

Tallinn University of
Technology



ADCP measurements for the collection of data
on current profiles and salinity and oxygen
content in the demersal zone in the area of the
wreck of the ferry *Estonia* (July–November
2021)
Report

Public procurement No. 241513

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ANNOTATION

The aim of the survey was to record the vertical profiles of the currents and the salinity, temperature, and oxygen concentration in the demersal zone in the area of the wreck of the ferry *Estonia* in conditions where the water column is stratified. The work was carried out using the SeaGuard II measurement platform from Aanderaa, which was connected to an acoustic Doppler current profiler and pressure, electrical conductivity, temperature, and oxygen sensors. The platform, connected to a submersible buoy and anchored to the seafloor, was deployed from the Transport Administration's vessel *EVA-316* in the vicinity of the wreck of the *Estonia* on 10 July 2021 at 59° 22.8299' N, 21° 38.8656' E. The depth of the seafloor at the measurement site was 74 m. The platform was retrieved by the Police and Border Guard Board's vessel *Kindral Kurvits* on 9 November 2021. The series of data collected over the nearly four months are presented in the annex to this report. The report describes the temporal variability of the currents across the whole water column, focusing in particular on the dynamics of the demersal zone. Periods of higher current velocity in the deep layer are identified, and, based on meteorological data for the measurement period, the conditions that prevailed during strong currents are described. The temporal variability of the salinity and dissolved oxygen concentration in the demersal zone in the area of the wreck of the *Estonia* during July to November 2021 is analysed.

The work has been carried out in accordance with the order of the Estonian Safety Investigation Bureau from 6 July 2021 and the procurement contract (public procurement reference number 241513) from 13 October 2021.

The measurements, data analysis, and preparation of the report were carried out with the involvement of experts Villu Kikas, Oliver Samlas, Kai Salm, Stella-Theresa Stoicescu, and Urmas Lips from the Department of Marine Systems of Tallinn University of Technology.

1. INTRODUCTION

During the period of 1994–2021, no long-term measurements of oceanographic parameters have been carried out at the shipwreck site of the *Estonia* in the northern Baltic Sea proper. In order to assess the dynamics of the water in the demersal zone and the variability of the environmental conditions retrospectively since 1994, it is necessary to utilise numerical modelling while taking into account the meteorological conditions prevailing at the time. The modelling results then need to be validated using measurement data from the area collected over as long a period as possible. In order to obtain data on the different meteorological and hydrographic conditions, the present operations are planned to involve measurements during the summer, when the water column is stratified, as well as during the winter, when the upper water layer down to the halocline is not stratified. Based on the data collected, a description will be given of the variability of the currents, salinity, and oxygen conditions in the demersal zone and how it relates to the prevailing meteorological conditions and/or physical processes.

This report presents the data collected and describes the situation with regard to and the variability over time of the currents, temperature, salinity, and oxygen concentration in the area of the wreck of the *Estonia* during the first measurement period, which ran from 10 July 2021 to 9 November 2021. Measurements in winter conditions will be carried out between December 2021 and March 2022 over a period of at least three months.

The work included the recording of vertical current profiles and time series in one-hour increments for the salinity, temperature, and oxygen content in the demersal zone. The measurements were carried out using the SeaGuard II measurement platform from Aanderaa, which was connected to an acoustic Doppler current profiler and pressure, electrical conductivity, temperature, and oxygen sensors. The depth of the sea at the measurement site (59° 22.8299' N, 21° 38.8656' E; all coordinates in the report are given in the WGS84 system) was 74 m. For the description of the currents in conditions where the water column is stratified, maximum current velocities near the seafloor are identified and an analysis of what these events might have been related to is presented. A description of the variability of salinity and oxygen conditions is presented. By extending these results to the period starting from September 1994 by means of model calculations in a later phase of the analysis, conclusions can be drawn, inter alia, regarding corrosion intensity. All of the data collected can be used for the validation of modelling results.

The report is structured as follows. Section 2 (measurements and data) explores the instrumentation used, the design of the buoy station, the sensors, the collected data, and the analysis methods. Additionally, the meteorological data used in the analysis are identified.

Section 3 presents the results. Subsection 3.1 describes the temporal variability of the currents across the water column. The dynamics of the demersal zone are explored separately. Time series for the currents and progressive vector diagrams are presented graphically, and statistical characteristics are presented for the currents, including maximum velocities, periods where the velocity exceeded a certain limit (e.g., 10 cm/s), and other parameters.

Subsection 3.2 describes the meteorological conditions during the measurement period based on ERA5 data, including wind statistics along with a wind rose, maximum speeds, and winds during periods of higher velocities near the seafloor. An analysis of what the mechanism for the generation of the high current velocities might have been, i.e. what kind of winds prevailed during high current

velocities (including with regard to the direction and the speed) in the area, is presented.

Subsection 3.3 describes the variability of salinity and dissolved oxygen concentration in the demersal zone throughout the measurement period, including when periods of no oxygen occurred and when oxygenated water was present in the area. The causes of this variability and the relationship between oxygen conditions and changes in currents and wind conditions are analysed.

Section 4 briefly summarises the findings and conclusions from the first measurement period.

2. DATA AND METHODOLOGY

The work was carried out using the SeaGuard II measurement platform from Aanderaa, which was connected to an acoustic Doppler current profiler (DCPS, sn 505), a pressure sensor (4117, sn 1857), a conductivity sensor (4319, sn 1545), and an oxygen optode (4835, sn 3766). All three of the latter sensors were also equipped with a temperature sensor. Sensor specifications are given in Table 2.1.

Table 2.1. Specifications for the sensors connected to the Aanderaa SeaGuard II platform used for the work.

Sensor/parameter	Unit	Range	Resolution	Accuracy
DCPS speed	cm/s	0–500	0.1	0.3
DCPS direction /compass	degree	0–360	0.1	2
Pressure	MPa	0–60	0.0001% of scale	0.01% of scale
Electrical conductivity	S/m	0–7.5	0.0002	0.005
Oxygen	µM	0–500	1	8
Oxygen	%	0–150	0.4	5
Temperature	°C	–4 – +36	0.001	0.03

Other technical specifications for the DCPS: frequency 600 kHz, vertical measurement range up to 80 m, layer thickness (vertical resolution) 0.5–5 m, concealed distance from sensor to first measurement interval 1 m, 4 transmitters/receivers, inclinometer accuracy with respect to vertical axis 0.5 degrees. The measurements were carried out using the following profiler configuration parameters: measurement range – from a depth of 70 m (i.e. 4 m from the seafloor, see explanation below) to the sea surface in two-metre increments (40 layers, 32 of which were in the water and not substantially perturbed by the signal reflected back from the water surface) and a measurement interval of 1 hour. The hourly result for the current velocity and direction was recorded as the mean value of 30 signals received over about 1.5 minutes.

To fix the SeaGuard II platform to the seafloor, a system equipped with a buoy and anchor was constructed (see Figure 2.1). The anchor of sufficient weight was fitted with a chain, which was connected to an acoustic trigger and which, in turn, was connected, by means of a shackle, to the SeaGuard II sensors. The length of the system from the anchor to the current profiler (DCPS) was 3 m, which, combined with the hidden measuring range of 1 m, yielded 4 m as the distance of the lower end of the first measuring range from the seafloor. The vertical position of the SeaGuard II platform in the water column was secured by means of a buoy with sufficiently high buoyancy, which was connected to the platform with a line of around 3 m.

