ALKOR-Berichte

Monitoring ecological consequences of marine munition in the Baltic Sea 2023

Cruise No. AL603

3rd – 16th October 2023,

Kiel (Germany) – Kiel (Germany)

„MecoMM-BS - II“

CONMAR

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2024

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1 Cruise Summary

1.1 Summary in English

The cruise AL603 ("MecoMM II") is one of three research cruises that take place in 2023 and 2024 and are an integral part of the ongoing research project CONMAR (conmarmunition. eu/), which deals with the ecological impact of dumped munitions in the German Baltic Sea. These expeditions ensure complete monitoring over several years. During this expedition, substances released from munitions on the seabed will also be analysed beyond national borders in order to better assess the pollution of the Baltic Sea. Several German research institutions are involved in the AL603 cruise, and there are contacts to scientists in Denmark (University of Aarhus). Our Danish partners have explicitly initiated investigations in a munitions dumping area near Aarhus and in Jammerland Bay. The overarching aim of AL603 and other MecoMM cruises is to provide the federal states and the federal government with a clear decision-making aid as to where and how the clearance and final disposal of munitions in the German Baltic Sea should be started and what negative consequences could be expected on various spatial and time scales if no action is taken. By extending the study to Danish waters, we hope to gain a better understanding of the distribution of munitions in the area under investigation.

1.2 Zusammenfassung

Die Fahrt AL603 ("MecoMM II") ist eine von drei Forschungsfahrten, die in den Jahren 2023 und 2024 stattfinden, und sind integraler Bestandteil des laufenden Forschungsprojekts CONMAR (conmarmunition. eu/), das sich mit den ökologischen Auswirkungen von versenkten Munitionsaltlasten in der deutschen Ostsee befasst. Diese Expeditionen gewährleisten eine vollständige Überwachung über mehrere Jahre. Freigesetzte Stoffe aus Munitionsaltlasten auf dem Meeresboden sollen während dieser Ausfahrt auch über nationale Grenzen hinaus untersucht werden, um eine Belastung der Ostsee besser einschaätzen zu können. An der Fahrt AL603 sind mehrere deutsche Forschungseinrichtungen beteiligt, und es gibt Kontakte zu Wissenschaftlern in Dänemark (Universität Aarhus). Explizit wurden Untersuchungen in der Nähe von Aarhus in einem Munitionsversenkungsgebiet sowie in der Jammerland-Bucht unseren dänischen Partnern initiiert. Das übergeordnete Ziel von AL603 und anderen MecoMM-Fahrten ist es, den Ländern und dem Bund eine klare Entscheidungshilfen zu liefern, wo und wie die Räumung und Endlagerung der Munitionsaltlasten in der deutschen Ostsee begonnen werden soll und welche negativen Folgen auf verschiedenen Raum- und Zeitskalen im Falle eines Nichthandelns zu erwarten wären. Mit der Ausweitung auf dänische Gewässer erhoffen wir, ein besseres Verständnis für die Verteilung der Munitionsverbindungen in dem untersuchten Gebiet.

2 Participants

2.1 Principal Investigators

Name	Institution
Greinert, Jens, Prof.	GEOMAR
Beck, Aaron J., Dr.	GEOMAR
Kampmeier, Mareike, M.Sc.	GEOMAR
Arinaitwe, Kenneth, Dr.	GEOMAR
Schöntag, Patricia, M.Sc.	GEOMAR
Seidel, Marc, Dr.	GEOMAR

2.2 Scientific Party

Name	Discipline	Institution
Greinert, Jens, Prof.	Marine Geology / Chief Scientist	GEOMAR
Beck, Aaron J., Dr. (Leg I)	Marine Geochemistry	GEOMAR
Kampmeier, Mareike	Marine Geology	GEOMAR
Arinaitwe, Kenneth, Dr.	Marine Geochemistry	GEOMAR
Siao, Jean Khoo (Leg II)	Marine Geochemistry	GEOMAR
Schöntag, Patricia (Leg I)	Underwater Vision and cameras	GEOMAR
Seidel, Marc, Dr.	AUV Magnetometers	GEOMAR
Von See, Benedikt	AUV Magnetometers	GEOMAR
Kurbjuhn, Torge (Leg I)	AUV	GEOMAR
Diller, Nikolaj	AUV	GEOMAR
Scheppukat, Danilo (Leg II)	AUV	GEOMAR
Gerhardus, Leonhard (Leg II)	AUV	GEOMAR
Weiss, Weiß	XOFOS, ROV	GEOMAR
Nolte, Gabriel	XOFOS, ROV	GEOMAR
Fabrizius, Eduard	XOFOS, ROV	GEOMAR

2.3 Participating Institutions

GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel

3 Research Program

3.1 Description of the Work Areas

Falshöft: **O**uter Flensburger Förde, appr. 3.5 nm north of Maasholm. Historic reports emphasize the dumping of grenades and cartridges by withdrawing German units. Because submarines were anchoring here during WWII, dumped torpedoes and depth charges can also be expected.

Aarhus: approximately 1 km away. This 3 km² area received approximately 20,000 tons of munitions post-World War II. Clearance efforts from 1967 onwards aimed to rid the area of munitions, clearing waterways and salvaging brass and steel casings. Despite clearance, sporadic munition objects are believed to persist.

Jammerland: This region encompasses locations where the Danish Navy detonated several mines.

Lübeck Bay: The inner Bay of Lübeck includes two munitions dumps: Haffkrug and Pelzerhaken. Pelzerhaken is located approx. 3.4 kilometres from the western coastline of the bay. It was used as an ammunition dump after the Second World War, where both German and Allied munitions of various kinds were stored. In 1971, heavy metal-rich blast furnace slag and fly ash from a metal smelter were dumped, possibly covering some of the munitions (Leipe et al., 2017; Leipe et al., 2005). After the site was deemed full, the remainder was dumped in Haffkrug, which is located approx. 3.5 km from Neustadt.

3.2 Aims of the Cruise

The special objectives of AL603 and the companion MecoMM cruises include:

a) Constraining the inventory of existing munitions on the seafloor (location, type, number, condition)
b) Evaluating chemical contamination by explosive compounds in the water column and sediment

The aim of the AL603 and other MecoMM cruises is to provide clear decision-making support to the German federal states and the federal government as to where and how clearance and final disposal of the munition contaminated sites in the German Baltic Sea should begin, and what negative consequences on different space and time scales would be expected under a no-action scenario.

3.3 Agenda of the Cruise

The planned work programme includes mapping of munitions and chemicals in water and sediment at regional level.

The regionally distributed stations will be supported by a more comprehensive chemical, biological, and geophysical surveys at sites known or suspected to be munitions contaminated:

- Use of CTD rosette samplers for water samples
- Bathymetric mapping of ammunition-contaminated/suspected areas with multibeam and towed sidescan sonar
- High-resolution mapping of areas contaminated by munitions using AUVs equipped with Cameras and magnetic sensors
- High-resolution optical observation with a small ROV (BlueROV)

- Mapping of munitions targets with a towed sled equipped with cameras and magnetic sensors ("XOFOS": Extended Ocean Floor Observation System)
- Measurement of dissolved explosive compounds on board with a prototype of a Lab-in a box system ("Xplotector")
- Analysis of bathymetric, magnetic and optical data on board using state-of-the-art technology (AI-supported ammunition detection, photogrammetric munitions detection, photogrammetric 3D reconstruction and photo documentation

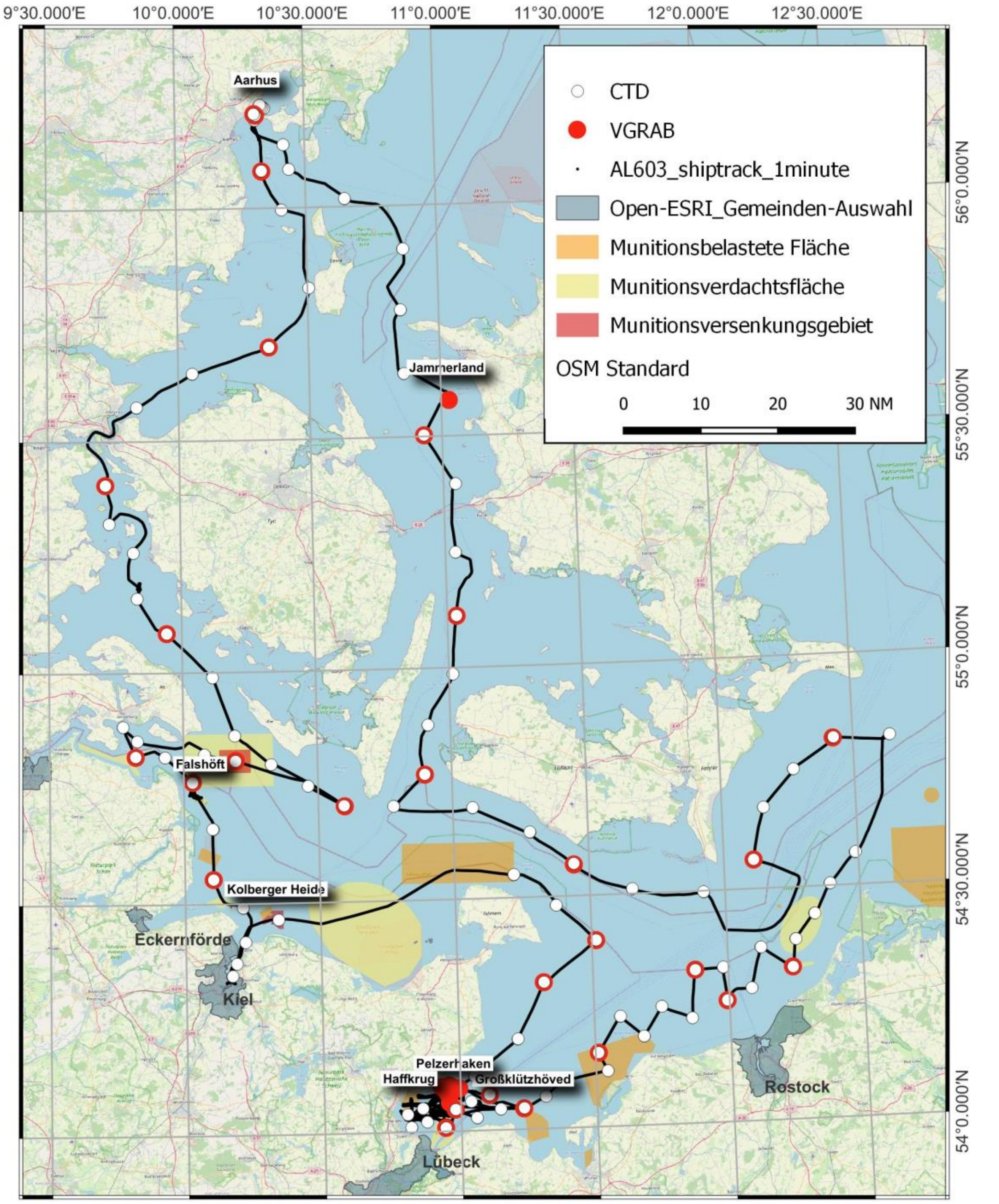

Fig. 3.1 Track chart of R/V ALKOR Cruise AL603. Five main working areas in Germany and Denmark (Falshöft, Aarhus, Jammerland and Lübeck Bay: Haffkrug and Pelzerhaken).

3.4 Measures to conduct responsible marine research

All measures were taken with regard to the Declaration of Responsible Marine Research, the Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area, and the Mitigation measures for the operation of seismic and hydroacoustic sources with pulsed sound emissions. During the cruise only high frequency, low energy hydroacoustic systems like SAS and SBP were in use. All these systems can and will be started with low energy (soft start). Mammals, particularly porpoises, could be scared away in such a way. During the entire cruise, we paid attention to any sightings of mammals in the working area. During measurements, no harmful chemicals were released.

4 Narrative of the Cruise

Week I:

The journey initiates on 3rd October with water sampling at predefined locations, consistently sampled during each MineMoni/MeCoMM expedition since 2018, progressing towards the first disposal site of this cruise: Falshöft, northwest of Maasholm. Due to adverse wind conditions (8 Bft), Autonomous Underwater Vehicle (AUV) dives could not be executed. Consequently, the afternoon of the first day is allocated to three eXtended Oceanfloor Observation System (XOFOS) deployments to verify two suspected points from previous expeditions. This reveals that one of the contacts corresponds to a stone reef rather than an anticipated munition deposit. Impeded by vegetation and visibility conditions, identification of the second contact proves challenging. Subsequently, a test dive is conducted using our small Remotely Operated Vehicle (ROV) Kaept‘n Blaubär to ensure the reliable functioning of sensors and a recently installed water scoop. Following a successful dive, the expedition proceeds into Danish waters, where the dispersion of explosive-related compounds in the water is to be measured. Water samples are collected for subsequent laboratory analysis post-voyage.

