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ORIGINAL RESEARCH ARTICLE

The pathway of the water exchange over the Gdańsk-Gotland Sill of the Baltic Sea and its impact on habitat formation during the stagnation period

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Abstract Water exchange between the deep basins of the Baltic Sea during stagnation periods ventilates the bottom layer. Such exchange may be local and associated with the seabed topography features. The aim of this study is to investigate the possible pathway of water exchange within the Gdańsk-Gotland Sill. A comprehensive study was conducted near the one of the local erosional trenches (depressions), comprising bathymetric survey using multibeam echosounder, water column CTD-sounding, tilt current meters mooring, and sampling of seabed deposits and macrozoobenthos. The absence of pelitic sediments even in the natural trench depressions was identified. The seabed is composed of dense clays with surface erosion signs. The presence of a current towards the Gotland Basin was recorded in the bottom layer of the erosional trench. This layer was characterized by increased salinity and dissolved oxygen concentration. The trench was also an area with macrozoobenthos richer in species composition

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and biomass. Moreover, indicator species of the North Sea waters were found exclusively within the erosional trench. Macrozoobenthic community structure and the age of benthic organisms confirm the existence of permanent water exchange directly from the Słupsk Furrow through the erosional trench, and indicate one of the advective pathways of water exchange between the deep Baltic Sea basins.

1. Introduction

The episodic Major Baltic Inflows (MBIs) from the North Sea through the Danish Straits to the Baltic Sea and their further advection through deep-sea furrows and troughs play a crucial role in the formation of the ecosystem of deep-sea basins. Well-aerated waters of the North Sea enrich the bottom layers with oxygen drastically changing the ecosystem (Bulczak et al., 2016; Elken and Matthäus, 2008; Fischer and Matthäus, 1996; Mohrholz et al., 2015; Matthäus and Franck, 1992; Nehring et al., 1995). Large inflows of the North Sea waters are relatively rare (Elken and Matthäus, 2008; Fischer and Matthäus, 1996; Matthäus and Franck, 1992). The absence of MBIs facilitates the stagnation of the deep-water areas of the Baltic Sea (Feistel et al., 2008). As a result, the hydrogen sulfide contamination destructive to complex life forms is developing. Advective water exchange plays a key role in ventilation of the near-bottom layer during stagnaton periods. In such periods, overflow through topographic barriers is apparently carried out in local areas, due to the features of the seabed topography. The seabed relief of the Gdańsk-Gotland Sill suggests the existence of such poorly studied water exchange pathways and, as a result, the existence of specific habitats in them.

The aim of this work is to study one of the erosional trench on the Gdańsk-Gotland Sill as one of the pathways of permanent near-bottom water exchange between the Gdańsk, Gotland Deeps and the Słupsk Furrow. Comprehensive research was aimed at studying habitats, including hydrological conditions, seabed deposits and macrozoobenthos. Hydrological conditions are the direct evidence of near-bottom water exchange, while lithological features and the structure of the macrozoobenthos community indicate the duration and intensity of such a process.

2. Study area

The Baltic Sea is a semi-enclosed sea connected with the North Sea through the narrow and shallow Danish Straits. Deep-water basins at the bottom of the Baltic Sea are distinguished, separated by sills and elevations. Recent seabed relief of the Baltic Sea was formed after the last deglaciation (Uścinowicz, 1999).

The Baltic Sea has a two-layered salinity distribution: a low-saline upper layer and a more saline deep layer. The Baltic Deep waters renewal occurs during the MBIs. The main pathways of the inflow water distribution through the depressions and furrows of the Baltic Sea are well known (Döös et al., 2004; Elken, 1996; Hagen and Feistel, 2004; Lehmann and Hinrichsen, 2000; Lehmann et al., 2002; Wieczorek, 2012; Zhurbas et al., 2004).

The Gdańsk-Gotland Sill appears to be a natural topographic barrier (with depths of 80—85 m) that hinders the near-bottom water exchange between the Gdańsk Deep and the Gotland Deep (Gelumbauskaite et al., 1999) (Figure 1).

The Quaternary sediments are underlaid by Devonian siltstones with sandstones interbeds, marls, limestones, dolomites with interbeds of marls, sandstones, clays. The Quaternary section of the research area reveals the moraine deposits overlain by dense clays of the Baltic Ice Lake (BIL) (Petrov, 2010). Moraine deposits of a total thickness up to 30 m are represented by brown sandy loams and loams with occurring gravel, pebbles, and boulders. BIL sediments are represented by brownish-gray varve clays, loams, and sandy loams. The clay fraction content amounted to 70%, in average, aleurite content amounted up to 30%. BIL sediments thickness in the depressions reaches 10 m. Modern sediments in the study area are represented by silts that fill depressions in the seabed relief.

The most common water pathway during the MBIs is from the Słupsk Furrow to the northeast along the eastern slope of the Hoburg Channel into the Gotland Deep. Sometimes, water moves along the southwestern slope of the Gdańsk Deep. The Gdańsk Deep turns out to be a kind of a buffer zone (Meier et al., 2006) where the inflow water cyclically fills the bottom layers and partially spreads northward to the Gotland Deep. This pathway is rather complicated and determined by the salinity and volume of inflow waters (Meier, 2007).

Large inflows that renew bottom layers in the Gdańsk Basin are quite rare. The most recent significant renewal to the bottom water was observed in 2014 (Mohrholz et al., 2015). Medium size inflows were recorded before and after this main inflow event (Naumann et al., 2016). The concentration of dissolved oxygen reached zero values in all deep-water troughs of the Baltic Sea in 2018 (Naumann et al., 2019).

The permanent halocline within the Gdańsk deep is located at depths of 60—70 m (Paka et al., 2019a), which predetermines the advective nature of water exchange in the bottom layer with the neighbouring basins, including the Gotland Deep. During the stagnation periods with the insignificant inflow volumes, water exchange over this sill occurs locally.

