Geological Survey of Sweden

Report within the government assignment Geological Storage of Carbon Dioxide in Sweden

Marine Geology – Southeast Baltic (Swedish EEZ)

Multibeam water column data measurements

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Abstract

As part of the government mandate of Carbon Capture and Storage (CCS), the Geological Survey of Sweden (SGU) conducted marine geological investigations in the Southeastern part of the Swedish Exclusive Economic Zone (EEZ) in the Baltic Sea (SEB), acquiring multibeam echosounder (MBES) data, including water-column information. The broader CCS government mandate extended over three years and involved several survey campaigns.

The aim of this report is to summarize the survey campaign in the SEB, including methodology, survey execution, and associated metadata, collected with focus on mapping previously mapped bedrock fault zones for potential observations of gas escape features.

The planned 2024 campaign intended to perform seismics, MBES, and a sub-bottom profiling in the SEB. Permit restrictions on instruments operating below 200 kHz required replanning, resulting in three additional survey campaigns. Two campaigns were redirected to Skåne, while the third was carried out in the Southeast Baltic (SEB) region of Swedish EEZ during August 2024. Gas-seepage detection relied on analysis of MBES water-column data and surface expressions. Of the allotted 34 survey days, 47% were used for data acquisition and the remainder for onboard data processing during weather standby, crew changes, mobilization, and transit.

Approximately 490 km² were mapped in SEB with MBES, providing good coverage of the prioritized fault zones. The MBES configuration allowed satisfactory detection capability near the survey lines, although performance decreased toward the outer swaths. Several fault zones in the region were not surveyed, leaving the possibility that gas-related seabed features remain undetected.

The survey successfully collected data of appropriate coverage and quality over the prioritized fault zones and generated MBES data suitable for assessing potential gas escape. However, gaps in spatial coverage and instrument constraints limit the completeness of any future interpretation.

Sammanfattning

Som en del av det fleråriga regeringsuppdraget Geologisk lagring av koldioxid i Sverige (CCS, Carbon, Capture and Storage) genomförde Sveriges geologiska undersökning (SGU) maringeologiska undersökningar i den sydöstra delen av Sveriges exklusiva ekonomiska zon (EEZ) i Östersjön, där data från flerstråleekolod (MBES) inklusive vattenkolumnsdata insamlades. Det övergripande regeringsuppdraget sträckte sig över tre år och omfattade flera undersökningar.

Syftet med denna rapport är att sammanfatta undersökningen i sydöstra delen av svensk ekonomisk zon i Östersjön (SEB) under 2024, inklusive metodik, genomförande och tillhörande metadata, med fokus på kartläggning av havsbottnen i områden där tidigare kartlagda berggrunds-förkastningar förekommer med syfte att identifiera potentiella gasutsläpp.

Den planerade undersökningen för 2024 avsåg att använda seismik, MBES och sedimentekolod i SEB. Restriktioner i tillstånd begränsade användningen av instrument som opererar under 200 kHz vilket krävde en omplanering och resulterade i tre ytterligare undersökningar. Två av undersökningarna omdirigerades till Skåne, medan den tredje genomfördews i SEB under september 2024. Detektering av gasutsläpp baserades på analys av vattenkolumnsdata från MBES samt ytliga indikatorer på havsbottenytan. Av de tilldelade 34 fältdagarna användes 47 % för datainsamling, medan resterande tid ägnades åt ombordbearbetning under väderuppehåll, besättningsbyten, mobilisering och transit.

Cirka 490 km² av havsbottenytan i SEB kartlades med MBES, vilket gav god täckning av de prioriterade förkastningszonerna. MBES-konfigurationen medgav tillfredsställande detektionsförmåga i närheten av mätlinjerna, även om observationsförmågan minskade mot ytterkanterna av svepen. Flera förkastningszoner i området undersöktes inte, vilket innebär att strukturer som indikerar gasläckage kan ha förblivit oupptäckta.

Undersökningen karakteriserade framgångsrikt prioriterade förkastningszoner och genererade MBES-data, användbar för att bedöma potentiella gasutsläpp. Begränsningar i täckning och instrumentkonfiguration reducerar dock fullständigheten i framtida tolkningar.

