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Mapping and monitoring brown algae reefs in the Baltic Sea

An integrated, multidisciplinary data approach

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Brown macroalgae like *Fucus serratus* and *Saccharina latissima* may contribute to blue carbon storage in the Baltic Sea, but their distribution and biomass e.g. in the German EEZ are poorly known. The ROVKA project addresses these knowledge gaps by investigating the occurrence and habitat characteristics of these species in three protected areas of the EEZ using an integrated hydroacoustic-optical approach for large-scale mapping and long-term monitoring. Multibeam echo sounder (MBES) surveys provide the spatial framework for mapping the study areas, combining broad spatial coverage with high-resolution information on seafloor morphology and acoustic backscatter properties. AUV-based side-scan sonar (SSS) surveys complement these data by resolving small-scale substrate features relevant to brown algal habitats. Optical data from towed camera systems, ROV and AUV deployments document algal presence at multiple scales; AUV photo mosaics enable quantitative assessments of population density and spatial patterns. Repeated surveys of fixed monitoring sites track temporal changes, and automated image analysis supports efficient species detection and integration with acoustic and environmental data. By linking optical observations, hydroacoustic data, environmental parameters and targeted biomass measurements, the project aims to develop spatial prediction models for brown algal occurrence and biomass across the wider study areas. The resulting framework will provide a basis for assessing the distribution and potential blue carbon storage contribution of brown algae and support future conservation, restoration and monitoring strategies in the German Baltic Sea EEZ. As the project has only been launched in 2026, this report focuses on the methodology, initial observations and conclusions drawn from the first field campaigns.

algae mapping | optical and hydroacoustic mapping | MBES | SSS | SAS | AUV
Algenkartierung | optische und hydroakustische Kartierung | MBES | SSS | SAS | AUV

Braunalgen wie *Fucus serratus* und *Saccharina latissima* können im Ostseeraum zur Kohlenstoffbindung beitragen, doch sind ihre Verbreitung und Biomasse in der deutschen Ausschließlichen Wirtschaftszone (AWZ) bislang unzureichend bekannt. Das Projekt ROVKA soll diese Wissenslücken schließen, indem es das Vorkommen und die Habitatcharakteristika dieser Arten in drei Schutzgebieten untersucht. Dafür wird ein integrierter hydroakustisch-optischer Ansatz zur großräumigen Kartierung und langfristigen Überwachung eingesetzt. Die Daten des Multibeam-Echolotes (MBES) liefern die Basis für die Kartierung der Untersuchungsgebiete mit hochauflösenden Informationen zu Morphologie und Beschaffenheit des Meeresbodens. AUV-basierte Seitensichtsonar(SSS)-Erkundungen ergänzen diese Daten, indem sie lokale Substratmerkmale auflösen, die für Braunalgen-Habitate relevant sind. Optische Daten von geschleppten Kamerasystemen, ROVs und AUVs dokumentieren das Algenvorkommen auf verschiedenen Skalen; Fotomosaik ermöglichen eine quantitative Abschätzung der Populationsdichte und die Identifizierung lokaler räumlicher Muster. Wiederholte Befahrungen festgelegter Überwachungsflächen erfassen zeitliche Veränderungen, und eine automatisierte Bildanalyse unterstützt eine effiziente Detektion der gesuchten Arten und damit die Integration mit akustischen und Umweltdaten. Durch die Verknüpfung optischer Beobachtungen, hydroakustischer Daten, Umweltparameter und gezielter Biomassemessungen zielt das Projekt darauf ab, räumliche Vorhersagemodelle für das Vorkommen und die Biomasse von Braunalgen in den größeren Untersuchungsgebieten zu entwickeln. Der daraus resultierende methodische Rahmen bildet die Grundlage, um die Verbreitung und den möglichen Beitrag zur Kohlenstoffbindung von Braunalgen zu bewerten und künftige Strategien für Schutz, Wiederherstellung und Monitoring in der deutschen Ostsee-AWZ zu unterstützen. Da das Projekt gerade erst im Jahr 2026 begonnen hat, stellt dieser Bericht die Methodik, erste Beobachtungen und Schlussfolgerungen aus den ersten Feldkampagnen vor.