Data on the temperature, salinity, and oxygen content in the demersal zone are presented in this report as measured at the depth of the SeaGuard II platform (71 m, i.e. 3 m from the seafloor). Temperature is given as the measured *in-situ* temperature in °C. Salinity values have been calculated based on

the temperature, electrical conductivity, and pressure, using TEOS-10¹ relationships, and the data are given in g/kg. Oxygen content is given as dissolved oxygen concentration in μM (or $\mu\text{mol/l}$) and saturation percentage.

The measurement system was deployed from the Transport Administration's vessel *EVA-316* in the sea near the wreck of the *Estonia* on 10 July 2021, at the coordinates 59° 22.8299' N, 21° 38.8656' E. The topography of the larger area together with the survey zone is shown in Figure 2.2, and a more detailed topography of the zone together with the location of the measurement system and the ERA5 meteorological data point is shown in Figure 2.3. The depth of the seafloor at the measurement site was 74 m. The platform was retrieved by the Police and Border Guard Board's vessel *Kindral Kurvits* on 9 November 2021. The data collected in their original form and converted into physical units are presented in the annex to this report.

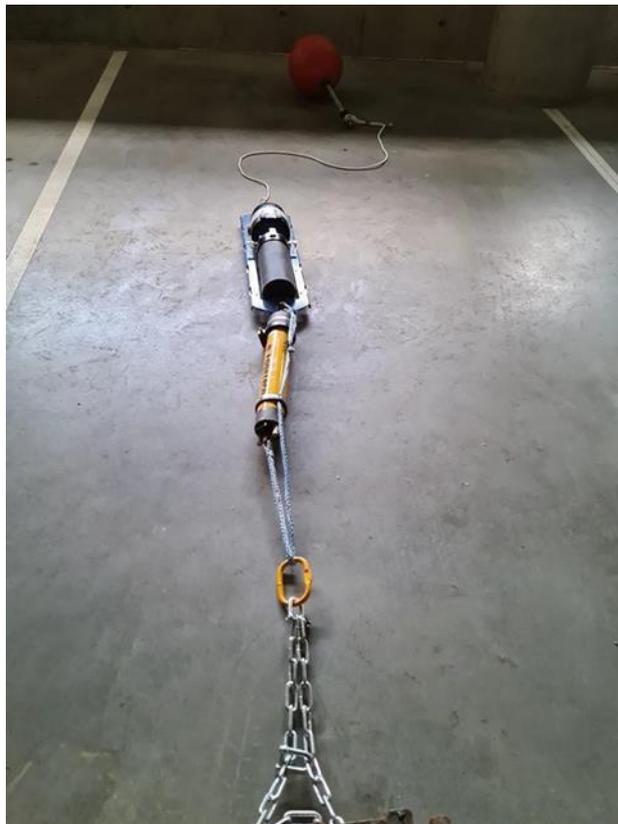


Figure 2.1. Buoy station configuration – buoy, Aanderaa SeaGuard II platform together with the acoustic Doppler current profiler and oxygen, temperature, and conductivity sensors, and acoustic trigger attached to an anchor.

The survey site lies north-west of Hiiumaa, within the Finnish EEZ, which geographically belongs to the northern Baltic Sea proper. On a larger scale, this is an area where the depth of the sea increases from north to south (Figure 2.2).

¹ IOC, SCOR, and IAPSO: The International Thermodynamic Equation of Seawater - 2010: Calculation and Use of Thermodynamic Properties, Intergovernmental Oceanographic Commission, Manuals and Guides No. 56

UNESCO, 196, 2010.

A more detailed look at the topography of the area shows that the seafloor in the immediate vicinity of the wreck of the *Estonia* and the SeaGuard II platform deployed in the sea for the first period (Figure 2.3) is highly variable. The measuring station was located about 2 km west of the wreck. The deeper area south of the wreck of the *Estonia* is connected to a slightly deeper area stretched out along an east-west axis north of the survey point. The survey station was located in a less pronounced (lower) furrow, which also has a roughly east-west orientation.

Meteorological data from the reanalysis product *ERA5 hourly data on single levels from 1979 to present* in the ERA5 database have been used to describe the meteorological conditions during the measurement period. Data on the u and v components of the wind at 10 m above sea level from the period of July to November 2021 were extracted from the database. The temporal resolution of the data is one hour and the horizontal resolution is $0.25^\circ \times 0.25^\circ$. The analysis was prepared using data from the nearest ERA5 grid point ($59^\circ 22.8' \text{ N}$, $21^\circ 40.8' \text{ E}$; see Figure 2.3).

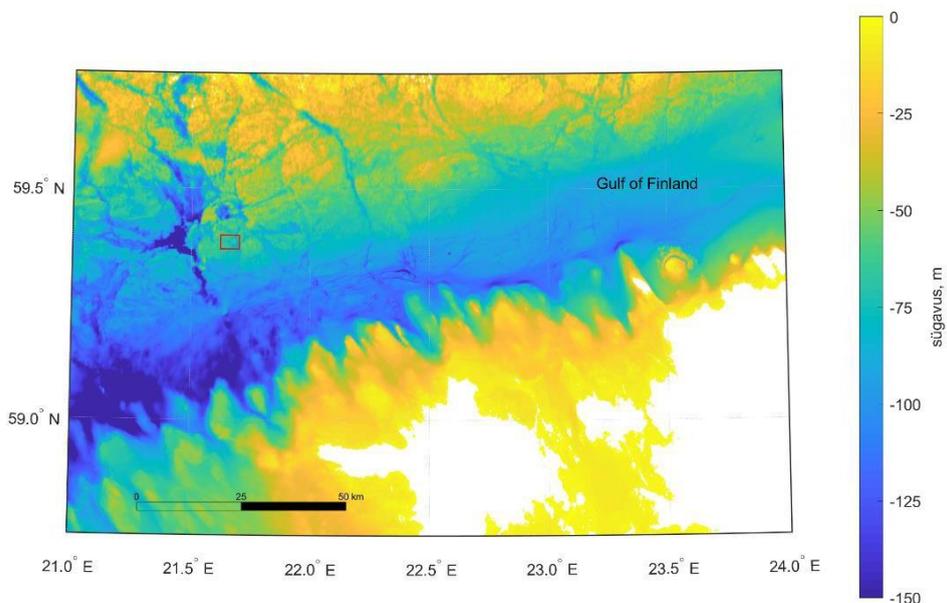


Figure 2.2. Topography of the northern Baltic Sea proper and the western section of the Gulf of Finland together with the survey location (red rectangle)