In Denmark, our target is a munitions disposal area just north-east of Aarhus. Prior to the expedition, research authorization for accessing the area was obtained from Danish authorities. During the night from Wednesday to Thursday, the area is mapped using a multibeam bathymetry system, searching for points of interest for subsequent investigation using AUVs, the ROV, and XOFOS. However, despite high-resolution hydroacoustic data, no definitive munition findings are recorded. The seabed alternates between sponge- and soft coral-covered stones and muddy sediments. Only one XOFOS dive identified suspicious contacts, though vegetation hindered unequivocal determination. A dense network of water samples around the restricted area aims to elucidate potential water contamination in proximity to the site.

Upon concluding investigations in this area, the expedition proceeds, collecting water samples, to Jammerland. Given recent evidence indicating that underwater detonations of munitions result in significant environmental contamination with explosive residues, the aim is to investigate the long-term effects of such contamination or assess the possibility of its absence.

While unequivocal munition contacts were not observed in the first week, successful technical trials were conducted. Equipped with sensors for recording light attenuation spectra and backscatter from the Helmholtz Center Hereon, along with a set of color calibration boards, the XOFOS conducted numerous measurements of optical water properties at various locations. These measurements serve to verify software developments for simulating underwater cameras with field data. Simulated underwater images provide a valuable foundation for advancing robust computer vision applications in water. The conducted measurements will ultimately enable the adjustment of artificial images to closely resemble real and physiologically accurate appearances.

Week II:
The research activities continue into the second week in the Lübeck Bay, where the focus is on ROV diving at as many points of interest as possible and mapping them for mass estimations. With a speed boat from the federal police a crew exchange was peformed between RV ALKOR and Neustadt i.H.. In addition, a delegation of the federal police came on board to get informed about state-of-the-art techniques for munition detection and monitoring.

However, a lot of work has been already done in Lübeck Bay, some munition piles were repeatedly surveyed via AUV photography. In preparation of munition clearance activities in spring 2024, all chosen sites should be documented regarding their current status. Several towed sidescan sonar missions complete multibeam seafloor mapping and its higher resolution, reveal even more suspicious contacts. By the end of the week, the weather turned and waves and wind prohibited AUV and ROV surveys in the eastern part of Lübeck Bay, Großklützhöved.

On the transit back to Kiel, all planned CTD and grab stations were conducted for a full chemical monitoring.

5 Preliminary Results

5.1 Geochemistry

(A. Beck[1], K. Arinatiwe[1])
[1]GEOMAR Helmholtz Center for Ocean Research Kiel

Water sampling and pre-processing for munition compound analyses
Water samples were collected from the German and Danish waters. The cruise track traveled from Kiel through the Little Belt to Aarhus, and returned to Kiel through the Great Belt, Arkona Basin and Lübeck Bay. Deep (bottom) samples (about 1-4 m above sediment) and near-surface (about 1-3 m below surface) were collected from 99 sampling stations (Figure 5.1; Table 10.1) using a CTD-Niskin rosette. Water samples for recovery tests were collected from selected CTD stations.

Additional deep-water samples were collected in very close proximity to munition dumps using niskin bottles mounted on a towed Ocean Floor Observation System (XOFOS) and/or a Remotely Operated Vehicle (ROV) from 13 sites during tows in Aarhus Bay, Jammerland Bay and and Lübeck Bay (Fig. 3.1,Table 10.1 (in appendix)).

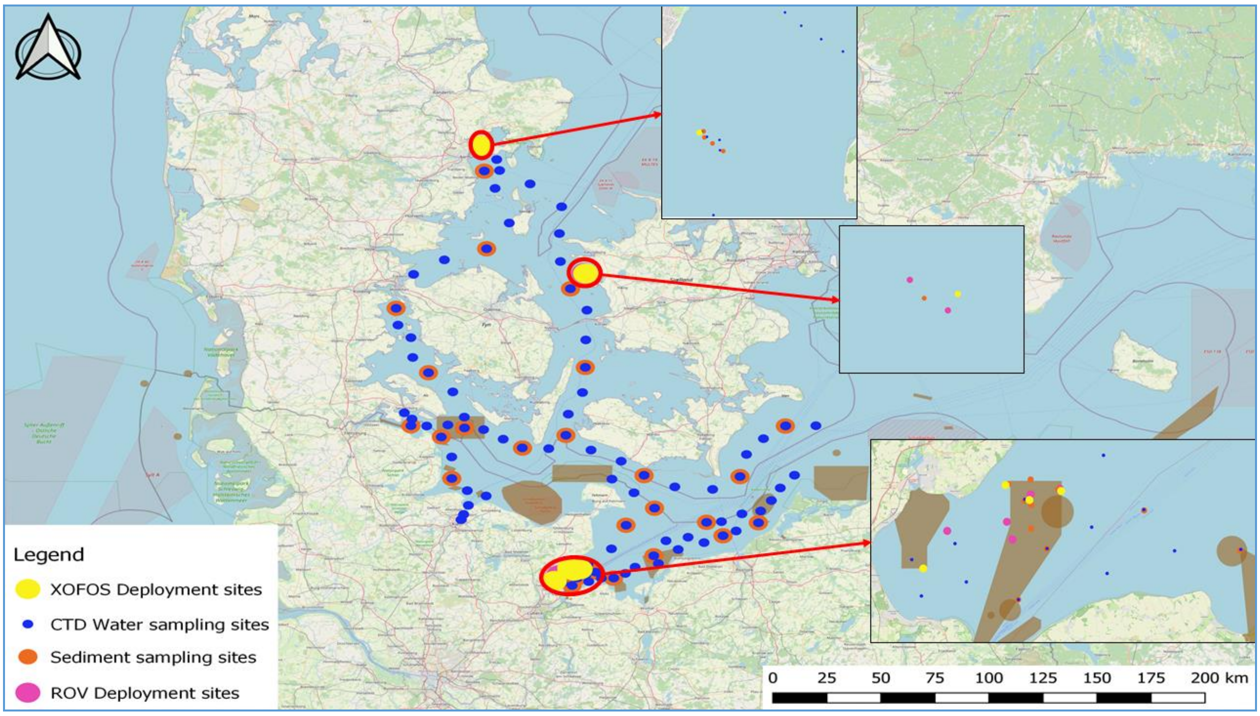

Fig. 5.1 Sampling sites for sediment and water samples collected for munition compound analysis during AL603 cruise.

All samples were spiked with internal standard, filtered (1.2µm glass fibre filters) and any MCs in the samples were extracted onto Solid phase extraction (SPE) cartridges. The MCs were eluted from the cartridges using acetonitrile. The samples (eluate), together with the filters, were brought back to GEOMAR for further processing.

Sediment sampling for MC analyses

Surface sediment samples (36 Van Veen Grabs; Fig. 3.1, Table 10.2) were collected with a Van Veen-type grab sampler for spatial profiling of MCs is sediment. The samples were stored frozen in Whirlpak sample bags and brought back to GEOMAR for further processing and analysis.

Shipboard measurements of dissolved munitions compounds

Deep water samples were collected with the CTD rosette at 64 stations for analysis by the now improved Xplotector LC-MS system during the first week of AL603.

The original system relied on a Microsaic MiD compact mass spectrometer to achieve detection limits on the order of 2 ng for trinitrotoluene (TNT). This MS could not detect dinitrobenzene (DNB), an important explosive in dumped munitions, and had relatively high detection limits for other target compounds. Therefore, a UV spectrometer had been included for detection of DNB, but abundant organic matter in seawater created interference with the UV analysis, making it less sensitive.

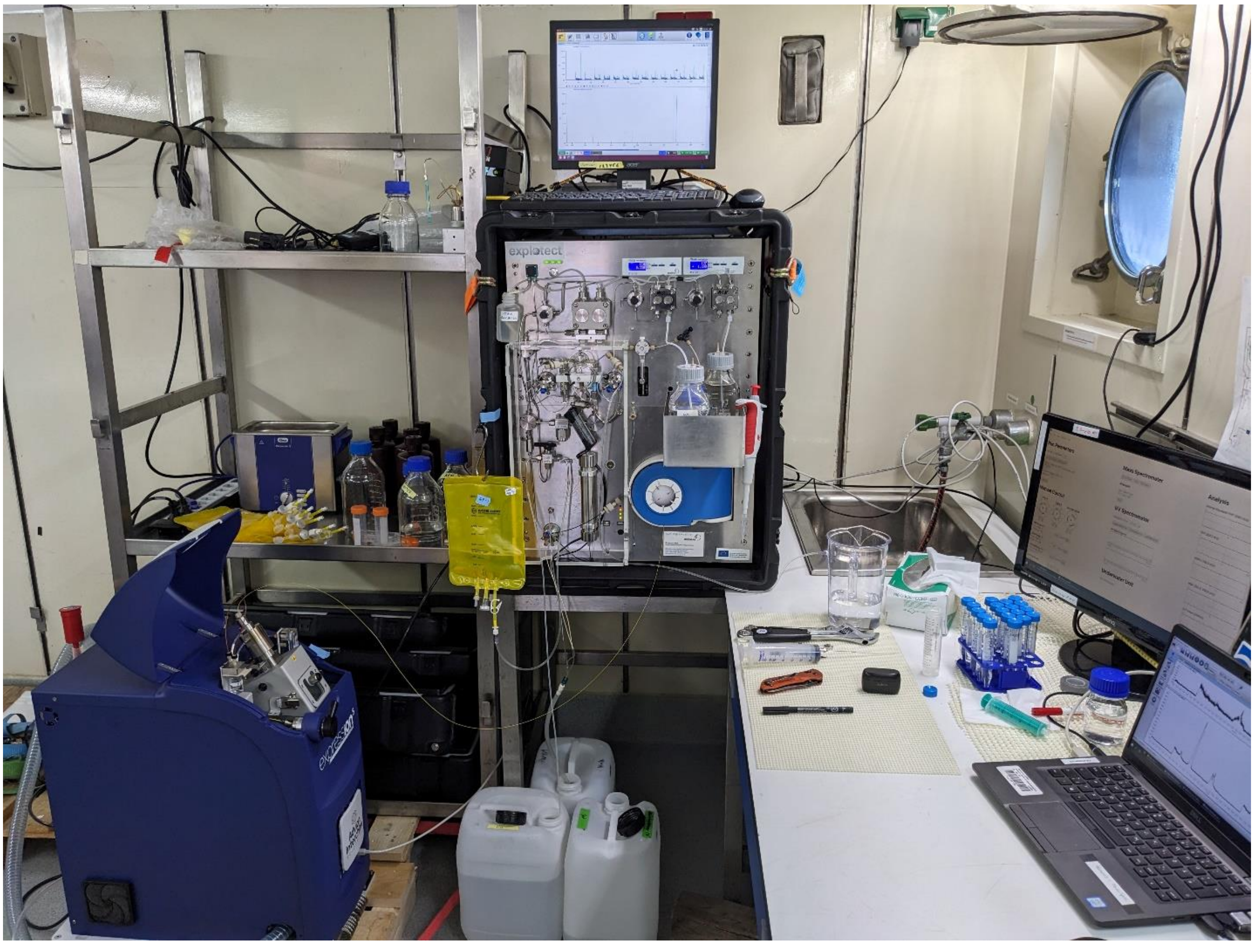

Fig. 5.2 The Xplotector system on the laboratory bench in the ALKOR wetlab on AL603. The CMS mass spectrometer is the blue instrument at the lower left of the image. The sample is split between the MiD:

As part of the VAMOS project, the Xplotector system was improved with an alternate compact mass spectrometer, the Advion expressionCMS (Fig. 5.2). The CMS is much more sensitive than the MiD, with a detection limit for TNT below 0.1 ng. It is also possible to detect DNB with the CMS, eliminating the need for the UV spectrometer unit. Cruise AL603 was the first field test of the CMS mass spectrometer with the Xplotector system.

Samples were collected in infusion bags and filtered (0.5 µm) inline by the Xplotector before preconcentration and analysis.

Preliminary results

General Water properties

Figures 5.3, 5.4 and 5.5 show physico-chemical properties of sea water along sections of the cruise. Stratification of salinity/conductivity is observed in Aarhus and Lübeck Bays. These profiles will be compared with MC profiles through multivariate analysis to elucidate underlying relationships, if any.

