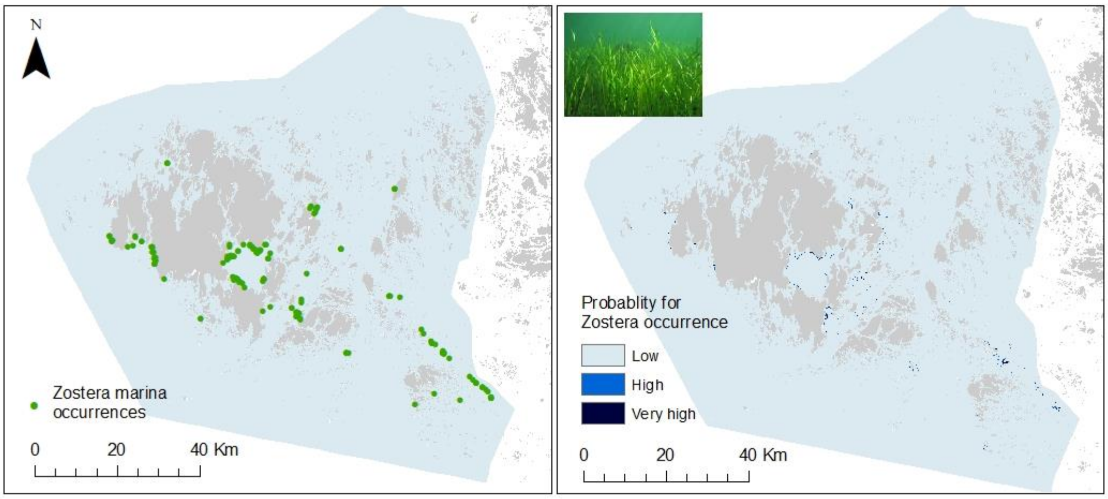

Figure 18. The occurrence of eelgrass *Zostera marina* (left), including occurrences from the surveys in 2017-2018 and surveys carried out by Husö biological station. The figure on the right shows the probability for *Zostera* presence within the Åland coastal waters. Photo: Metsähallitus Parks and Wildlife Finland.
Figur 18. Förekomster av ålgräs Zostera marina (vänster), baserat på inventeringar 2017–2018 samt på tidigare undersökningar gjorda av Husö biologiska station. Figuren till höger visar en rumslig modell över sannolika förekomster av Zostera inom de åländska havsområdena. Foto: Forststyrelsen

The probability model produced for *Zostera* showed that distance to sand, depth and exposure were the most important factors affecting the distribution of *Zostera* (tab. 1), coinciding with earlier findings (DOWNIE et al. 2013). The species occurs in shallow, relatively exposed areas, close to sandy shores. According to the model, the most important areas for *Zostera* in Åland coastal waters have already been covered by surveys. This is understandable, as the existing *Zostera* model covering the whole Finland was partly used to plan the surveys. However, there were also some areas that showed high probability for *Zostera* occurrence but are yet unmapped, e.g. areas in western Eckerö, in Föglö and in Vårdö. These areas need to be mapped in further projects.

Blue mussel beds - *Mytilus edulis*

Mytilus occurred commonly across the study area at all depths surveyed. This can be clearly seen, not only on the map showing occurrences with ≥ 20% *Mytilus* coverage (fig. 19), but also on the figures that describe the communities occurring on hard substrates within the surveyed area (fig. 10). Up to 40% coverages of *Mytilus* were still found in 25 m depth (and even 85% in 24 m depth in Lågskär area), indicating that *Mytilus* occurs in relatively high coverages also deeper than 25 m. These deeper areas should be included in the surveys, to get an idea on how deep *Mytilus* occurs within the Åland coastal waters.

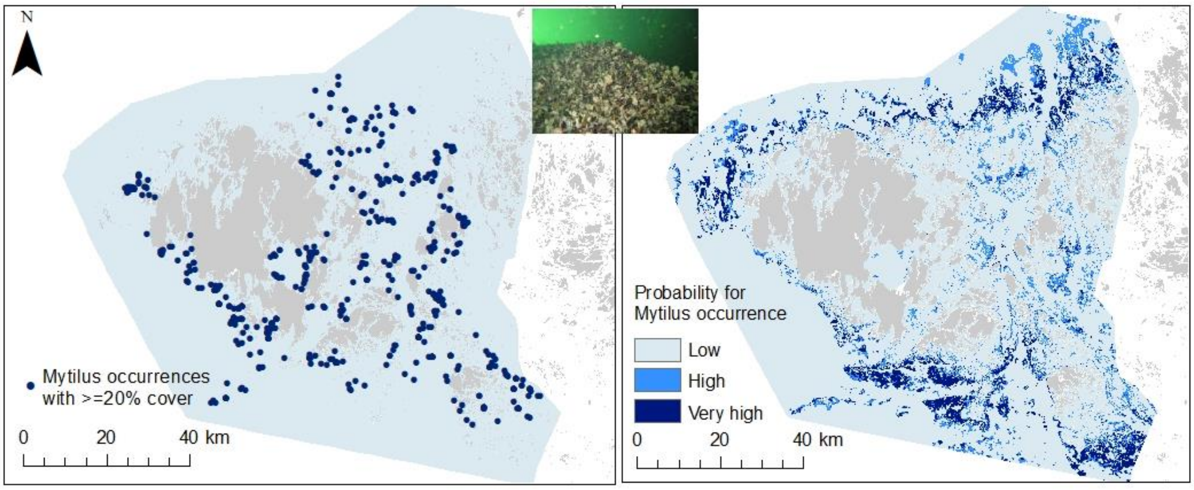

Figure 19. The occurrence of *Mytilus* beds (≥ 20% coverage), including occurrences from the surveys 2017-2018 and NANNUT-project. The figure on the right shows the probability of presence for *Mytilus* within the Åland coastal waters. Photo: Metsähallitus Parks and Wildlife Finland.
Figur 19. Förekomster av blåmusslor ≥ 20% täckningsgrad (vänster), baserat på inventeringar 2017–2018 samt på resultat från NANNUT- projektet. Figuren till höger visar en rumslig modell över sannolika förekomster av Mytilus inom de åländska havsområdena. Foto: Forststyrelsen.

3.6 The lower limits of indicator species

Where possible, the lower occurrence limits were checked for species used in assessing the status of the coastal areas in relation to the Water Framework Directive in the Åland Islands (WFD, HOLGERSSON 2013). This was done mainly to collect baseline information on the depth distribution of these species in different environments and to support their use as indicators. At some sites, the recording of the lower limit of occurrence was not possible due to e.g. gently sloping shores, or occasionally the species of interest did not occur at all on/near transects. Sometimes recoding the lower limit was not possible due to time constraints in the field. The sites (and associated waterbodies), where lower limits of occurrence were checked, are presented in fig. 20.

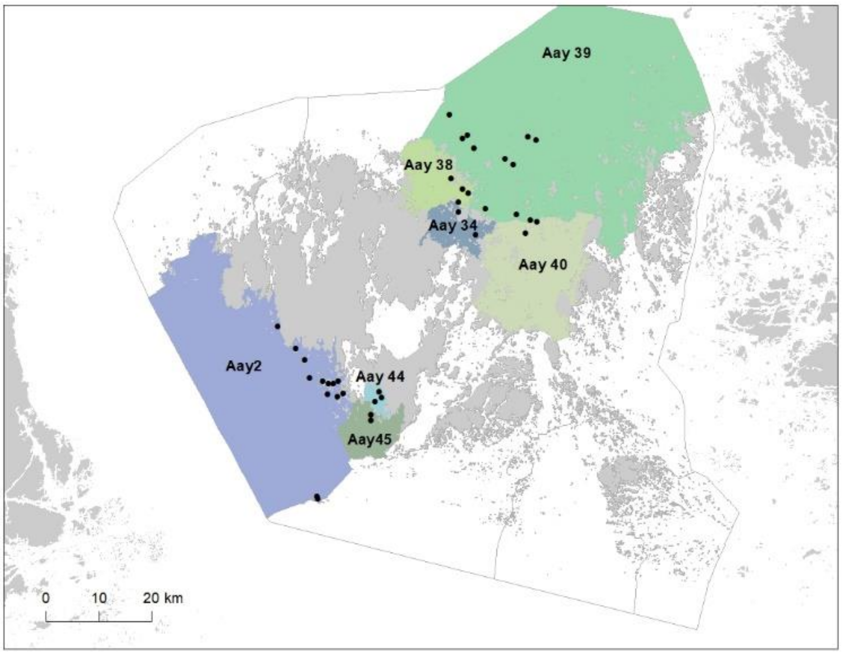

Figure 20. The sites and the waterbodies (defined in relation to the Water Framework Directive) where the lower limits of occurrence were checked for species used as indicator species in Åland.
Figur 20. Områden och vattenförekomster (definierade i enlighet med Ramdirektivet för vatten), där den maximala djuputbredningen hos indikatorarter undersöktes i åländska havsområden.

The lower limits of indicator species varied between the waterbodies (tab. 2). For the algal species (except for *Cladophora rupestris*), the deepest lower limits were often either in Norra Delet, or in södra Ålands Hav. For vascular plants and *Tolypella nidifica*, relatively deep occurrences were found also in Simskälafjärden and in Nabbfjärden.

Table 2. The lower occurrence limits of indicator species used in assessing the status of the coastal areas in relation to the Water Framework Directive (WFD). The table shows the mean lower limits (in meters) within waterbodies used in WFD assessments. The number of dive-transects where recording the lower limit of occurrence of the species was possible, is given in brackets.
Tabell 2. Gränser för de djupaste förekomsterna av indikatorarter som används för att utvärdera statusen i kustområden i enlighet med vattenramdirektivet (WFD). I tabellen visas de djupaste förekomsterna i medeltal (i meter) inom respektive vattenområde som används vid WFD bedömningar. Antalet dyktransekter där de djupaste förekomsterna kunde registreras är angivna i parentes.

Species	**Aay2** Ålands hav södra	**Aay34** Simskäla-fjärden	**Aay38** Boxö-fjärden	**Aay39** Norra Delet	**Aay40** Södra Delet	**Aay44** Nabb-fjärden	**Aay45** Röd-hamns-fjärden
Stuckenia pectinata	6.1 (8)	7.2 (1)	5.1 (4)	4.9 (2)	3.7 (2)	6.9 (2)	4.0 (1)
Zostera marina	5.9 (2)						
Tolypella nidifica	6.2 (3)		4.3 (3)	5.5 (3)	5.1 (1)	6.7 (1)	
Cladophora rupestris	1.3 (2)	1.4 (1)	1.2 (1)	3.6 (10)			4.2 (2)
Fucus vesiculosus	2.9 (8)	2.3 (2)	3.0 (4)	5.4 (11)	2.9 (2)		1.5 (1)
Sphacelaria arctica	5.0 (1)						
Coccotylus / Phyllophora	5.7 (1)			5.1 (4)	3.8 (1)		
Furcellaria lumbricalis	5.0 (3)		2.0 (1)	7.3 (9)		2.3 (1)	
Rhodomela confervoides	12 (2)			10.8 (3)			

4 Discussion

4.1 Evaluation of the methods

The methods used during the project were mainly adopted from the National VELMU program and have therefore been tested and developed over a decade in marine surveys within the Finnish marine area. In general, the sampling design and the used field methods functioned well, and enabled building a general picture of habitat distribution and characteristics across the survey area. The use of similar methodology as in mainland Finland is also important to ensure the comparability of the data.

In Åland, the deeper areas were left unmapped within the survey areas, due to the cable length of the drop-video (25 m.) As the data on *Mytilus* indicated high coverages down to 25 m depth, also areas > 25 m deep should be included to the surveys in the future, especially where the probability for *Mytilus* occurrence is high (e.g. generally rocky areas).

Relating to Natura 2000 habitats specifically, the uncertainties related to what constitutes a sandbank, are currently hardening their efficient mapping. Here, only elevations of certain size that had sandy substrate based on geological surveys were "officially" identified as sandbanks. However, many shallow sandy areas identified during the biological surveys, hosting *Zostera* and/or *Chara* -meadows, were not included in the habitat delineations (unless they were regarded as underwater parts of esker islands). Biologically these shallow areas in connection to islands or sandy shores are often more valuable in terms of biodiversity, than deeper occurring sandbanks. Therefore, their inclusion to the Natura 2000 habitat sandbank should be considered.