There are several erosional trenches on the southeastern slope of the Gotland Deep that can be involved in the bottom water exchange between the Baltic Sea sub-basins. The study area is one of such erosional trenches in the Southeastern Baltic Sea (Figure 2). At the top of the erosional

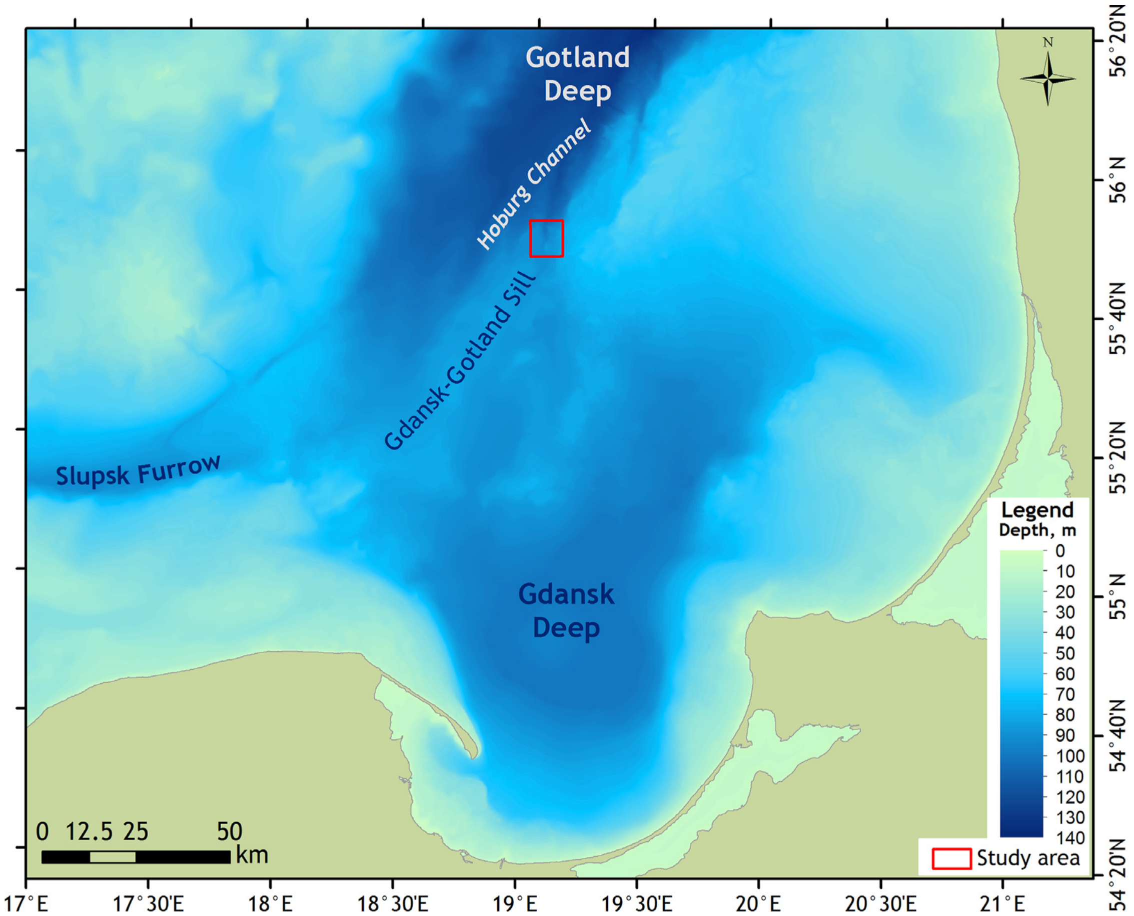

Figure 1 The location of the study area. (Seabed relief: Gelumbauskaite et al., 1999.)

trench, the depths are about 85 m reaching the depth of 110 m in the northern part of the study area.

3. Material and methods

The study was conducted in two stages: the first one in May 2019 was carried out on board the research vessel r/v *Akademik Nikolaj Strakhov*, and was aimed at studying seabed topography and hydrological conditions. The second stage performed in July 2019 on board the r/v *Akademik Boris Petrov*, and was aimed at studying seabed deposits, macrozoobenthos communities, and hydrological conditions (see Figure 2).

3.1. Seabed topography

The seabed topography was surveyed on May 19, 2019, using multibeam echosounder RESON SeaBat 8111. The system operates at a central frequency of 100 kHz and forms 101 beams at a spacing of 1.5° (across- and along-track), with an angular coverage sector of up to 150°. A range resolution is 3.7 cm.

To consider the survey system's angular misalignments the patch test was conducted at the start of the survey. Data processing was carried out using PDS 2000 software. Profile of the sound velocity in water was applied before data processing. Sounding was performed using the Idronaut Ocean Seven 316 Plus probe. The Digital Terrain Model (DTM) calculation and morphological analysis of the seabed were performed using ArcGIS software.

3.2. CTD sounding

CTD sounding was performed on May 19 and July 20, 2019 using Idronaut Ocean Seven 316 Plus probe. Soundings were carried out from the surface to the bottom (the probe did not reach the bottom ~0.5 m). Measurements were taken in the mode of free sliding of autonomous probe along the cable. The speed of lowering the devices was about 0.7—0.8 m/s.

Characteristics of the sensors installed on the device are given in Table 1.

3.3. Measuring velocity and direction of bottom currents

The inclinometric meters — Tilt Current Meters (TCM) — were used to measure the velocity and direction of bottom currents. These devices record the tilt of their own vertical axis under the influence of hydrodynamic pressure of the horizontal flow (Hansen et al., 2017; Sheremet, 2010).