Introduction

The Geological Survey of Sweden (SGU) has as a part of the seismic investigation for the government mandate for Carbon Capture and Storage (CCS) gathered marine geological data in form of multibeam echosounders with water column data in Southeast part of the Swedish Exclusive Economic Zone (EEZ) in the Baltic (SEB). This report summarises the survey efforts, challenges faced and presents the result from the survey is constrained to metadata description.

Survey Summary

The CCS project has run over three years and has had multiple survey campaigns; each such survey milestone is illustrated in Figure 1 illustrating the campaigns during the length of the project. In total a total of 4 400 line-km has been surveyed (Skåne and Southeast Baltic EEZ combined). Each of the survey campaigns has had its own regions of focus for the data collection, the campaign surveying the area in the Swedish economic zone of the southeast Baltic Sea is described in further detail in this chapter.

In 2024, the plan was to survey an area in the southeastern part of the Swedish Baltic Sea Exclusive Economic Zone (SEB) using seismics, multibeam, and a sub-bottom profiler (Figure 2). However, due to challenges with permits limiting usage of all instruments under 200 kHz (i.e. seismics and sub-bottom profiler), three additional survey campaigns were planned at short notice. Two campaigns were performed in the area south of Skåne and are described in the report on marine geological measurements around Skåne. The third campaign was performed in the southeast part of the Swedish Exclusive Economic Zone in the Baltic Sea during August of 2024. The campaign aimed to map potential gas escape from areas around previously mapped bedrock faults using multibeam sonar water-column data and bathymetrical data to detect surface features.

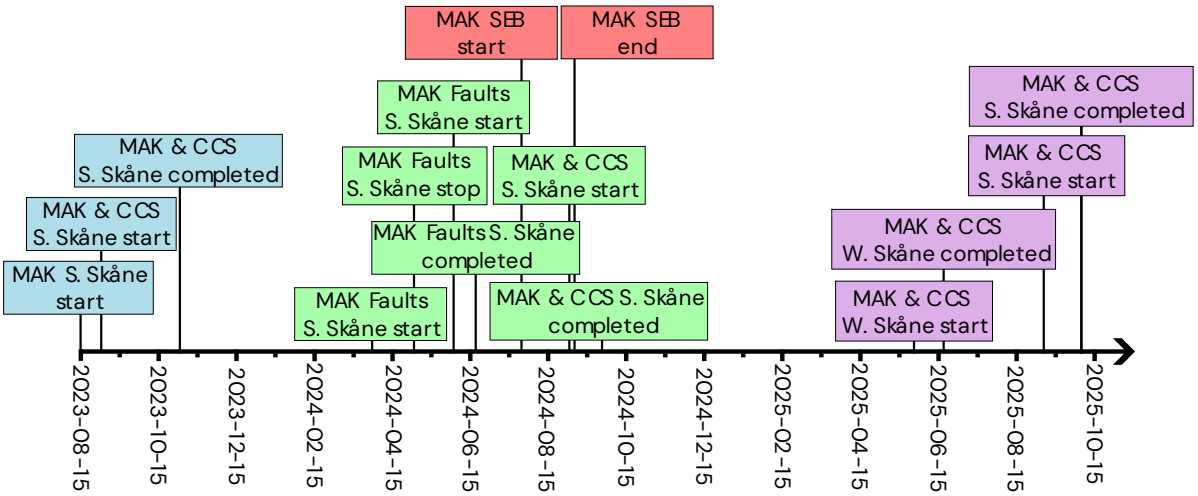

Figure 1. Survey milestones for the whole CCS marine geology project. SEB (Southeast Baltic) is dealt with in this report.

The allotted survey time of 34 days for the SEB survey in 2024 was spent in accordance with Figure 3. The figure is based on a day-by-day account. Time spent on weather standby/onboard processing is on the better side of expected for the vessel working in this very exposed area in August. Crew changes were held with at one day per week and often coincided with weather standby and mobilisations efforts, limiting their effect on survey time. The transit time represents the time spent on transit to and from the survey area from the vessels home port of Stockholm. The time spent on mobilisation was spent starting up the vessel after summer standby, sensor was shortly tested as they are hull mounted and calibrated during at the startup of the survey season.