Related to habitat-building species, it would be valuable, at least in some cases, to obtain more information on their occurrences than water depth and the species coverage at survey point. For example, the size of different underwater meadows (*Zostera marina,* Charophytes, vascular plants in sheltered bays, also *Fucus* zones) is currently difficult to assess based on point data only, unless sampling is very dense. Knowledge on meadow size, and also density, would be beneficial e.g. when valuing the meadows, or in designing marine protected areas. Today, the large-scale calculations on area that a species occupies (e.g. when reporting their status) are generally based on models, that may vary, depending on the modelling method or probability thresholds set for presence. To obtain more hands-on-information on meadow size, different acoustic methods could be tested during the surveys, e.g. the MX Biosonics Aquatic Habitat Echosounder available at Husö Biological Station. The method enables obtaining data on the vegetation volume together with substrate data and depth (BACKMAN 2017). This kind of data would also aid in the delineation of habitats that are defined mainly based on geomorphology and substrate, e.g. sandbanks.

4.2 Areas for future mapping

Regarding geological surveys, the majority of the marine areas of the Åland islands remain unmapped. Therefore, there are still many interesting areas, e.g. the sandy areas in western Eckerö, as well as a shallow reef area far south in the Exclusive Economic Zone (EEZ) that reaches to approximately 7 m depth in the open sea.

As the areas mapped during the biological surveys in 2017-2018 covered mainly the southern coast and the southeastern archipelago, as well as parts of the eastern and northeastern archipelago (Saltvik, Sund, Vårdö, Sottunga), the areas that are still largely unmapped are located in western / northwestern Åland as well as in the easternmost archipelago, in Brändö. As the focus in the surveys were mainly on sandbanks and reefs, many of the more sheltered areas, (that may fulfill the criteria for habitats listed in the Habitats Directive: Large shallow inlets and bays, Lagoons, Boreal Baltic narrow inlets) were also left unmapped. Although some of the bays and sounds have been studied in earlier studies (e.g. SNICKARS 2008, ELEVEENS MAARSE 2013), there are still many areas, where very little or no information on biological communities exists.

Also, the remote archipelagos south of Föglö and Kökar were not included in this project. The area is especially interesting, as it was predicted to host red algal communities, recently reported endangered in the Finnish “red book” (KONTULA & RAUNIO 2018). Regarding red algae, also the areas south of Mariehamn and Lemland are of particular interest, as the red algal belts were exceptionally rich, both in species number and in coverage at some sites in the area. More attention could be paid to these areas to investigate the occurrence of various red algae in more detail.

Also, the *Zostera* model revealed some unmapped areas where the probability for *Zostera* occurrence were high, e.g. in northern Eckerö and in Vårdö.

In addition to areas within the Åland coastal waters, there are also some areas of particular interest in the EEZ. Perhaps the most interesting area is located far south in the EEZ, a shallow reef area, that is important to seals, water fowl and perhaps even to harbor porpoise.

4.3 The nature areas of particular interest

As a whole, the archipelago of the Åland Islands represents a unique environment that due to its mosaic-like character hosts many different kinds of underwater habitats. Although there are areas, that are relatively heavily impacted by human activities (e.g. ferry traffic, fish-farming), the area as a whole, is much less impacted by human activities than the adjacent Archipelago Sea (HELCOM 2018). There are also many rather remote archipelago areas where the direct anthropogenic impacts can be considered low. After completing the 2017-2018 surveys, some areas with particularly high nature values were identified within the survey areas (fig. 21). It must be noted, that although these areas are here highlighted as being particularly valuable in terms of underwater nature, future surveys may reveal other diverse or otherwise important areas also within the already surveyed areas, e.g. areas with threatened species. There are also some smaller sites with valuable underwater nature outside the areas now highlighted. It is also emphasized that only the areas covered by the surveys in 2017-2018 are included.

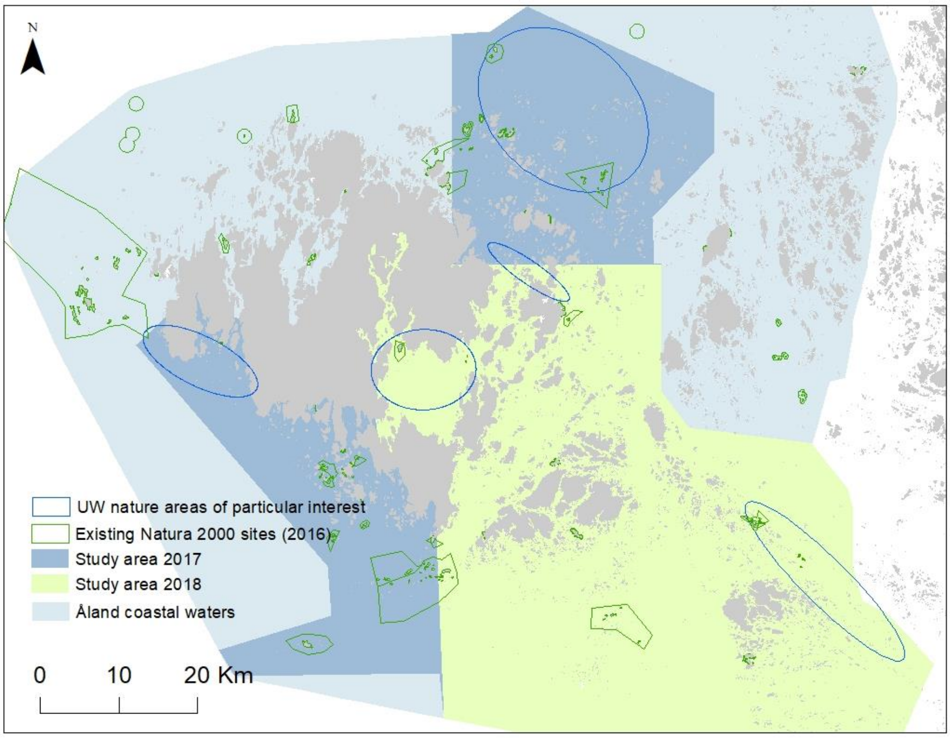

Figure 21. Areas that can be considered of high nature value (blue ellipses) within the *areas surveyed in 2017-18. Also the existing Natura 2000 sites area shown (green).*

Figur 21. Områden som har höga naturvärden (blå ellipser) i de inventerade områdena 2017–2018. Det existerande Natura 2000 nätverket visas också (gröna områden).

The Kökar esker area, especially its southern part constitutes a very unique area, with a chain of typical esker islands. The islands consist mainly of sorted gravel and stones and the underwater parts mostly of sand. The islands have unique flora (von NUMERS, 2018) and *Zostera marina* meadows occur commonly in the underwater parts. Some of the islands are already protected within Natura 2000 sites (Långskär, Sandskär, Örskär) but many remain unprotected, especially when it comes to their underwater parts. Northwest of Sottunga, the esker formation is less pronounced, but is evident again in Vårdö, where the southern parts of Sandö have particularly diverse *Chara* -meadows as well as *Zostera* -meadows.

The outer parts of the archipelago northeast of the Åland main island (Saltvik, Vårdö) is generally very remote and relatively unaffected by human activities. The area hosts hundreds of islands that are truly representative cases of the Natura 2000 habitat Boreal Baltic islets and small islands. In addition, there are many rocky reefs in the area. *Fucus vesiculosus* is much more abundant in this area than in the other surveyed areas (fig. 10) and based on the data it seems that *Fucus* is today more commonly found in the northern parts of Åland than in the southern parts. Also, *Mytilus* reefs are common in the northern outer archipelago where the species occurs at least down to 25 m depth (deeper areas not mapped). There are already some Natura 2000 sites within the area, smaller site Rannö in the far north and larger Vikarskären -area further south, all including also the underwater environment.

The western coast of Eckerö with its sandy bottoms and *Zostera* -meadows occurring along the shores of main Åland Island is worth mentioning. Despite the generally rocky shores, the underwater areas are often sandy, especially in shallow embayments. However, the conducted surveys covered only the southern part of the western coast, thus more surveys are needed in the area to describe it in full. In addition to the western coast of Eckerö, *Zostera* was found commonly on the western side of Hammarudda.

Lumparn, especially its northern part, is particularly interesting due to the doming structures that occur commonly in the area. *Zostera* meadows were also common in the near shore sandy areas (ENGSTRÖM 2018).

5 Conclusions

During the project, a lot of new information on the underwater biodiversity occurring within the Åland coastal waters was gained. This information can be easily used for example when planning different human activities within the sea area (Maritime Spatial Planning, MSP) or when planning new marine protected areas (MPAs). The information obtained on Natura 2000 habitats is of particular importance, when the extent and the status of the habitats are reported to the EU every six years. The data was already used in the Habitat Directives reporting in 2019. The data on underwater biodiversity also contributes to the development of efficient monitoring of underwater vegetation and/or *Mytilus* beds, related to the Water Framework Directive and the Marine Strategy Framework Directive.

Despite the large amounts of data gathered, there are still gaps in knowledge and a large proportion of the marine area of the Åland Islands remain unmapped. Therefore, it is important, to continue the mapping efforts in the area also in the future, to reach a level of knowledge that would enable a true ecosystem-based management of the marine areas.

6 Acknowledgements

We are grateful to the staff at Husö biological station, especially to Dennis Hellström for his help with the boat and field equipment, and Tony Cederberg and Martin Snickars for assistance with various practical issues. Floriaan Eveleens Maarse helped with the collation of the data and assisted in the dives at Lågskär. Linn Engström carried out the surveys in the Lumparn area. Thank you also to the people at the Rescue Department in Mariehamn who took their time to fill up our scuba tanks during the surveys and to the Coast Guard who assisted the surveys in the Lågskär area. We are also very grateful to all the nice people around the Åland Islands who made our job easier by giving us access to their private docks.

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Annex I

Acoustic-seismic survey in Åland for mapping marine Natura 2000 habitats, 2016

Kimmo Alvi

EUROPEISKA UNIONEN
Europeiska
havs- och fiskerifonden

Ålands landskapsregering

GTK
gtk.fi

INDEX

Appendices:

1 Introduction

During summer 2016 Geological Survey of Finland (GTK) conducted marine geological surveys in five selected study areas around Åland archipelago. The surveys were part of the project ”Mapping Marine Natura 2000 habitats in Åland” conducted in co-operation with Åbo Akademi and funded by European Maritime and Fisheries Fund (EMFF) and the Government of Åland.

The aim of this survey was to produce detailed geological information of all five study areas to be used in identification and classification of different underwater habitats, as background data for modeling and also to be used for guiding the selection of areas of interest for biological field work.

Case study areas were chosen based on prior knowledge of the particulate geological features of the area, such as Kökar esker formation and the gas domes in Lumparn and also on existing data from VELMU project.

The survey was carried out with GTK’s research vessels R/V Geomari and survey boat Gridi between 5.7-8.9.2016.

In this report, research methods, survey equipment and main geological features of the study areas, in the form of bathymetric- and marine geological maps are presented.

2 Description of the area

Figure 1 shows the location of the survey areas. Naming of the study areas goes throughout this report as presented in table1. Areas 1-3 (*Sottunga N, Sottunga E, Kökar E*- respectively) are all located along the same NW- SE oriented continuous bedrock fracture zone, which is reflected in their bathymetric conditions. Area 4 (*Degerö W*), located between Degerö and Lemland is more shallow and also exposed to South-Westerly winds. Area 5 (Lumparn) is geographically very different from other areas, since it is almost totally land-locked with just one natural outlet connecting it with the surrounding sea areas.

What characterizes the seabed of the Åland area, is its diversity in terms of bathymetric features and local changes in exposure to wind induced waves and currents. These factors affect the sediment transportation, erosion and deposition so that as a result the areal distribution of bottom sediments is extremely “patchy”.

