Tallinn University of
Technology

Seawater Turbidity Survey

Final report

Public procurement No. 244026

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TABLE OF CONTENTS

1. INTRODUCTION

The investigation into the wreck of M/S *Estonia* aims to identify the causes of the previously unknown damage to the ship. To this end, in order to perform the necessary theoretical calculations and carry out modelling, a 3D model of the ship will be created. Information on environmental parameters and the dynamics of seawater is required to successfully conduct primary marine surveys at this stage of the investigation. However, high seawater turbidity, i.e. poor underwater visibility, could constitute a major obstacle in carrying out the surveys.

The objective of this survey was to collect data on seawater turbidity and other environmental parameters both prior to the start of and during primary marine surveys. The contracting authority is the Estonian Safety Investigation Bureau (hereinafter 'contracting authority' or 'ESIB'). The specific terms of reference were as follows:

1) To measure seawater turbidity from the surface of the water down to, at minimum, four metres from the seabed, taking into account the space required for turning the equipment around. In order to obtain a complete picture of the turbidity of the water, the measurements must be taken at a frequency of 0.5 Hz, i.e. at least once every two seconds. At least two dives must be performed per hour;
2) To measure the oxygen content, temperature, and salinity of the seawater from the surface of the water down to, at minimum, four metres from the seabed at intervals of at least 1 hour;
3) To process, analyse, interpret, and visualise the collected data.

The measurements were conducted from 13 April to 1 June 2022, which also included the preliminary laser scanning survey period (23–27 May 2022). The data sent by the underwater glider via satellite links were forwarded to the contracting authority on an ongoing basis: once a week during the first period and once every two days shortly before and during the laser scanning survey. All measured data were stored on the internal memory card of the glider and downloaded during battery replacement and after the retrieval of the glider from the water. This report provides a brief overview of the measurements conducted, the results obtained and the data submitted to the contracting authority. The report includes all (quality-controlled) raw data and processed data which were interpolated to 0.5 dbar (*ca*. 0.5 m) interval depth profiles.

The work has been carried out in accordance with the public contract awarded by the Estonian Safety Investigation Bureau (public procurement reference number 244026) on 6 January 2022. The measurements, data analysis, and preparation of the report were carried out with the involvement of the experts Kai Salm, Taavi Liblik, Villu Kikas, Fred Buschmann, and Urmas Lips from the Department of Marine Systems of Tallinn University of Technology.

2. EQUIPMENT AND MEASUREMENTS

A shallow-water model of the Slocum G2 underwater glider from Teledyne Webb Research (glider *Mia*; Figure 2.1) with a maximum operating depth of 200 m, which is in use at the Tallinn University of Technology, was used as the measurement platform. The glider is an autonomous device that is able to move along a predefined trajectory and record seawater temperature, salinity, turbidity, oxygen concentration, and chlorophyll A and fluorescence profiles. The sampling frequency of the above parameters is 0.5 Hz (i.e., one sample per two seconds). The parameters given for the mission included the coordinates 59° 22.7655' N, 021° 40.7054' E for the profiling position of the glider with, as well as conditions for the glider to turn around before it gets 300 metres away from this point. As the glider has to surface in order to check its location, one measurement cycle was programmed to consist of three dives, after which the glider returned to the surface and transmitted the prescribed data and recorded its position.

For this experiment, the glider was delivered to the survey site on 13 April 2022, using the Transport Administration's hydrographic survey ship *Jakob Prei*.

On 2022 May 2022, a trip was scheduled to the survey area using the research vessel *Salme* of the Tallinn University of Technology to replace the glider's batteries and perform maintenance.