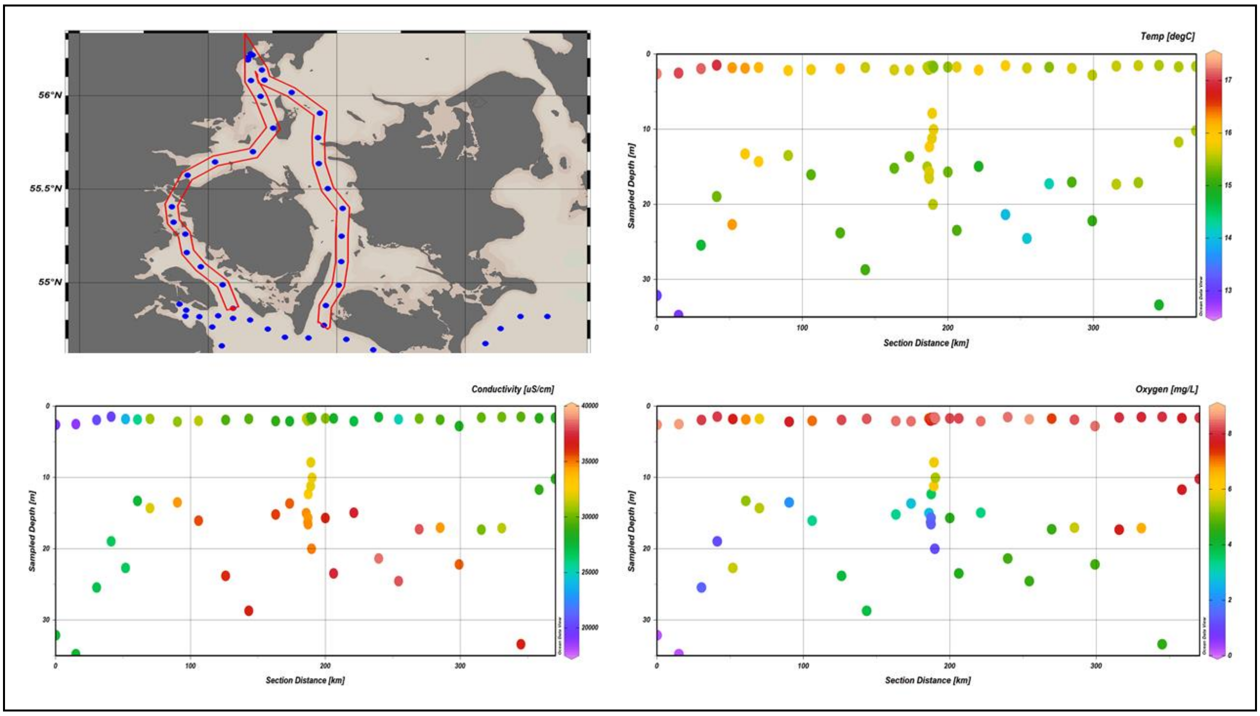

Fig. 5.3 Vertical profiles of Temperature, oxygen and conductivity for the Kiel - Aarhus Bay - Great Belt section of the AL603 cruise track.

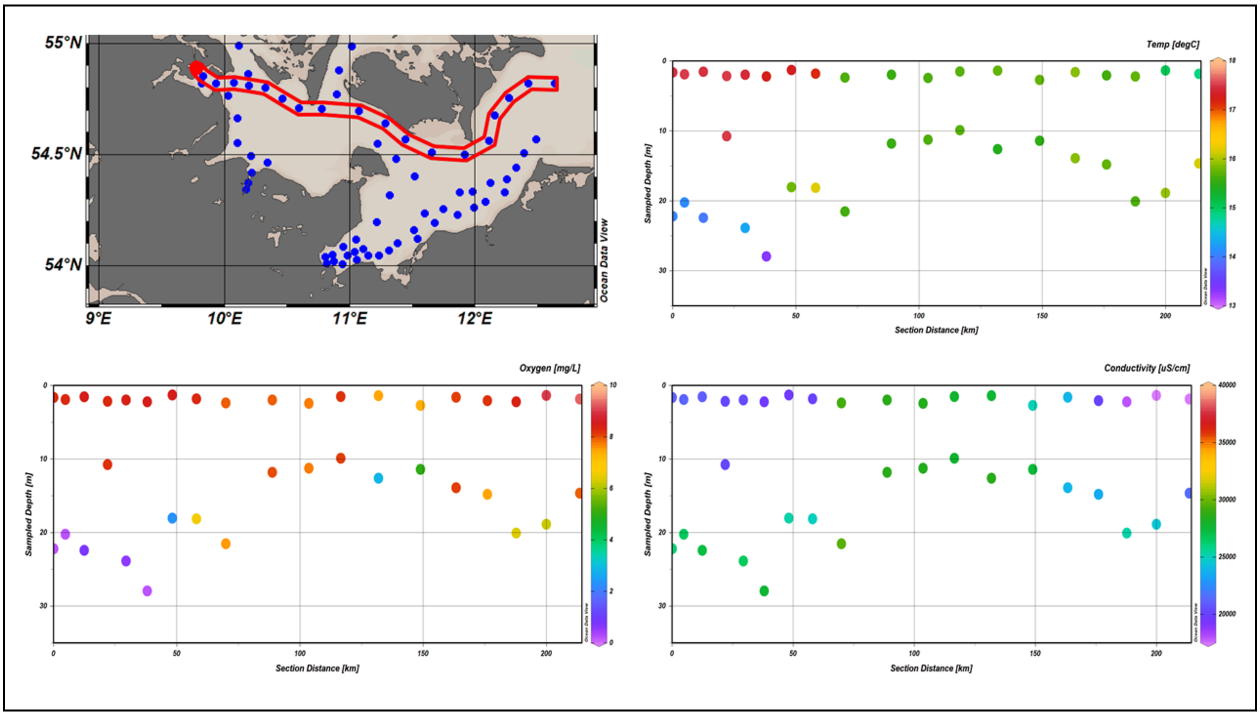

Fig. 5.4 Vertical profiles of temperature, oxygen and conductivity for the Flensborg Fjord - Arkona-Basin section of the AL603 cruise track (West-East transect of the southern Danish Waters of the Baltic Sea).

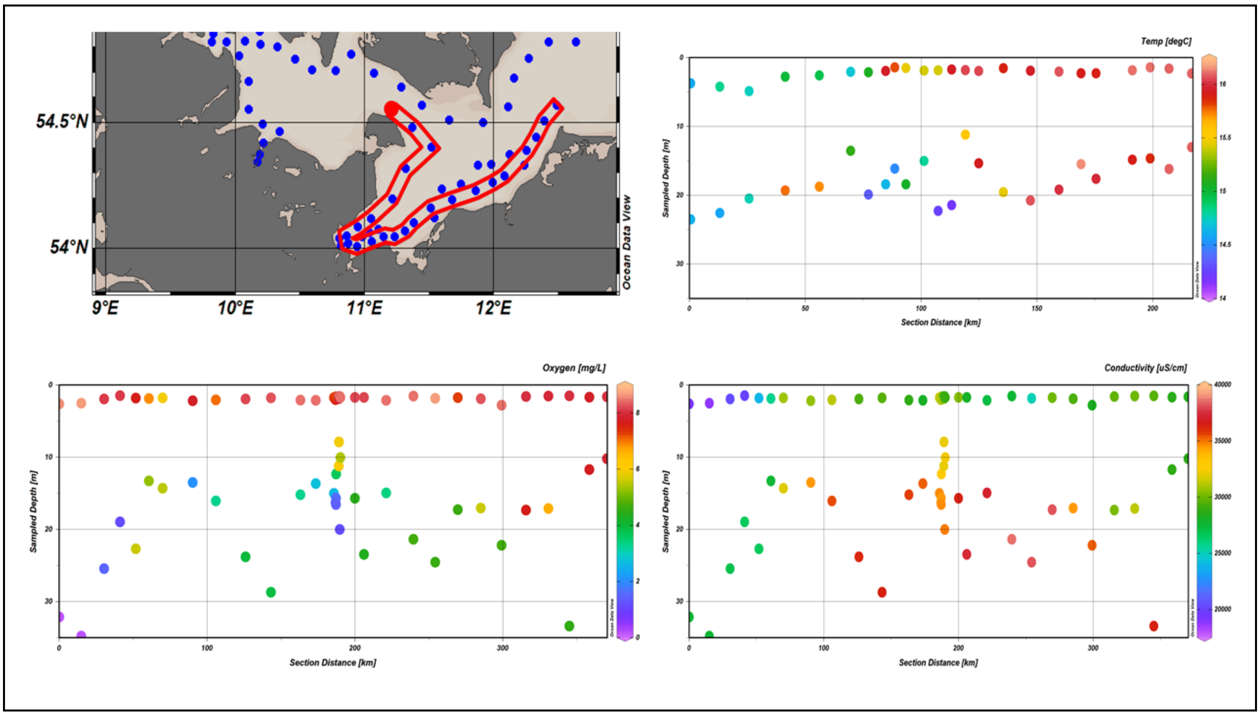

Fig. 5.5 Vertical profiles of temperature, oxygen and conductivity the Lübeck Bay section of the AL603 cruise track.

Measurements with the Explotector

Detectable levels of TNT were measured in 48 of the samples (62%), and spatial trends showed a few localized hotspots (Fig. 5.5). Concentrations were low throughout the sampled region, with a maximum of 1.25 ng/L measured at a station near Rostock. Other hotspots were Aarhus Bay (TNT concentrations up to 1.23 ng/L) and Jammerland Bugt (up to 0.94 ng/L). Other explosive compounds were below detection limits.

This is the first time TNT concentrations have been mapped in this region. The measured levels are generally lower than found in German coastal waters, which typically range between 1 and 25 ng/L. The results indicate either limited release of chemicals from underwater munitions or rapid mixing and dilution, especially in the area of saline deepwater inflow from the North Sea. A few surface water samples from the low salinity layer were also tested for TNT, but nothing was detected. Concentrations measured during AL603 were approximately six orders of magnitude lower than the threshold at which biological toxic effects would be likely.

The first field tests of the CMS mass spectrometer were an unqualified success. The system proved stable and robust, even during poor weather (winds up to 9 Bft and waves >2 m). Although many samples had TNT concentrations near the CMS detection limit, they were nonetheless possible to detect. Nothing was detected with the less-sensitive MiD instrument. Future work will focus on improving the detection of other target compounds and expanding the analytical suite to include chemical warfare agents and other environmental contaminants.

5.2 Acoustic Seafloor Mapping via Ship Based Multibeam

(M. Kampmeier[1], J. Greinert[1])
[1]GEOMAR Helmholtz Center for Ocean Research Kiel

High-resolution mapping has been executed in the dumpsites Kolberger Heide and Lübeck Bay on previous cruises: POS530, L13-20, AL548, AL567, AL583 and AL590. The detailed description is not repeated here again.

The surveys were conducted with 120° swath width and included calibration lines for a patch test. The working areas are close to Aarhus and Jammerland (Denmark) and inside Lübeck Bay. Before each multibeam station a sound velocity profile was obtained using the Valeport Swift SVP Profiler.

During survey potential munition targets were annotated using the acquisition software. On a second processing PC the data were parallel postprocessed using Qimera. As the multibeam mounting plate in the moonpool needed to be moved up and down to attach/detach the AUV USBL, recalibration lines were run before/during every multibeam survey/station. The Qimera Patch Test Tool was used to correct for roll bias per area. SVP profiles were taken for every new survey. Data artifacts were removed manually in Qimera and the data exported as GeoTiffs. The size of the covered area is given in Table 5.1.

Preliminary results

Table 5.1 MBES Coverage per area.

Area	Coverage
Aarhus	2.7 km²
Jammerland Bay	1.3 km²
Lübeck Bay	6.1 km²

Aarhus

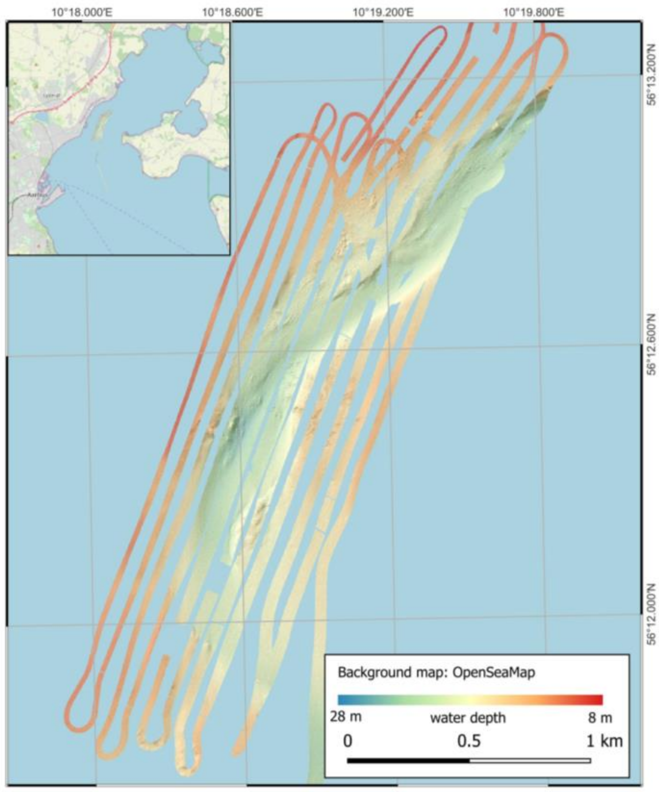

Fig. 5.6 Map of the mapped area in vicinity to Aarhus. The bathymetry ranges from 8 to 28 meters. Additional stations are indicated on the map.

The munition dumpsite north-east of Aarhus was mapped with the multibeam system, but due to time restrictions, it could not be mapped with full coverage. To gain a good overview of the area a profile spacing of 75 m was chosen. The water depth ranges from 8 to 28 meters and in the center of the mapped area is a shallow meandering channel located. The seafloor is composed of rather homogeneous sediment with some ripples in the northern part. Patches of stones are spread throughout the area and are often combined with the occurrence of small mounds or ridges. This might be an indicator for a geological origin. Stones and munitions from a certain size, cannot be easily distinguished in multibeam data and those indicators can help for a first assessment. It cannot be ruled out that some of the stone-like patches might contain munitions.