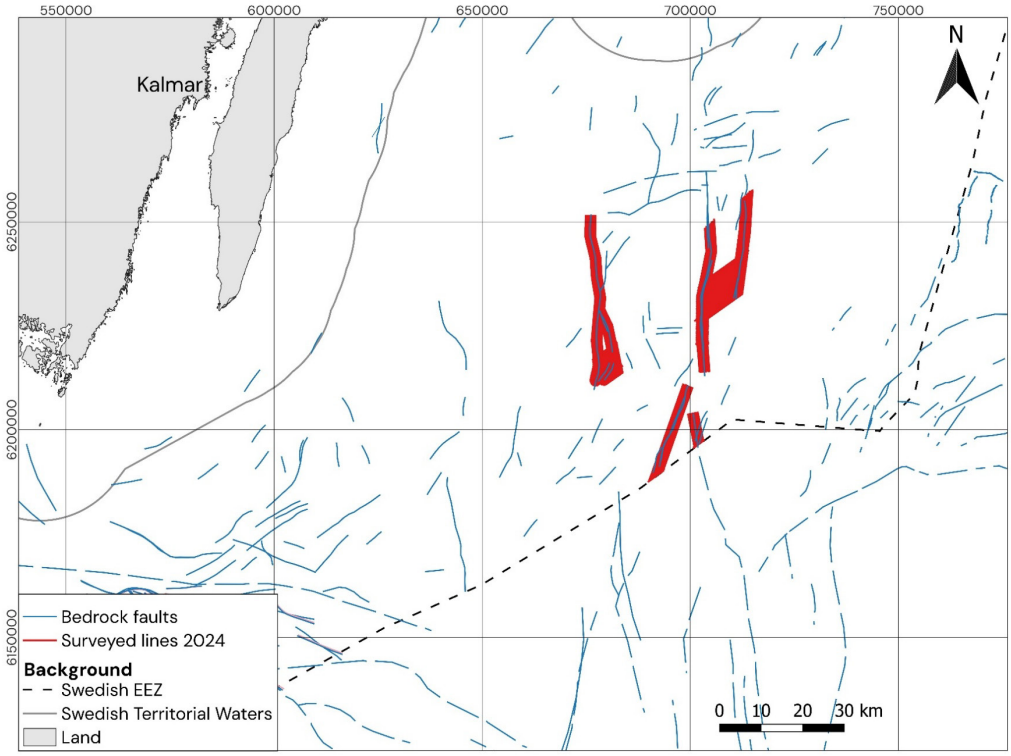

Figure 2. Survey areas southeast part of the Swedish Baltic Sea exclusive economic zone.

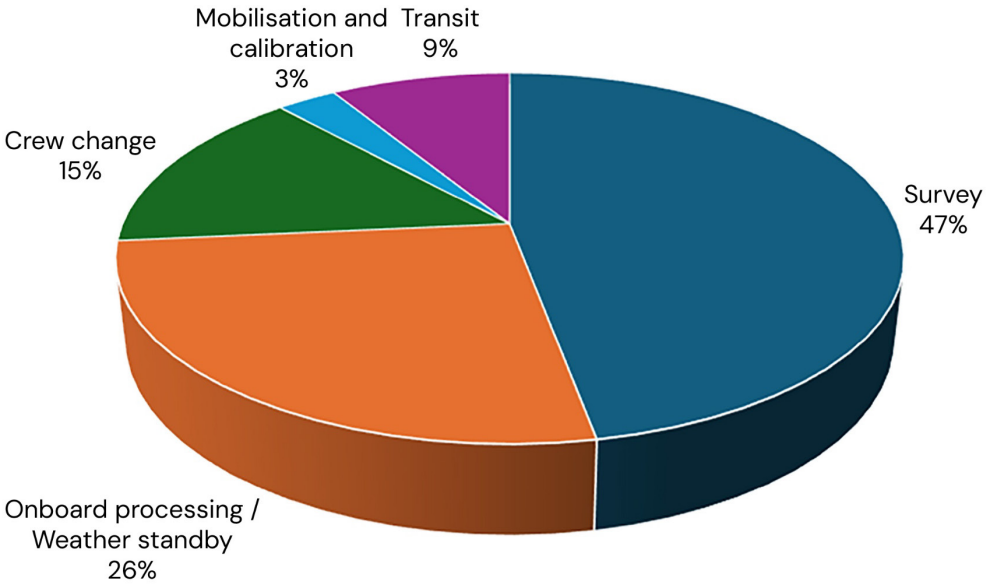

Figure 3. Days spent of allotted survey time in southeast part of the Swedish Baltic Sea exclusive economic zone (2024).