2. The parameters of the glider's mission remained the same as during its first launch on 13 April 2022. In order to control the quality of the glider's sensors, additional probing was carried out using two CTD probes: OS320plus (manufacturer: Idronaut S.r.l) and SBE19plus (manufacturer: Sea-Bird Scientific). Water samples were taken for laboratory analysis to determine the content of oxygen and suspended solids. For laser scanning, the location of the glider was moved south/southwest of the area of the wreck of M/S *Estonia,* the central coordinates of the survey area were 59° 22.5400' N, 021° 40.5000' E. The initial survey location was resumed on 28 May 2022. Vessel *VKC-346* of Tuukritööde OÜ was used to retrieve the glider after the end of the measurement period on 1 June 2022.

Figure 2.1. Glider *Mia* before the survey cycle at the location of the wreck of M/S *Estonia* on 13 April 2022.

The glider conducted measurements at the specified location in the area of the wreck of M/S *Estonia* within a 300 m radius (as an exception, the glider left the area only during the laser scanning survey when its location was moved south/southwest). By way of illustration, Figure 2.2 shows the surfacing points of the glider between
27. April 2022 and 5 May 2022. As an exception, on 6 May 2022, the glider drifted approximately 1 km northwest of the measurement location when it was ordered to remain on the surface for maintenance and battery replacement.

Vertical profiles were recorded up to a depth of 4 m from the bottom of the sea, i.e. at a maximum depth of 88 to 90 m. The diving cycles are illustrated by the graph in Figure 2.3, which shows the trajectories of the dives that took place on 9 and 10 May. To avoid collision with the sea bottom, the front of the glider is equipped with an altimeter that measures the altitude of the glider above the sea bottom. As the topography of the area is variable and the depth in the location of laser scanning was not as great, the glider recorded profiles during this period at a maximum depth of 82 m.

Figure 2.2. Surfacing points of the glider *Mia* in the area of the wreck of M/S *Estonia*. As an example, the period from 27 April to 5 May 2022 is shown.

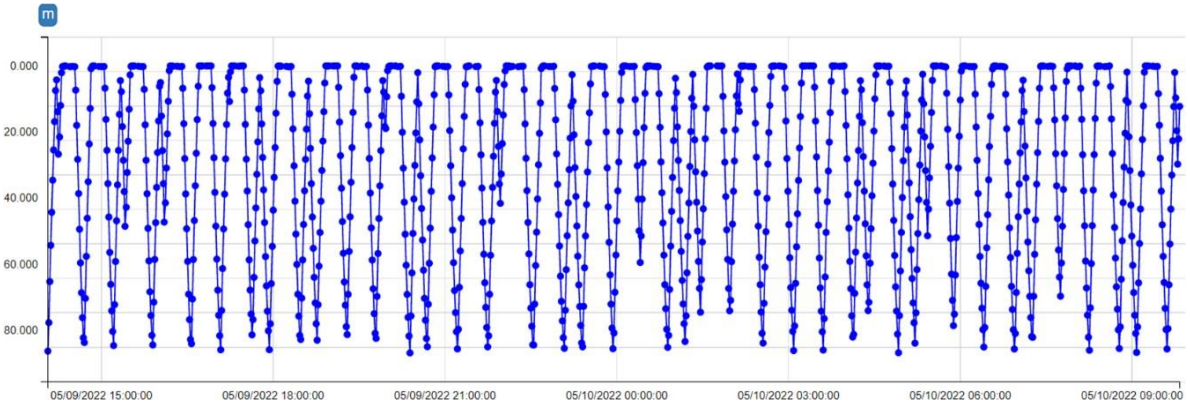

Figure 2.3. Diving trajectories of the glider *Mia* in the area of the wreck of M/S *Estonia* – the examples are from dives on 9 and 10 May 2022 (depth in metres on the vertical axis and time on the horizontal axis).

Data exchange with the glider was organised in such a way that every tenth measurement during the measurement period was transmitted to the server of the Department of Marine Systems. Also taking into account the sampling frequency of 0.5 Hz and the glider's average vertical speed of 10 cm/s, this ensured one data series per every 2 m of each profile. The data sent via satellite links was forwarded to the contracting authority once a week during the first period of measurement and once every two days shortly before and during laser scanning. Promptly transmitted data included the vertical profiles of temperature, salinity, turbidity and oxygen saturation at 2 dbar (2 m) intervals. The raw data recorded on the internal memory card of the glider and all the processed data for the entire measurement period are handed over together with this report. Data file structures are described in the section following the next.