One XOFOS track was conducted above a suspicious structure, but the visibility was low and a few objects, which could be seen turned out be rocks covered with sessile fauna.

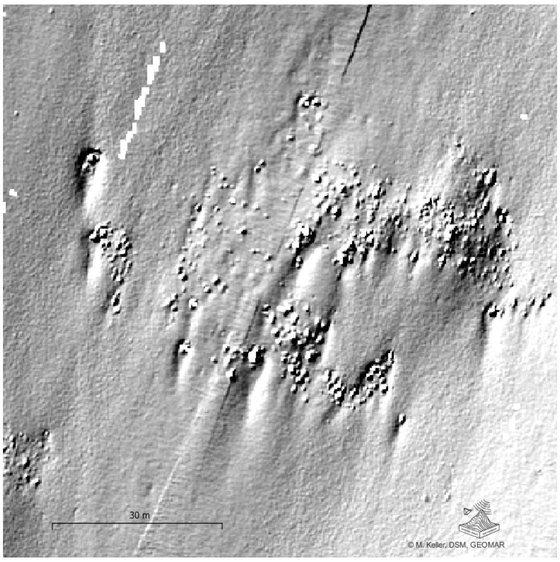

Fig. 5.7 Analytical hillshade from the bathymetry of the Aarhus munition dumpsite, showing objects on the seafloor, which cannot be clearly identified as stones or munitions.

Jammerland Bay

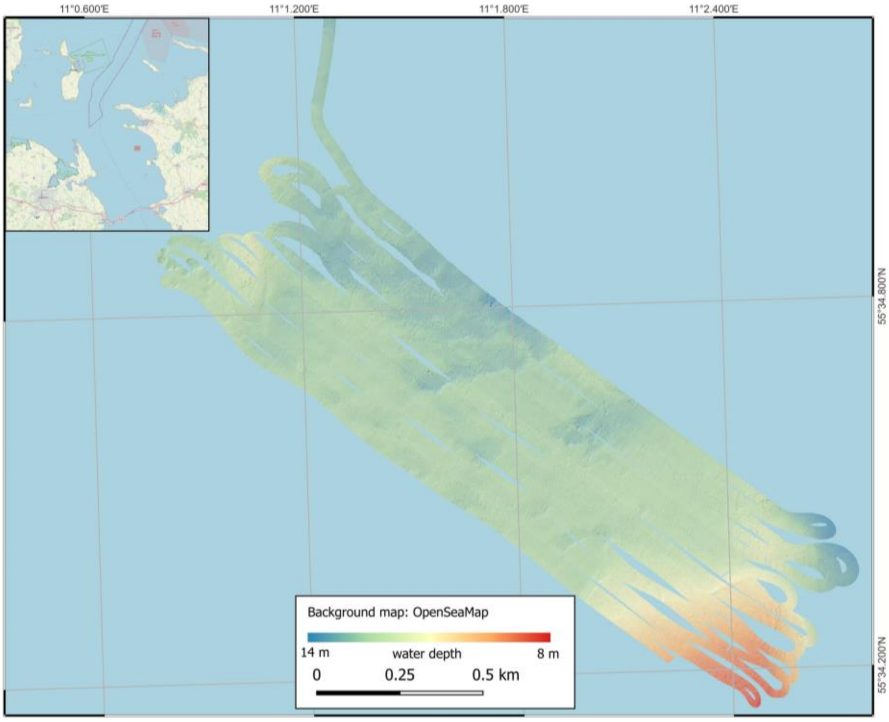

Fig. 5.8 Map of the mapped area in Jammerland Bay. The bathymetry ranges from 8 to 14 meters. Additional stations are indicated on the map.

In Jammerland Bay a profile spacing of 50 meters was chosen, in order to get some coverage, eventhough the overlap is not given for every water depth. The seafloor is mostly even and is characterized by pockmarks and larger-scale washouts (ca 50 m length) (Fig. 5.9 and Fig. 5.10). There are some patches with stones and four torpedo-shaped objects (6 m length) (Fig. 5.11). Ground-truthing via ROV and XOFOS revealed that these objects were tree trunks. Craters from previous detonations were not found.

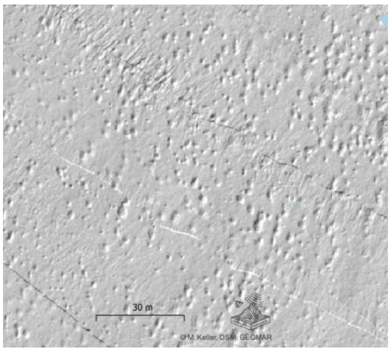

Fig. 5.9 Analytical hillshade from the bathymetry of the Jammerland Bay, showing pockmarks on the seafloor.

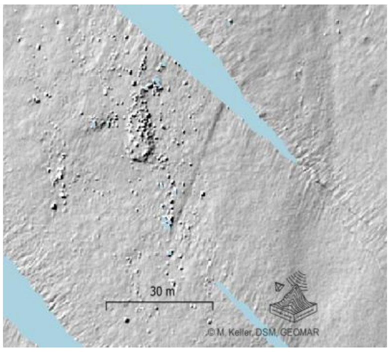

Fig. 5.10 Analytical hillshade from the bathymetry of the Jammerland Bay, showing a patch of stones on the seafloor.

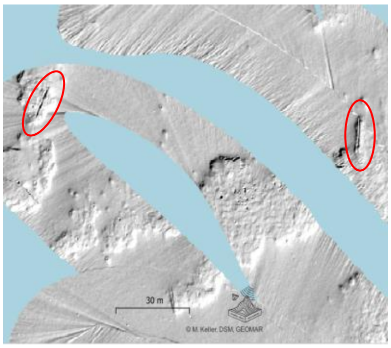

Fig. 5.11 Analytical hillshade from the bathymetry of the Jammerland Bay, showing two tree trunks (red circles) on the seafloor.

Lübeck Bay:

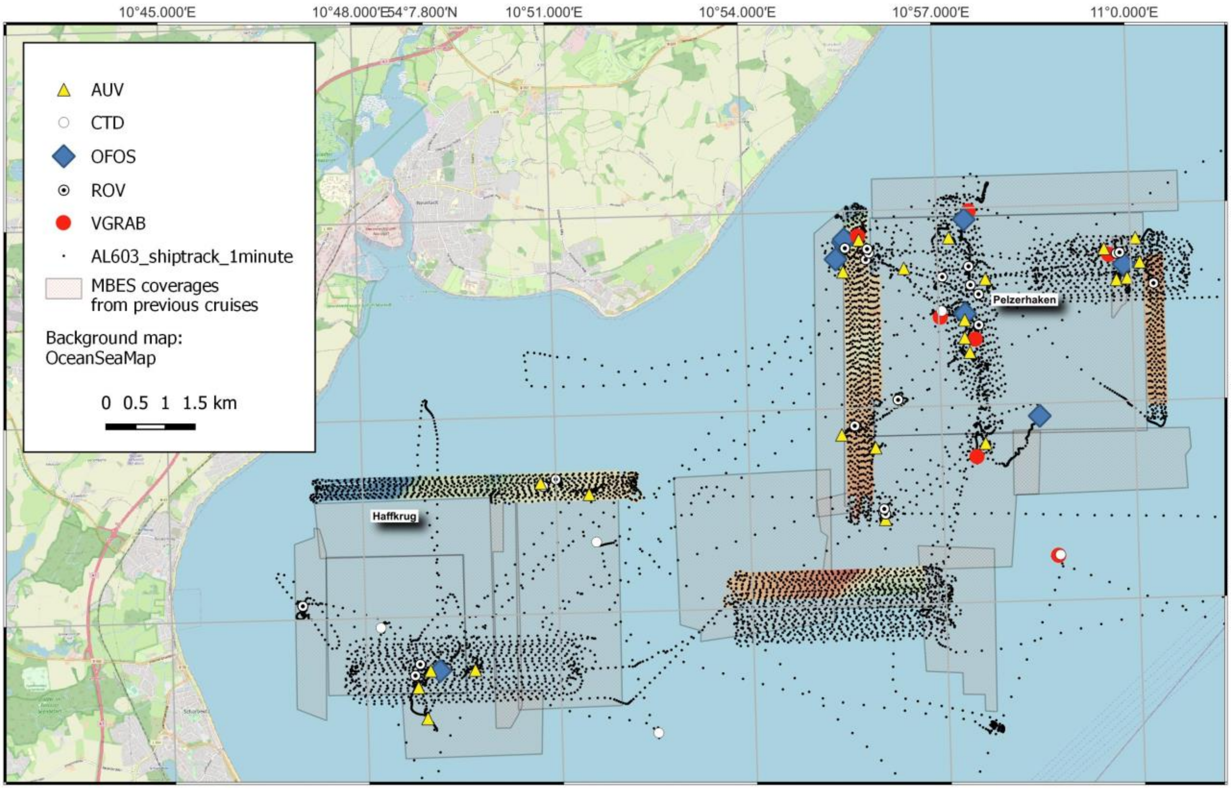

Fig. 5.12 Map of Lübeck Bay with the extent of MBES coverages from previous cruises and MBES bathymetry from AL603. Main work has been done in Pelzerhaken with numerous AUV and ROV stations.

In Lübeck Bay the munition dumpsites of Haffkrug and Pelzerhaken the MBES mapping from previous cruises was extended. New munition contacts could be detected and in the east of Pelzerhaken, two new sediment dumpings were found. Their diameters are 100 and 200 m and they extent up to 3 m above the seafloor (Fig. 5.13). Older MBES data show no munitions contacts in this area, so it must be assumed that no munitions have been covered by the sediment dumping in recent times.

Fig. 5.13 Bathymetry data of the eastern part of the Pelzerhaken dumpsite. In this area, sediment is still dumped onto the seafloor.

Only a few possible contacts were indicated in Haffkrug, but the fact that there are a number of marks on the seabed from boat anchors suggests that the dump does not extend further north.

5.3 Sidescan Sonar Mapping

(M. Kampmeier[1], J. Greinert[1])
[1]GEOMAR Helmholtz Center for Ocean Research Kiel

A towed sidescan sonar (scanfish Edgetech 4200) from the Alfred Wegner Institute (AWI) was used to map the dumpsites in Lübeck Bay. The seafloor was scanned with high and low frequency in ca 10 m altitude and range was set to 60 m to each side. Data recording was done by the Edgetech discover software and processed in SonarWiz. During post-processing *.XTF files for high and low frequency were added in SonarWiz for bottom-tracking and layback-correction. For heading the ship's course made good (CMG) was applied and an EGN gain filter for each frequency calculated. Mosaics were exported as geotiff tiles (CRS: UTM 32).

The high resolution provides more details of object shape and therefore improves the identification of munition contacts (Fig. 5.14). In Haffkrug a number of munition boxes were identified, which was not possible based on the MBES data.

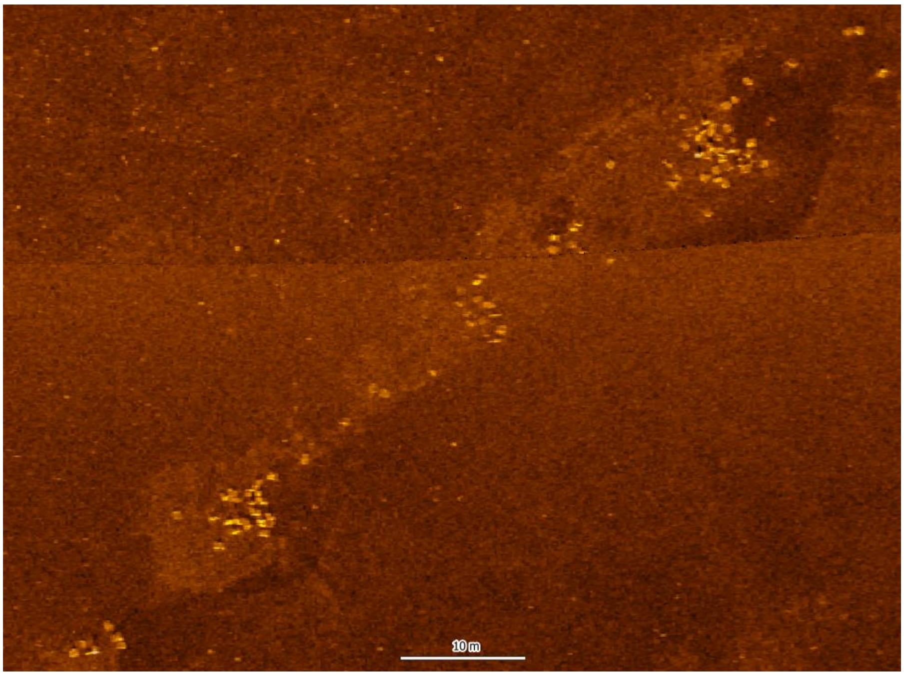

Fig. 5.14 Sidescan Sonar image of a pile composed of munition boxes in Haffkrug. It is possible to see the square shape of the objects and identify them as boxes.