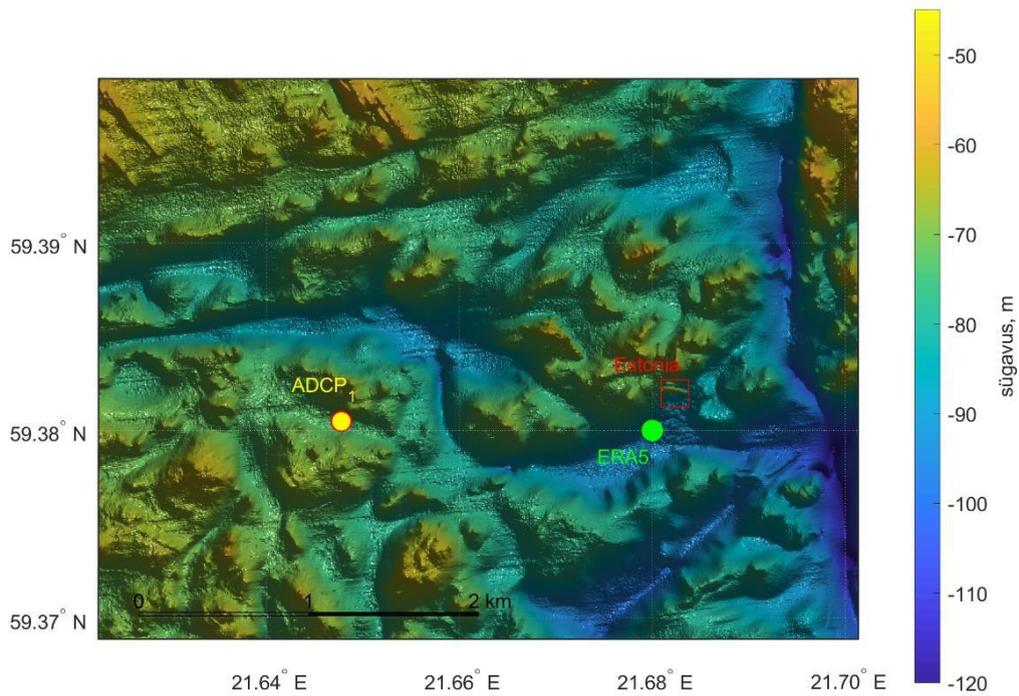


Figure 2.3. Detailed topography of the area of the wreck of the ferry *Estonia* together with the locations of the ferry (red square, *Estonia*, coordinates 59° 22.9252' N, 021° 40.8451' E), the meteorological data point (green circle, ERA5), and the survey platform (yellow circle, ADCP1) during the first survey period.

3. RESULTS

3.1. CURRENTS

The vertical distribution of the current velocity and its temporal variability during the survey period is shown in Figure

3.1. The figure shows that in July to August, the currents in the surface layer, which is separated from the lower layers by a seasonal thermocline, were stronger than lower in the water column. In September, higher velocities were also occasionally recorded in the upper section of the water column. The upper layer with higher velocities was 30–35 m thick during this period, as the thermocline had probably shifted deeper down as a result of mixing. Temporal variability was characterised by short-lived column-wide events of stronger currents. A velocity gradient at a depth of about 60 m, which may be related to the halocline, was also characteristic. At times, the currents were weaker at lower depths than higher up, while occasionally maximum current velocities occurred precisely in the demersal zone.

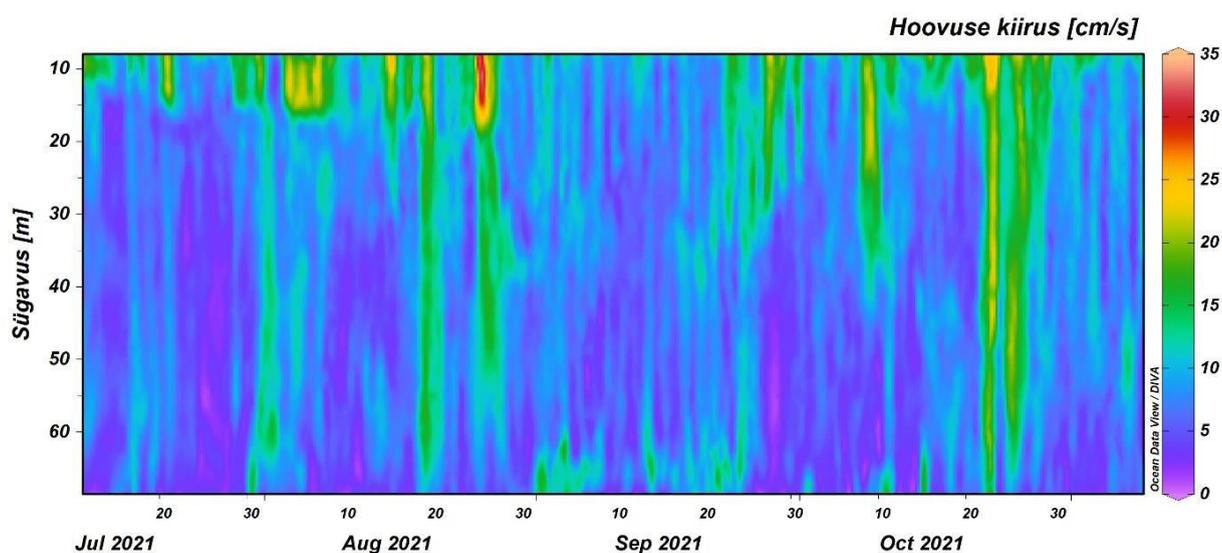


Figure 3.1. Changes over time in the vertical distribution of current velocities in the area of the wreck of the *Estonia* over the measurement period from 10 July to 9 November 2021.

The variability of the currents in the demersal zone is described below through statistical parameters such as mean velocity and maximum velocity (Table 3.1). A layer of water up to 16 m thick as measured from the seabed was selected for analysis. The mean current velocity during the measurement period was 6–7 cm/s in the observed layer. The median value was even lower, meaning that most of the time the current velocity was below 6 cm/s. Maximum recorded velocities over four months were 32–35 cm/s, where the maximum value occurred in the layer at a depth of 64–66 m.

Table 3.1. Statistical indicators of the recorded current velocity in the demersal zone per 2 m layer in the area of the wreck of the *Estonia* for the period 10 July to 9 November 2021.

Depth (m)	Arithmetic mean (cm/s)	Median (cm/s)	Maximum velocity (cm/s)
66–68	6.0	5.2	32.1
64–66	6.8	5.9	35.4
62–64	6.9	6.0	31.2
60–62	6.8	6.0	32.3
58–60	6.9	6.0	26.7
56–58	7.1	6.3	28.0
Averages	6.7	5.9	30.9