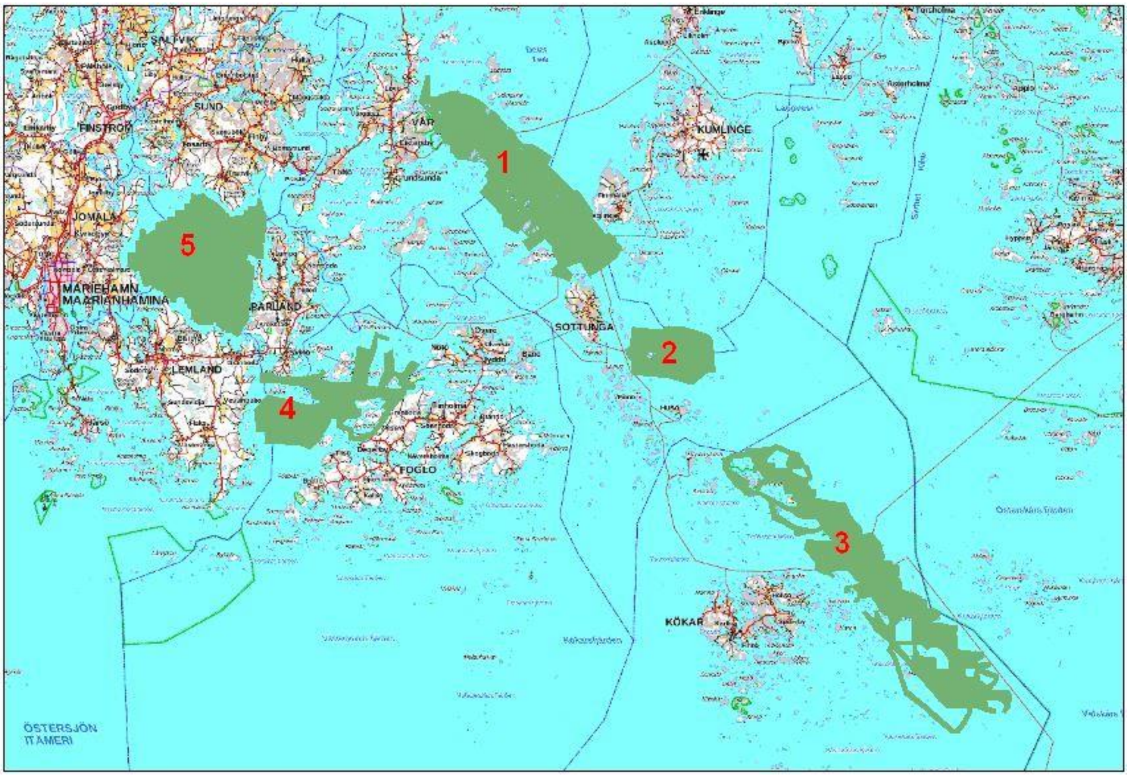

Figure 1. Case study areas, surveyed for nature type identification in Åland Archipelago in 2016.

Table 1. Description of study areas

Name of the survey area	Survey line km:s	Coverage of interpreted area (km^2)
1. Sottunga N	162	82
2. Sottunga E	57	24
3. Kökar E	306	98
4. Degerö W	110	45
5. Lumparn	262	72
Total:	**897**	**321**

The basic geologic and stratigraphic features of the Baltic Sea and the Åland archipelago are well known and well documented.

The bedrock of the Åland area consists mainly of pre-Cambrian granites, with a strong relief. In Lumparn area, there are also younger Cambrian- and Ordovician sedimentary rocks (Winterhalter, 1982). The bedrock is covered by postglacial sediments, common in all of the Baltic Sea. The postglacial sediments are deposited after the retreat of the Weichselian ice sheet, which covered the Fennoscandian shield during the latest ice age (115 000 – 11 600 BP).

Sediment classification, used in this report goes by the Baltic Sea stages method in which all geological units are related to a specific Baltic Sea stage (table 2). This differs from the CUAL (Combined Use of Allostratigraphy and Lithostratigraphy) method, widely used in stratigraphy in the rest of the world (as presented in Virtasalo, et. al 2014).

Table 2. The Baltic Sea stages and to what times and sedimentary types they correspond (Virtasalo, 2014).

Baltic Sea Stages	**Sediment**	**CUAL Sediment**	**Time (BP)**
Retreat of ice sheet	Till	Till	ca. 16 000
		Glacial outwash	
The Baltic Ice Lake	Glacial Clay		16 000 – 11 600
		Glaciolacustrine rhytmites	
(Yoldia Sea)		Debrites	(11 600 – 10 700)
Ancylus lake stage	Ancylus sediment	Postglacial lacustrine clays	10 700 – 7700
Litorina Sea	Litorina sediment	Brackish-water mud drifts (lower)	7700 - 4400
Limnea Sea	Recent muds	Brackish-water mud drifts (upper)	4400 - Present
		Recent muds	

In addition to the sediments in table 2, the classification in this report includes also *Sand and Gravel* and *Glacio-aquatic mixed sediment*, which correspond to Glacial outwash in CUAL method. A complete list of sediment classes in this report from older to younger is as follows: ***1) Bedrock, 2) Till, 3) Sand and gravel, 4) Glacio aquatic mixed sediment, 5) Glacial clay, 6) Ancylus clay, 7) Litorina clay, 8) Recent mud.***

3 Material and methods

3.1 Acoustic survey methods

Acoustic profiling is accomplished by towing or mounting to the vessel, a sound source that emits acoustic energy in timed intervals behind a research vessel. The transmitted acoustic energy is reflected from boundaries between various layers with different acoustic impedances (i.e. the water-sediment interface or boundaries between geologic units). Acoustic impedance is defined by the bulk density of the medium times the velocity of the sound within that medium. The reflected acoustic signal is received either by a ship-towed hydrophone, or with a receiver system, by the same tuned transducer array that generates the outgoing source signal. The receiver converts the reflected signal to an analogue signal. The analogue signal is digitized, displayed, and logged with a computer. The data can then be processed and imported to computer software for interpretation. The higher frequencies of operation provide the highest resolution, but are limited in amount of penetration below the sea floor. The lower frequencies provide more penetration, but less resolution respectively.

Side Scan Sonar is a marine geophysical technique that is used to image the sea floor. The method uses pulses of sound (sonar) transmitted across the sea bottom from a towed transducer or towfish. The sound pulses reflect off of relief or objects that project above the bottom. The strength and travel time of reflected pulses are recorded and processed into an image or picture of the bottom. The technique resembles aerial photography of the sea floor with illuminated, as well as shaded areas. The difference is that side scan sonar illuminates the sea floor with a pulse of sound rather than light. Since it uses sound, side scan sonar can detect the sea floor even in murky or turbid water.

Multibeam echosounder is a type of sonar that is used to map the bathymetry of the seabed. Like other sonar systems, multibeam systems emit sound waves in a fan shape beneath a ship's hull. The amount of time it takes for the sound waves to bounce off the seabed and return to a receiver is used to determine water depth. A detailed 3d- bathymetric image of the surveyed area can be constructed from multibeam data.

3.2 Survey equipment

- 1. Atlas Fansweep 20-200 multibeam*
  - Frequency 200 kHz
  - Coverage up to 12 times water depth, operator selectable
  - Depth range 0,5-300 m
  - Accuracy 0,05 m ± 0,2 % depth for coverage up to 6 times water depth
  - Ping rate up to 16 Hz
  - Resolution 1440 soundings per ping
  - Reson SVP 15T sound velocity profiler and Micro SV C-keel probe
- 2. Klein System 3000 side scan sonar*/ Klein 595 side scan sonar**
  - Frequency 100 kHz / 500 kHz
  - Horizontal beam width 0,7° / 0,21°
  - Vertical beam width 40°
  - Maximum range 600m / 150m
- 3. MD 28 kHz echo sounder* **
  - Frequency 28 kHz
  - Beam angle 24° (-3 dB)
  - Transmission power 1,5 kW
  - Impedance 120 ohm
- 4. Massa TR-61A Chirp*
  - Frequency range 3,5 – 8 kHz
  - Input power max. 500 W
- 5. ELMA reflection seismic* **
  - Frequency 250-1300 Hz
  - Single channel
  - Sound source
    - Electric input 100 J
    - 2 pulses per second
    - acoustic output 135 dB (re 1 uBar / 1 m)
  - Hydrophone
    - Active 6 m / 24 elements
    - Preamplifier 24 dB

**R/V Geomari*

***Survey boat Gridi*

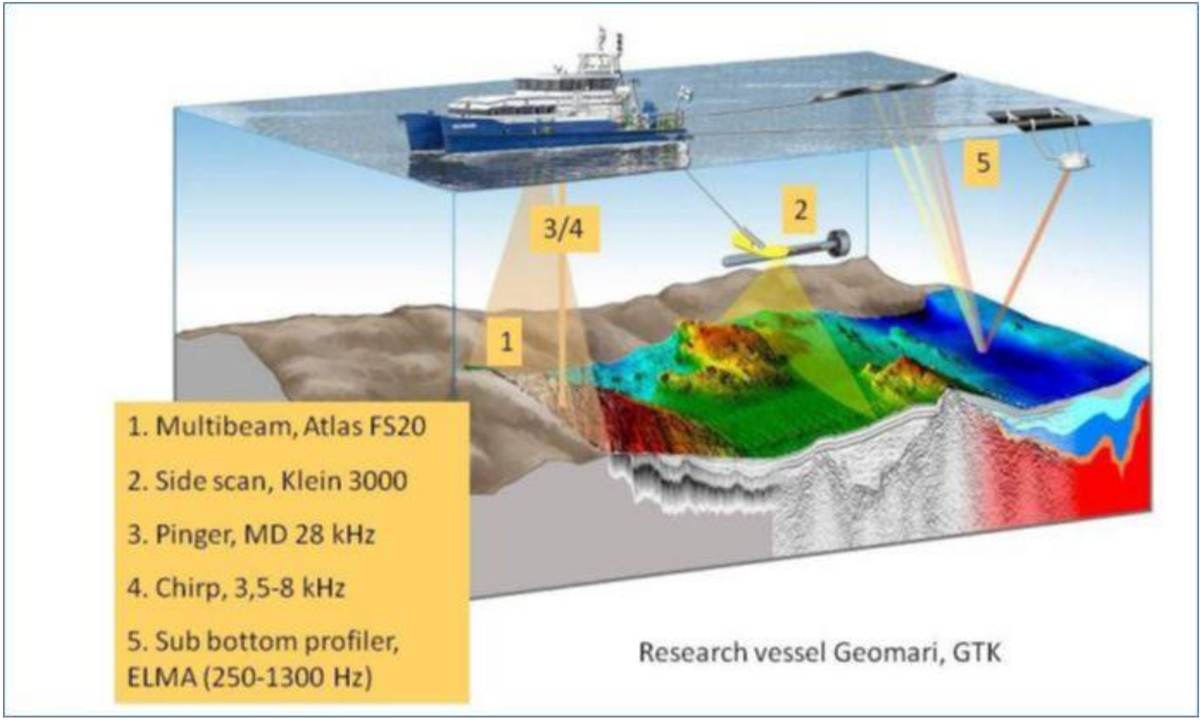

Figure 2. A schematic illustration of acoustic- seismic survey equipment.

3.3 Processing and interpretation of acoustic data

Acoustic profiles are created by interpreting the return signals. Some amount of the signal energy is lost during transmission; the energy lost is dependent on the wavelength, a.k.a. the frequency. The deeper down the signal travels, the weaker the reflection becomes. As the signal propagates through different material it behaves differently, indicating changes in the material density. The return signal is visualized, with time on the y-axis and distance on the x-axis. Later the time of the signal can be corrected into depth, but it is important to understand that two identically thick layers with different density will be shown as being different thickness on the visualized profiles. This is because the difference in density allows for the signal to pass at different velocity, and as such can be misleading if you do not understand the principle of how the acoustic depth sounding works. When interpreting an acoustic profile you look for changes and differences in how the signal is presented. The presence, or lack of, strong reflectors are a good indication for a change in lithology or stratigraphy, especially if the section was previously dominated by the opposite (Nanda, N.C. 2016).

Acoustic profiles and side scan sonar data were collected and processed with MDCS/MDPS software package (OY Meridata Finland Ltd). Boundaries between different geological units were interpreted, they were digitized and given seismic velocity values, respectively. Time travel values were then converted into meters and thickness of different units could be established. Digitized boundaries were stored in table form with a positioning data and depth values (distance from water surface) in 25m interval. Tables also include the water depth (depth of water- sediment interface).

Figure 3 shows an example of an acoustic profile of a single survey line processed with different frequencies.

Multibeam echosounder data was collected and processed with Hypack software. Esri ArcGis software was used for map production.