Challenges Faced

A number of the project's risks have been resolved; their consequences and the actions taken within the project are presented in Table 1.

Table 1. Challenges faced during the course of the project.

Challenge	Consequence	Actioned
Permits for geophysical survey in the southeast part of Swedish Baltic EEZ were denied 2024	No survey using equipment under 200 kHz in the planned area	• Quick re-planned survey scope around bedrock faults using MBES (frequency over 200 kHz) with Water column data in the area an additional survey in the area South of Skåne. • Further discussions with governing agency (Länsstyrelsen Gotland) resulting in a full MKB being filed.
Permits for geophysical survey in the southeast part of Swedish Baltic EEZ were delayed until midway through September 2025	No survey using equipment under 200 kHz in the planned area	• Fallback plans in place of extended survey in Öresund and further denser surveys south of Skåne
Red (classified) IT-infrastructure not available for workers in Gothenburg until midway through 2024	Backlog of data-processing and interpretation mainly affecting sub-bottom and surficial geology interpretation	• Red IT capability in Gothenburg has been increased • Interpretation scope adjusted to fit timeline
Amount of vessel time spent on mobilisation and demobilisation of seismic equipment	A total of 16 % of the vessel time allotted to the project was spent of mobilisation and demobilisation causing less actual survey time than planned for.	• The extra time spent has increased SGU's capability to operate its newly acquired seismic system. • Efficiency measures were taken resulting in the time spent decreasing for each mobilisation required.

Geological Background

A brief presentation of the surface geology and bathymetrical information was compiled and described exclusively from the open source EMODnet (European Marine Observation and Data Network) database (EMODnet Bathymetry 2024, EMODnet Geology 2025). The substrate map has a resolution of 1:1 100 000 there the original substrate categories provided by SGU are presented from the "Multiscale – folk 5" product. For the bathymetrical information the data has a grid resolution of approximately 115 x 115 m. Within the survey areas of SEB the water depth varies between approximately 30 to 80 m (Figure 4), and the dominating surficial substrate is glacial clay and minor parts of the seabed surface are covered by postglacial -clay, -sand and gravel (Figure 5).