3. CONCISE DESCRIPTION OF MEASUREMENT RESULTS

The variability of the environmental parameters during the entire measurement period is illustrated in Figures 3.1 to 3.5. At the beginning of the measurement period, the seawater turbidity in the water column was relatively low. A significant change occurred in the demersal zone from 24 April 2022 when a high-turbidity water mass entered the area (Figure 3.1). During the period from 27 April to 30 April, the maximum turbidity values exceeded 4 NTU at a depth of approximately 80 m. From 30 April onwards, the turbidity of the demersal zone started to decrease, however, at first, the turbid layer of water rose upwards. After 4 May, the turbid layer of water started to sink. In mid-May, the turbidity in the demersal zone started to increase again and the boundary of the layer started to rise. This period (especially after 20 May) was characterised by the occurrence of a relatively narrow layer of highly turbid water and a decrease in turbidity below this layer in the demersal zone (see Figure 3.2).

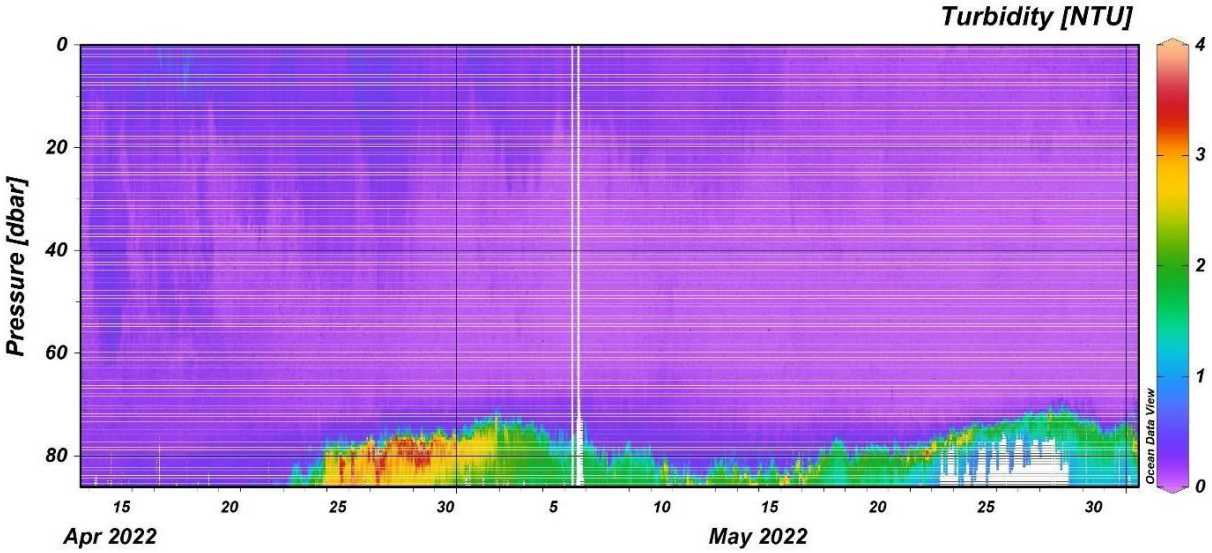

Figure 3.1. Temporal variability of water turbidity in the water column in the area of the wreck of M/S *Estonia* based on measurements taken by the glider *Mia* between 13 April 2022 and 1 June 2022.