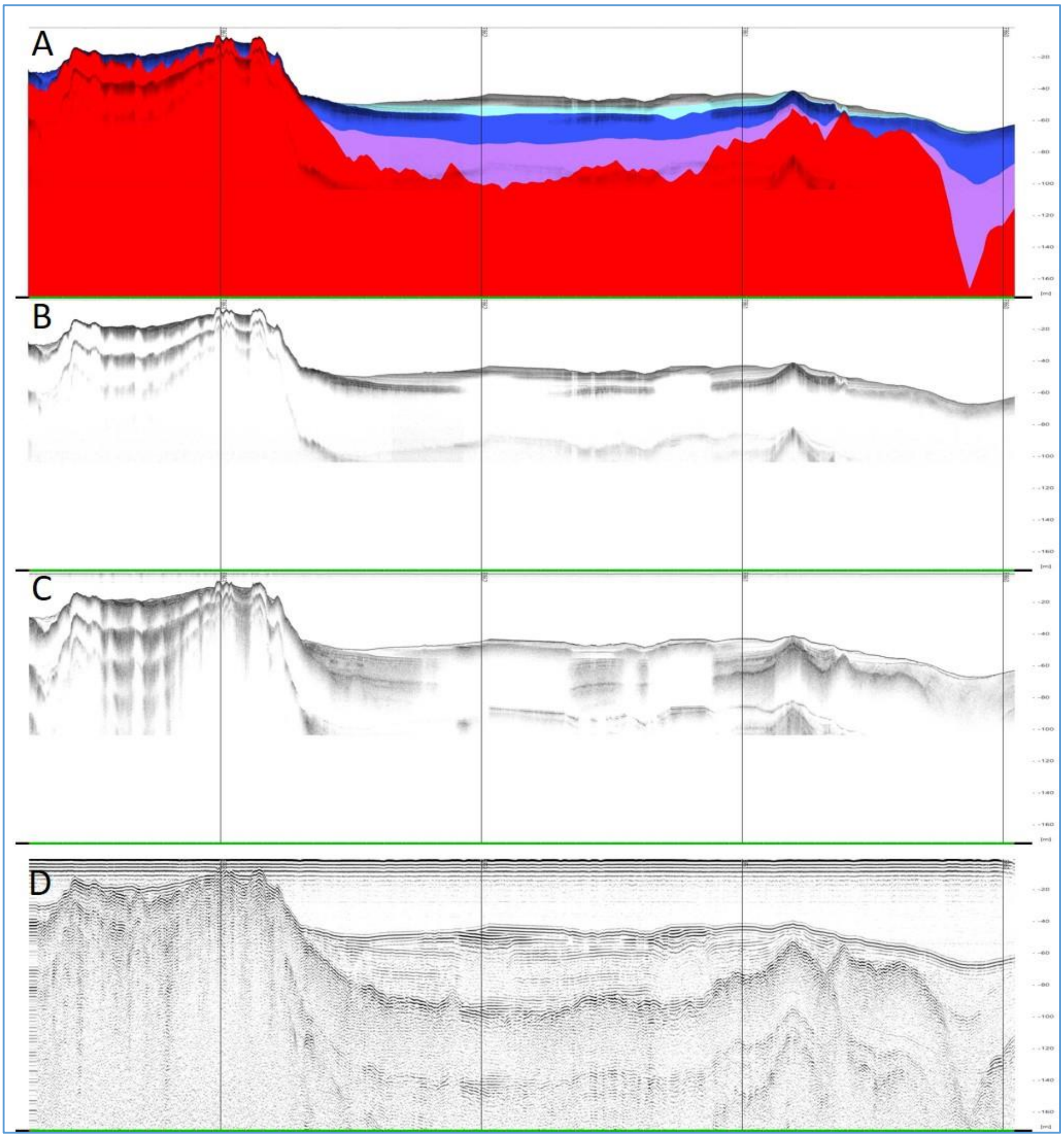

Figure 3. Acoustic profile of a single survey line; A) interpretation on top of 28 kHz Pinger image, B) 28 kHz Pinger image, C) 4 kHz Chirp image, D) ELMA reflection seismic image

4 Results

Figure 4 shows the combined interpreted marine geological map of all five survey areas. More detailed geological- and bathymetric maps of each individual area are presented in appendices 1- 5.

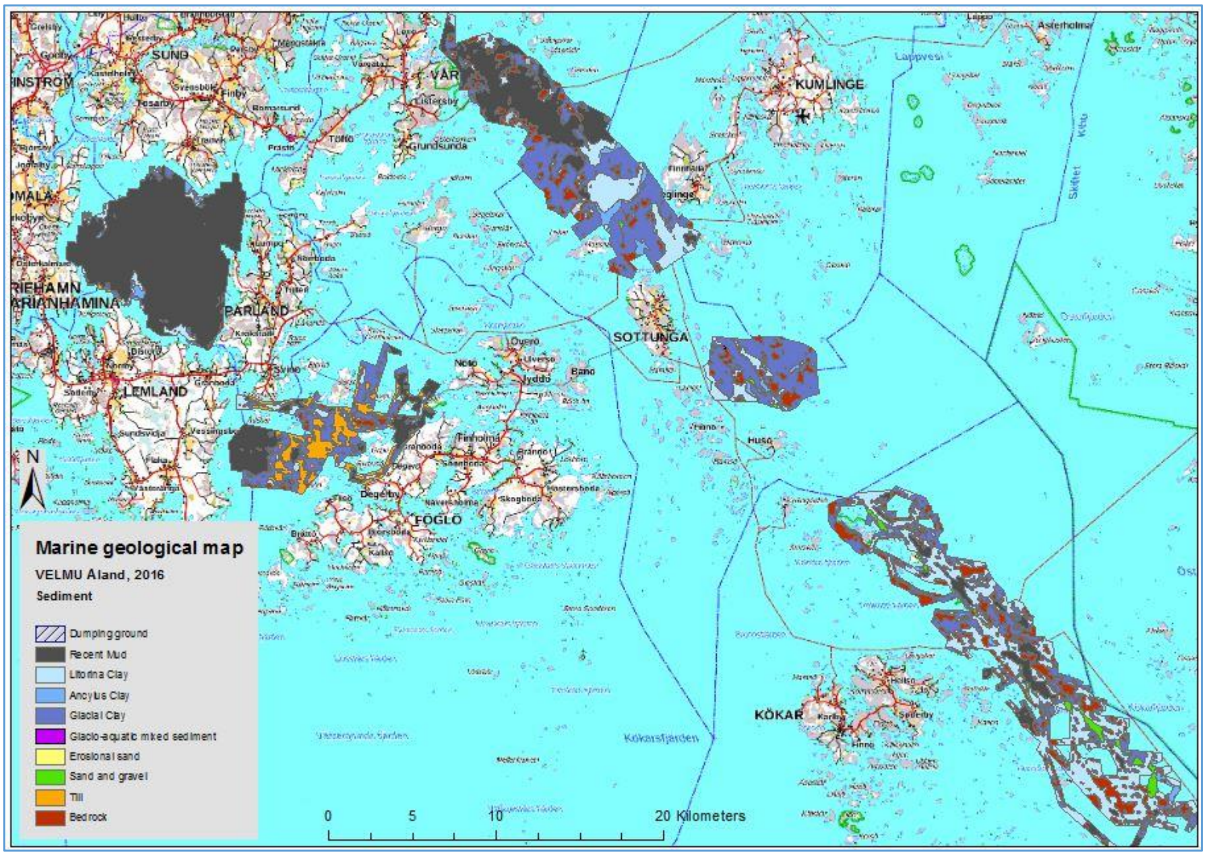

Figure 4. Marine geological map of survey areas in Åland in 2016.

Survey areas 1-4 are characterized by strong erosional features and the surface sediment distribution is quite patchy. Bedrock outcrops are abundant, especially in Kökar E. There is a sand formation, which extends from southern parts of Kökar E all the way to northern parts of Sottunga N. It is for the most parts buried underneath younger sediments and only partially exposed on the seabed. It is most likely an underwater part/extension of Kökar esker formation which can be observed on nearby esker islands as well.

Survey areas 1-3 are connected by a deep channel (see bathymetric maps in app. 1-5) which appears to be part of a bedrock fracture zone. This can be seen in acoustic profiles as a deep depression in bedrock surface. Sediments along this channel are heavily eroded, which is a clear sign of strong bottom currents (Figure 5). It is a common occurrence that in such areas there is a thin layer of erosional sand- usually no more than mere few cm's- on the surface of clay bottom. This can lead into misinterpretations if bottom sediments are classified based on visual (diving, cameras, side scan sonar, etc.) observations only, without access to acoustic profile data.

The thickness of post glacial sediments in all five survey areas is usually between 20-60m but varies greatly in different parts of each survey area from total absence to more than 100m in other parts. The thickest sediment beds are found in the deep channel, connecting survey areas 1-3.

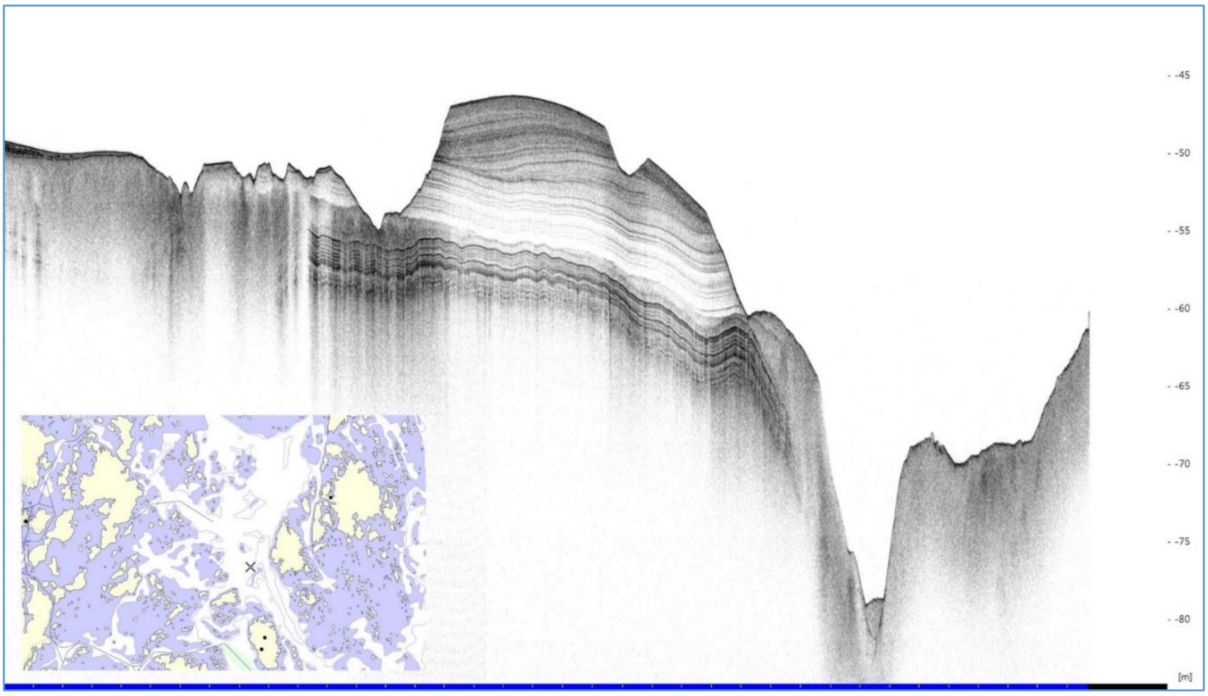

Figure 5. Heavily eroded bottom sediments in the area 1 (Sottunga N). Location is marked with X in the small picture. Acoustic profile from 28kHz Pinger.

There are large sedimentation areas in the northern part of Sottunga N, western part of Degerö W and especially in Lumparn. Degerö W is the only survey area where till is exposed. The thickness of the till bed is usually between 2-3m.

Lumparn is a meteorite crater, which is almost completely surrounded by land. There is an outlet in the NE part of the area and all the water exchange with the surrounding sea areas goes through this single outlet. Water depth is quite shallow and the bathymetry flat. Almost all of the Lumparn seabed is sedimentation area with a thick cover of recent mud.

The most striking feature of Lumparn is the presence of gas-charged sediments and resulting gas domes, visible on the seabed (Figure 6). The domes are usually between 20-30 m in diameter and they rise normally about 0.5-1m above the seabed surface (Figure 7).