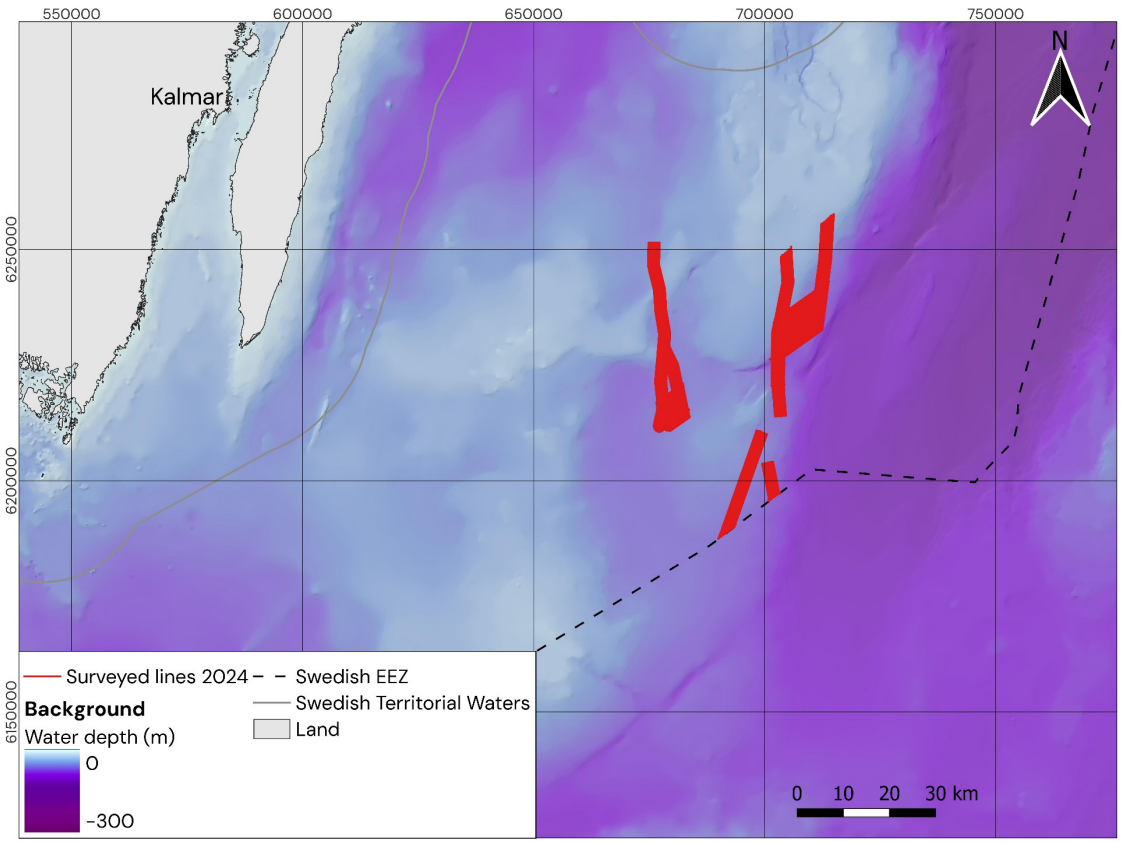

Figure 4. Bathymetrical overview of the SEB area provided from EMODnet.

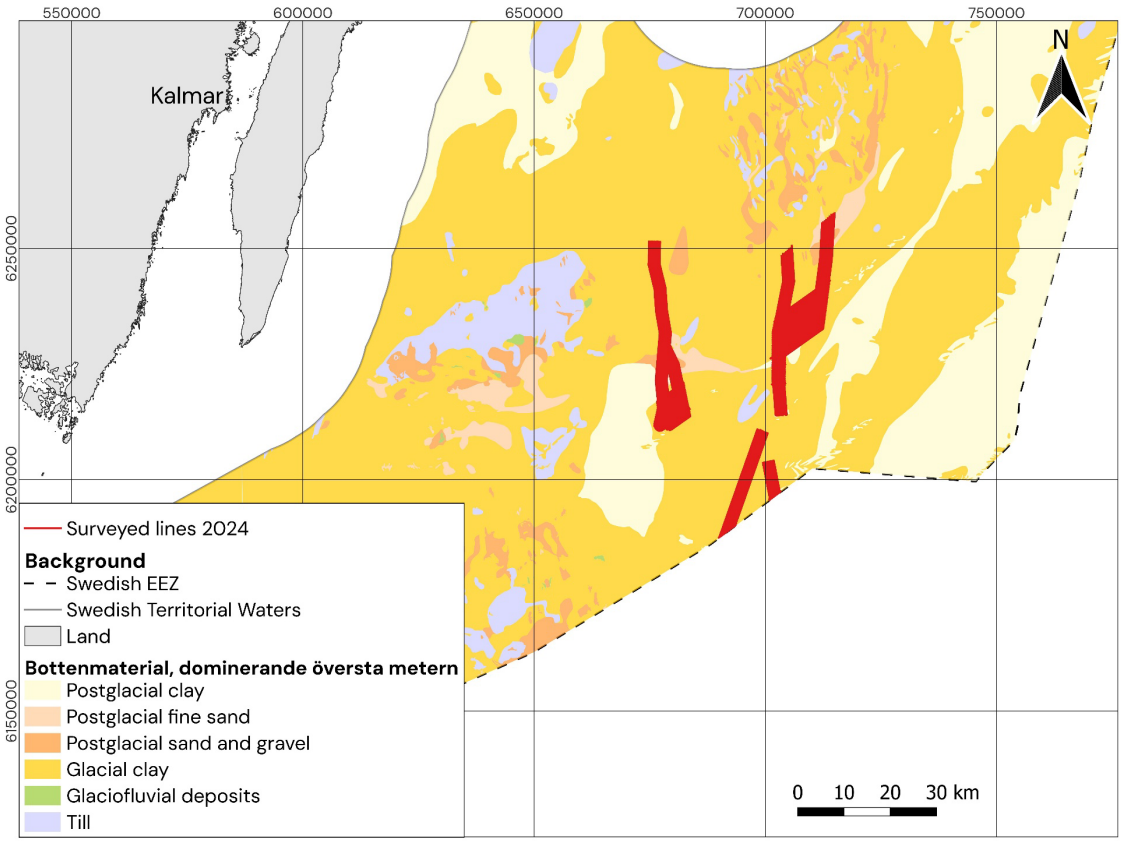

Figure 5. SGU classified substrate types in the SEB area from the marine geological map of Sweden (1:500 000) published by SGU.