5.4 AUV Mapping

(N. Diller[1], D. Scheppukat[1], L. Gerhardus[1])
[1]GEOMAR Helmholtz Center for Ocean Research Kiel

Description IQUA Robotics AUVs

ANTON and KALLE are configurable autonomous underwater vehicles (AUVs) of the type Girona500/Girona1000 by IQUA Robotics. The general structure of the Girona1000 is very similar to the Girona500, but several improvements have been made to allow missions with depths of up to 1000 m instead of 500 m. Both types comprise of three torpedo-shaped hulls with 0.3 m in diameter and 1.5 m in length, are hold together by an aluminum frame, provide a good hydrodynamic performance and offer sufficient space for five thrusters, an advanced integrated navigation system, several means for communication and sensor payloads. The overall dimensions of these vehicles are 1 m in height, 1 m in width, 1.5 m in length and a weight of less than 200kg. The two upper hulls, which contain most of the buoyancy foam and the electronics housing, are positively buoyant, while the lower one contains heavier elements such as the batteries and the payload. This particular arrangement of the components makes the separation between the centre of gravity and the centre of buoyancy about 11 cm, which is significantly more than any typical torpedo shape design. This provides passive stability in pitch and roll even at low speeds, making it suitable for imaging surveys. Another advantage of the Girona500/Girona1000 is its capability to be easily reconfigurable for different tasks.

The COLA2 infrastructure on the Girona500 AUVs is the central control software, developed by IQUA Robotics (Girona, Spain). In case of ANTON, the communication under and above water is controlled by BELUGA, developed by the GEOMAR AUV group. For KALLE, the original communication module was used, as the AUV arrived at GEOMAR just before the cruise.

In addition to the navigational sensors like INS (Inertial Navigation System), DVL (Doppler Velocity Log), Pressure Sensor, USBL and GPS, a CTD (Conductivity, Temperature, Depth) type Seabird FastCAT SBE49 is mounted by default.

An overview of all components for navigation and optional payload can be found in Table 5.2.

Table 5.2 Overview of components for navigation and optional payload.

System	Device	Description
Navigation	INS: iXblue Phins Compact C3	The internal navigation unit that processes sensor data and provides position information. The error of this INS is in range of 0.15° for heading and 0.05° for roll and pitch. This leads to a 0.3% position accuracy
	DVL: Teledyne RDI Explorer 600 kHz (ANTON)	The device measures the velocity relative to the sea floor and its altitude.
	DVL: Teledyne Tasman 300 kHz (KALLE)	
	Pressure sensor: Valeport ultraP	The sensor measures the pressure and converts it to water depth.
	USBL: Evologics S2CR 18/34	The Evologics S2CR 18/34 modem combines underwater communications and positioning and enables the vehicle‘s integration into the BELUGA network.
	GPS: Quectel L86 GNSS (ANTON)	The GPS is used to determine the absolute position at the surface.
	GPS: U-Blox ZED-F9P (KALLE)	
	Sonar: Tritech Gemini 720im	Multibeam imaging sonar in a compact housing that has a depth rating of 750 m. Mounted forward-looking at the top edge of the AUV as a preparation of obstacle avoidance
Payload	Sea-Bird SBE 49 FastCAT	The device acquires the conductivity, temperature and pressure of the surrounding water and calculates the sound velocity.
	CoraMo mk II	CoraMo mk II camera is a down- or forward-looking camera

	Camera	system for photographic surveys, built by the AUV team of GEOMAR. It can take up to two images per second with a resolution of 12.34 MP. CoraMo supports connections for eight high power LEDs that are arranged in a ring around the camera.
	Norbit Wideband Multibeam Sonar WBMS	Compact wideband multibeam sonar for high resolution bathymetry. With a flexible swath coverage of 5 – 210° and 256 – 512 beams. The nominal operating frequency is 400 kHz (frequency agility 200 – 700 kHz) with an adaptive ping rate of up to 60 Hz.
	Fluorometer Seabird ECO FLNTURTD	Chlorophyll and turbidity sensor with 6000 m depth rating. Fluorescence is measured with an excitation wavelength of 470 nm, an emission wavelength of 695 nm and a typical range of 0 to 50 µg/l Chl. Turbidity is measured with a wavelength of 700 nm and a sensitivity of 0.013 NTU. The sample rate of up to 8 Hz is user selectable.
	Optode: Aanderaa Optode 4330	The device provides dissolved oxygen [µM], relative air saturation [%] and ambient temperature [°C], as well as the raw data the final sensor values are based on.
	Magnetometer: Sensys MX3D UW	The system consists of up to five single magnetometers connected to one data acquisition unit. Each magnetometer is sampling three dimensions with a rate of 200 Hz.
	Sidescan: Marine Sonic Arc Scout MKII	Sidescan Sonar with operating frequencies of 900 kHz, 80 m range with 10 cm along track resolution and 1800kHz, 25m range with 5 cm along track resolution.

Missions can have a duration of up to 9 hours and a total length of about 10 kilometres, depending on settings, payload and environmental conditions like currents and diving depth. The maximum speed is 1m/s while the minimum speed is not limited, even hovering at one point for an arbitrary amount of time is possible.

Table 5.3 Quality list of AUV data products.

AUV dives AL603

name	mosaic-DEM quality	area
Luise_321	good	Aarhus
Luise_322	good	Aarhus
Luise_323	good	Aarhus
Luise_324	bad	Aarhus
Luise_325	low	Aarhus
Luise_326	low	Jammerland
Luise_327	bad	Jammerland
Luise_328	bad	Jammerland
Anton_297	good	Haffkrug
Anton_298	bad	Haffkrug
Anton_299	bad	Haffkrug
Anton_300	bad	Haffkrug
Luise_334	bad	Haffkrug
Luise_335	good	Haffkrug

Anton_293	good	Pelzerhaken
Anton_294	low	Pelzerhaken
Anton_295	good	Pelzerhaken
Anton_296	good	Pelzerhaken
Anton_301	bad	Pelzerhaken
Anton_302	good	Pelzerhaken
Anton_303	bad	Pelzerhaken
Anton_304	good	Pelzerhaken
Anton_305	bad	Pelzerhaken
Luise_329	bad	Pelzerhaken
Luise_330	bad	Pelzerhaken
Luise_331	good	Pelzerhaken
Luise_332	good	Pelzerhaken
Luise_333	good	Pelzerhaken
Luise_336	low	Pelzerhaken
Luise_337	good	Pelzerhaken
Luise_338	bad	Pelzerhaken
Luise_339	good	Pelzerhaken
Luise_340	good	Pelzerhaken

Because of low visibility underwater, 50 % of the photo mosaics and DEMs failed and are not usable.

In Aarhus the photomosaics revealed possible objects to be stones with sessile ascidiae on top.

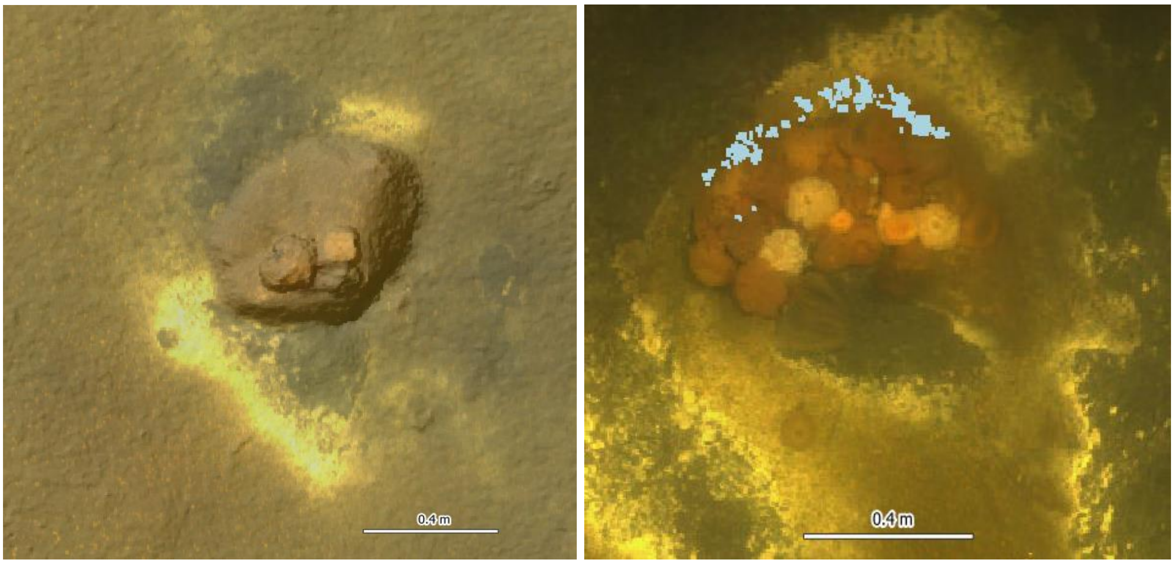

Fig. 5.15 Two examples of stones on the seafloor in the munition dumpsite of Aarhus. Photomosaics were done with AUV-based imagery and show stones that are covered with sessile organisms (ascidiae).

5.5 Optical Observations by Towed XOFOS

(G. Nolte[1], T. Weiß[1], J. Greinert[1], M. Kampmeier[1])
[1]GEOMAR Helmholtz Center for Ocean Research Kiel

The XOFOS (eXtended Ocean Floor Observation System) was used to perform video observations of the seafloor with real-time annotation using the OFOP software. Live data is streamed through the mobile fibre optic winch from GEOMAR. The video was recorded online in HD quality for online annotation and control. In addition to the USBL, a downward-facing ADCP enhanced the positioning, which was calculated and recorded via OFOP.

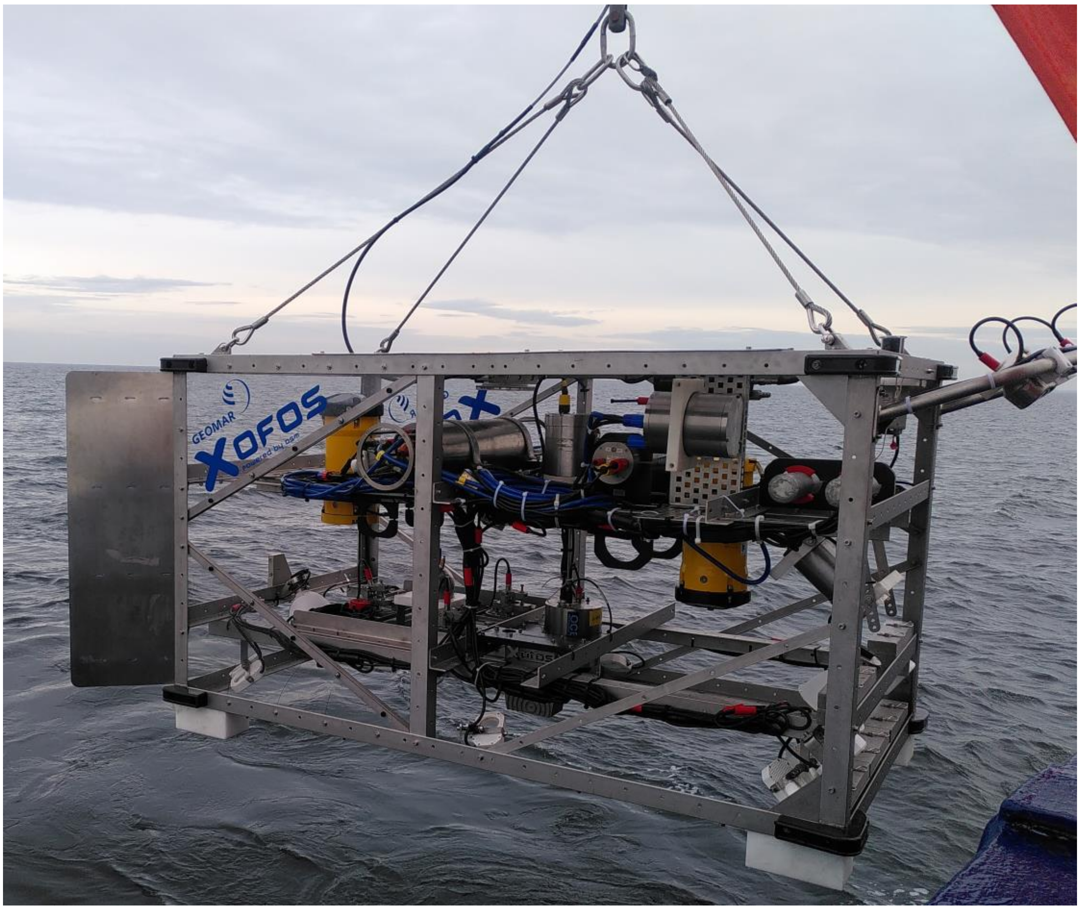

Fig. 5.16 The video sledge XOFOS is equipped with two HD video cameras, one still camera, two ADCPs, an IMU, a CTD, USBL and LED lights. It is towed behind the vessel over the A-frame and data is online recorded over the fibre optical cable of the mobile GEOMAR winch.