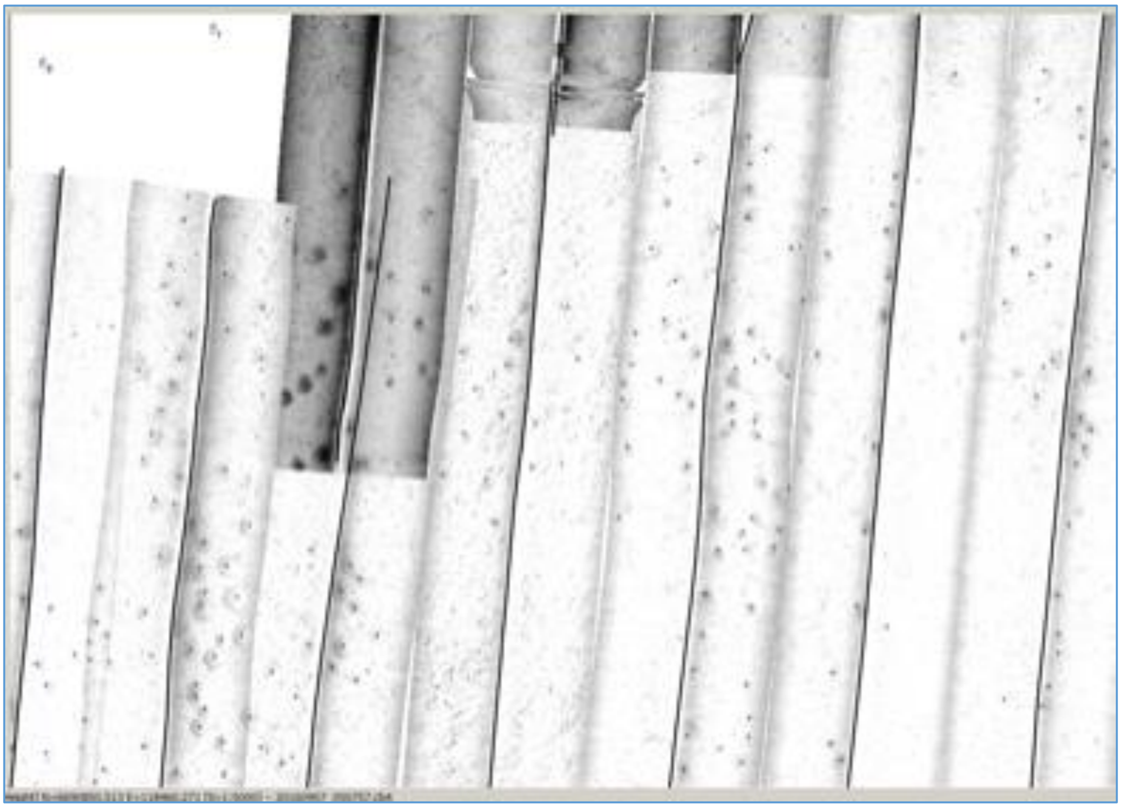

Figure 6. A close-up of a side scan mosaic from Lumparn. Dark dots are gas domes, with a diameter of about 30m. Distance between survey lines is 250m.

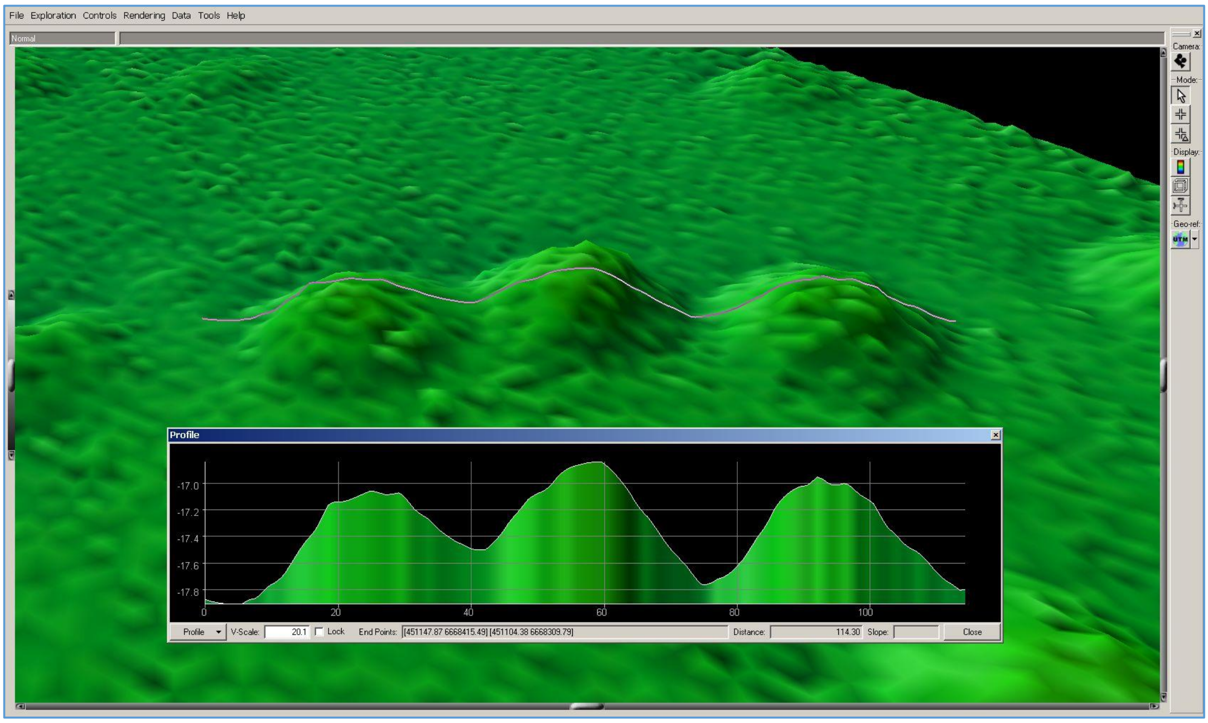

Figure 7. A multibeam echosounder image of the seabed in Lumparn with gas domes protruding from the bottom. A profile across the three domes in the center is shown in the smaller image. (Note! The vertical dimension is exaggerated.)

There are literally thousands of gas domes, mainly in the northern part of Lumparn (Figure 8). Their occurrence is limited in the areas shallower than ~20m. A more thorough description of sediment features and gas-charged sediments in Lumparn is given in Master's thesis by Alexandra Nyman (Nyman, 2018).

The amount of the domes and their extent was mapped in detail for the first time from the data, collected during this survey.

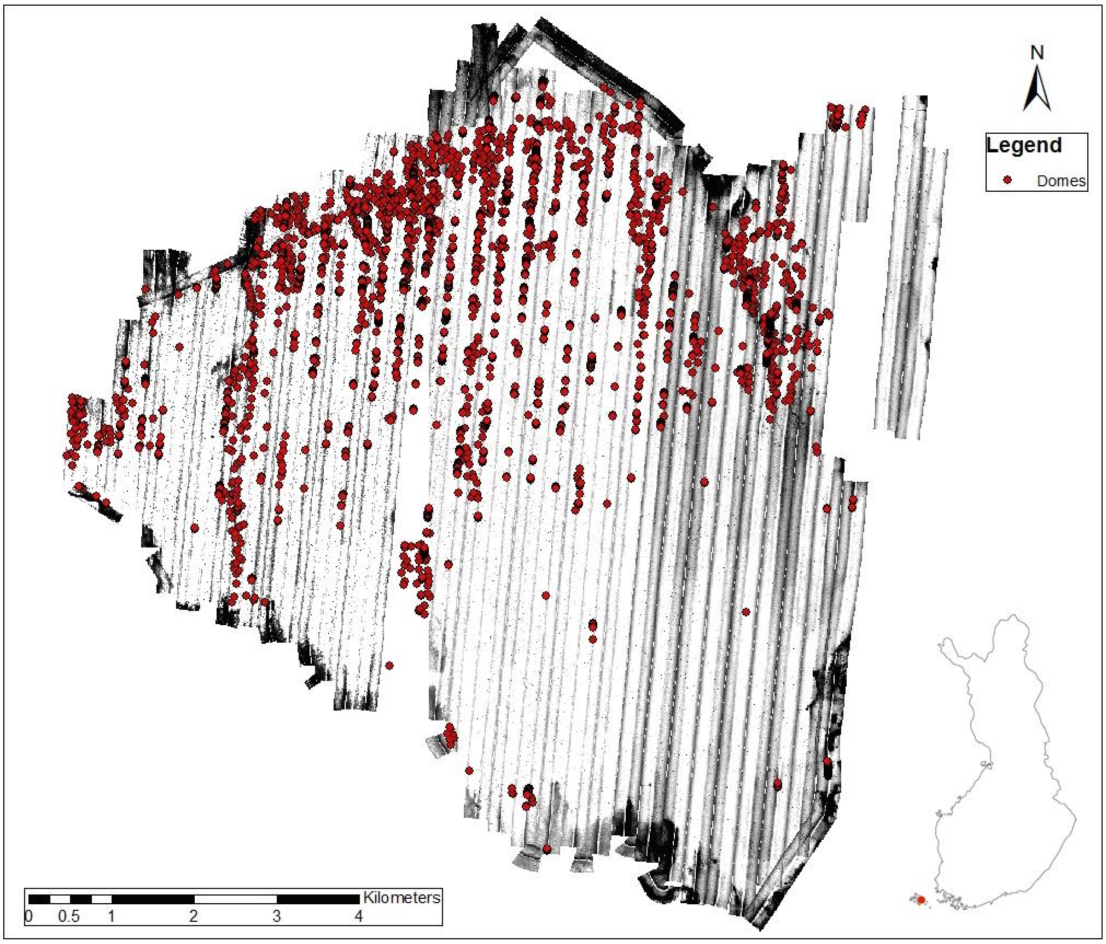

Figure 8. Distribution of the gas domes mapped out from both the acoustic profiles and side scan sonograms in Lumparn (Nyman, 2018).

A number of disturbance structures were observed from acoustic profiles in several survey lines. These are structures that cut or distort the continuous acoustic banding or boundaries of the identified geologic units and that can be, with any amount of certainty, said to have been formed after the initial sediment deposition. Most of these disturbance structures are found in the northern part of Sottunga N area (Figure 8).

Most observed disturbance structures are concentrated near the possible bedrock fracture zones. Stratigraphically, their occurrence is limited in the geological unit that represents varved glacial deposits (Glacial clay), with alternating clay and silt layers.

Similar structures have been reported previously from the Archipelago Sea and also from Olkiluoto area in Western Finland (Hutri and Kotilainen, 2006). The most likely scenario for their formation is that the disturbances were caused by palaeoseismicity, i.e. one or several earthquakes in short time after the de-glaciation. Their location near the possible bedrock fractures strongly suggest that old fracture zones were reactivated due to released stress during and after the ice retreat.

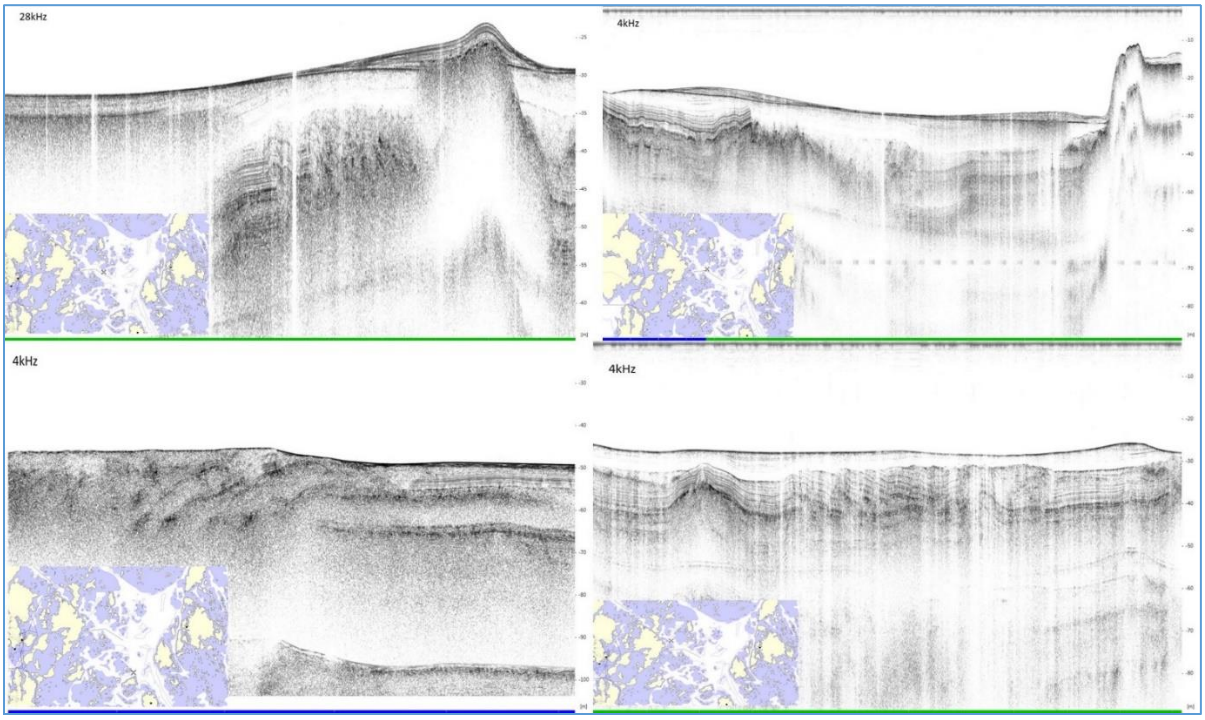

Figure 9. Four examples of disturbance structures in varved Glacial clay in Sottunga N area. Locations are marked with X in small boxes.