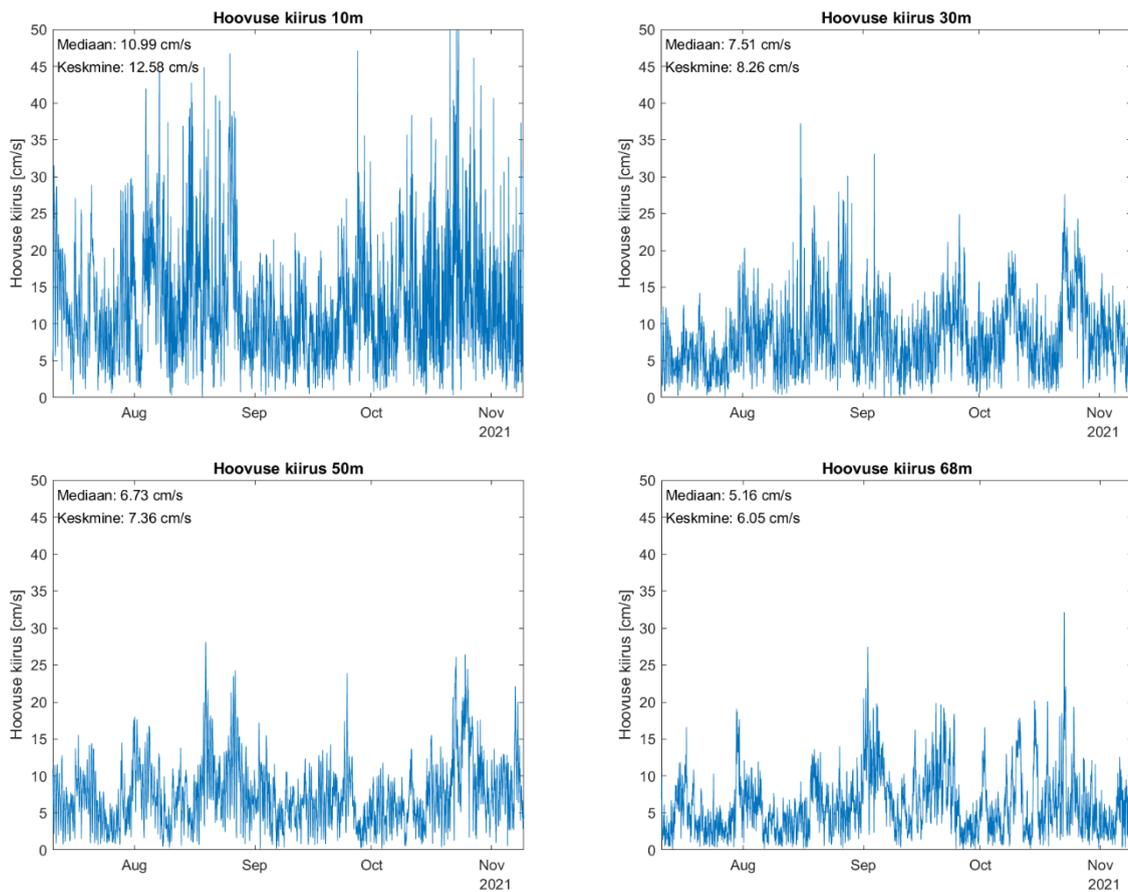


Figure 3.2. Current velocity history at depths of 8–10 m, 28–30 m, 48–50 m, and 66–68 m in the area of the wreck of the *Estonia* over the measurement period from 10 July to 9 November 2021.

Comparing the measured current velocities between the different layers, it can be seen that the maximum velocities occurred in the surface layer (see for example Figure 3.2, 8–10 m), while the lowest maximum values were recorded in the intermediate layer (Figure 3.2, 48–50 m). Compared to the maximum current velocity of 32 cm/s recorded at 64–66 m, the velocities in the surface layer exceeded 60 cm/s (8–10 m), while at 28–30 m they reached 37 cm/s. In the intermediate layer, at a depth of 48–50 m, the recorded maximum current velocity was 28 cm/s.

In the demersal zone, the current velocity exceeded 20 cm/s for a longer period only on two occasions: 1–2 September 2021 and 22–23 October 2021. Current velocities above 10 cm/s occurred relatively frequently, on average during two longer periods each month (Figure 3.3). On average, demersal currents were stronger in September and October and weaker in July and August.

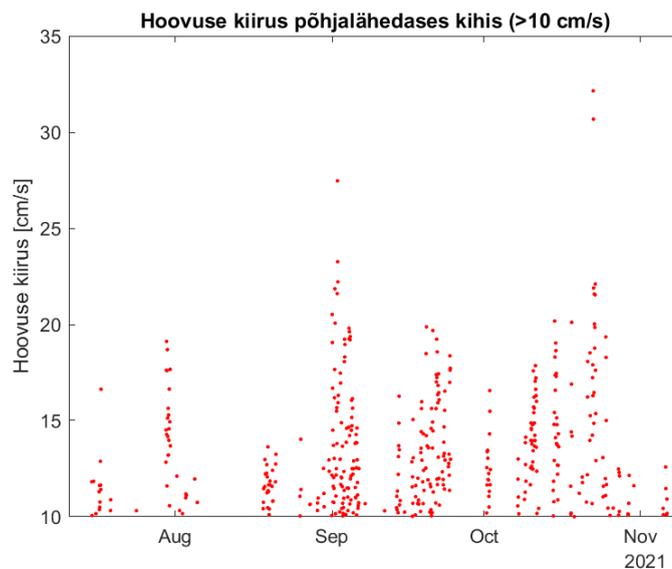


Figure 3.3. Current velocities above 10 cm/s, measured at a depth of 66–68 in the area of the wreck of the *Estonia* during the period 10 July to 9 November 2021.

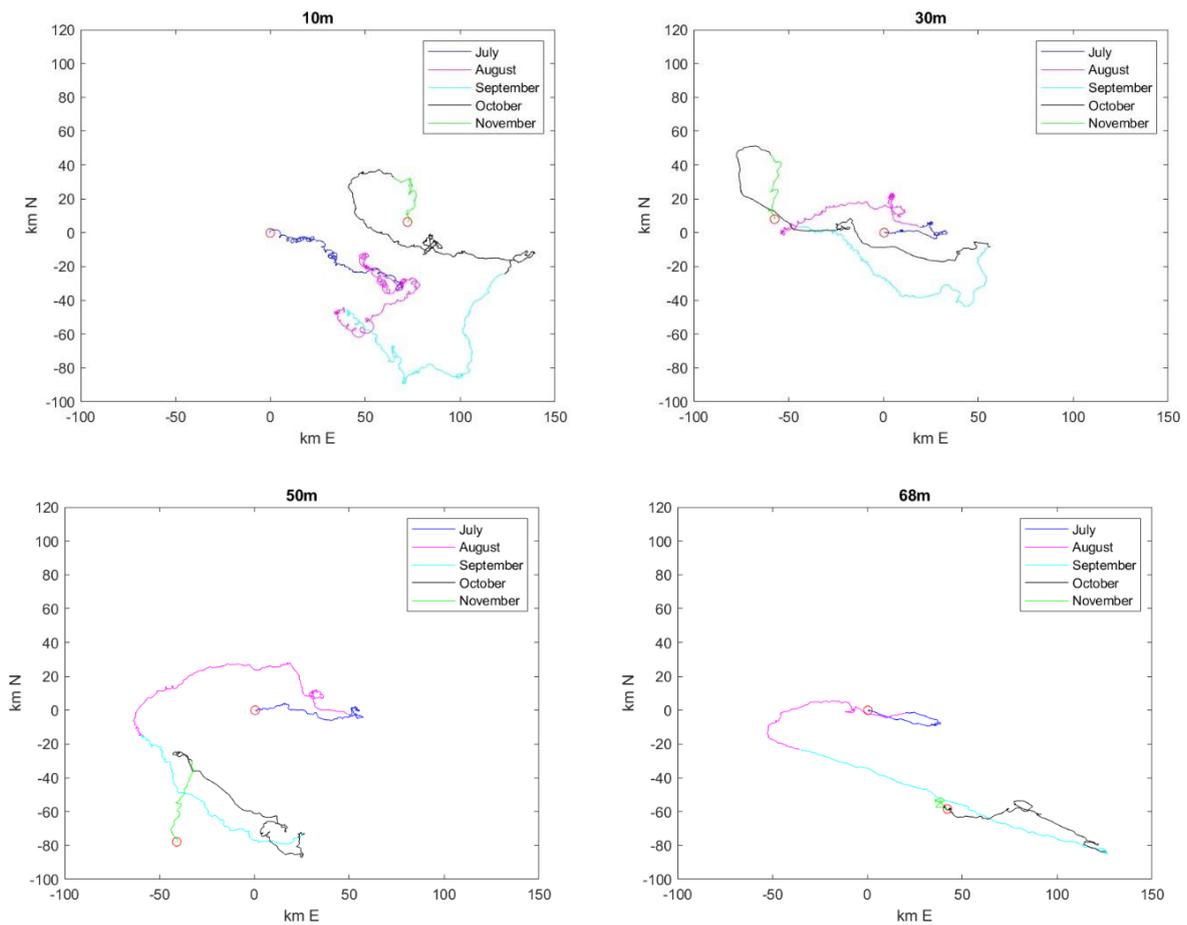


Figure 3.4. Current progressive vector diagrams at depths of 10 m, 30 m, 50 m, and 68 m in the area of the wreck of the *Estonia* over the measurement period from 10 July to 9 November 2021.