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Introduction

In the context of climate change-mitigation, oceans play an important role as natural carbon sinks. Marine organisms take up CO₂ and can facilitate its long-term storage in marine sediments, a process commonly referred to as blue carbon potential (BCP). While seagrass meadows and salt marshes are established blue carbon ecosystems in the Baltic Sea (Koplin et al. 2025; Stevenson et al. 2023), other macrophytes, particularly brown algae, are increasingly recognised as potential contributors. Through photosynthesis, macroalgae, like *Sacharina Latissima* (SL) and *Fucus Serratus* (FS), assimilate substantial amounts of CO₂ and may contribute to marine carbon sequestration. However, data on their distribution in German marine waters are incomplete, and little is known about the long-term storage of carbon in algal biomass. Increasing eutrophication and ocean warming, including marine heatwaves, may threaten brown algae and their potential role in carbon sequestration. Thus, spatially detailed and repeated monitoring studies are needed.

The Nature Restoration Regulation (Regulation (EU) 2024/1991) provides an important framework for protecting biodiversity, conserving habitats and restoring degraded ecosystems to strengthen climate resilience. Against this background, the Federal Agency for Nature Conservation (Bundesamt für Naturschutz; BfN), in collaboration with the Geomar Helmholtz Centre for Ocean Research Kiel, launched the ROVKA project, »Baltic Sea Reefs – Occurrence and Climate Protection Benefits of *Fucus* and *Saccharina* in the German EEZ«. The project addresses knowledge gaps on the occurrence and distribution of the named two brown algae species FS and SL in the German Baltic Sea Exclusive Economic Zone (EEZ), providing a basis for future conservation, restoration and monitoring strategies.

As the project was launched only at the beginning of 2026, the analyses presented here remain preliminary and do not show final results. Instead, the applied methods, initial observations and challenges identified during the first field campaigns are presented. Two expeditions, conducted in November 2025 and May 2026, have provided insights into species distribution and potential seasonal variability. High-resolution hydroacoustic mapping and optical surveys using sensors installed on or deployed from the research vessels, autonomous underwater vehicles (AUVs), and remotely operated vehicles (ROVs) are being conducted to develop machine-learning models for predicting species occurrence across the wider study areas by linking image-based observations with hydroacoustic data. The study covers three marine protected areas (MPAs) within the German Baltic Sea EEZ: Fehmarnbelt, Kadetrinne and Adler-

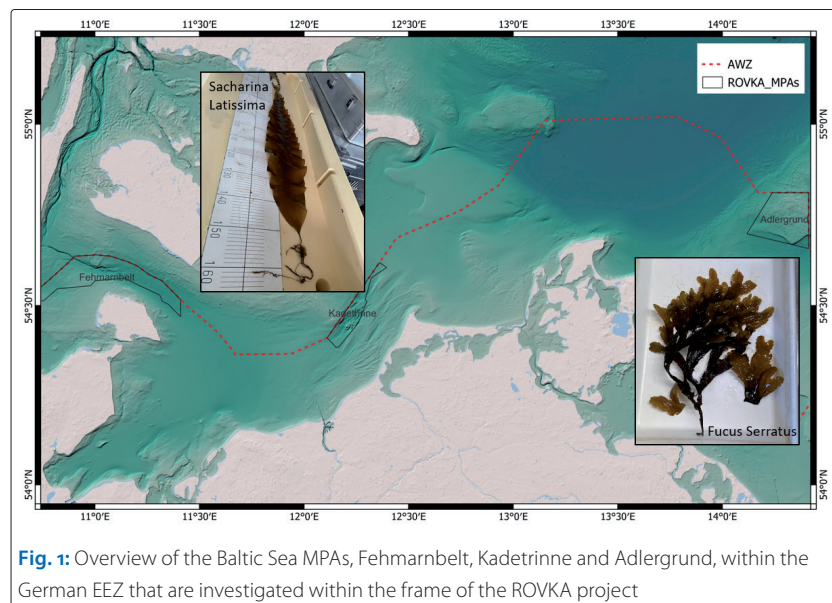


Fig. 1: Overview of the Baltic Sea MPAs, Fehmarnbelt, Kadetrinne and Adlergrund, within the German EEZ that are investigated within the frame of the ROVKA project

grund (Fig. 1). It focuses on SL in the Fehmarnbelt and Kadetrinne, whereas FS is the target species in the Adlergrund area. In Adlergrund, FS has so far only been detected at depths of up to approximately 10 m and is therefore largely restricted to shallow reef areas in the northern part of the MPA.