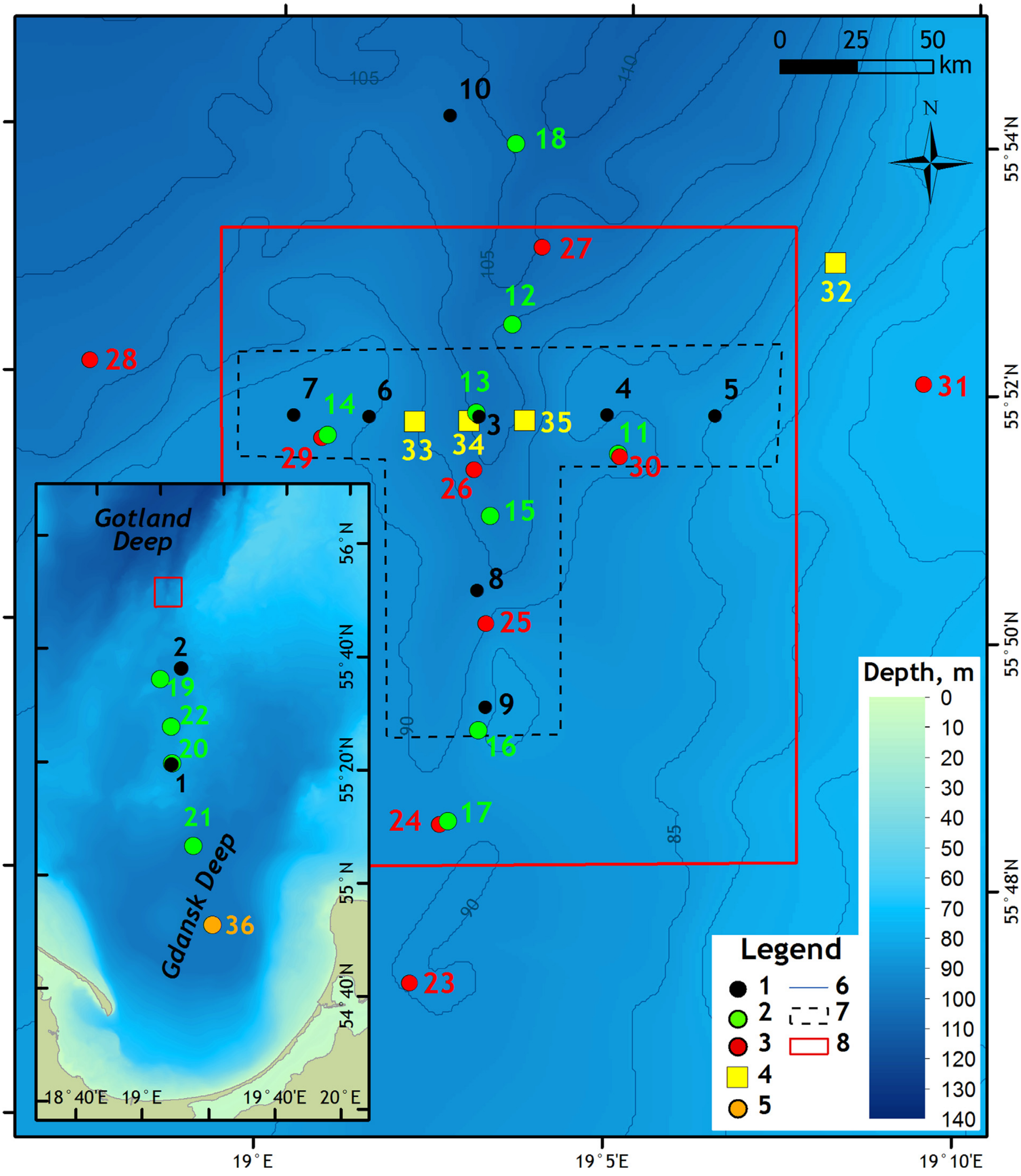

Figure 2 Scheme of performed complex measurements. Legend: 1 — CTD-sounding performed on May 19, 2019; 2 — CTD-sounding performed on July 20, 2019; 3 — Seabed deposits and benthic sampling stations performed on July 20, 2019; 4 — Tilt current meters (TCM) mooring stations; 5 — Annual monitoring station #36; 6 — Isobaths [m]; 7 — Work area with a multibeam echosounder; 8 — Study area. Inset: location of additional stations outside the Study area (Seabed relief: Gelumbauskaite et al., 1999).

In the experiment, the TCM with positive buoyancy of the original design (Paka et al., 2019b) developed at the Atlantic Branch of the Shirshov Institute of Oceanology of the Russian Academy of Sciences was used.

A three-component accelerometer and a magnetometer, which were stationary placed inside the TCM, were used to consider the angle and the direction of the deviation from the vertical. Recording was performed continuously with a frequency of 5 Hz from July 16 to July 19, 2019. Magnetic compass resolution is 1°, accuracy is 5°. Velocity resolution is 1 cm/s, accuracy at angles of deviation varies from 5 to 60°. Error is 5%. The range of measured velocity rates is 0—60 cm/s. To eliminate a possible error of unsuccessful device installation, the meters were paired with the backup devices. When analyzing the data, correlation of the device pairs was performed.

Table 1 Metrological characteristics of sensors installed on Idronaut Ocean Seven 316 Plus probe.

Characteristic / Parameter	Model	Measuring range	Accuracy
Electrical conductivity [mS/m]	IDRONAUT. 7-electrode quartz cell	0—70	0.003
Temperature [°C]	IDRONAUT. Platinum thermoelectrode	−3—50	0.002
Pressure [dBa]	IDRONAUT. Piezoresistive sensor	0—1000	0.05% of the measured value
Dissolved oxygen [%]	IDRONAUT. Pressure compensated polarographic sensor	0—500	1

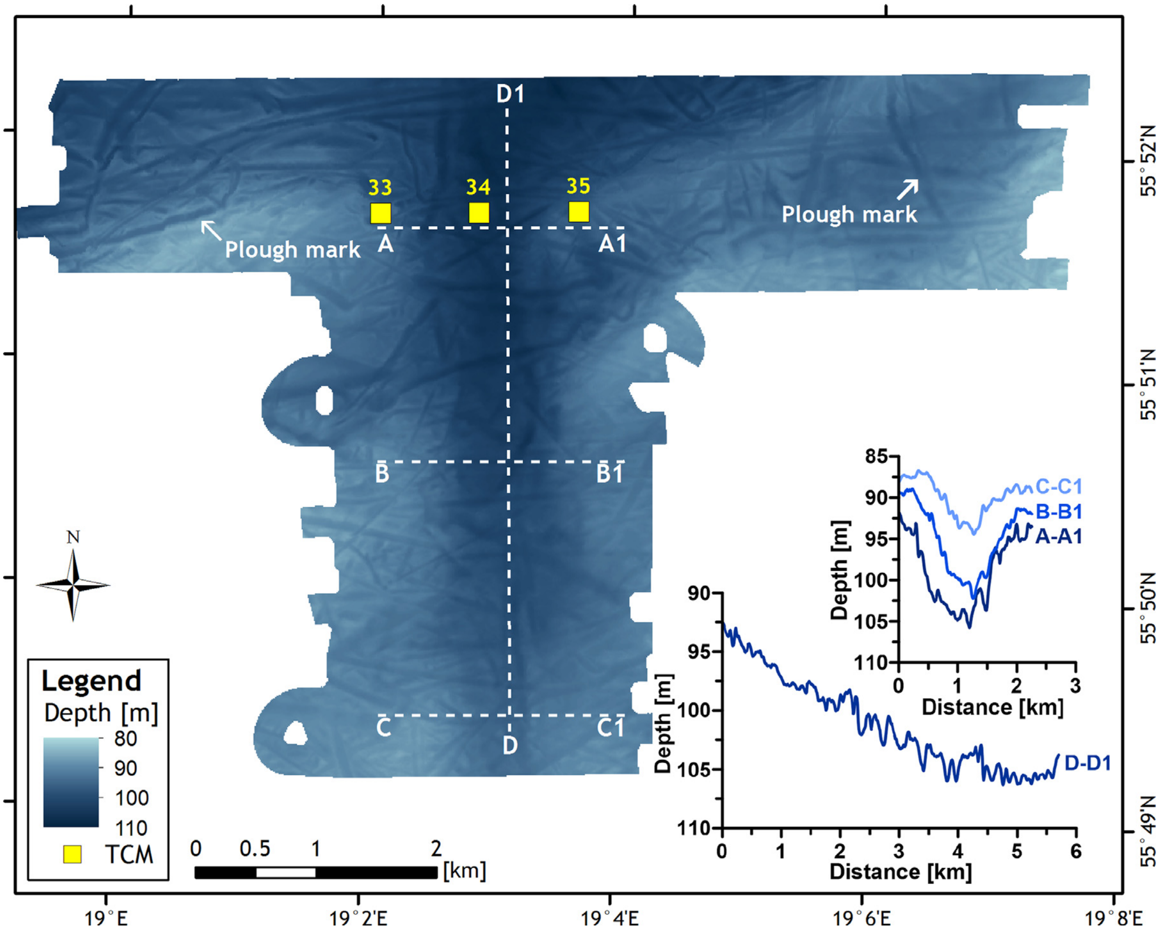

Figure 3 Seabed topography in one of the erosional trench on the Gdańsk-Gotland Sill and the adjacent area, and the bottom velocity meters position. Insets demonstrate seabed relief along lines A-A1, B-B1, C-C1, and D-D1.