The overlying sediments appear to be undisturbed, which indicates that whatever event(s) caused the disturbances was not only sudden but also temporary.

5 Conclusions

Geological Survey of Finland conducted acoustic-seismic surveys in Åland during summer 2016. Surveys were performed in five pre-selected study areas, in order to produce marine geological information to be used in identification, classification and modelling of underwater habitats.

All together the amount of survey lines totaled to almost 900 km and the extent of total interpreted area was 321 km^2.

Survey data was interpreted and bathymetric- and marine geological maps were composed accordingly. The distribution of post-glacial sediments in study areas is very patchy, due to strong currents and exposure to the wind induced waves. An underwater extension of Kökar esker formation was found. It is partially exposed on the seabed but mainly buried under younger sediments. Large sedimentation areas were found from Sottunga N area and especially from Lumparn.

Lumparn area is characterized by presence of gas-charged sediments and resulting gas domes, which are found in large numbers mainly in the northern part of Lumparn. Detailed information about the gas domes was acquired from the survey data.

Several disturbance structures, indicating palaeoseismic events were also observed in acoustic profiles. These structures are concentrated near the bedrock fractures, mainly in Sottunga N.

6 References

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Nyman, A. (2018) An acoustic investigation of postglacial sediments and associated structures of Lumparn bay, Åland. Pro-gradu avhandling, Åbo Akademi.

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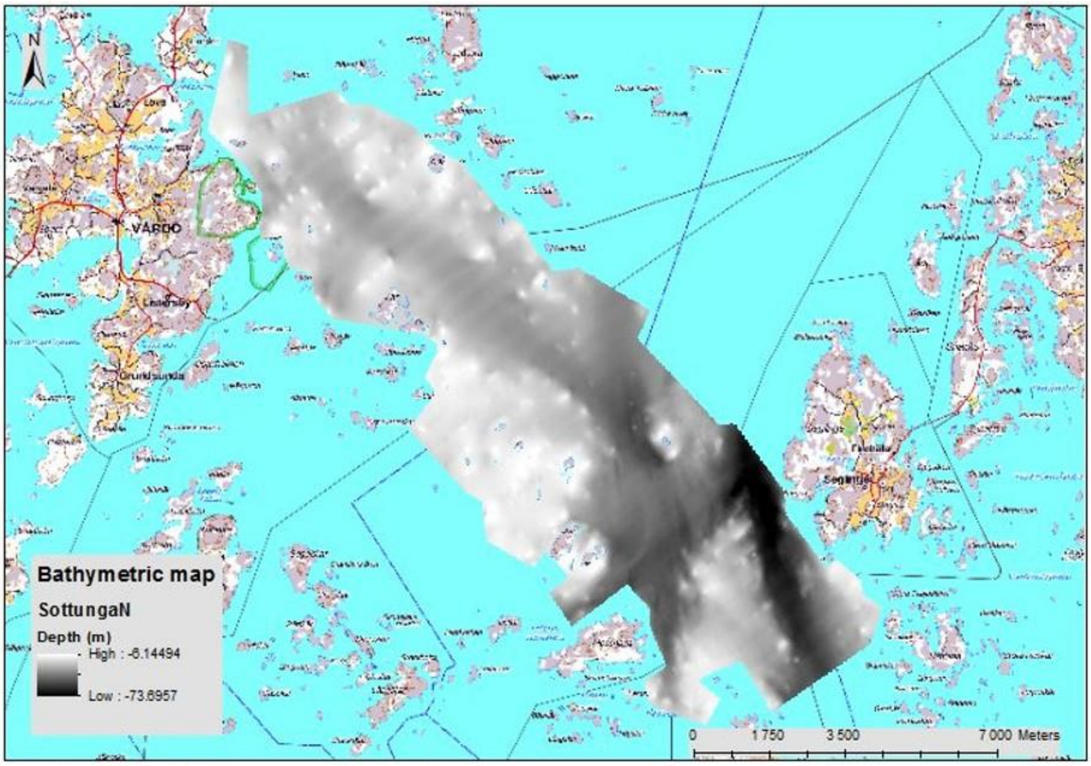
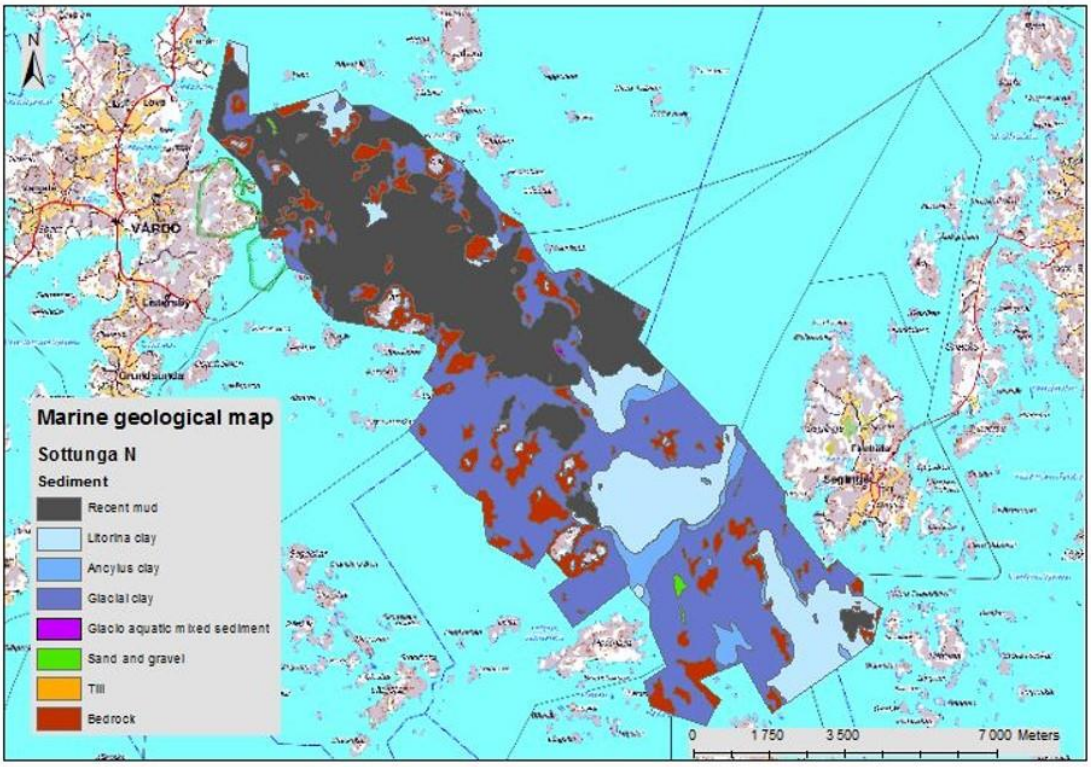
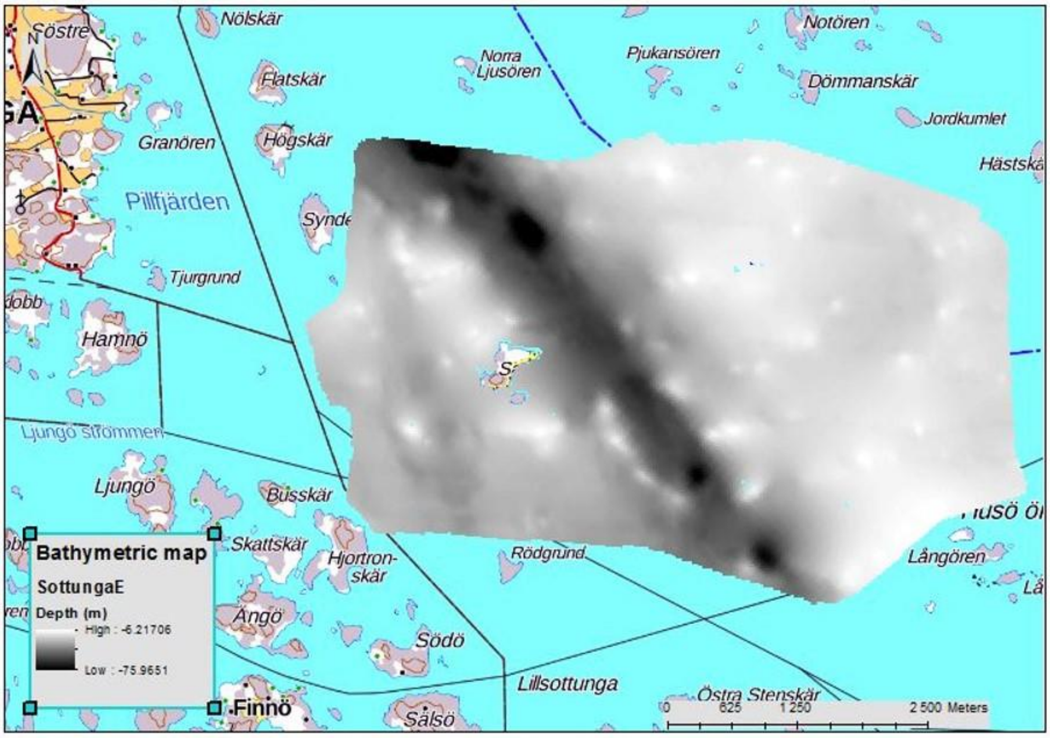
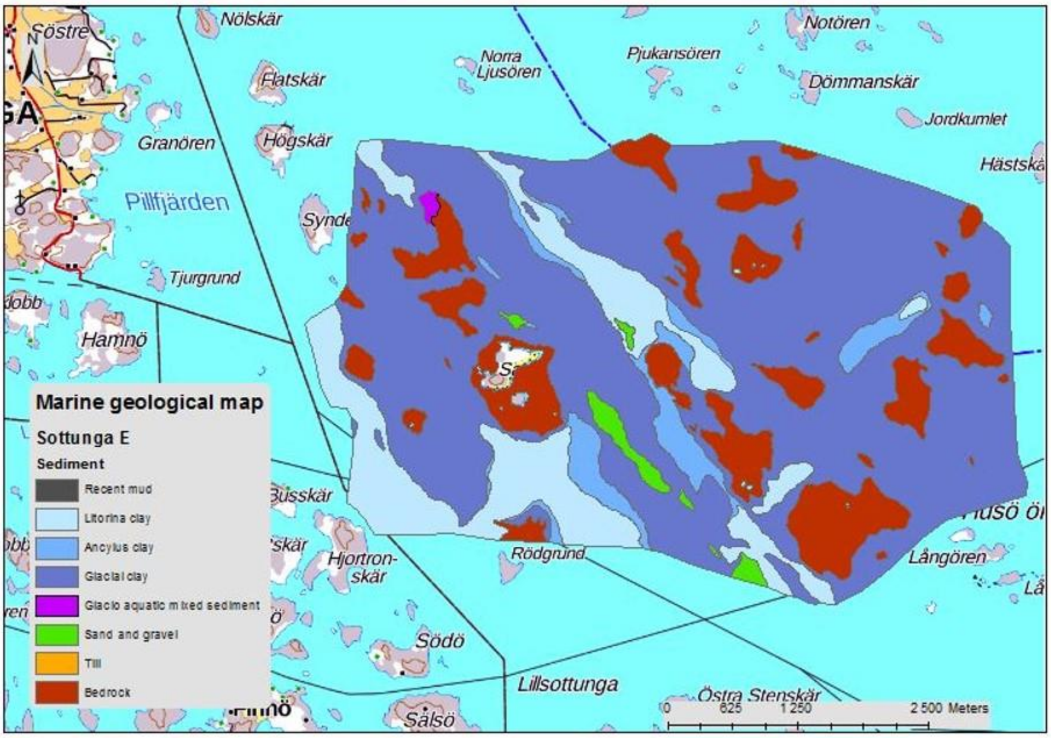
Appendix 1.