Methodology

In general, a range of methods are available for the optical and hydroacoustic surveying of the seafloor. One objective of the project is to identify and evaluate the most suitable approaches for effectively mapping and monitoring the target brown algal species.

Different hydroacoustic and optical methods have been and will be applied. In addition to substrate characteristics, light availability is essential for algal growth, making water depth a key factor in habitat assessments. Bathymetric data will therefore form the basis of this study and will be acquired across the entire area of the MPAs. AUV-based side-scan sonar (SSS) and synthetic aperture sonar (SAS) will subsequently provide information on substrate characteristics, while optical surveys will provide data on the presence and absence of the target algae, as well as quantitative and qualitative information on their stocks. Systematic repetition of selected optical surveys across different seasons over the six-year project-period will allow for an assessment of changes in habitats and macrophyte communities over time. By integrating these complementary datasets, a spatial habitat model will be developed to predict the occurrence of the target species across the study areas, at a spatial resolution constrained by MBES data.

Hydroacoustic surveys

MBES surveys: Bathymetric data are acquired using the hull-mounted multibeam echo sounder

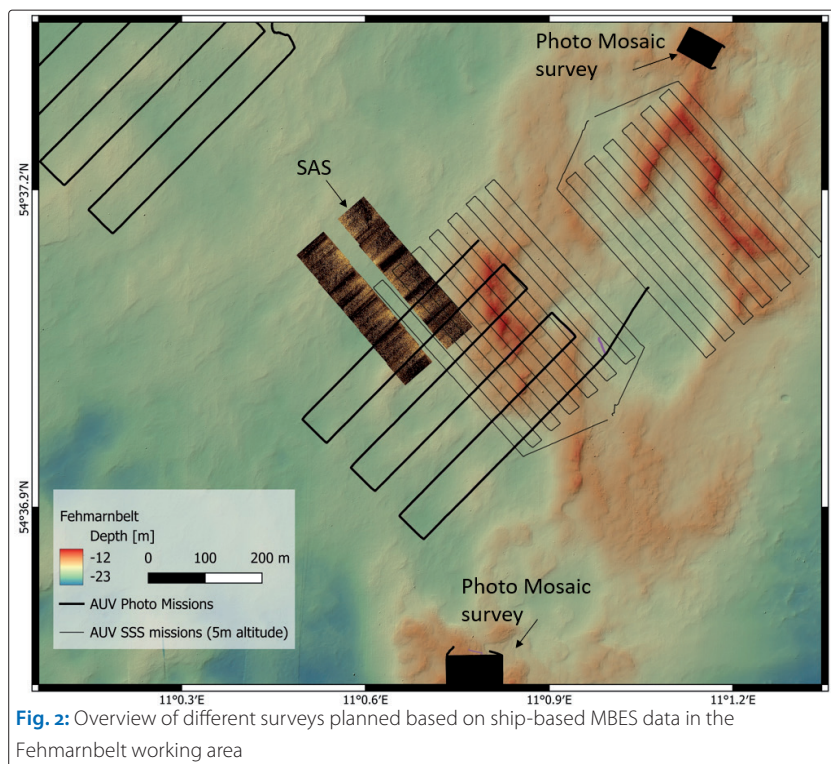


Fig. 2: Overview of different surveys planned based on ship-based MBES data in the Fehmarnbelt working area

(MBES) system from RV *Alkor* (Kongsberg EM2040), which can achieve a spatial resolution of several tens of centimetres at the water depths in which we operate (10 to 25 m). The system allows the use

of multiple acoustic frequencies ranging from 200 to 400 kHz. The MBES data serve two purposes: first, they form the basis of our fieldwork and support the planning and deployment of other sensor platforms (Fig. 2); second, they form the basis for the prediction model that we aimed to be developed. With its wide swath coverage and relatively low personnel requirements, MBES mapping is a highly efficient tool for monitoring large areas of the seafloor. In addition to depth information, a range of terrain characteristics will be derived from the bathymetric data, including slope, aspect, topographic position index (TPI), terrain roughness and other relevant geomorphological parameters. The bathymetric dataset will be complemented by backscatter data, providing additional information on seabed characteristics and substrate composition. These characteristics will be used to classify the terrain, provide insights into environmental conditions and generate relevant input variables for the habitat model.