3.4. Sampling of seabed deposits and macrozoobenthos

Sampling of seabed deposits and macrozoobenthos was carried out by a loaded Van Veen bottom grab (capture area is 0.1 m^2, weight is 20 kg). Four samples were taken at each station. After the bottom grab was raised up, the samples were examined.

Primary processing of macrozoobenthos samples was carried out on board the vessel. Samples were washed in a benthic bag having 0.4 mm mesh size. If fractions of seabed deposits did not pass through a sieve of a benthic bag, the "elutriation" method was used. The washed sample residue was placed in the containers for storage and transportation, where they were fixed with a 4% solution of formaldehyde neutralized by sodium bicarbonate. Further processing was performed in the laboratory conditions (Dybern et al., 1976; HELCOM, 1988; Methodical..., 1983; Romanova, 1983).

3.5. Laboratory identification of species composition, biomass, and macrozoobenthos abundance

Macrozoobenthos sampling was performed using Olympus SX51 microscope at 10 times magnification. Species or taxonomic ranks (genus *Mytilus* Linnaeus, 1758; *Reophax* Montfort, 1808; *Cribroelphidium* Cushman and Brönnimann, 1948) of macrozoobenthos were identified. The number of individuals of each species or taxonomic rank was calculated separately. After being counted, they were dried on filter paper and weighed. The group method was employed to determine the mass of each species or taxonomic rank

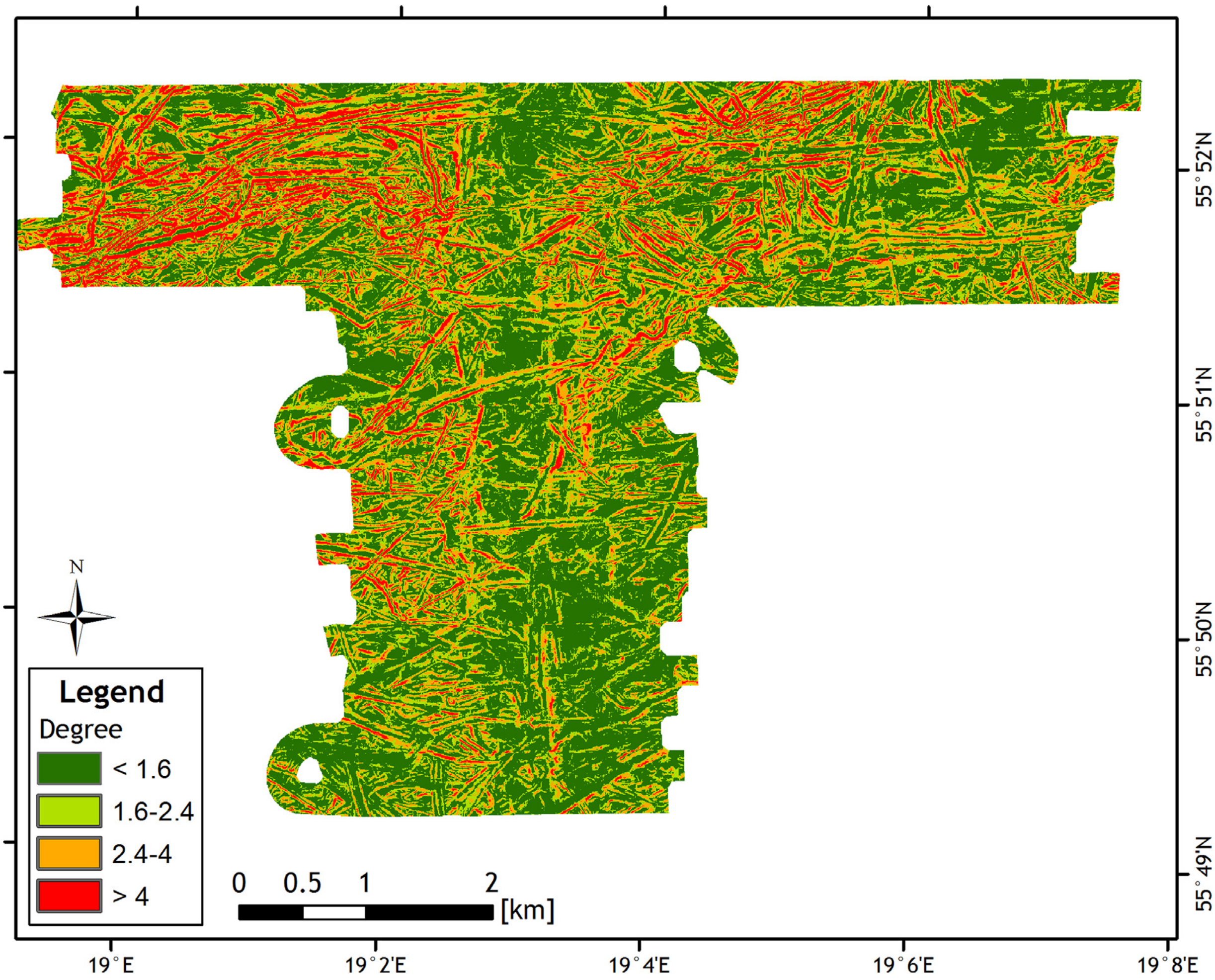

Figure 4 Angles of inclination of the bottom surface in the erosional trench.

using AND DX-300 WP analytical balance having an accuracy of 0.001 g. The obtained data on the number of individuals and the mass of each species or taxonomic rank were counted per 1 m^2 of the bottom area.

Synonyms of identified taxa are given in accordance with the World Register of Marine Species (WoRMS, 2020).

4. Results

4.1. Seabed relief

The erosional trench is a V-shaped and elongated from south to north, forming a kind of "bottle neck" in the plan (Figure 3). There is a mean 2.2 m/km depth increase along the thalweg of the erosional trench (line D-D1), and a depth difference between the southern and northern part of the erosional trench at the research site is about 13 m. The erosional trench widens toward the base in cross section in a northerly direction.

One of the mesorelief peculiarities is the presence of so-called "plough marks", which are surface relict traces of iceberg ploughing (Beckholmen and Tirén, 2009; Elhammer et al., 1988), formed at the early stages of the Baltic Sea Basin formation.

The flattening of the plough mark slopes along the thalweg of the erosional trench indicates the long-term existence of bottom currents and marks the erosional trench as a limited area in which water exchange occurs periodically (Figure 4).