The variability of turbidity described above was related to the exchange of water masses in the area. The increase in the turbidity of the demersal zone in the last week of April was caused by the inflow of saltier, oxygen-deficient water to the survey area (Figures 3.4 and 3.5). Typically, the maximum turbidity values occurred in the layer directly below halocline (where salinity sharply increased with depth and oxygen concentrations dropped to near zero). The depth interval with the highest turbidity moved together with the halocline, for instance, on 28 May, maximum turbidity occurred at a depth of 72–74 m (Figure 3.2). Initial analysis of the collected data suggests that, similarly to the deepest areas of the Gulf of Finland, the turbidity of the demersal zone in the area of the wreck of M/S *Estonia* is higher under the conditions of strong water column stratification. Strong stratification, which is more likely to occur from spring to autumn, causes higher salinity, lower oxygen levels and higher turbidity in the demersal zone.

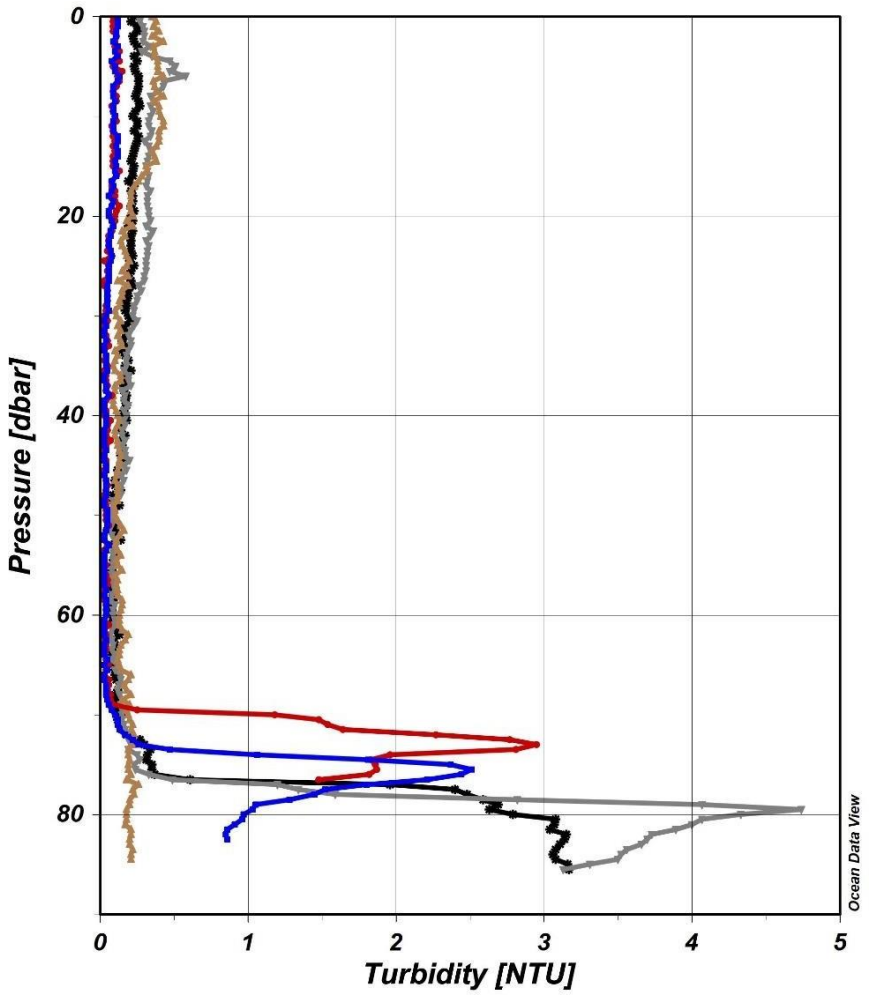

Figure 3.2. Select vertical profiles of water turbidity in the area of the wreck of M/S *Estonia* based on measurements taken by the glider *Mia*.

Examples are from 13 April (beige line), 25 April (black line), 27 April (grey line), 24 May (blue line), and 28 May (red line) of 2022.