MBES data have previously been used successfully to detect marine vegetation, either through point-cloud analysis (Held and Schneider von Deimling 2019) or water-column data (e.g. McGonigle et al. 2010; Porskamp et al. 2022; Nau et al. 2025). However, the two target species differ considerably in morphology and, consequently, acoustic detectability. FS grows vertically in dense tufts, extending several tens of centimetres into the water column (Fig. 3), and may therefore be detectable in MBES data. In contrast, SL lies flat on the seafloor (Fig. 4) and is expected to be largely acoustically invisible. For SL, other environmental parameters derived from seafloor morphology may therefore serve as proxies for assessing macrophyte presence.

To date, hydroacoustic surveys have aimed to achieve broad spatial coverage of the study areas, with MBES settings selected accordingly, including swath width, frequency, survey-line overlap and beam spacing. In the next phase, targeted hydroacoustic experiments will be conducted in areas with known algal patches that exhibit slightly anomalous signal patterns in the MBES data (Fig. 3). These experiments will investigate the acoustic characteristics and angular dependence of the acoustic response of FS patches. The same areas will be surveyed using the other methods applied in the project, enabling correlations between the different data content to be established and used for spatial prediction across the wider study areas.

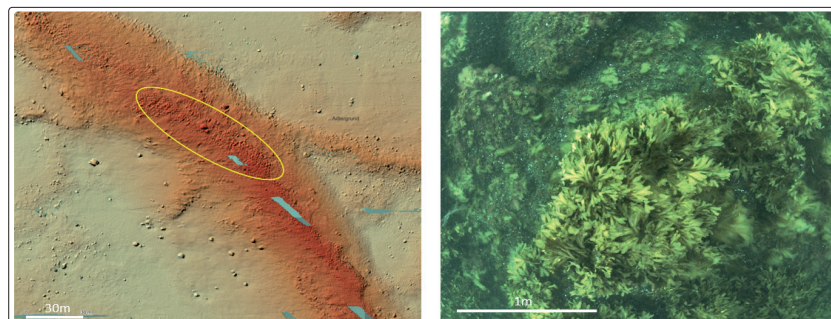


Fig. 3: Left: A bathymetric map section showing an esker ridge in Adlergrund, whose summit reaches a water depth of about 10 metres. In this area, the acoustic signal appears different than in other locations (marked in yellow) and could be related to the presence of FS patches. Right: FS in AUV-obtained image from Adlergrund working area

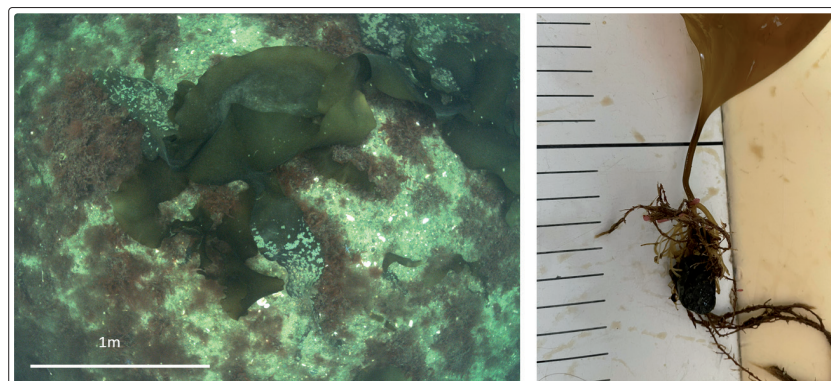


Fig. 4: Left: SL in Fehmarnbelt growing on substrate like mussels and pebbles. Right: Foot of SL individual attached to a few centimetre sized pebble stone

SSS and SAS surveys: In addition to MBES surveys, AUVs (deployed types: Sparus II from Iqua Robotics equipped with Marine Sonic Sea Scan ARC SSS, REMUS 6000 equipped with Edgetech SSS) are used to conduct SSS surveys, providing substrate data at a resolution of 2 to 5 cm (Greinert et al. 2024).