4.2. The structure of the water column

4.2.1. May 2019

The water advection was noticed in the bottom layer of the erosional trench on May 19. The water coming from the Gdańsk-Gotland Sill descended the erosional trench forming a kind of a "tongue" with increased salinity (12.00—12.25 psu) and temperature (7.0—7.1°C) (Figure 5). The cross-section, in the deep (northern) part of the erosional trench showed the advective water filling the erosional trench to the top of the slope edge (Figure 6). A layer with the minimum dissolved oxygen concentration (1.96—2.5 mg/l) and salinity ranging from 11.5 to 12 psu, was detected at depths from 88 to 98 m. The oxygen minimum for the water of identical salinity was not detected outside the erosional trench (Figure 7). The oxygen concentration increased slightly (up to 3 mg/l) at depths deeper than the minimum layer.

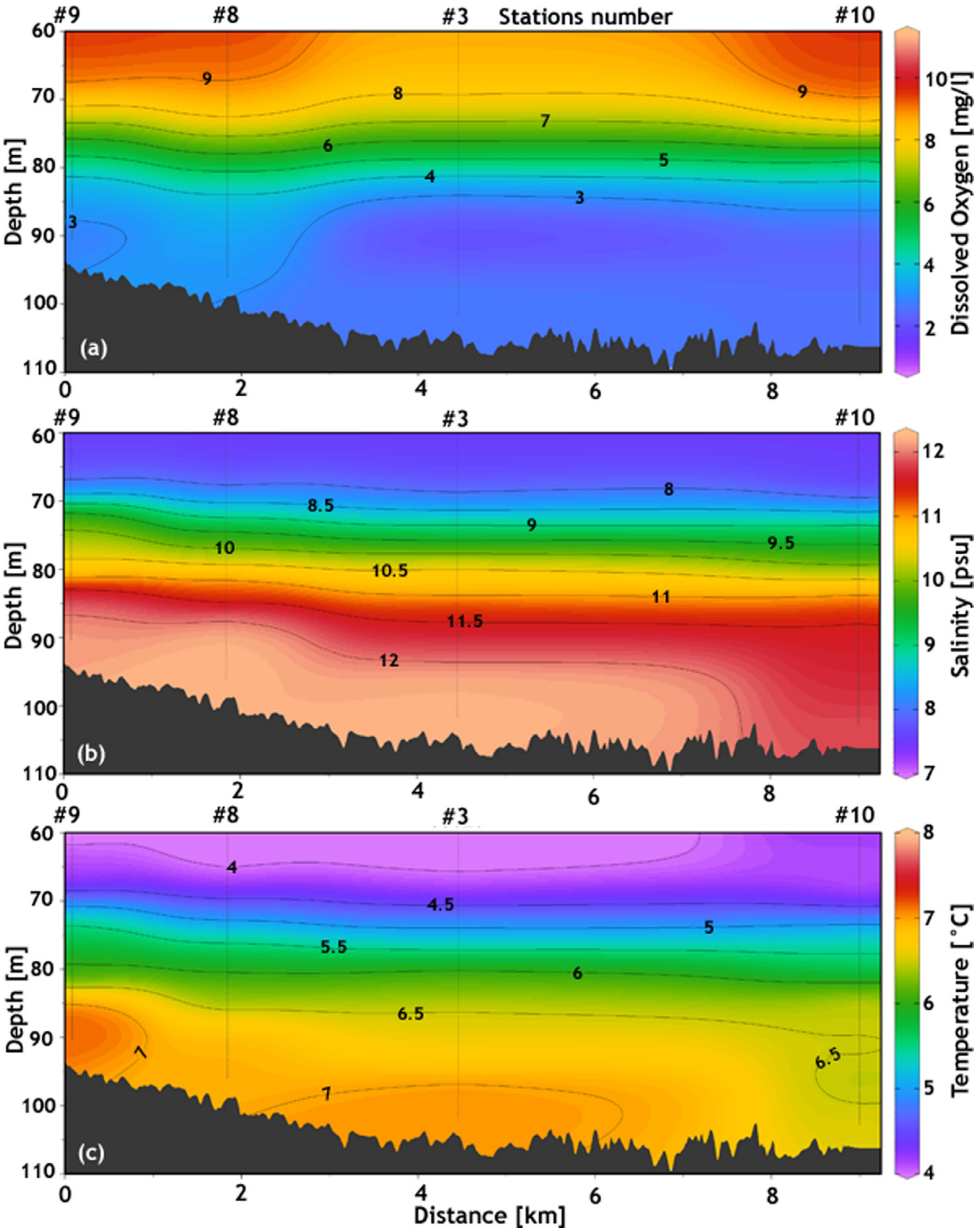

Figure 5 Vertical distribution of dissolved oxygen (a), salinity (b), and temperature (c) over the thalweg of the one of the erosional trench on the Gdańsk-Gotland Sill from south to north in May 2019.

The central part of the Gdańsk Deep (station #36) had elevated oxygen concentrations (up to 3 mg/l or more) at depths of 83—98 m with a maximum at a depth of 92 m (4.74 mg/l) on May 20. The salinity of this layer was 11.58—12.62 psu, the temperature varied from 6.8 to 8.1°C, which proved the development of water advection from the western regions of the sea. There was observed the minimum of oxygen concentration of 2.56 mg/l and a characteristic salinity of 10.90—11.57 psu above the advective waters 73—83 m deep (Figure 7).

The minimum oxygen concentration was detected at depths of 75—80 m on the Gdańsk-Gotland Sill. The halocline with a thickness of 17 m experienced the salinity gradient less pronounced in comparison with the Gdańsk Deep (see Figure 7).

4.2.2. July 2019

The July temperature and salinity in the bottom layer of the erosional trench decreased to 6.4—6.5°C and 11.67—11.89 psu respectively. The concentration of dissolved oxygen increased to 3.5—4.0 mg/l in comparison with measurements in May (Figures 8 and 9).

A minimum oxygen layer with concentrations of less than 1 mg/l was detected above the erosional trench, at depths