5.6 Linking Sea Water Inherent Optical Properties With Visual Image Appearance

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We made optical measurements in combination with images of color calibration boards to quantify the effect that inherent optical properties of the water have on the appearance of images. This analysis serves as validation of theoretical image formation models that we use in marine photogrammetry and computer vision in two aspects: a) to generate physically sound simulations of underwater images (visual digital twins) as training data in neural networks or evaluation references; b) to invert water effects on images for contrast enhancement, removal of artificial light effects and restoration of true color.

Both is used as foundation to develop more robust computer vision applications designed for the requirements of open waters.

The optics of water in a specific place and time are described by its light absorption and scattering spectra in combination with its volume scattering function (VSF).

A WetLabs AC-S was deployed to measure attenuation and absorption. Scattering can be concluded from their difference. The volume scattering function was measured with two redundant Sea-Bird ECO-VSF Sensors. However, the principle of accurately measuring VSFs is technically very complex. The applied sensors use estimation techniques based on multiple strong assumptions by Sullivan et. al. (2005). Whether their results give acceptable accuracy is a question that has to be evaluated in post-processing.

Fig. 5.17 ECO-VSFs mounted to XOFOS such that the sensors optical path is not obstructed by the frame.

Table 5.4 Deployed devices with most important specifications (more details in referenced manuals).

Device	Parameter	Output Unit	Sampling Rate	Resolution	Description
WetLabs AC-S (Sea-Bird Scientific, 2023)	Attenuation Absorption	1/m	4 Hz	Spectral: 83 wavelength between ~ 400 nm and 780 nm	Two seperate dark tubes filled with sea water and sensor/detector on the ends cite manual
Sea-Bird ECO-VSF (Wet Labs, 2007)	Volume Scattering	ADC Counts	1 Hz	12 bit	Small band light source and 3 detectors in different orientations
O.I.S. Camera System (Bornhöft, 2018) (Nikon Corporation, 2015)	Image	-	1/6 Hz	Spatial: 6000x4000 px Color: 12 bit oder 14 bit	Ocean Imaging System, illuminated with two flashes
Sea-Bird DH4 (Sea-Bird Scientific, 2006)	-	-	-	-	Data handler to store data and control devices 8 min device deployment delay after power on

The Ocean Imaging Camera System (OIS) was used to make images from a set of three color calibration boards designed for water color and lighting analysis. Three squared boards of increasing size are placed in a pyramid with 0.5 difference between each other and 0.5 m below the XOFOS frame. See Fig. 5.18.

They consist of four large black and white segments. White color gives insight in attenuation of the whole visual light spectrum since it reflects all wavelength. However, observations of additional known colors are required to overcome ambiguities in infering water properties from those images. Black color has the lowest reflection. Therefore, it is chosen as second color to have only a minimal amount of confounding light that is scattered onto the neighbouring white surface.

In the boards corners are Aruco markers so that the exact position of each board with respect to the camera can be determined. This will allow to compose a dublicate view of each board image in a computer graphics engine (e.g. Mitsuba, Blender…) that is without water. With this reference images the effect of water can be clearly separeted from the object (board) color, which is usually not possible for underwater images.

Fig. 5.18 Three color calibration boards are attached in the center of the XOFOS. They visualize light absorption and scattering.

5.7 Optical Groundtruth via ROV

(G. Nolte[1], T. Weiß[1])
[1]GEOMAR Helmholtz Center for Ocean Research Kiel

BlueROV – Käpt'n Blaubär

During the AL603, a BlueROV2 modified by GEOMAR was deployed. The mini-ROV bears the name Käpt`n Blaubär and is used for reconnaissance and monitoring purposes.

Prior to the AL603, several modifications were made to the ROV, which can dive up to 300 metres, which were tested and used during the expedition:

A water sampling system was connected to the underside of the ROV, which is able to take four 500ml water samples. Relays can be switched via the remote control so that each sample bottle can be closed in a targeted manner.

The battery system has been modified and tested for the first time on the AL603 to enable the batteries to be changed more quickly between dives. It now consists of three separate pressure tubes, each with a battery, which no longer need to be opened every time the battery is changed or charged. The pressure tubes now also have an additional 24 V output, which is required for the Evelogics USBL transponder. In addition, the pressure tubes now have a charging connection.

The handling, the voltage and charging infrastructure in general and the plug connections (which have to withstand high currents) were tested.

The ROV was also used to successfully recover a mooring that was deployed in July 2023. The difficulty here was that there was only a loop under tension on the mooring to which a rope had to be attached. The ROV was equipped with an approx. 40 cm long PE rod to which a ‘jolly hooker’ was attached. This was positioned at the height of the camera so that the jolly hook could be guided precisely through the loop and the mooring recovered.

During the AL603, 20 dives were successfully completed with the BlueROV2.

Fig. 5.19 BlueROV2 with mounted "Jolly Hook".

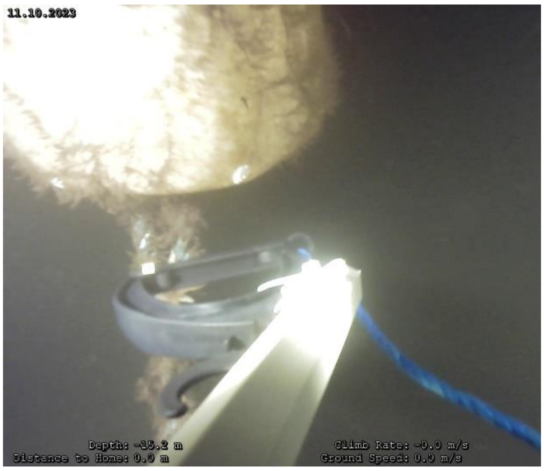

Fig. 5.20 Camera image shortly before threading.

PIVOT ROV -Deep Trekker

In addition to the Blue ROV, another mini-ROV was used for reconnaissance and testing purposes during the AL603 journey. This was the PIVOT ROV from Deep Trekker. The ROV has a maximum diving depth of 300 metres. Communication with the vehicle takes place with the aid of a remote control via a data cable (length = 300 metres). An X150 USBL from SeaTrac was used for navigation, which was installed in the Alkor's moonpool. There is an X010 SeaTrac beacon on the ROV, which responds to the acoustic position requests from the USBL. This enables the ROV to be positioned relative to the USBL transmitter head. Absolute positions can be calculated in the lat-long coordinate system using the USBL software supplied. It is also possible to distribute the position data in the network.

The ROV also has a DVL (Doppler Velocity Log). This allows the speed over ground to be estimated and improves local navigation. It also enables the ROV to operate in hover mode. The ROV remains stationary in this mode. This has proven to be very helpful when observing munition objects. Especially in strong currents. The ROV's camera is installed in the upper front area and has HD resolution. It is possible to change the angle of inclination.

During the AL603 journey, various aspects of the ROV's deployment were of interest. On the one hand, the aim was to realize the missions with the help of the existing data workflows and infrastructure. The DSM working group uses the OFOP annotation software to document ROV dives. It was therefore essential to transfer and process the navigation data to OFOP in the correct format. The workflow and all settings in the PinPoint app of SeaTrac and in OFOP were documented in a manual.

Furthermore, the system was compared with the BlueROV in operational use. The focus here was on the more powerful thrusters, the DVL and the more powerful battery system. The system was also presented during a visit by the German Federal Police.

A total of 10 dives were made during the cruise.

Fig. 5.21 The Deep Trekker ROV on board of the RV ALKOR.

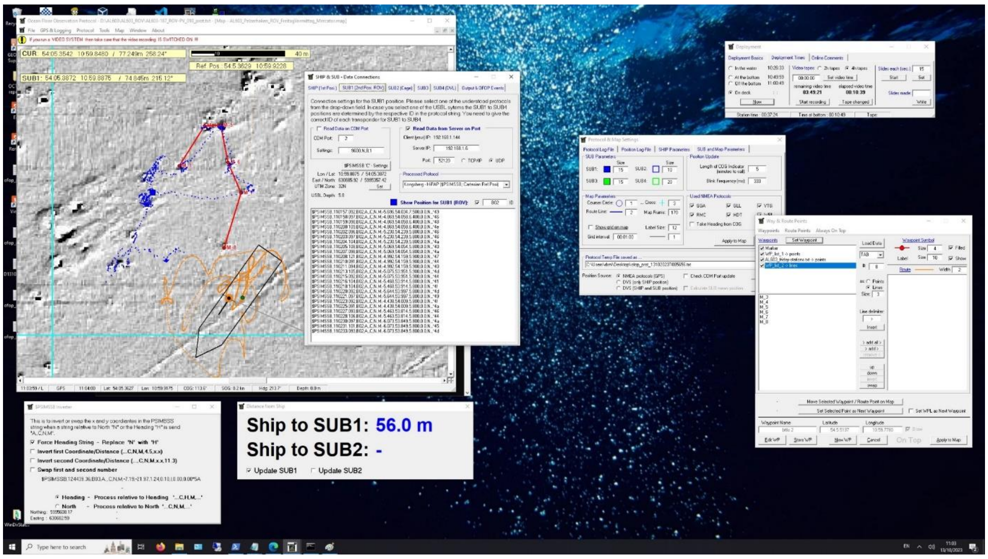

Fig. 5.22 An overview during a PIVOT ROV mission in the OFOP software. The ROV positions are shown in blue. The ship is shown in orange. A planned track is shown in red.

6 Data and Sample Storage and Availability

Seafloor mapping data (multibeam, photographs, magnetic and GIS projects) are stored on GEOMAR servers with access control and are only available to project internal staff. Munition findings will be reported to corresponding authorities (EOD squads and the Navy underwater data centre in Rostock). Data will be provided to project members if required. Data including navigation data from munition findings will not be made publicly available. Position data from munition locations will not be uploaded onto the GEOMAR data management server OSIS. Access to such sensitive data is restricted. Bathymetric data from within Danish waters will be made available to the Danish agencies. All data, which do not contain any sensitive munition data will be uploaded to the data archive PANGEA.

7 Stationlist AL603

7.1 Overall Station List

Due to data sensitivity, the positions accuracy has been decreased to 100 m.

Station	Event Time	Action	Latitude (deg)	Longitude (deg)
AL603_0_TSG_start	10/3/2023 6:27	profile start	54.344	10.170
AL603_0_TSG_end	10/15/2023 19:27	profile end	54.360	10.165
AL603_1_CTD-001_a	10/3/2023 6:34	in the water	54.344	10.169
AL603_1_CTD-001_b	10/3/2023 6:17	in the water	54.345	10.171
AL603_2_CTD-002	10/3/2023 7:03	in the water	54.371	10.188
AL603_3_CTD-003	10/3/2023 7:38	in the water	54.417	10.221
AL603_4_CTD-004	10/3/2023 8:23	in the water	54.492	10.213
AL603_5_VGRAB-01	10/3/2023 9:19	in the water	54.553	10.105
AL603_5_CTD-005	10/3/2023 9:12	in the water	54.553	10.105
AL603_6_CTD-006	10/3/2023 10:10	in the water	54.662	10.105
AL603_7_XOFOS-01	10/3/2023 11:26	in the water	54.741	10.029
AL603_8_XOFOS-02	10/3/2023 12:10	in the water	54.740	10.032
AL603_9_XOFOS-03	10/3/2023 13:24	in the water	54.732	10.055
AL603_10_ROV_BlueROV-001	10/3/2023 14:47	in the water	54.733	10.045
AL603_11_ROV_BlueROV-002	10/3/2023 15:45	in the water	54.732	10.049
AL603_12_VGRAB-02	10/3/2023 17:04	in the water	54.764	10.033
AL603_12_CTD-007	10/3/2023 16:54	in the water	54.763	10.032
AL603_13_CTD-008	10/3/2023 17:48	in the water	54.818	9.931
AL603_14_VGRAB-03	10/3/2023 18:40	in the water	54.819	9.821
AL603_14_CTD-009	10/3/2023 18:32	in the water	54.820	9.821
AL603_15_CTD-010	10/3/2023 19:22	in the water	54.885	9.775
AL603_16_CTD-011	10/3/2023 19:54	in the water	54.853	9.828
AL603_17_CTD-012	10/3/2023 21:10	in the water	54.823	10.078
AL603_18_VGRAB-04	10/3/2023 21:53	in the water	54.809	10.194
AL603_18_CTD-013	10/3/2023 21:47	in the water	54.809	10.194
AL603_19_CTD-014	10/3/2023 23:18	in the water	54.752	10.463
AL603_20_CTD-015	10/4/2023 0:06	in the water	54.708	10.596
AL603_21_VGRAB-05	10/4/2023 0:10	in the water	54.707	10.598