The progressive vector diagrams show the prevailing direction and strength of flow over longer periods. Figure 3.4 shows that, although the flow was occasionally clearly directional and strong, the total movement over the whole period was between 50 and 80 km at all depths. This corresponds to an average flow or residual current velocity of less than 1 cm/s. In the demersal zone, the prevailing flow direction was east-southeasterly or west-northwesterly, which is consistent with the topography of the area (see Figures 2.2 and 2.3). In mid-July the flow direction was east-southeasterly, becoming west-northwesterly in late July. In August, this direction was maintained until it became southwesterly and later east-southeasterly. This direction was maintained throughout September. In October, the prevailing flow direction was west-northwesterly. In November, the currents in the demersal zone were relatively weak.

Higher in the water column, there was a greater variety of periodically dominating flow directions. While in the demersal zone, the overall flow direction for the period was southeasterly, at a depth of 50 m it was southwesterly. In the upper two water layers shown in Figure 3.4, the variability of the currents/flow was relatively similar, but the overall direction for the whole period in the surface layer (8–10 m) was easterly, while at a depth of 28–30 m it was westerly (at the start of the measurement period, these two water layers were separated by a thermocline).

3.2. EFFECT OF METEOROLOGICAL CONDITIONS ON CURRENT DYNAMICS

During the survey period, southwesterly winds prevailed in the area, although north-northwesterly, south-southeasterly, and east-northeasterly winds occurred frequently as well (Figure 3.5). Wind speeds exceeded 15 m/s only for westerly winds. The 24-hour smoothed wind speed graph shows the alternation of periods of stronger and weaker winds of a couple of days' long throughout the survey period (Figure 2.6). On average, winds were weaker in July and August and stronger in the second half of the survey period, in September and October. The maximum wind speeds were recorded in the second half of October.

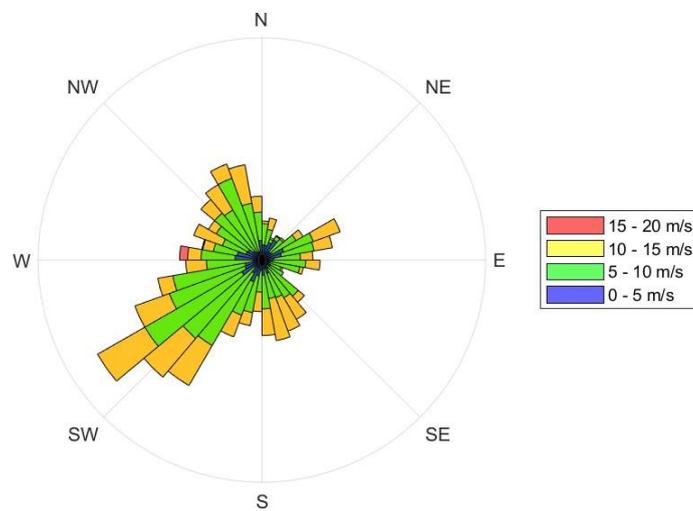


Figure 3.5. Wind rose based on modelling results obtained from the nearest ERA5 point to the survey area (wind speed at 10 m above sea level) during the survey period from 10 July to 9 November 2021.

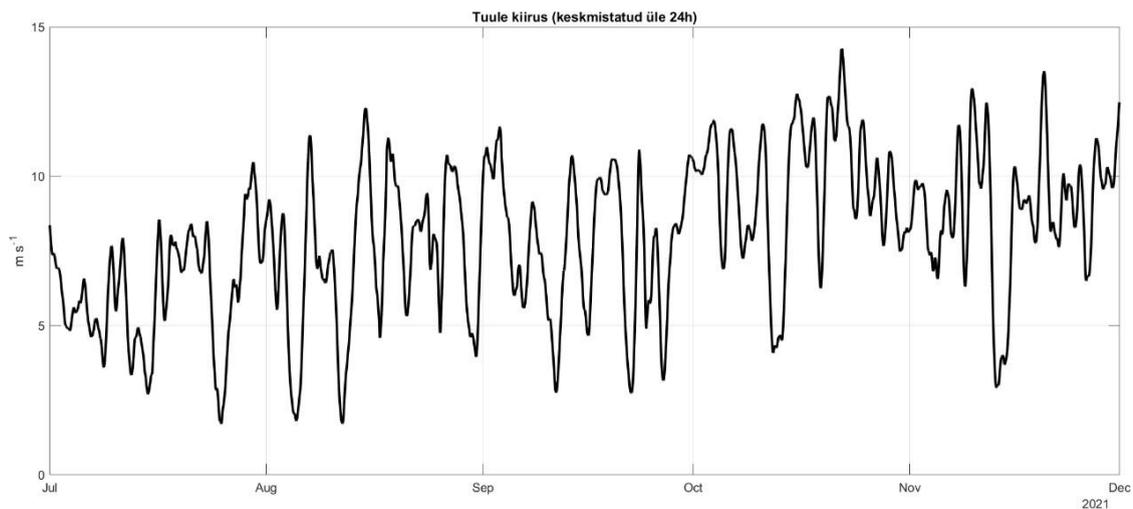


Figure 3.6. 24-hour smoothed wind speeds based on modelling results obtained from the nearest ERA5 point to the survey area for July to November 2021.

The daily average wind vectors also show the high variability of the meteorological conditions over periods of a few days' long (Figure 3.7). Longer periods of stronger winds from a particular direction prevailed from late August to early September, when northerly winds prevailed, and from late September to early October and in late October, when southerly winds prevailed. During the period with the highest wind speeds in the second half of October, the direction of the wind varied.