Scientific Aim

The scientific aim for the result in this report is to:

(1) Present a summary of the survey, methodology and metadata from the survey.

Method

Multibeam

High-resolution bathymetry and backscatter were collected using a hull mounted Kongsberg EM2040 dual-head multibeam echo sounder (MBES) on board *The Geological Survey of Sweden*'s research vessel *R/V Ocean Surveyor*. The MBES was operating at a fixed frequency of 300 kHz with a short continuous wave (CW) pulse. Data was logged using the Kongsberg Seafloor Information System (SIS 4) software in the ALL-file format. Sound velocity was measured continuously at the transducer using a Valeport mini SVS (sound velocity sensor) and sound velocity through the water column was measured by taking discrete profiles using a Moving Vessel Profiler (MVP) system equipped with an AML sound velocity probe. Sound velocity profiles were taken at regular intervals in the survey area with the aim of not using profiles older than 6 hours ensuring that profiles older than 6 hours were not used, but generally the sampling frequency was much higher (roughly at least one profile per hour).

To maximize backscatter coverage during the survey, which was a priority, the outer opening angles on port and starboard were set to 75° at the expense of outer beam bathymetry data quality. The inner opening angles were set to 10° to provide a suitable overlap between the swaths of the two sonar heads.

In addition, water column data was logged in SIS 4 on a subset of survey lines that follow previously interpreted fault lines (Sopher et al. 2014) to investigate the potential leakage of gas through geological weaknesses within the CCS project survey area. Water column data were logged directly into the Kongsberg ALL files, which integrated backscatter measurements with vessel position and motion data in a single file. It is important to note that with the large outer opening angles (75°) that were used during data collection a large portion of the water column data falls outside the minimum slant range and therefore is susceptible to seafloor interference which could impact the ability to detect gas seeps. Additionally, the coverage of the beam fan increases with distance from the survey vessel, meaning that when survey lines are run with small overlaps a significant portion of the water column between those lines are not mapped. Gas flares occurring in this zone are therefore unlikely to be detected.

MBES Data Processing

The bathymetry data was processed in QPS Qimera (2.6.2). Raw depths were height referenced using the SWEN17_RH2000 placing the data on a common height scale that refers to the zero in the Swedish National Height System 2000 (RH2000) (Lilje et al. 2007). Sound velocity profiles were applied to the data using the real time scheduling option and if needed an SVP crossfade of 60 seconds was used to smooth out transitions between profiles. GPS position and height data was evaluated using the time-series editor and if large spikes or jumps were detected in the height it was removed, and data was interpolated between the start and end point of the height position error. Data cleaning was done using primarily the medium spline filter to remove large errors and any remaining errors were edited out manually.

Seafloor backscatter was processed in the QPS Fledermaus Geocoder Toolbox (FMGT, ver. 7.11.0). Backscatter data was made into a mosaic using automatic processing after which the histogram was manually adjusted to display the differences in backscatter intensity in as clear way as possible.

Water column backscatter from the MBES system was processed using the QPS Fledermaus Midwater (FMMidwater, v.7.11.0.2112) software. Here the raw sonar files were first converted to the Generic Water Column (GWC) file format. Because the EM2040 multibeam on Ocean Surveyor consists of two sonar heads, two separate GWC files were created, one for each head.

Results

Detailed Metadata of Measurements

As SGU has not been able to survey the planned survey area in the due to the very restrictive Natura2000 permit, the data acquired during this survey provides little to no new sedimentary knowledge of the area. The collected data (MBES with Water Column data) is deemed to be of lesser use to evaluate if the area has potential for CCS. This in combination with the fact that the Swedish armed forces consider the area sensitive for the nation's defence has resulted in SGU's decision to not publish the acquired dataset. The presentation of the bathymetry and backscatter data, distribution of potential gas seeps and interpreted seabed geology are thus constrained to metadata description.

During the 2024 mapping campaign of SEB, special emphasis was placed on the detection of geological structures relating to current and past gas seepage from deeper geological layers in the area. Primarily structures that would indicate the presence of pockmarks, such as round, craterlike depressions in the seafloor accompanied by changes in seafloor backscatter because of the mixing of surface sediments by escaping gas were targeted.