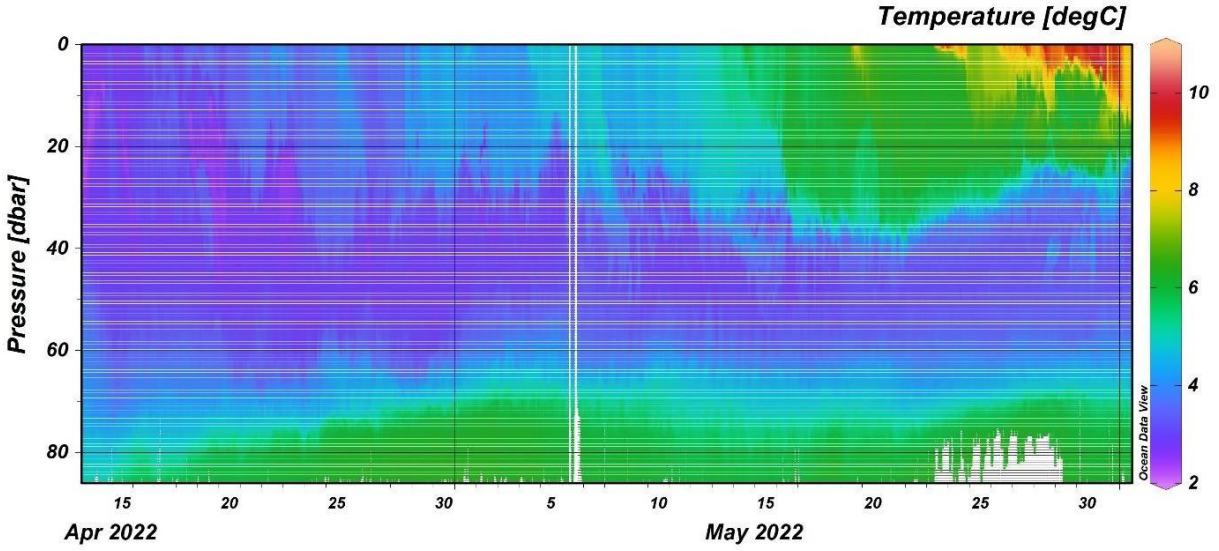

Figure 3.2. Temporal variability of temperature in the water column in the area of the wreck of M/S *Estonia* based on measurements taken by the glider *Mia* between 13 April 2022 and 1 June 2022.