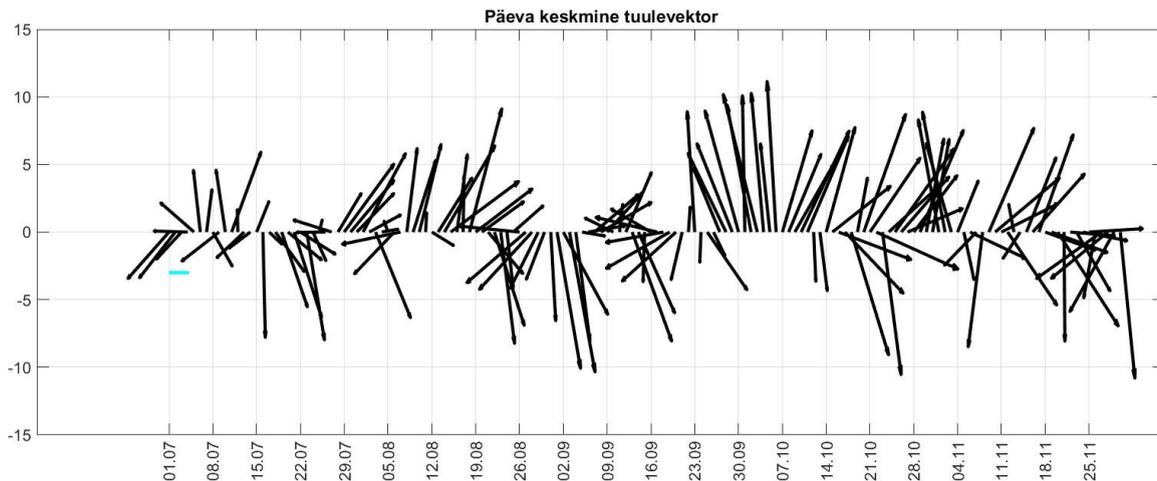


Figure 3.7. Daily average wind vectors based on modelling results obtained from the nearest ERA5 point to the survey area for July to November 2021.

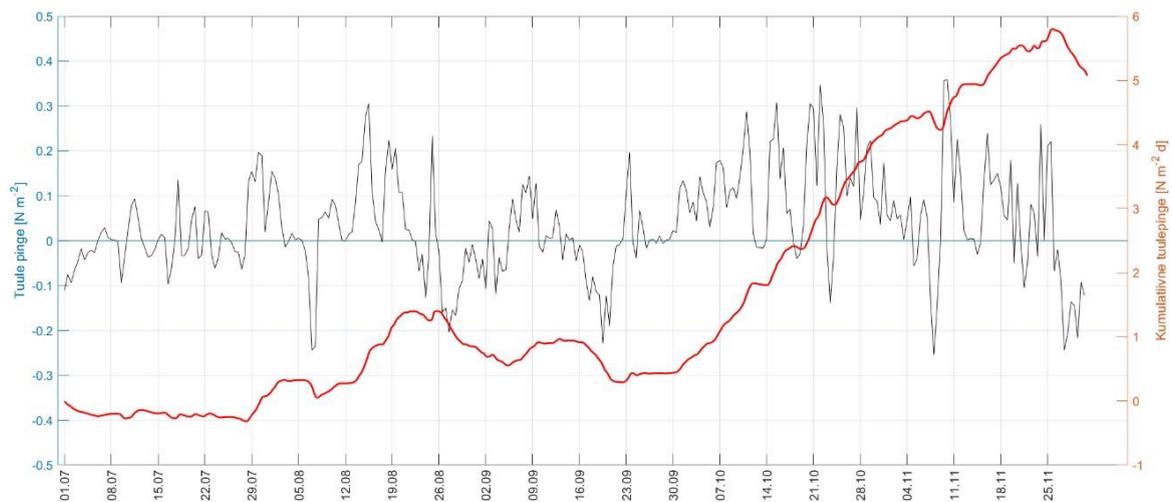


Figure 3.8. 6-hour smoothed wind stress (black line) and cumulative wind stress (red line) based on modelling results obtained from the nearest ERA5 point to the survey area during the survey period from 10 July 2021 to 9 November 2021. The shown wind stress component has a positive northeasterly direction (rotated 45 degrees clockwise from the north axis).

The wind stress time series also shows that southwesterly winds dominated during the survey period (Figure 3.8). Only a few shorter periods of northeasterly winds or of an opposite wind stress maximum can be seen: early August, late August to early September, mid-September, and early

November. The influence of southwesterly winds clearly dominates in October, as demonstrated by the cumulative wind stress graph: the cumulative stress rises sharply throughout nearly the entire month of October (Figure 3.8).

A comparison of the prevailing winds and the dominant flow directions at different depths (see Figure 3.4) reveals that the flow in the surface layer followed the wind more closely (i.e. directly influenced by wind stress) than in the deeper layers. In the demersal zone, flow was predominantly directed against the wind or perpendicular to the wind, presumably also influenced by the local topography. For example, during the prevailing of the north-northwesterly winds in late August and early September, the flow direction in the demersal zone was east-southeasterly, while during the prevailing of the south-southwesterly winds in October, it was west-northwesterly. This kind of opposite flow at different depths is characteristic of the Baltic Sea in conditions where the water column is stratified, as has been demonstrated by measurements conducted in the Gulf of Finland (for example, Lips et al., 2017²; Suhhova et al., 2018³).

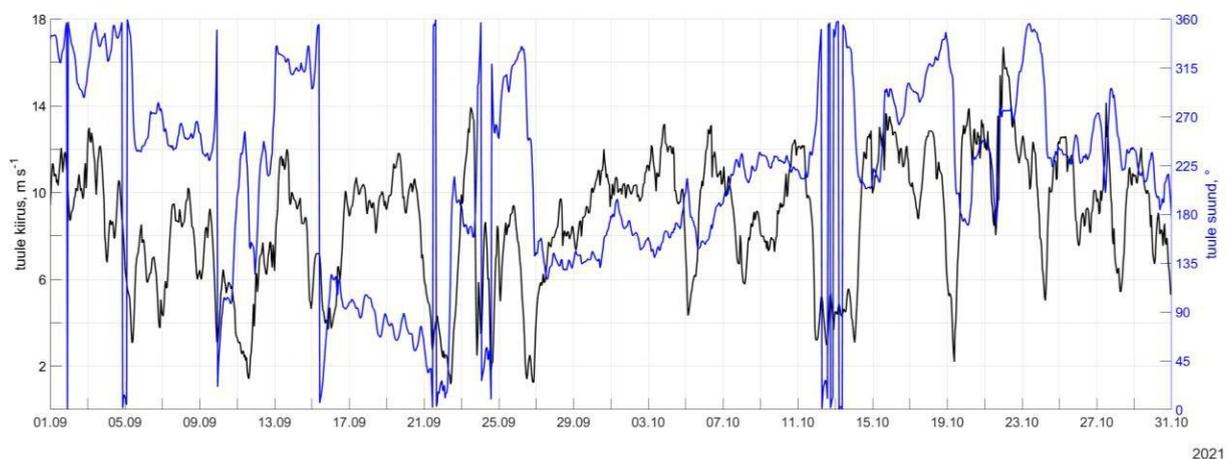


Figure 3.9. Wind speed and direction based on modelling results obtained from the nearest ERA5 point to the survey area for September to October 2021.

In the context of the present survey, it was important to identify the meteorological conditions that occurred during the recording of the maximum current velocities in the demersal zone. Velocities above 20 cm/s were recorded on 1–2 September 2021 during a period of strong north-northwesterly winds and on 22–23 October 2021, which coincided with the highest wind speeds recorded during the entire survey period, when the winds blew from the west (Figure 3.9). The maximum current velocity in the demersal zone was recorded at 24 cm/s during the first of these periods and at 35 cm/s during the second.

Analysing in more detail the simultaneous changes in wind conditions and currents, it can be seen that the strong winds which prevailed during the first days of September, blowing predominantly from the north, generated a strong eastward current in the demersal zone (Figure 3.10). That is to say, the demersal current was directed 90 degrees to the left relative to the wind.