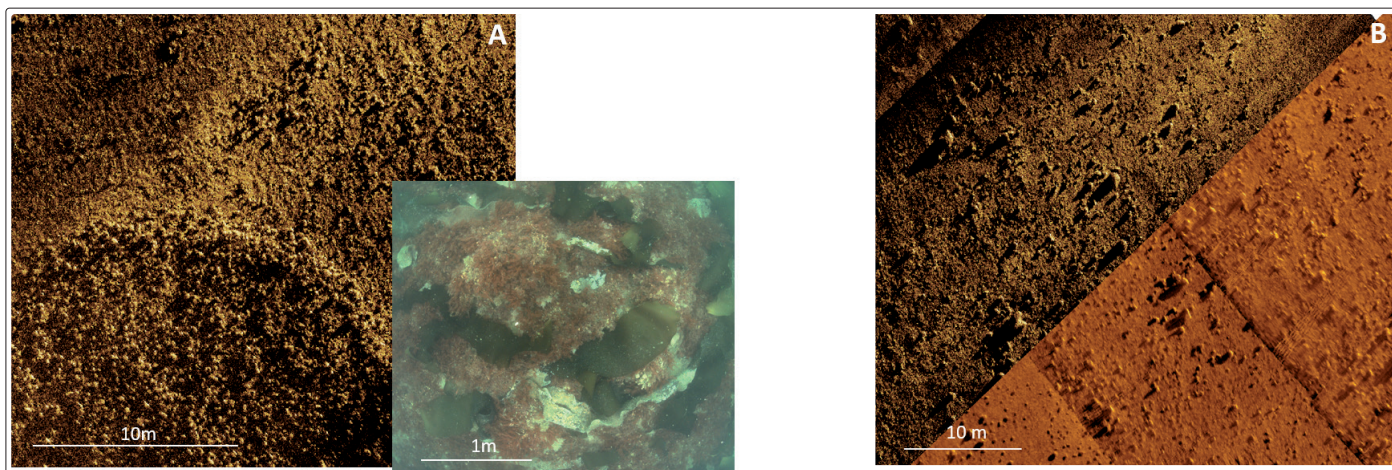


Fig. 5: A: This SAS image shows a seabed patch with a circular elevated feature that is overgrown by an algae meadow comprising SL and red algae.

The SAS data clearly shows the substrate on which they grow, but the algae cover itself is not directly detectable.

B: A seabed patch that was mapped using the AUV-based SSS (lower right corner) and the SAS (upper left corner)

SSS enables the detection and characterisation of small-scale hard-substrate features, such as pebbles and shell fragments, which can provide suitable habitat for SL but cannot be adequately resolved by MBES data (Fig. 4). Thus, SSS complements the MBES data by capturing substrate features relevant to target species occurrence beyond the boulder-dominated reef structures.

All study areas have previously been fully mapped using towed SSS systems in several other projects (Marx et al. 2023, 2024; Naumann et al. 2026). Although these datasets have a lower spatial resolution than the AUV-based SSS data, they provide a valuable basis for assessing changes in substrate conditions over time. In addition to AUV-based SSS, SAS (Kraken MINSAS 60-120) data have been collected at selected locations. Initial tests in the Fehmarnbelt using a towed frame operated approximately 5 m above the seafloor achieved spatial resolutions of up to 2 cm (Fig. 5). In the coming years we will further investigate using ship-based SAS in selected monitoring locations, as this has the great advantage of less technical efforts with platforms as AUVs by keeping a range-independent high resolution.

Optical methods

Image data acquisition: Direct observation of macrophytes requires optical methods, including towed camera systems, ROVs (here BlueROV2 from Blue Robotics) or AUVs (deployed type: Girona500 with Geomar-developed camera and lightning system). The ROV is used for targeted dives to obtain an initial impression of an area, ground-truth specific assumptions and to collect samples, while towed camera systems enable surveys along longer transects. AUV-based imaging offers several advantages, including autonomous operation close to the seafloor while the research vessel can be used elsewhere, as well as the repeatability of

pre-programmed missions, enabling direct comparison of datasets for long-term monitoring. Two types of AUV missions are conducted: »exploration missions«, which cover larger areas without lateral image overlap to provide a broad overview, and