Bathymetric map
SottungaN
Depth (m)
High : -6.14494
Low : -73.6957
VÅRDÖ
0 1 750 3 500 7 000 Meters

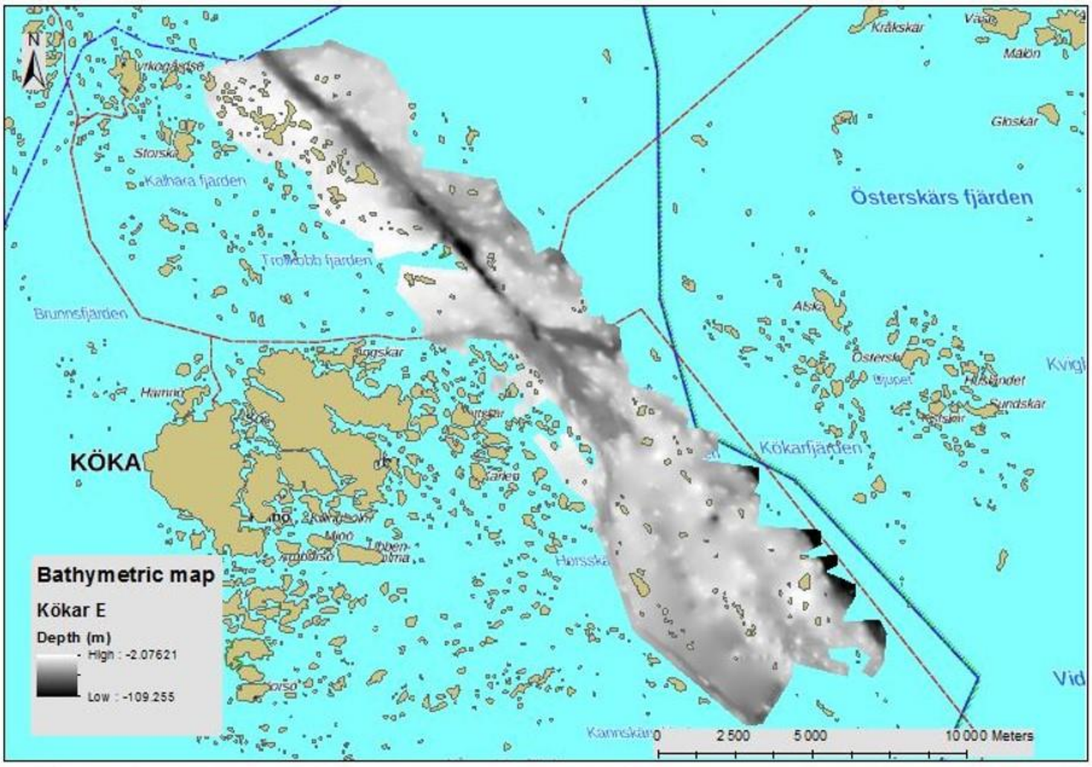

Marine geological map
Sottunga N
Sediment
Recent mud
Litorina clay
Ancylus clay
Glacial clay
Glacio aquatic mixed sediment
Sand and gravel
Till
Bedrock
VÅRDÖ
0 1 750 3 500 7 000 Meters

Appendix 2.

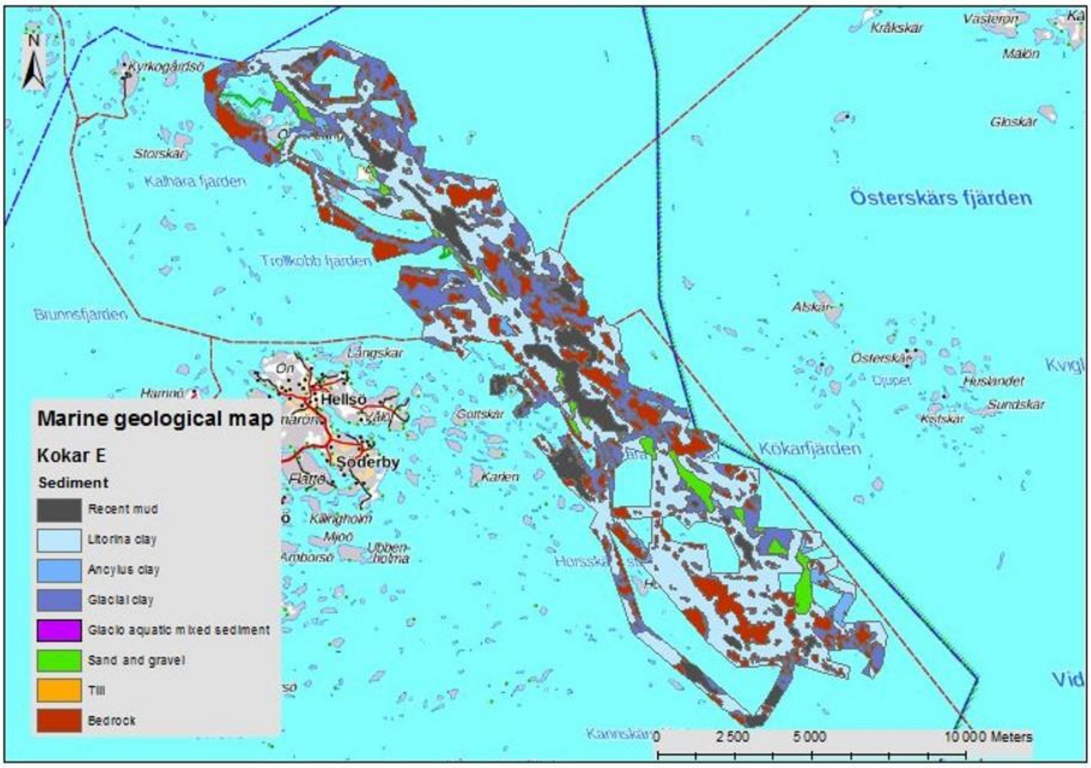

Bathymetric map
SottungaE
Depth (m)
High : -6.21706
Low : -75.9651
Nölskär
Norra Ljusören
Pjukansören
Notören
Dömmanskär
Jordkumlet
Hästskä
Flatskär
Högskär
Granören
Pillfjärden
Tjurgrund
Hamnö
Ljungö strömmen
Ljungö
Busskär
Skattskär
Hjortron-skär
Rödgrund
Ångö
Södö
Lillsottunga
Östra Stenskär
Finnö
Sälsö
Långören
0 625 1 250 2 500 Meters


Marine geological map
Sottunga E
Sediment
Recent mud
Litorina clay
Ancylus clay
Glacial clay
Glacio aquatic mixed sediment
Sand and gravel
Till
Bedrock
Nölskär
Norra Ljusören
Pjukansören
Notören
Dömmanskär
Jordkumlet
Hästskä
Flatskär
Högskär
Granören
Pillfjärden
Tjurgrund
Hamnö
Busskär
Hjortron-skär
Rödgrund
Södö
Lillsottunga
Östra Stenskär
Sälsö
Långören
0 625 1 250 2 500 Meters

Appendix 3.

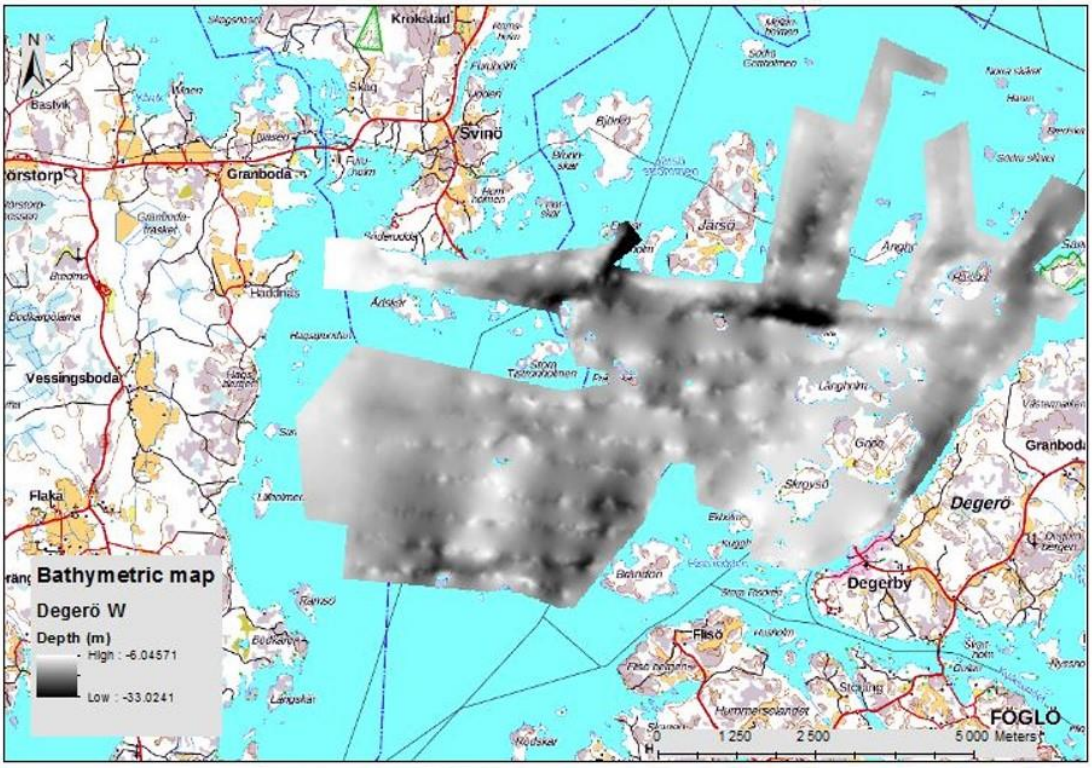


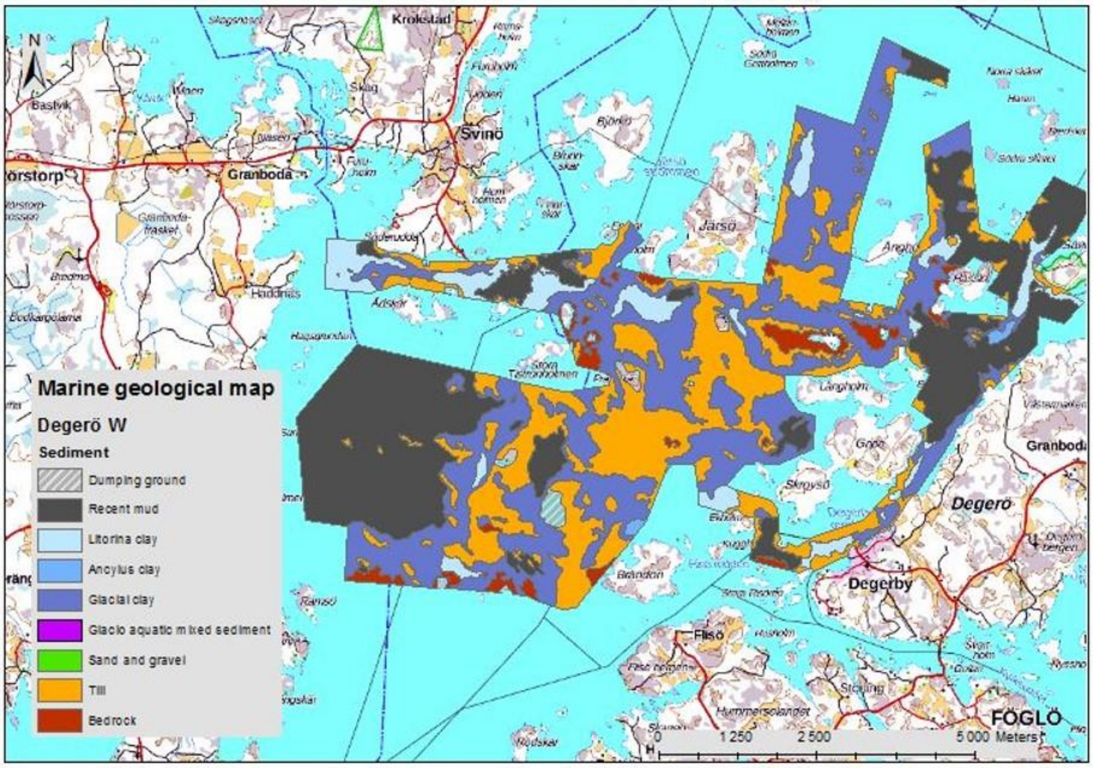
Bathymetric map
Kökar E
Depth (m)
High : -2.07621
Low : -109.255
0 2 500 5 000 10 000 Meters
N
Kråkskär
Malön
Glosskär
Österskärs fjärden
Kalhara fjärden
Trollkobb fjärden
Brunnsfjärden
KÖKA
Kökarfjärden
Vid