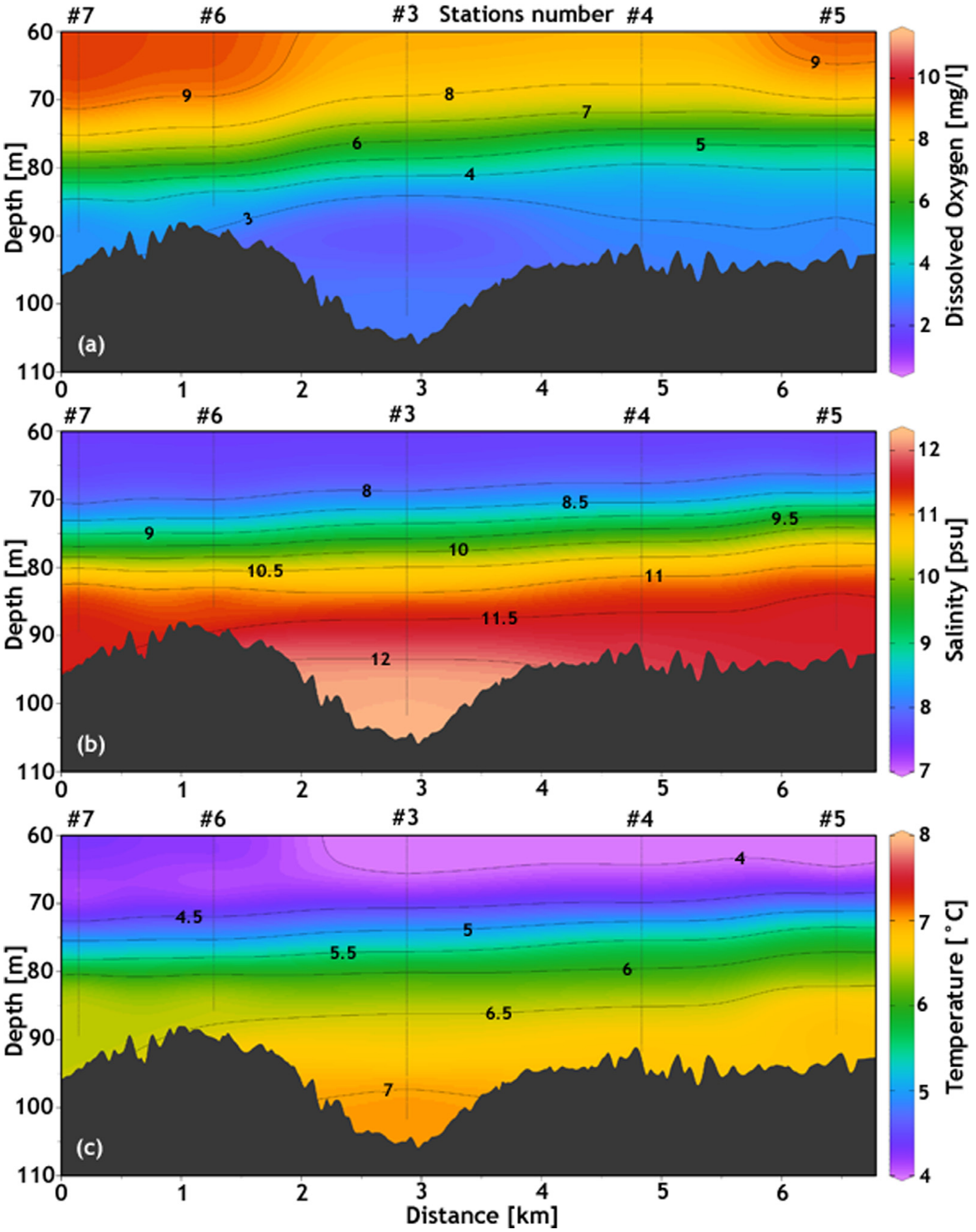

Figure 6 Vertical distribution of dissolved oxygen (a), salinity (b), and temperature (c) in the deep (northern) part of the erosional trench on the Gdańsk-Gotland Sill in May 2019.

of 75—86 m, which spread near the bottom outside the erosional trench (Figure 8a).

The central part of the Gdańsk Deep (station #36) showed the same salinity value in the 86—87 m layer, the dissolved oxygen concentration in which was 4.0—4.2 mg/l. No intermediate minimum of oxygen was detected in the Gdańsk Deep and the Gotland Deep, and its concentration gradually decreased near the bottom (Figure 10).

An oxygen minimum was detected at depths of 73—78 m with an oxygen concentration of about 1 mg/l on the Gdańsk-Gotland Sill. An increase in temperature and the salinity gradient (see Figure 10) was noticed in this layer.

4.3. Bottom currents

The TCM detected the maximum velocities reaching 20 cm/s in the thalweg of the erosional trench (TCM #34, see Figure 3). Due to the Coriolis force, the current deflects toward the right to the eastern slope of the erosional trench, where its maximum velocities are also recorded (TCM #35). On the western slope of the erosional trench (TCM #33) experienced the current velocities did not exceed 5 cm/s, periodically forming a counterflow. In general, the current was directed northward along the slope of the erosional trench. The current ap-

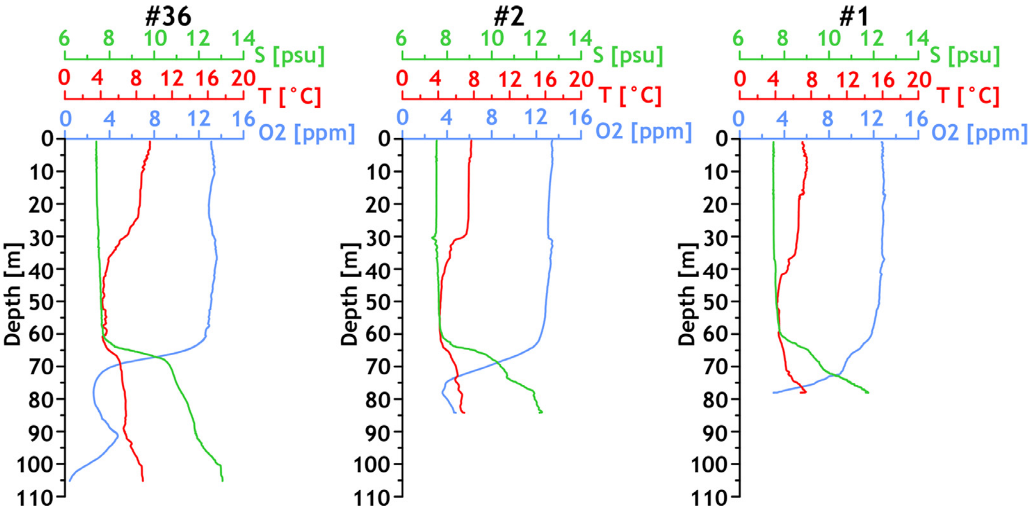

Figure 7 Vertical distribution of temperature, salinity, and dissolved oxygen in the Gdańsk Deep (stations #36 and #1) and on the Gdańsk-Gotland Sill (station #2).

peared to be unstable (Figure 11) at the background station (TCM #32).

4.4. Seabed deposits

Seabed deposits in the erosional trench were mostly dense homogeneous clays of the early stages of the Baltic Sea Basin formation. The clays ranged from grey to reddish in color and contained isolated inclusions of gravel in the horizon of 5—10 cm. The upper layer of 0—5 cm was water-encroached and unconsolidated with a high content of gravel and sand. Modern silts were found only in natural traps of sedimentary material outside the erosional trench at stations #28 and #31 — in the plough marks. They were represented by gray pelitic silts 6—8 cm thick with black fluffy layer 0.5—0.6 cm thick at a depth of about 100 m, and gray aleurite-pelitic silts with an oxidized surface layer at a depth of about 70 m. Depth of 70 m is the boundary of silt accumulation in this area, coinciding with the oxycline and the halocline. The pelite material does not accumulate above this boundary. Fine sediments in plough marks were found exclusively outside the erosional trench, which indicates the absence of the sediment accumulation interfering bottom currents. Thus, the erosional trench turns out to be a washed surface with signs of recent erosion.