² Lips, U., Laanemets, J., Lips, I., Liblik, T., Suhhova, I., Suursaar, Ü. (2017). Wind-driven residual circulation and related oxygen and nutrient dynamics in the Gulf of Finland (Baltic Sea) in winter. *Estuarine Coastal and Shelf Science*, 195, 4–15. DOI: 10.1016/j.ecss.2016.10.006.

³ Suhhova, I.; Liblik, T.; Lilover, M.-J.; Lips, U. (2018). A descriptive analysis of the linkage between the vertical stratification and current oscillations in the Gulf of Finland. *Boreal Environment Research*, 23, 83–103.

The fastest current recorded was generated by strong westerly winds on 20–24 October. It can be seen that variation in the wind corresponds to a variable current, but for a brief period and at the highest velocity, the direction of the current is opposite to that of the wind. It is likely that the direction of the current with the highest velocity is influenced by the general configuration of the basin and the local topography at the location of the current meter. A more in-depth analysis will be carried out in the second phase of the work, when measurement data from winter conditions will also be available.

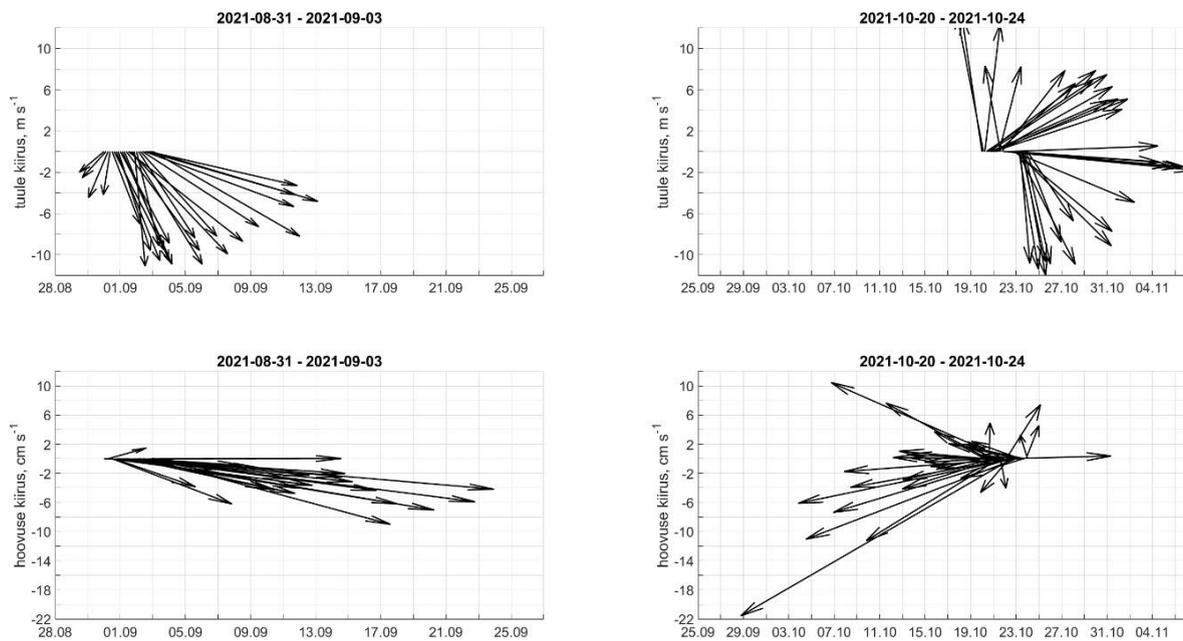


Figure 3.10. Wind (upper panels) and demersal current (66–68 m; lower panels) vectors for two selected periods: 31 August to 3 September (panels on the left) and 20 October to 24 October.

3.3. SALINITY, TEMPERATURE, AND OXYGEN

The variability of the salinity, temperature, and oxygen content in the demersal zone in the area of the wreck of the ferry *Estonia* is characterised by the average, minimum, and maximum values of these parameters over the measurement period, as shown in Table 3.2. The temperature varied between 4.14 and 6.95 °C, salinity between 7.47 and 10.95 g/kg, and oxygen content between 0 and 248 μM , or 0 and 63% of saturation. The average temperature in the demersal zone during the measurement period was 5.42 °C and the salinity was 9.12 g/kg. Oxygen conditions are not so much characterised by the average concentration as by alternation between anoxic conditions and conditions of higher oxygen content.

Table 3.2. Recorded minimum, maximum, and average values for temperature, salinity, and oxygen content in the demersal zone in the area of the wreck of the ferry *Estonia* during the period 10 July to 9 November 2021.

Parameter	Minimum	Maximum	Average
Temperature (°C)	4.14	6.95	5.42
Salinity (g/kg)	7.47	10.95	9.12
Oxygen (µM)	0	248	98
Oxygen (%)	0	63	25

Periodic anoxic conditions (lack of oxygen) were recorded in the demersal zone. Increased salinity was detected as occurring concomitantly with this anoxia (Figure 3.11, salinity > 10 g/kg). As salinity decreased, the oxygen content of the water increased. The anoxic periods recorded occurred in the second half of August, in mid-September, and in late September / early October. Towards the end of the measurement period, from mid-October onwards, oxygen concentrations increased and salinity decreased until the end of the measurements. The vertical extent of anoxic or hypoxic conditions in the water column can be assessed using vertical oxygen profiles. The extent of hypoxia in conditions of demersal oxygen deficiency is usually related to the depth of the halocline (see, for example, Stoicescu et al., 2019⁴). More detailed assessments will be presented in the final report on these operations.

The simultaneous increase in salinity and decrease in oxygen content suggests that the low oxygen values in the area of the wreck of the *Estonia* did not arise on site, but were caused by changes in water masses in the survey area. A saltier, less oxygen-rich water mass probably entered the survey area from the south, from the deeper regions of the Baltic Sea. During these periods of sharply decreasing oxygen content or prolonged anoxic conditions, eastward flow predominated in the demersal zone. This means that, although the water mass presumably originated from south of the survey area, it entered the area from the west along a topographic channel. The decrease in salinity and the simultaneous increase in oxygen content, which occurred, for example, in early October, indicates that during these periods, water that was lower in salinity entered the area from a region with a weaker halocline in the north or east (from the direction of the Gulf of Finland). During this period, westward flow predominated in the demersal zone.

In mid-October, oxygen conditions began to improve and salinity started to decrease, but unlike before, when temperature and salinity followed the same trend, this time the decrease in salinity was accompanied by an increase in temperature (Figure 3.12). Such changes indicate vertical mixing, i.e. the water in the demersal zone and in the upper layers of water (lower salinity and higher temperature) in the survey area mixed together due to strong winds and convection in autumn caused by the cooling of the surface layer.

⁴ Stoicescu, S.-T., Lips, U., Liblik, T. (2019). Assessment of Eutrophication Status Based on Sub-Surface Oxygen Conditions in the Gulf of Finland (Baltic Sea). *Frontiers in Marine Science*, 6, UNSP 54. DOI: 10.3389/fmars.2019.00054.