A total area of approximately 490 km^2 was covered with MBES data. Coverage of each prioritized fault zone was generally satisfactory, although the MBES survey setup limited the ability to detect potential gas flares in the outer swaths (Figure 6). However, several fault zones within the area were not investigated, meaning that structures potentially indicative of gas seepage may remain undetected (Figure 2).

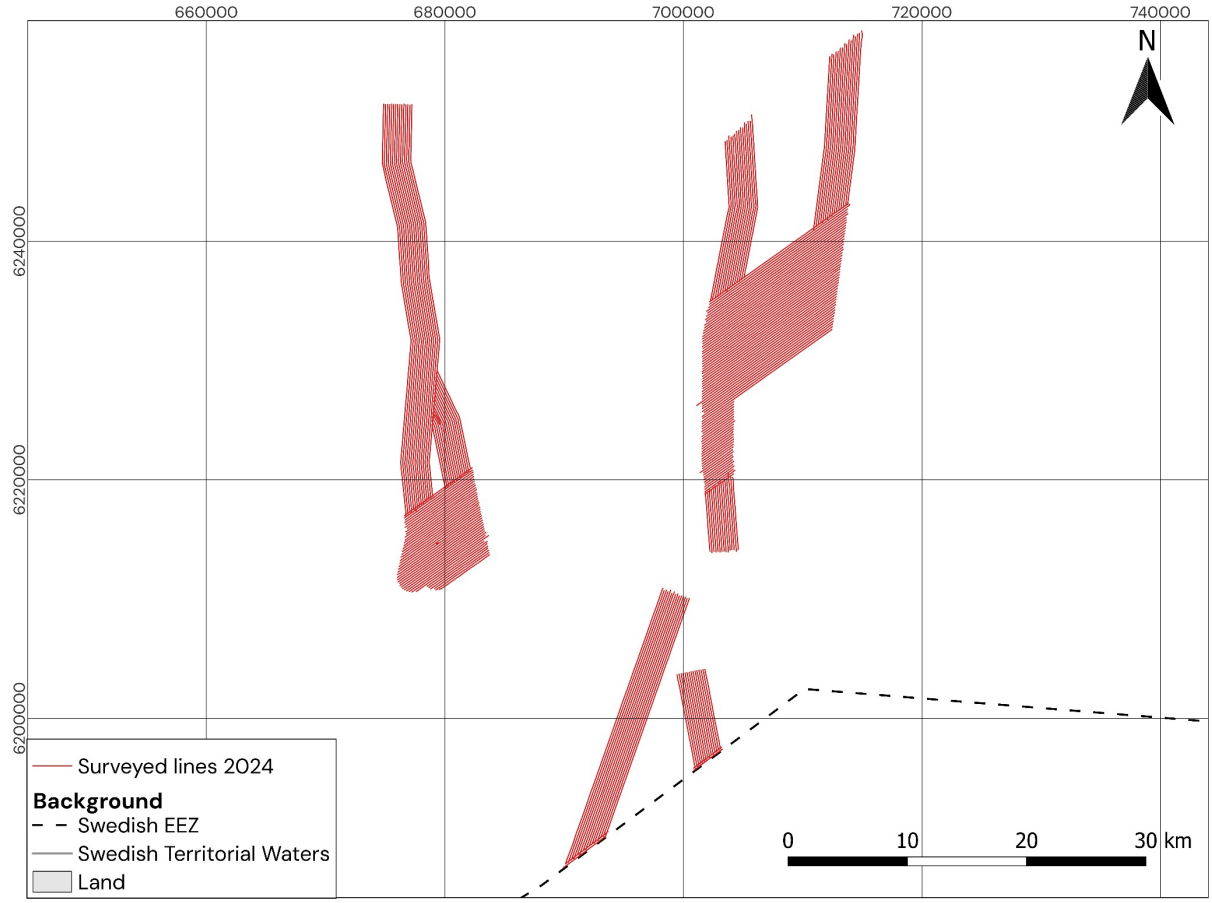

Figure 6. Overview of the survey line density and coverage. The survey line spacing is 300 m.

Conclusions

- High density data have been collected and processed on six faults in the survey area.
- Further analysis of this dataset and the survey for CCS purposes is restricted by the Natura2000 permit.

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