4.5. Macrozoobenthos

A total of 25 taxa were found in the macrozoobenthos community in the Study area. Twenty two taxa were identified up to the species level. Three taxa were identified up to the genus level: *Mytilus* spp. *juv.*, *Reophax* spp., and *Cribroelphidium* spp.

For the first time in the investigated part of the South-eastern Baltic Sea, 7 taxa were found: polychaete *Polydora ciliata* (Johnston, 1838), amphipod *Dyopedos monacanthus* (Metzger, 1875), ostracod *Palmoconcha laevata* (Norman, 1865), hydroids *Halitholus yoldiaearcticae* (Birula, 1897), *Campanulina pumila* (Clark, 1875), *Opercularella lacerata* (Johnston, 1847), and *Melicertum octocostatum* (M. Sars, 1835) (Gusev and Rudinskaya, 2017; Ponomarenko and Krechik, 2018).

All first recorded species, as well as polychaete *Scoloplos armiger* (Müller, 1776), halacarid *Halacarellus capuzinus* (Lohmann, 1893), ostracod *Paracyprideis fennica* (Hirschmann, 1909), bivalve *Astarte borealis* (Schumacher, 1817), nemertine *Lineus ruber* (Müller, 1774), foraminifera *Reophax* spp., and *Cribroelphidium* spp. appear to be indicators of high salinity waters that enter the Baltic Sea with the North Sea inflows.

Significant differences in macrozoobenthos within the erosional trench and outside it were manifested in species diversity, abundance and biomass. Twenty two species were found in the erosional trench (stations ##23—27), and 15 species were found outside its boundaries (stations ##28—31). *P. ciliata, H. capuzinus, D. monacanthus, P. laevata, C. pumila, O. lacerata, M. octocostatum, A. borealis, L. ruber*, and *Cribroelphidium* spp. were recorded in the erosional trench only, and *Hediste diversicolor* (O.F. Müller, 1776), *Pygospio elegans* (Claparède, 1863) and *Candona neglecta* (Baird, 1845) were found outside the erosional trench. Abundance and biomass of macrozoobenthos in the erosional trench (796 ± 123 ind./m^2 and 23.93 ± 11.86 g/m^2) significantly exceeded the similar values outside its boundaries (250 ± 82 ind./m^2 and 2.93 ± 2.35 g/m^2) due to the development of bivalves (Figure 12).

The predominant species of polychaetes in the erosional trench and outside its boundaries appeared to be *S. armiger*, whose abundance was 38% (301 ind./m^2) and 29% (73 ind./m^2), respectively. In the erosional trench, bivalves dominated the biomass. Out of the 81.2% of the total number of bivalves, 80.2% (19.2 g/m^2) of the relative biomass was formed by *A. borealis* species. Outside the erosional trench, hydroids prevailed. *H. yoldiaearcticae* and *Gonothyraea loveni* (Allman, 1859) turned out to be the two dominated species of hydroids. The biomass of *G. loveni* in the erosional trench and outside it was approximately at the same level of 1.63 g/m^2 and 1.43 g/m^2, respectively. The biomass of *H. yoldiaearcticae* species in the erosional trench (2.49 g/m^2) was almost two times higher than outside it (1.30 g/m^2).

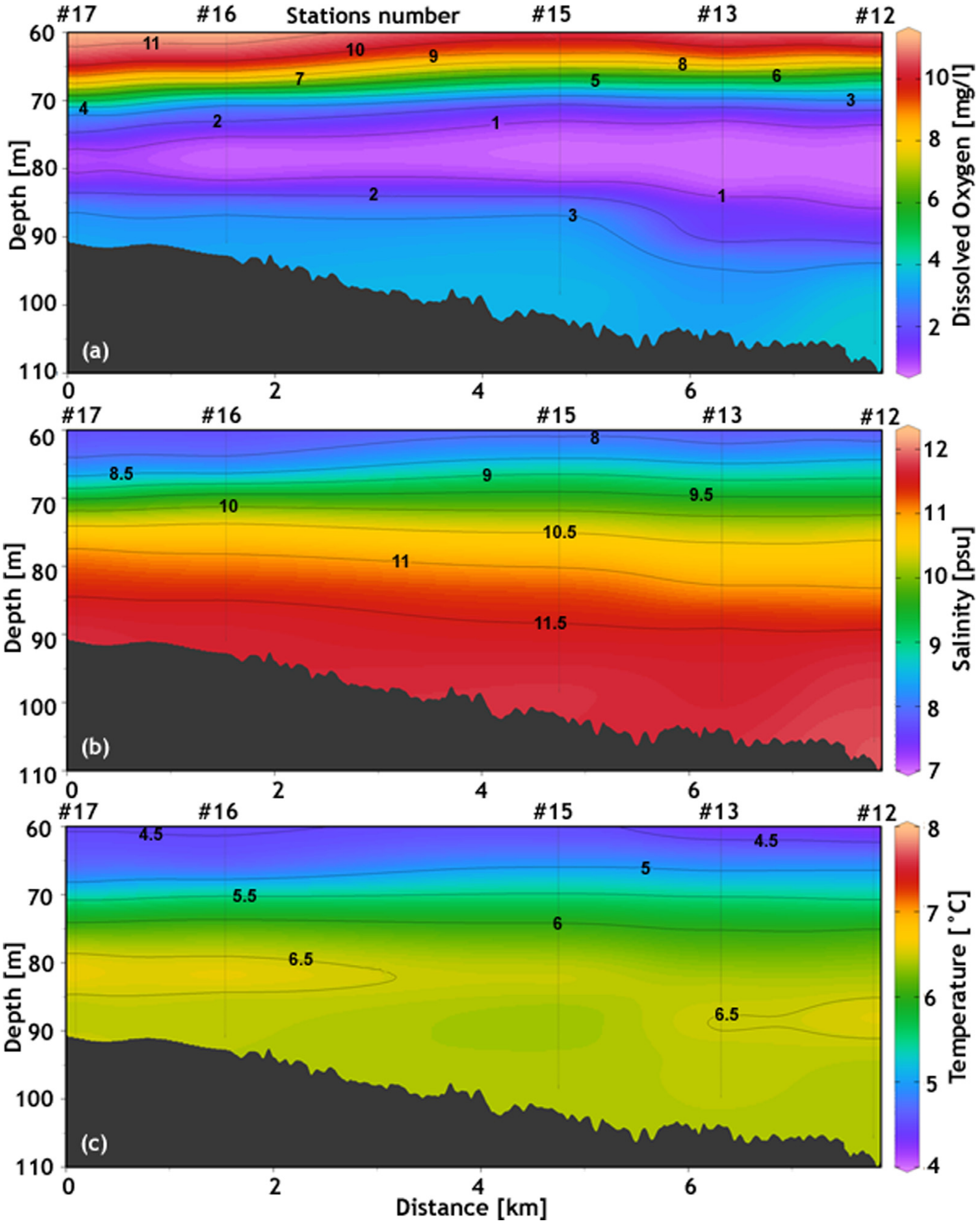

Figure 8 Vertical distribution of dissolved oxygen (a), salinity (b), and temperature (c) over the thalweg of the erosional trench on the Gdańsk-Gotland Sill from south to north in July 2019.