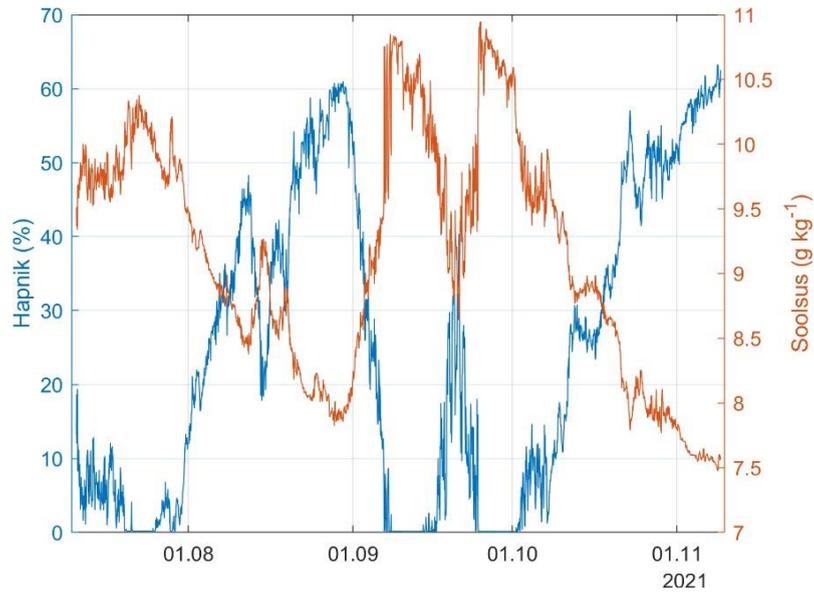


Figure 3.11. History of dissolved oxygen concentration (%; blue line) and salinity (g/kg; red line) in the demersal zone in the area of the wreck of the *Estonia* during the period 10 July to 9 November 2021.

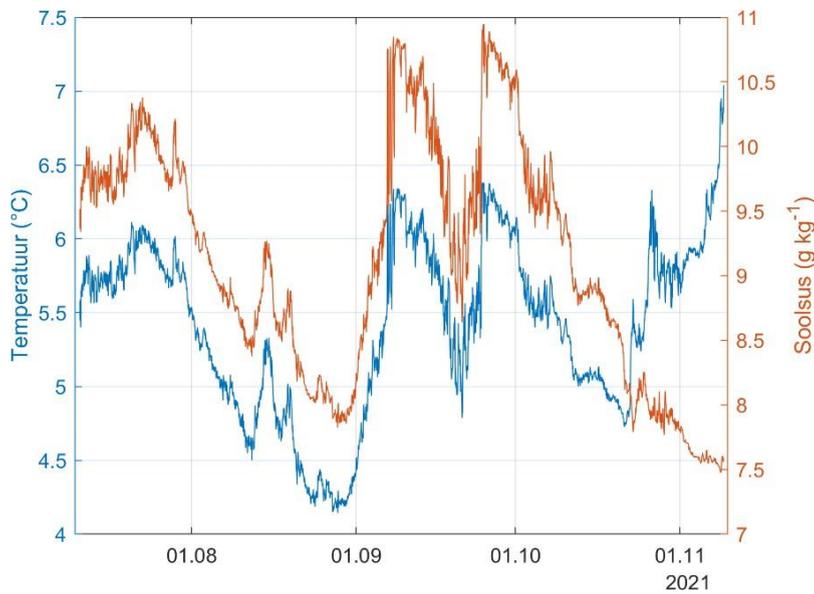


Figure 3.12. History of temperature (°C; blue line) and salinity (g/kg; red line) in the demersal zone in the area of the wreck of the *Estonia* during the period 10 July to 9 November 2021.

4. SUMMARY

The aim of the survey was to record the vertical profiles of the currents and the salinity, temperature, and oxygen concentration in the demersal zone in the area of the wreck of the ferry *Estonia* over a period of at least three months in conditions where the water column is stratified. The work was carried out using the SeaGuard II measurement platform from Aanderaa, which was connected to an acoustic Doppler current profiler and pressure, electrical conductivity, oxygen, and temperature sensors. Measurements were carried out between 10 July 2021 and 9 November 2021 at the coordinates 59° 22.8299' N, 21° 38.8656' E, at a depth of 74 m.

This report gives a preliminary description of the measurement results, focusing on demersal zone dynamics. The main findings and conclusions from the preliminary analysis are as follows:

- Currents in the demersal zone reached maximum velocities of up to 35 cm/s.
- The median current velocity near the seafloor was 6 cm/s, although shorter periods of current velocities above 20 cm/s occurred, and, each month, longer periods of current velocities above 10 cm/s were observed as well.
- Stronger demersal currents were associated with stronger winds; for example, the maximum velocity was measured during a storm on 22–23 October 2021.
- Current velocities near the seafloor were higher in autumn (September and October) than in July and August.
- Flow in the demersal zone in the survey area was predominantly directed against the wind.
- Oxygen concentration in the demersal zone varied between zero (anoxic environment) and 63% of saturation, which was related to the exchange of water masses in the area.
- Increased salinity in the demersal zone was accompanied by decreased oxygen content, and vice versa: increases in oxygen concentration occurred in combination with decreases in salinity.
- The increase in oxygen content and temperature and decrease in salinity in the demersal zone recorded in October 2021 was probably related to vertical mixing in the water column.

Measurement data have been appended to the report both in their original form and as time series of verified and calculated physical quantities.

ANNEX 1.

Raw data from the memory card of the SeaGuard II have been appended to the report (files Data000.bin, Data001.bin, Data002.bin, Data003.bin, Data004.bin, Data005.bin, and Data006.bin) along with information about the configuration of the instrument (Config.xml) and the setup of the measurements (Layout.xml). All these files can be read using the dedicated software application DataStudio 3D (Aanderaa).

All of the raw data, in physical units, for the entire measurement period, extracted using the abovementioned software application from Aanderaa, have also been saved and transmitted as *.csv and *.xlsx files (Estonia_Jul- Nov_2021.csv and Estonia_Jul-Nov_2021.xlsx), which can be read using word processing and spreadsheet software (e.g., Excel). These files contain both preliminary measurement data and information on the current profile measurement quality and the state of the instrumentation over the measurement period.

The measurement data have been formatted as a separate Excel file containing only quality-controlled data from sensors and calculated values of physical quantities. The table columns show the following data:

- Record Time – time of day (UTC) Record Number – number of the data series
- Conductivity [mS/cm] – electrical conductivity
- Temperature[Deg.C] – water temperature (measured by the conductivity sensor)
- Salinity[PSU] – calculated salinity in PSU
- Salinity[g/kg] – calculated salinity in g/kg
- Density[kg/m³] – calculated density of water
- Soundspeed[m/s] – calculated speed of propagation of sound in the water
- Pressure[kPa] – pressure
- Temperature[DegC] – temperature (measured by the pressure sensor)
- O2Concentration[uM] – dissolved oxygen concentration in the water (in μM , i.e. $\mu\text{mol/l}$)
AirSaturation[%] – oxygen saturation percentage
- Temperature[Deg.C] – temperature (measured by the oxygen optode)

The following columns show the measured (sensor DCPS #505) and calculated parameters of currents in all layers from 70–68 m to 6–4 m, taking into account the measured current velocities and the orientation of the instrument as recorded by the compass:

- modulus of current velocity (Horizontal Speed [cm/s]),
- current direction (Direction [Deg.M]),
- northward component of current velocity (North Speed [cm/s]),
- eastward component of current velocity (East Speed [cm/s]).