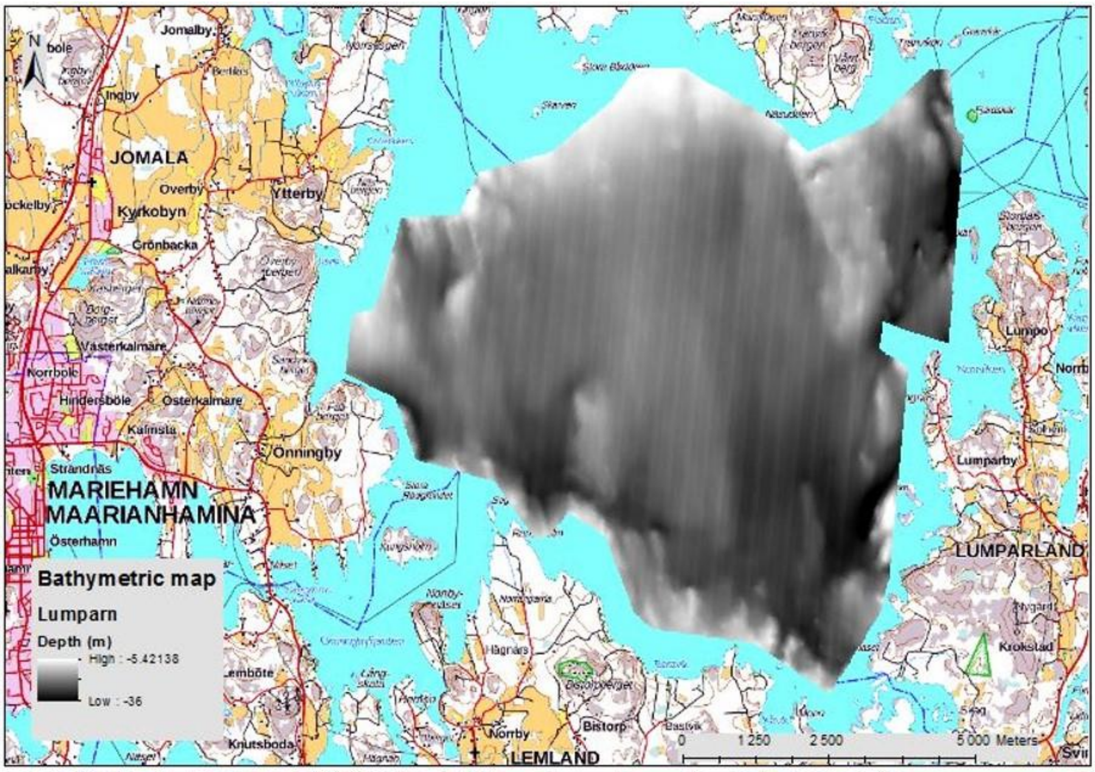
Marine geological map
Kokar E
Sediment
Recent mud
Litorina clay
Ancylus clay
Glacial clay
Glacio aquatic mixed sediment
Sand and gravel
Till
Bedrock
0 2 500 5 000 10 000 Meters
N
Kråkskär
Malön
Glosskär
Österskärs fjärden
Kalhara fjärden
Trollkobb fjärden
Brunnsfjärden
Storskär
Hellsö
Söderby
Kökarfjärden
Vid

Appendix 4.

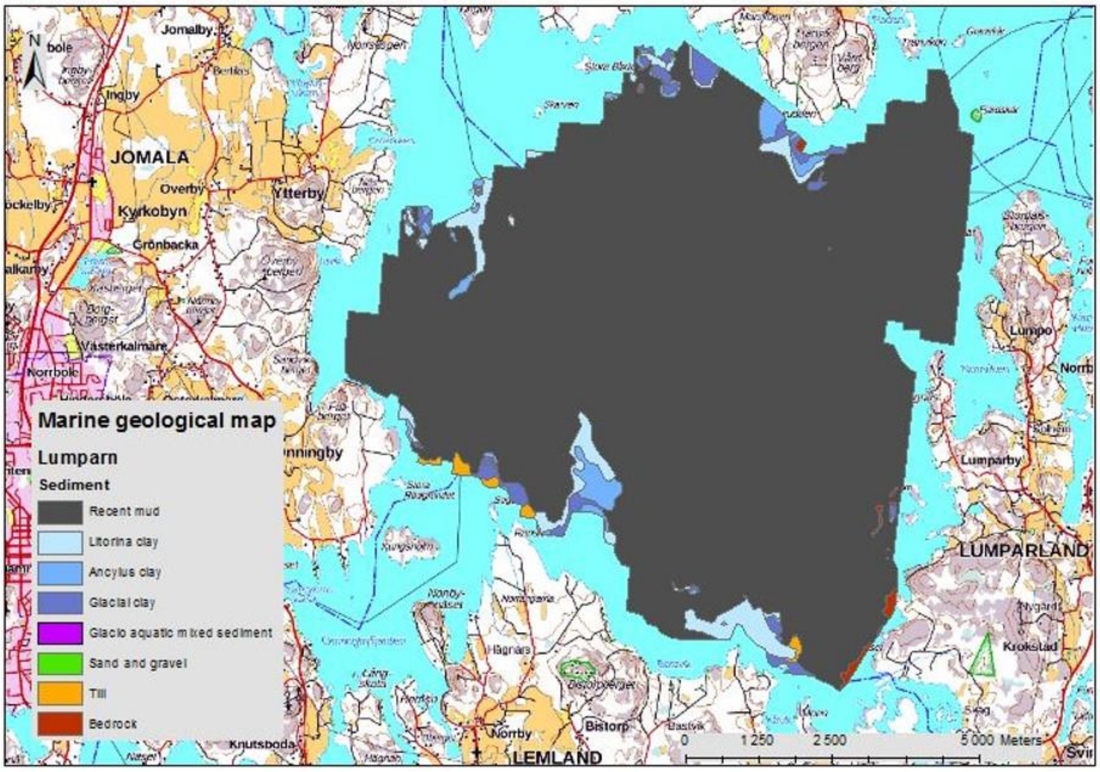

Bathymetric map
Degerö W
Depth (m)
High : -6.04571
Low : -33.0241
0 1 250 2 500 5 000 Meters
Krokstad
Svinö
Granboda
Vessingsboda
Flaka
Degerö
Degerby
Flisö
FÖGLÖ


Marine geological map
Degerö W
Sediment
Dumping ground
Recent mud
Litorina clay
Ancylus clay
Glacial clay
Glacio aquatic mixed sediment
Sand and gravel
Till
Bedrock
0 1 250 2 500 5 000 Meters
Krokstad
Svinö
Granboda
Degerö
Degerby
Flisö
FÖGLÖ

Appendix 5.



Bathymetric map
Lumparn
Depth (m)
High : -5.42138
Low : -36
0 1 250 2 500 5 000 Meters
JOMALA
MARIEHAMN
MAARIANHAMINA
LUMPARLAND
LEMLAND



Marine geological map
Lumparn
Sediment
Recent mud
Litorina clay
Ancylus clay
Glacial clay
Glacio aquatic mixed sediment
Sand and gravel
Till
Bedrock
0 1 250 2 500 5 000 Meters
JOMALA
LUMPARLAND
LEMLAND

Annex II

Nature types (Sandbank, Reef, Baltic Esker Island, and Leaking gas areas) for geologically mapped case study areas around Åland

22nd February 2018

Anu Kaskela, GTK

Intro

During summer 2016 GTK conducted marine geological surveys in selected case study areas around Åland Island in order to produce detailed geological information on the marine geological features and nature types. Case study areas were chosen based on existing knowledge and VELMU data (e.g. Kaskela & Rinne, 2018). Below the methods to identify nature types Sandbanks (1110), Reefs, Baltic Esker Islands (1610), and Submarine structures made by leaking gases (1180) are described.

Data

The following data was in use in identifying nature types:

- Marine geological maps for case study areas
  - Maps were made on the basis of interpreted seismo-acoustic soundings/profiles and bathymetry data
- Bathymetry model interpolated from Multibeam echosounder (MBES) data (5 m point distance), raster size 25 m for the case study areas.
  - Benthic terrain Modeller (BTM) was used to calculate Bathymetric Position Index (BPI) from the bathymetry model with a neighborhood size of 300 m (resembles models made for the Archipelago Sea; Kaskela & Rinne, 2018). The BPI values define if the area is higher (>0) or lower (<0) than its neighborhood.
- VELMU bathymetry model, raster size 20 m
  - BPI 300 m (Kaskela & Rinne, 2018)
- Terrestrial geological (Quaternary) data (GTK), scale 1:200 000

Method & Results

Sandbanks (1110)

Sandbanks are elevated, elongated, rounded or irregular topographic features, permanently submerged and predominantly surrounded by deeper water. They consist mainly of sandy sediments, but larger grain sizes, including boulders and cobbles, or smaller grain sizes including mud may also be present on a sandbank. (European Commission, 2013).

Glacifluvial sand and gravel areas that were not in direct contact with esker islands were interpreted as potential sandbank areas. In many cases, these areas are actually submarine continuations of the eskers that do not reach the water level. The potential sandbanks were further analysed based on BPI^{300m}. The submarine sand and gravel areas that matched with $BPI^{300m}>100$ are elevated structures and most likely meet the physical criteria of sand bank definition (field: B300m_Y100=1). The potential sandbank data set includes also other submarine sand and gravel areas (field: B300m_Y100=0). The average BPI^{300m} value is included for all potential sandbanks (field: B300m_AVG). Most of the sandbanks indicate somewhat elevated structure i.e. positive BPI value.

It is possible that there are sandbanks outside the GTK's field survey areas. For instance, the terrestrial data shows sandy areas in the western Åland area and it could be that there are marine sand close to these areas as well.

Reefs (1170)

Reefs can be either biogenic concretions or of geogenic origin. They are hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone. Hard compact substrata are: rocks (including soft rock, e.g. chalk), boulders and cobbles (generally >64 mm in diameter). (European Commission, 2013).

Submarine areas interpreted as bedrock or till were considered as hard compact substrata. Similar to sandbanks the bedrock and till areas that matched with BPI^{300m}>100 are elevated structures and most likely meet the physical criteria of the reef definition (field: B300m_Y100=1). The potential reef data includes also bedrock and till areas that do not meet the before mentioned criteria (field: B300m_Y100=0). The average BPI^{300m} value is included for all potential reefs for further analysis (field: B300m_AVG) and most of the potential reefs indicate somewhat elevated structure i.e. positive BPI value.

Submarine structures made by leaking gases (1180)

Submarine structures made by leaking gases are submarine structures consisting of sandstone slabs, pavements, and pillars up to 4 m high, formed by aggregation of carbonate cement resulting from microbial oxidation of gas emissions, mainly methane. The formations are interspersed with gas vents that intermittently release gas. Bubbling reefs and carbonate structures within pockmarks are types of leaking gas areas. (European Commission, 2013)

Leaking gas is typical to the Lumparn case study area and several gas "domes" have been identified there. More information on the leaking gas domes can be found from Nyman (2018). The Lumparn gas area does not fulfill the Habitat criteria e.g. pockmarks included in the habitat description are depressions in soft sediment areas and the leaking gas sites found from the Lumparn are elevated structures. However, the Lumparn gas area is geologically special. Even though pockmarks/gas sites have been found from other Finnish areas as well, the gas field has not been as extensive as in Lumparn. Here, the leaking gas areas were outlined based on the domes identified from the side scan data and seismic profiles as well as from the multibeam bathymetry data.

Baltic esker islands (1610)

Baltic esker islands are glaciofluvial islands consisting mainly of relatively well sorted sand, gravel or less commonly of till. They may also have scattered stones and boulders. (European Commission, 2013).

The gravelly and sandy islands were extracted from the terrestrial quaternary data. These islands were compared with aerial images (by Kaskela & J-P Palmu, GTK) to verify that they are eskers. The submarine continuations of the esker islands were analysed in case study areas based on marine geological maps. If the submarine area interpreted as a glacifluvial sand and gravel was in contact with esker island, they were interpreted as submarine continuations of the esker islands. These islands were mainly part of the Kökar esker. In addition, few potential submarine continuations were mapped outside case study areas based on terrestrial data and BPI analysis made from the VELMU bathymetry with a neighborhood size 300 m. The average BPI^{300m} values of either case study bathymetry or VELMU bathymetry (of outside case areas) are included in the data (field: B300m_AVG).

It should be noted that island Sändön included an esker formation, but the whole island was not considered as an esker formation.

No submarine caves were found from the case study areas.

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(detta nummer, present no)

ISSN: 0787-5460
ISBN: 978-952-12-3797-3

2019