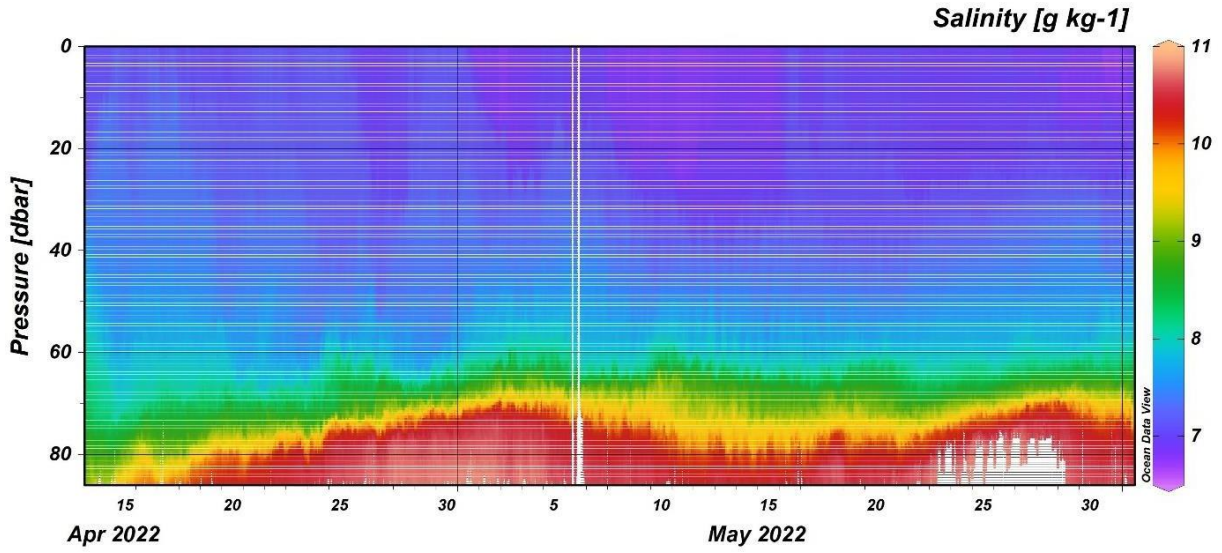

Figure 3.3. Temporal variability of salinity in the water column in the area of the wreck of M/S *Estonia* based on measurements taken by the glider *Mia* between 13 April 2022 and 1 June 2022.

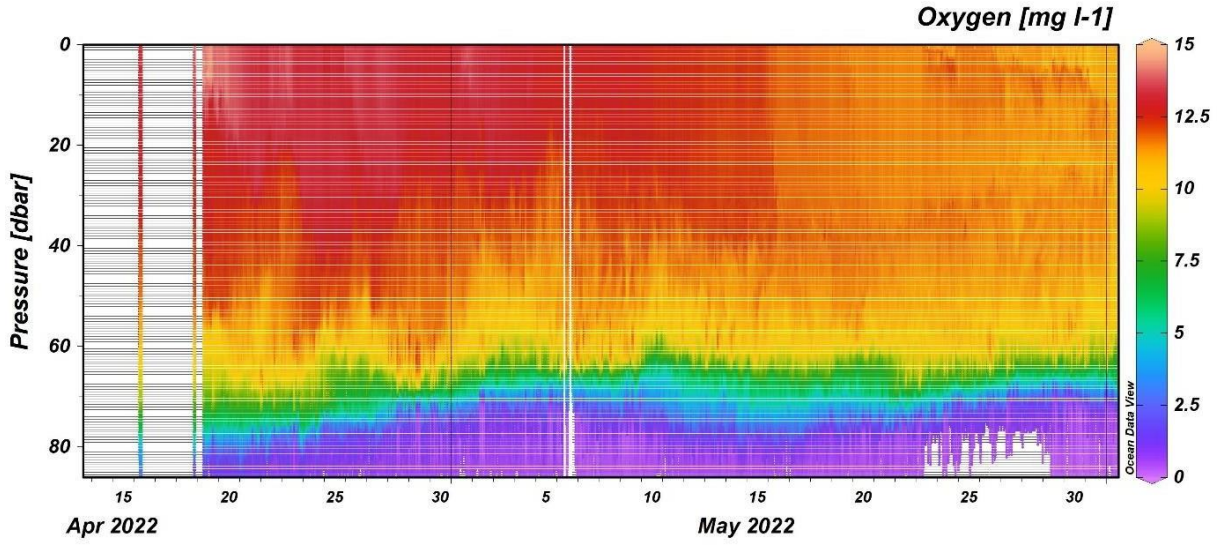

Figure 3.4. Temporal variability of oxygen concentration in the water column in the area of the wreck of M/S *Estonia* based on measurements taken by the glider *Mia* between 13 April 2022 and 1 June 2022 (real-time recording of oxygen content data was disrupted up to 19 April).

4. DATA TRANSMITTED

During the survey period, data were transmitted to the contracting authority at weekly or two-day intervals. The raw data transmitted by the glider were recorded in NetCDF format, with the names and units of the parameters of each data series defined in the data file. The processed data were submitted as a text file, in which each ascent and descent of the glider was defined as a separate profile at 2 dbar (2 m) intervals. The data files contained the following data in columns:

- Station – profile number
- Year, Month, Day, Hour, Minute – profile time
- Pressure [dbar] – pressure in decibars (roughly corresponding to depth; at 2 m intervals)
- Temperature [degC] – water temperature
- Salinity [g kg-1] – salinity in grams per kilogram
- Turbidity [NTU] – water turbidity in Nephelometric Turbidity Units
- Oxygen [percent] – oxygen saturation level as a percentage

If the data for a certain parameter were not available at a certain depth and time, the value 'NaN' was used in its place in the data file.