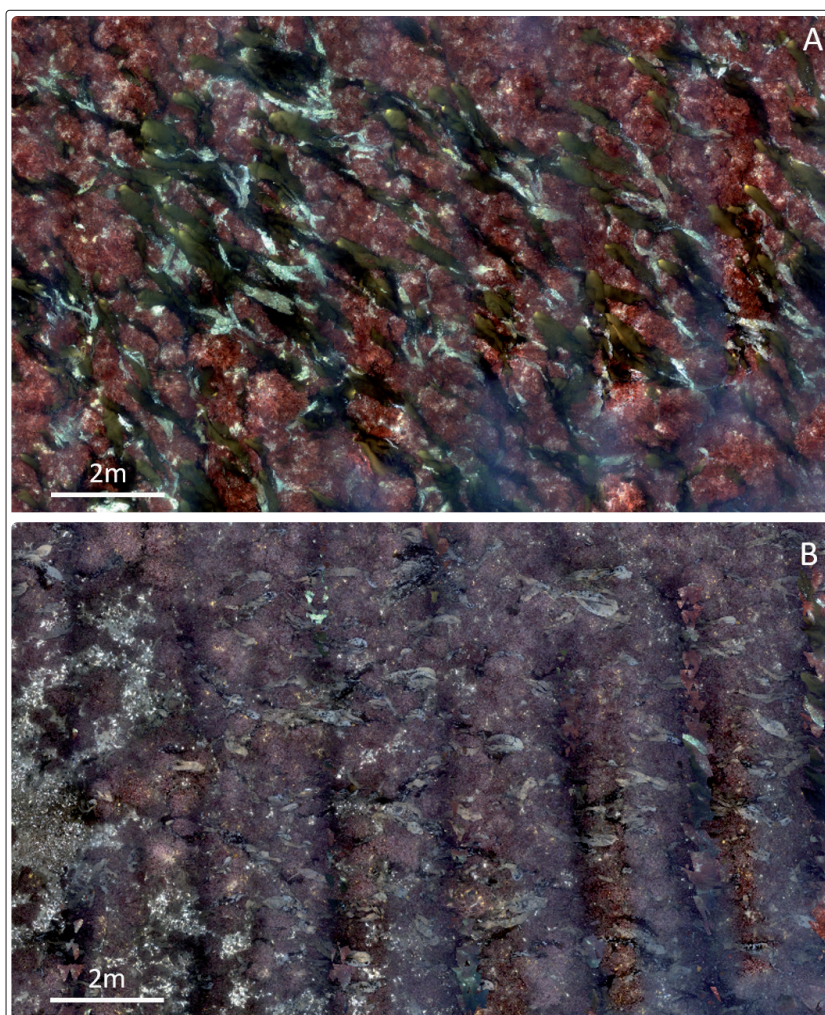


Fig. 6: Section of photo mosaics from the same algae meadow contained from red algae and SL in May 2026 (A) and November 2025 (B)

»mosaic missions«, in which overlapping survey lines enable the images to be combined into a spatially continuous mosaic (Greinert et al. 2024). These data enable precise quantitative and qualitative assessments of specific areas and the brown algal populations found there (Fig. 6). The resulting mosaics also facilitate the spatial alignment of repeated surveys, as multiple identifiable features within the mosaic can serve as reference points for aligning datasets acquired at different times.

Automatic image detection: Several approaches for the automated analysis of image data are being investigated. A YOLO-based approach (Redmon et al. 2016) is being applied to automatically detect the target algae. For SL, individuals generally contrast clearly from the surrounding substrate, facilitating automated detection. A current version of the YOLO-based model already produces promising results, successfully detecting algae across different missions and in areas with contrasting terrain characteristics, from pronounced morphological elevations (>3 m) to smoother, undulating terrain with only slight elevations (≤ 1 m), and consequently differing surrounding backgrounds. Further training data will be generated through manual annotation in BIIGLE (Langenkämper et al. 2017) to optimise the model and ultimately integrate it into the processing pipeline for automated analysis of newly acquired data. However, model performance may be affected by variations in water turbidity and resulting pixel colour. Images acquired in November differ considerably in colour from those collected in May (Fig. 6), likely due to seasonal differences in the optical properties of the water column and the algae themselves. Consequently, separate models or additional seasonal training data may be required to ensure reliable automated detection across seasons.