AL603_22_CTD-016	10/4/2023 1:35	in the water	54.800	10.327
AL603_23_CTD-017	10/4/2023 2:25	in the water	54.863	10.192
AL603_24_CTD-018	10/4/2023 3:31	in the water	54.989	10.113
AL603_25_VGRAB-06	10/4/2023 4:41	in the water	55.085	9.943
AL603_25_CTD-019	10/4/2023 4:35	in the water	55.085	9.943
AL603_26_CTD-020	10/4/2023 5:32	in the water	55.161	9.834
AL603_27_AUV-LUISE_mission-test	10/4/2023 6:46	in the water	55.183	9.844
AL603_27_AUV-ANTON_mission-test	10/4/2023 6:10	in the water	55.183	9.842
AL603_28_XOFOS-04	10/4/2023 7:11	in the water	55.183	9.843
AL603_29_MBES-start	10/4/2023 8:40	profile start	55.183	9.844
AL603_29_MBES-end	10/4/2023 9:41	profile end	55.181	9.843
AL603_29_MBES	10/4/2023 8:26	in the water	55.184	9.836
AL603_30_CTD-021	10/4/2023 10:27	in the water	55.260	9.821
AL603_31_CTD-022	10/4/2023 11:42	in the water	55.323	9.731
AL603_32_CTD-023	10/4/2023 12:32	in the water	55.406	9.718
AL603_33_VGRAB-07	10/4/2023 12:38	in the water	55.406	9.718
AL603_34_CTD-024	10/4/2023 14:28	in the water	55.574	9.840
AL603_35_XOFOS-05	10/4/2023 14:39	in the water	55.573	9.839
AL603_36_CTD-025	10/4/2023 16:09	in the water	55.645	10.054
AL603_37_VGRAB-08	10/4/2023 17:23	in the water	55.700	10.347
AL603_37_CTD-026	10/4/2023 17:17	in the water	55.700	10.348
AL603_38_CTD-027	10/4/2023 18:34	in the water	55.826	10.505
AL603_39_CTD-028	10/4/2023 20:16	in the water	55.996	10.406
AL603_40_VGRAB-09	10/4/2023 21:08	in the water	56.080	10.332
AL603_40_CTD-029	10/4/2023 21:02	in the water	56.081	10.332
AL603_41_MBES-end	10/5/2023 5:02	profile end	56.218	10.318
AL603_41_MBES-start	10/4/2023 23:06	profile start	56.196	10.315
AL603_42_AUV-LUISE_mission-321	10/5/2023 6:30	in the water	56.198	10.309
AL603_43_ROV_BlueROV-003	10/5/2023 7:49	in the water	56.196	10.306
AL603_44_CTD-030	10/5/2023 10:13	in the water	56.203	10.306
AL603_45_CTD-031	10/5/2023 10:28	in the water	56.200	10.311
AL603_46_CTD-032	10/5/2023 10:38	in the water	56.202	10.311
AL603_47_CTD-033	10/5/2023 10:44	in the water	56.203	10.307
AL603_48_VGRAB-10	10/5/2023 10:58	in the water	56.200	10.312
AL603_49_VGRAB-11	10/5/2023 11:05	in the water	56.202	10.309
AL603_50_VGRAB-12	10/5/2023 11:14	in the water	56.202	10.306
AL603_51_VGRAB-13	10/5/2023 11:20	in the water	56.203	10.306
AL603_52_AUV-LUISE_mission-322	10/5/2023 11:48	in the water	56.200	10.305
AL603_53_XOFOS-06	10/5/2023 13:29	in the water	56.203	10.305
AL603_54_CTD-034	10/5/2023 15:28	in the water	56.223	10.330
AL603_55_CTD-035	10/5/2023 15:48	in the water	56.220	10.334
AL603_56_CTD-036	10/5/2023 16:00	in the water	56.218	10.340
AL603_57_CTD-037	10/5/2023 16:19	in the water	56.216	10.346
AL603_58_CTD-038	10/5/2023 16:45	in the water	56.190	10.309
AL603_59_CTD-039	10/5/2023 17:25	in the water	56.136	10.418
AL603_60_CTD-040	10/5/2023 17:52	in the water	56.083	10.438
AL603_61_CTD-041	10/5/2023 18:54	in the water	56.018	10.650

AL603_62_CTD-042	10/5/2023 20:06	in the water	55.906	10.869
AL603_63_CTD-043	10/5/2023 21:09	in the water	55.775	10.854
AL603_64_CTD-044	10/5/2023 22:11	in the water	55.637	10.861
AL603_65_SVP-01	10/5/2023 23:01	in the water	55.591	11.021
AL603_66_MBES-start	10/5/2023 23:12	profile start	55.585	11.021
AL603_66_MBES-end	10/6/2023 5:10	profile end	55.570	11.038
AL603_67_XOFOS-07	10/6/2023 7:17	in the water	55.578	11.036
AL603_68_AUV-LUISE_mission-323	10/6/2023 7:46	in the water	55.575	11.032
AL603_69_ROV_BlueROV-004	10/6/2023 10:45	in the water	55.576	11.034
AL603_71_ROV_BlueROV-006	10/6/2023 12:34	in the water	55.581	11.016
AL603_72_VGRAB-14	10/6/2023 13:16	in the water	55.577	11.029
AL603_73_VGRAB-15	10/6/2023 14:16	in the water	55.503	10.931
AL603_73_CTD-045	10/6/2023 14:03	in the water	55.503	10.930
AL603_74_CTD-046	10/6/2023 15:10	in the water	55.396	11.045
AL603_75_CTD-047	10/6/2023 16:15	in the water	55.249	11.037
AL603_76_VGRAB-16	10/6/2023 17:28	in the water	55.112	11.034
AL603_76_CTD-048	10/6/2023 17:22	in the water	55.112	11.034
AL603_77_CTD-049	10/6/2023 18:22	in the water	54.986	11.015
AL603_78_CTD-050	10/6/2023 19:19	in the water	54.878	10.916
AL603_79_VGRAB-17	10/6/2023 20:16	in the water	54.771	10.899
AL603_79_CTD-051	10/6/2023 20:11	in the water	54.772	10.899
AL603_80_CTD-052	10/6/2023 21:04	in the water	54.704	10.780
AL603_81_CTD-053	10/6/2023 22:15	in the water	54.697	11.074
AL603_82_CTD-054	10/6/2023 23:08	in the water	54.641	11.283
AL603_83_CTD-055	10/6/2023 23:52	in the water	54.570	11.443
AL603_84_VGRAB-18	10/6/2023 23:58	in the water	54.568	11.443
AL603_85_CTD-056	10/7/2023 0:49	in the water	54.511	11.657
AL603_86_CTD-057	10/7/2023 1:45	in the water	54.498	11.920
AL603_87_VGRAB-19	10/7/2023 4:33	in the water	54.563	12.110
AL603_87_CTD-058	10/7/2023 4:26	in the water	54.563	12.110
AL603_88_CTD-059	10/7/2023 5:25	in the water	54.675	12.155
AL603_89_CTD-060	10/7/2023 6:10	in the water	54.754	12.273
AL603_90_CTD-061_a	10/7/2023 7:08	in the water	54.818	12.427
AL603_90_CTD-061_b	10/7/2023 7:03	in the water	54.819	12.428
AL603_91_VGRAB-20	10/7/2023 7:13	in the water	54.818	12.426
AL603_92_CTD-062	10/7/2023 8:10	in the water	54.819	12.638
AL603_93_XOFOS-08	10/7/2023 8:13	in the water	54.819	12.638
AL603_94_CTD-063	10/7/2023 10:43	in the water	54.570	12.489
AL603_95_CTD-064	10/7/2023 11:20	in the water	54.505	12.390
AL603_96_CTD-065	10/7/2023 11:53	in the water	54.442	12.328
AL603_97_XOFOS-11	10/7/2023 12:06	profile start	54.442	12.326
AL603_97_XOFOS-09	10/7/2023 12:02	in the water	54.442	12.326
AL603_98_CTD-066	10/7/2023 13:05	in the water	54.388	12.254
AL603_99_CTD-067	10/7/2023 13:39	in the water	54.328	12.239
AL603_100_VGRAB-21	10/7/2023 13:45	in the water	54.329	12.238
AL603_101_XOFOS-10	10/7/2023 13:56	in the water	54.328	12.235
AL603_102_CTD-068	10/7/2023 14:56	in the water	54.374	12.124

AL603_103_CTD-069	10/7/2023 15:34	in the water	54.287	12.083
AL603_104_VGRAB-22	10/7/2023 16:15	in the water	54.262	11.992
AL603_104_CTD-070	10/7/2023 16:10	in the water	54.263	11.992
AL603_105_CTD-071	10/7/2023 16:49	in the water	54.334	11.981
AL603_106_VGRAB-23	10/7/2023 17:28	in the water	54.331	11.877
AL603_106_CTD-072	10/7/2023 17:21	in the water	54.331	11.877
AL603_107_CTD-073	10/7/2023 18:15	in the water	54.227	11.860
AL603_108_CTD-074	10/7/2023 18:51	in the water	54.255	11.749
AL603_109_CTD-075	10/7/2023 19:28	in the water	54.192	11.680
AL603_110_CTD-076	10/7/2023 20:05	in the water	54.237	11.595
AL603_111_CTD-077	10/7/2023 20:54	in the water	54.160	11.510
AL603_112_VGRAB-24	10/7/2023 21:00	in the water	54.160	11.511
AL603_113_CTD-078	10/7/2023 21:25	in the water	54.120	11.542
AL603_114_CTD-079	10/7/2023 22:08	in the water	54.102	11.381
AL603_115_CTD-080	10/7/2023 22:37	in the water	54.070	11.312
AL603_116_CTD-081	10/7/2023 23:07	in the water	54.046	11.232
AL603_117_VGRAB-25	10/7/2023 23:11	in the water	54.045	11.230
AL603_118_SVP-02	10/8/2023 0:13	in the water	54.096	11.005
AL603_119_MBES	10/8/2023 5:20	profile end	54.069	11.008
AL603_119_MBES	10/8/2023 0:29	profile start	54.093	11.003
AL603_120_AUV-ANTON_mission-293	10/8/2023 6:27	in the water	54.096	10.953
AL603_121_AUV-LUISE_mission-324	10/8/2023 7:06	in the water	54.078	10.958
AL603_122_ROV_BlueROV-007	10/8/2023 10:53	in the water	54.090	10.951
AL603_123_ROV_BlueROV-008	10/8/2023 11:54	in the water	54.091	10.958
AL603_124_AUV-ANTON_mission-294	10/8/2023 12:55	in the water	54.083	10.957
AL603_125_AUV-LUISE_mission-325	10/8/2023 13:38	in the water	54.091	10.941
AL603_126_ROV_BlueROV-009	10/8/2023 14:11	in the water	54.087	10.960
AL603_127_MBES-start	10/8/2023 16:33	profile start	54.098	10.926
AL603_127_MBES-end	10/9/2023 5:40	profile end	54.071	10.934
AL603_127_SVP-03	10/8/2023 16:21	in the water	54.099	10.925
AL603_128_AUV-ANTON_mission-295	10/9/2023 6:23	in the water	54.095	11.001
AL603_129_AUV-LUISE_mission-326	10/9/2023 7:11	in the water	54.093	10.993
AL603_130_ROV_BlueROV-010	10/9/2023 7:40	in the water	54.088	11.006
AL603_131_ROV_BlueROV-011	10/9/2023 8:30	in the water	54.093	10.997
AL603_132_ROV_PivotROV-001	10/9/2023 12:41	in the water	54.093	10.932
AL603_132_ROV_PivotROV-002	10/9/2023 12:09	in the water	54.094	10.932
AL603_132_ROV_PivotROV-003	10/9/2023 11:22	in the water	54.094	10.932
AL603_133_AUV-ANTON_mission-296	10/9/2023 13:30	in the water	54.096	10.930
AL603_134_AUV-LUISE_mission-327	10/9/2023 13:52	in the water	54.091	10.926
AL603_135_ROV_PivotROV-004	10/9/2023 14:14	in the water	54.094	10.926
AL603_136_ROV_BlueROV-012	10/9/2023 16:12	in the water	54.055	10.935
AL603_138_MBES-start	10/9/2023 17:37	profile start	54.057	10.839
AL603_138_MBES-end	10/10/2023 6:08	profile end	54.061	10.867
AL603_139_AUV-ANTON_mission-297	10/10/2023 6:43	in the water	54.032	10.816
AL603_140_MBES	10/10/2023 8:25	profile end	54.032	10.812
AL603_140_MBES	10/10/2023 8:18	profile start	54.032	10.819
AL603_141_ROV_PivotROV-005	10/10/2023 8:48	in the water	54.033	10.814