After the end of the mission, all the recorded data were downloaded from the glider's memory card, including the values of the recorded parameters and the respective parameter values characterising the movement and functioning of the glider (incl. the times and coordinates of measurements). All the raw data collected during the survey period that passed quality control are provided in NetCDF format as a single file 'mia20220413_qc.nc'. The following variables are presented in the data file: 'm_present_time', 'sci_m_present_time', 'sci_ctd41cp_timestamp', 'sci_flntu_timestamp', 'sci_oxy4_timestamp', 'm_gps_lat', 'm_gps_lon', 'm_water_pressure', 'sci_water_pressure', 'sci_water_temp', 'sci_water_cond', 'sci_flntu_chlor_units', 'sci_flntu_turb_units', 'sci_oxy4_temp', 'sci_oxy4_oxygen', 'sci_oxy4_saturation', 'm_pressure', 'm_depth', 'm_water_depth', 'm_water_temp', 'm_water_cond', 'tot_num_surfacings', 'tot_num_half_yos', 'm_gps_lat_interp', 'm_gps_lon_interp'. Each data series includes the names and units of the parameter as well as a brief description (i.e., what each specific data series represents).

Processed data are presented as vertical profiles between a depth of 0 and 90 m. Profiles have a vertical interval of 0.5 dbar, which corresponds to a depth interval of 0.5 m. If profile data were not available at a specific depth, the value is marked as 99999. The processed data are provided in NetCDF format in three separate files: 'mia20220413_qc_CTD_interp.nc' (contains data on temperature, conductivity, salinity and density), 'mia20220413_qc_OXY_interp.nc' (oxygen concentration profiles), and 'mia20220413_qc_FLNTU_interp.nc' (turbidity profiles).

In addition, processed data are also provided as a text file 'glider_mia_2022_processed.dat', which follows the ODV format, meaning each measurement series includes both time and location data and the profile number. A total of 5,484 vertical profiles of temperature (°C), salinity (g/kg), relative density (seawater density minus 1,000; kg/m^{-3}), oxygen concentration (mg/l) and saturation (%), and water turbidity (NTU) were processed in the data files. The salinity and density of seawater were calculated on the basis of the measured pressure, temperature and conductivity data using TEOS-10[1] formulas.

[1] IOC, SCOR & IAPSO (2010). Dynamic height anomaly. In The international thermodynamic equation of seawater - 2010: Calculation and use of thermodynamic properties (Manuals and Guides No. 56, pp. 48–49). UNESCO.

5. SUMMARY

Between 13 April and 1 June, measurements of environmental parameters were carried out in the area of the wreck of M/S *Estonia*.

The objective of this survey was to collect data on seawater turbidity and other environmental parameters both prior to the start of and during primary marine surveys. The Slocum G2 underwater glider from Teledyne Webb Research was used for measurements. Seawater temperature, salinity, turbidity, oxygen concentration and chlorophyll A vertical fluorescence profiles were recorded. The data were transmitted on an ongoing basis both in raw and processed form once a week during the first period and once every two days shortly before and during laser scanning.

Almost during the entire survey period, except for the first ten days, there was a highly turbid demersal layer of water in the area, which was caused by the inflow of saltier and oxygen-deficient water to the survey area. Similarly to the deepest areas of the Gulf of Finland, the turbidity of the demersal zone in the area of the wreck of M/S *Estonia* is higher under the conditions of strong water column stratification. Considering that stronger stratification is more likely to occur from spring to autumn, it can be concluded that the turbidity of the demersal water layer is also higher during that period, which may impede the conduct of optical surveys.

All the raw data collected during the survey period (that passed quality control) and processed data are submitted to the contracting authority together with this report. The files of processed data contain a total of 5,484 vertical profiles of temperature, salinity, oxygen content and water turbidity.