For FS, automated detection of individual specimens is most likely not feasible using this approach. Instead, larger existing patches may be automatically identified and their spatial extent estimated. Imagery acquired in the Adlergrund area

in May 2026 shows FS clearly distinguishable from the surrounding filamentous green algae (Fig. 3). However, its detectability may differ in autumn, when the filamentous algae are no longer present and FS may therefore exhibit different visual characteristics.

An additional output of generating photomosaics (here Agisoft Metashape, version 1.8.3) is the generation of a high-resolution 3D model of the surveyed mosaic area (Fig. 7). Through feature matching across overlapping images, the relative camera position and orientation a 3D point cloud is generated, enabling the reconstruction of a digital elevation model (DEM) with millimetre-scale spatial resolution. The resulting DEM provides a highly detailed representation of the seafloor morphology and complements the available bathymetric data at ultra-high spatial resolution.

The DEM also enables accurate spatial alignment of the image mosaic with the ship-based bathymetric dataset, correcting for slight spatial offset between the AUV-derived optical data and the ship-based bathymetry improving the geometric alignment between the two datasets.

AUV mosaic missions will be conducted repeatedly within designated »monitoring areas« throughout the project to assess small-scale spatial variability, complementing the larger-scale occurrence and distribution data obtained from towed-camera and AUV-based overview surveys. Image annotations will be incorporated into the habitat model, while targeted sampling dives will provide direct correlations between image-based observations and biomass. These relationships will support estimates of algal biomass and, consequently, BCP across the German EEZ.

Discussion

Several challenges need to be considered during the analysis. As the target algae are attached to hard substrates, their occurrence is expected primarily in reef habitats (Darr et al. 2022), characterised by boulder fields or rocky ridges. The roughness and heterogeneity of these substrates generate strong and spatially variable backscatter in both SSS and MBES data, which may mask the comparatively weak acoustic signal of attached macroalgae. Moreover, the presence of boulder fields cannot be directly equated with algal occurrence, as individual boulders are not necessarily colonised by the target species.

During the first two expeditions, visibility conditions were favourable, resulting in high-quality imagery suitable for automated detection. SL generally occurs in association with other macroalgal species, predominantly red algae, rather than in dense monospecific stands. Nevertheless, its distribution can be assessed semi-quantitatively by distinguishing areas of high and low density and

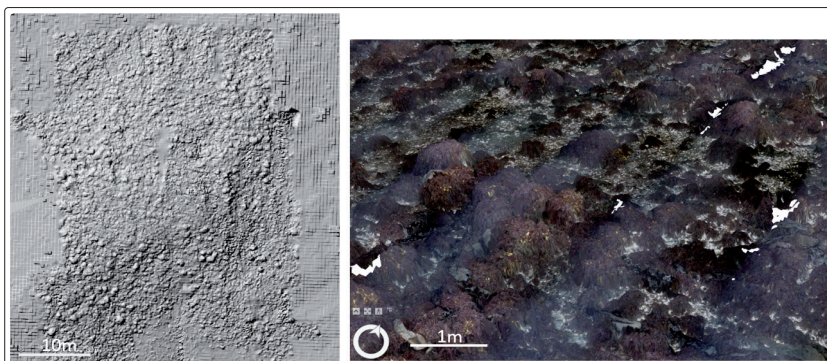


Fig. 7: Left: DEM derived from photo mosaic (mm-resolution) overlaid on ship-based bathymetric data (25 cm) resolution. Right: A section of the photo mosaic in 3D (using Esri ArcPro)

areas of non-occurrence. The relatively large and visually distinct SL blades also facilitate automated image-based detection of individual algae that allow the specimen size to be estimated. Repeated observations may therefore provide insights into growth dynamics and spatial variation on specimen size.

Preliminary analyses indicate higher SL densities on locally elevated areas, even where topographic differences are small (approximately 1 m), highlighting the importance of high-resolution bathymetric data. Such fine-scale variations would not be adequately captured by SSS alone. Image data from November 2025 and May 2026 already reveal pronounced seasonal differences in the appearance and distribution of SL in the Fehmarn Belt (Fig. 6). Upcoming surveys in Adlergrund will enable the investigation of seasonal patterns in FS patches under different environmental conditions and help assess their implications for the methods used.

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