AL603_142_AUV-LUISE_mission-328	10/10/2023 10:17	in the water	54.058	10.859
AL603_143_AUV-ANTON_mission-298	10/10/2023 10:48	in the water	54.060	10.846
AL603_144_ROV_BlueROV-013	10/10/2023 11:27	in the water	54.060	10.850
AL603_145_ROV_BlueROV-014	10/10/2023 12:26	in the water	54.059	10.847
AL603_146_XOFOS-11	10/10/2023 14:09	in the water	54.032	10.819
AL603_147_SSS-01-end	10/10/2023 22:45	profile end	54.072	10.961
AL603_147_SSS-01-end	10/10/2023 16:32	profile start	54.099	10.960
AL603_147_SSS-01	10/10/2023 16:08	in the water	54.103	10.963
AL603_148_SVP-04	10/10/2023 22:56	in the water	54.070	10.960
AL603_149_MBES-start	10/10/2023 23:23	profile start	54.046	10.944
AL603_149_MBES-end	10/11/2023 5:29	profile end	54.042	10.934
AL603_150_XOFOS-12	10/11/2023 6:14	in the water	54.084	10.957
AL603_151_AUV-ANTON_mission-299	10/11/2023 7:59	in the water	54.032	10.828
AL603_152_MBES-start	10/11/2023 7:56	profile start	54.032	10.828
AL603_152_MBES-end	10/11/2023 9:06	profile end	54.036	10.791
AL603_153_ROV_PivotROV-006	10/11/2023 9:51	in the water	54.042	10.784
AL603_154_AUV-LUISE_mission-329	10/11/2023 11:24	in the water	54.029	10.813
AL603_155_AUV-ANTON_mission-300	10/11/2023 13:41	in the water	54.025	10.815
AL603_156_CTD-082	10/11/2023 15:22	in the water	54.039	10.804
AL603_157_CTD-083	10/11/2023 15:52	in the water	54.011	10.816
AL603_158_ROV_BlueROV-015	10/11/2023 16:56	in the water	54.031	10.812
AL603_159_CTD-084	10/11/2023 17:33	in the water	54.021	10.875
AL603_160_CTD-085	10/11/2023 17:56	in the water	54.051	10.860
AL603_161_CTD-086	10/11/2023 18:37	in the water	54.008	10.943
AL603_162_VGRAB-26	10/11/2023 18:45	in the water	54.008	10.942
AL603_163_CTD-087	10/11/2023 19:16	in the water	54.047	10.980
AL603_164_VGRAB-27	10/11/2023 19:23	in the water	54.047	10.979
AL603_165_CTD-088	10/11/2023 19:57	in the water	54.028	11.058
AL603_166_CTD-089	10/11/2023 20:30	in the water	54.063	11.038
AL603_167_CTD-090	10/11/2023 21:04	in the water	54.045	11.145
AL603_168_CTD-091	10/11/2023 21:29	in the water	54.077	11.105
AL603_169_VGRAB-28	10/11/2023 21:35	in the water	54.076	11.106
AL603_170_SSS-02	10/11/2023 22:09	in the water	54.084	11.051
AL603_171_ROV_BlueROV-016	10/12/2023 6:13	in the water	54.067	10.928
AL603_172_AUV-LUISE_mission-330	10/12/2023 6:59	in the water	54.064	10.933
AL603_173_AUV-ANTON_mission-301	10/12/2023 7:35	in the water	54.066	10.924
AL603_174_ROV_PivotROV-007	10/12/2023 8:10	in the water	54.071	10.939
AL603_175_ROV_BlueROV-017	10/12/2023 10:28	in the water	54.054	10.935
AL603_178_AUV-ANTON_mission-302	10/12/2023 13:01	in the water	54.080	10.957
AL603_179_ROV_BlueROV-018	10/12/2023 13:51	in the water	54.088	10.958
AL603_180_ROV_PivotROV-009	10/12/2023 16:39	in the water	54.082	10.960
AL603_181_SVP-05	10/12/2023 17:45	in the water	54.039	10.944
AL603_182_MBES-start	10/12/2023 18:00	profile start	54.042	10.944
AL603_182_MBES-end	10/12/2023 18:16	profile end	54.042	10.920
AL603_183_SSS-03	10/12/2023 20:02	in the water	54.037	10.887
AL603_184_AUV-LUISE_mission-331	10/13/2023 7:49	in the water	54.089	10.962
AL603_185_AUV-ANTON_mission-303	10/13/2023 8:25	in the water	54.089	10.999

AL603_186_ROV_BlueROV-019	10/13/2023 8:56	in the water	54.092	10.996
AL603_188_XOFOS-13	10/13/2023 12:33	in the water	54.091	10.998
AL603_189_AUV-ANTON_mission-304	10/13/2023 13:18	in the water	54.088	10.996
AL603_190_AUV-LUISE_mission-332	10/13/2023 13:39	in the water	54.091	11.002
AL603_191_SSS-04	10/13/2023 16:32	in the water	54.092	10.936
AL603_192_AUV-ANTON_mission-305	10/14/2023 7:27	in the water	54.064	10.961
AL603_193_AUV-LUISE_mission-333	10/14/2023 7:55	in the water	54.053	10.935
AL603_194_SSS-05	10/14/2023 8:40	in the water	54.032	10.870
AL603_195_XOFOS-14	10/14/2023 12:17	in the water	54.068	10.975
AL603_196_XOFOS-15	10/14/2023 13:52	in the water	54.098	10.957
AL603_197_MBES-start	10/14/2023 16:37	profile start	54.042	10.943
AL603_197_MBES-end	10/15/2023 3:24	profile end	54.035	10.945
AL603_197_SVP-06	10/14/2023 16:09	in the water	54.042	10.951
AL603_198_ROV_BlueROV-020	10/15/2023 6:11	in the water	54.054	10.934
AL603_199_VGRAB-29	10/15/2023 6:49	in the water	54.062	10.959
AL603_200_VGRAB-30	10/15/2023 7:05	in the water	54.080	10.959
AL603_201_VGRAB-31	10/15/2023 7:35	in the water	54.092	10.994
AL603_202_VGRAB-32	10/15/2023 7:54	in the water	54.100	10.958
AL603_203_VGRAB-33	10/15/2023 8:09	in the water	54.096	10.930
AL603_204_XOFOS-16	10/15/2023 8:41	in the water	54.096	10.926
AL603_205_CTD-092	10/15/2023 9:46	in the water	54.084	10.951
AL603_206_VGRAB-34	10/15/2023 9:54	in the water	54.084	10.950
AL603_207_CTD-093	10/15/2023 10:24	in the water	54.118	11.053
AL603_208_CTD-094	10/15/2023 11:15	in the water	54.196	11.216
AL603_209_VGRAB-35	10/15/2023 12:13	in the water	54.316	11.317
AL603_209_CTD-095	10/15/2023 12:08	in the water	54.316	11.318
AL603_210_VGRAB-36	10/15/2023 13:17	in the water	54.402	11.516
AL603_210_CTD-096	10/15/2023 13:09	in the water	54.403	11.516
AL603_211_CTD-097	10/15/2023 14:15	in the water	54.481	11.373
AL603_212_CTD-098	10/15/2023 15:10	in the water	54.550	11.219
AL603_213_CTD-099	10/15/2023 18:30	in the water	54.465	10.344

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10 Appendices

Table 10.1 Sites for water sampling using the CTD-Niskin rosette during the AL603 cruise.

Device	Latitude (deg)	Longitude (deg)	Device	Latitude (deg)	Longitude (deg)
CTD1	54.34454	10.17111	**CTD51**	54.77162	10.89892
CTD2	54.37094	10.18761	**CTD52**	54.70421	10.77966
CTD3	54.41711	10.22082	**CTD53**	54.69694	11.07371
CTD4	54.49173	10.21306	**CTD54**	54.64078	11.28347
CTD5	54.55321	10.10523	**CTD55**	54.56965	11.443
CTD6	54.66219	10.10484	**CTD56**	54.51089	11.65673
CTD7	54.76294	10.03228	**CTD57**	54.49818	11.91979
CTD8	54.81809	9.930992	**CTD58**	54.56307	12.11037
CTD9	54.81988	9.821372	**CTD59**	54.6749	12.15538
CTD10	54.88465	9.775333	**CTD60**	54.7544	12.27333
CTD11	54.85337	9.828115	**CTD61**	54.81894	12.42775
CTD12	54.82336	10.07806	**CTD62**	54.81948	12.63827
CTD13	54.80855	10.19393	**CTD63**	54.5698	12.48938
CTD14	54.75195	10.46284	**CTD64**	54.50515	12.39032
CTD15	54.70807	10.59554	**CTD65**	54.44158	12.32839
CTD16	54.79994	10.32659	**CTD66**	54.38829	12.2539
CTD17	54.86291	10.19233	**CTD67**	54.32841	12.23901
CTD18	54.98929	10.1126	**CTD68**	54.37381	12.12358
CTD19	55.08521	9.943166	**CTD69**	54.28681	12.08349
CTD20	55.16138	9.833697	**CTD70**	54.26263	11.99226
CTD21	55.26007	9.821112	**CTD71**	54.33411	11.98104
CTD22	55.32257	9.731006	**CTD72**	54.33063	11.87745
CTD23	55.40596	9.718187	**CTD73**	54.22735	11.86009
CTD24	55.57379	9.839579	**CTD74**	54.25479	11.74904
CTD25	55.64516	10.05371	**CTD75**	54.19216	11.68002
CTD26	55.69999	10.34755	**CTD76**	54.23688	11.59547
CTD27	55.82624	10.50495	**CTD77**	54.16001	11.51014
CTD28	55.99563	10.40632	**CTD78**	54.12032	11.54241
CTD29	56.08052	10.33168	**CTD79**	54.10189	11.38052
CTD30	56.20337	10.30564	**CTD80**	54.06971	11.31243
CTD31	56.20042	10.31093	**CTD81**	54.04628	11.23153
CTD32	56.20207	10.31079	**CTD82**	54.03853	10.80391
CTD33	56.20257	10.3072	**CTD83**	54.0108	10.81646

CTD34	56.22251	10.32962		**CTD84**	54.02149	10.87486
CTD35	56.22038	10.33428		**CTD85**	54.05074	10.86008
CTD36	56.21822	10.34002		**CTD86**	54.00803	10.94252
CTD37	56.21625	10.34627		**CTD87**	54.04692	10.97975
CTD38	56.19001	10.30905		**CTD88**	54.02799	11.0578
CTD39	56.13635	10.4177		**CTD89**	54.06326	11.03773
CTD40	56.08295	10.43758		**CTD90**	54.04525	11.14546
CTD41	56.0175	10.64978		**CTD91**	54.07661	11.10545
CTD42	55.90591	10.86938		**CTD92**	54.08442	10.9508
CTD43	55.77459	10.85369		**CTD93**	54.11798	11.05308
CTD44	55.63698	10.86085		**CTD94**	54.19561	11.21598
CTD45	55.50305	10.93047		**CTD95**	54.316	11.31821
CTD46	55.39648	11.0455		**CTD96**	54.403	11.51579
CTD47	55.24885	11.03738		**CTD97**	54.48092	11.37256
CTD48	55.11206	11.0343		**CTD98**	54.55006	11.21929
CTD49	54.9862	11.01451		**CTD99**	54.46469	10.34408
CTD50	54.8777	10.91564				

Table 10.2 Sampling sites for water (using the XOFOS and ROV) and sediment during the AL603 cruise.

Device	**Latitude (deg)**	**Longitude (deg)**		**Device**	**Latitude (deg)**	**Longitude (deg)**
VGRAB1	54.55322	10.10537		VGRAB28	54.07599	11.10588
VGRAB2	54.76369	10.03285		VGRAB29	54.06218	10.95887
VGRAB3	54.81917	9.821019		VGRAB30	54.08003	10.95926
VGRAB4	54.80878	10.19449		VGRAB31	54.09235	10.9943
VGRAB5	54.70705	10.5975		VGRAB32	54.09954	10.95836
VGRAB6	55.08521	9.943049		VGRAB33	54.09616	10.92959
VGRAB7	55.40582	9.717877		VGRAB34	54.08351	10.95037
VGRAB8	55.69974	10.34745		VGRAB35	54.31571	11.31701
VGRAB9	56.07965	10.33158		VGRAB36	54.40249	11.51557
VGRAB10	56.20028	10.31188				
VGRAB11	56.20151	10.30877		**Device**	**Latitude (deg)**	**Longitude (deg)**
VGRAB12	56.20247	10.30646		OFOS1	56.20323	10.305
VGRAB13	56.20345	10.30622		OFOS2	54.03178	10.81888
VGRAB14	55.57729	11.02897		OFOS3	54.08394	10.95682
VGRAB15	55.50253	10.931		OFOS4	54.09079	10.99811
VGRAB16	55.11159	11.03447		OFOS5	55.57778	11.03594
VGRAB17	54.771	10.89924		OFOS6	54.09527	10.92575
VGRAB18	54.56765	11.44284				
VGRAB19	54.56273	12.11009		**Device**	**Latitude (deg)**	**Longitude (deg)**
VGRAB20	54.81782	12.42561		ROV1	55.57587	11.03388
VGRAB21	54.32858	12.23789		ROV2	55.57944	11.026
VGRAB22	54.26217	11.99186		ROV3	54.06042	10.84998
VGRAB23	54.33082	11.87726		ROV4	54.06734	10.92753
VGRAB24	54.15995	11.51092		ROV5	54.05383	10.93487

VGRAB25	54.04539	11.23045		ROV6	54.08827	10.95839
VGRAB26	54.00805	10.94207		ROV7	54.09247	10.9963
VGRAB27	54.04684	10.97923		ROV8	54.05403	10.93441