5. Discussion

5.1. Lithological and geomorphological evidences of the hydrodynamics in the erosional trench

The absence of pelitic material in the plough marks in the erosional trench indicates intensive lithodynamic activity. Bottom currents here did not allow the accumulation of modern sediments, in contrast to the adjacent parts of the bottom where conditions for the accumulation of sediments occurred. Apparently, outside the erosional trench, the currents are either rarer or weaker.

The originating of icebergs from the ice shelves of Fennoscandia was possible no later than Ancylus Lake stage (Uscinowicz, 2011), which determine the age of the plough marks as more than ten thousand years. After their formation up to the present time, the slopes of the plough marks have flattened along the thalweg of the erosional trench, which may indicate that this trench was involved in the water exchange for the long period of time.

5.2. Pathways of water exchange in the bottom layer on the Gdańsk-Gotland Sill

Vertical distribution of temperature, salinity, and dissolved oxygen on the Gdańsk-Gotland Sill in May, 2019 indicated the entry of near-bottom water from the Gdańsk Deep due to advective ponding from the Słupsk Furrow. A minimum

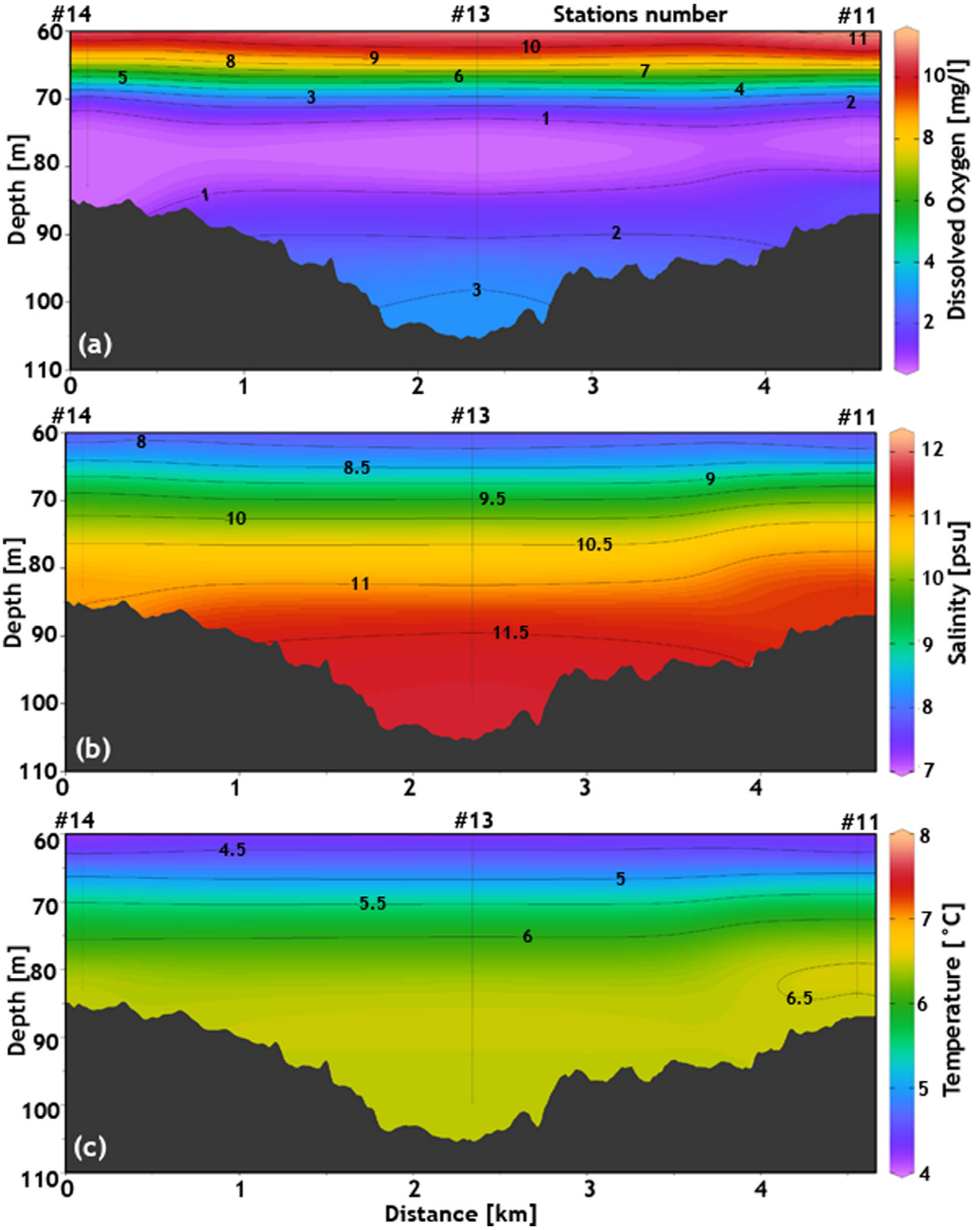

Figure 9 Vertical distribution of dissolved oxygen (a), salinity (b), and temperature (c) in the deep (northern) part of the erosional trench in July 2019.

of oxygen was observed both in the Gdańsk Deep and on the Gdańsk-Gotland Sill. The local oxygen minimum formed above the erosional trench at a depth of 90 m is likely to be a consequence of the involvement of this minimum by the flow along the erosional trench. A step-like vertical structure of salinity distribution in the bottom layer to the south of the erosional trench (station #2) indicates the presence of a zone of mixing of the bottom water from the Gdańsk Deep with the water from the Słupsk Furrow (see Figure 7). Due to salinity in the bottom layer of the erosional trench, the initial horizon from the Gdańsk Deep could be about 95 m.

The advection weakening in the Gdańsk Deep in July led to weakening of the overflow over the sill and reducing the role of the Gdańsk Deep. Vertical distribution of oxygen in the erosional trench and absence of an intermediate oxygen minimum in the Gdańsk Deep indicate the inflow of aerated water in the bottom layer from the Słupsk Furrow along the Gdańsk-Gotland Sill.

Thus, it is obvious that in the absence of MBIs during the development of advection of waters into the Gdańsk Deep, the oxygen regime in the erosional trench deteriorates. Oxygen conditions are restored when advection in the Gdańsk Deep decreases and bottom water flows from the Słupsk Furrow along the Gdańsk-Gotland Sill.

Assumptions that the water could have come from the Gotland Deep turn out to contradict the data obtained on

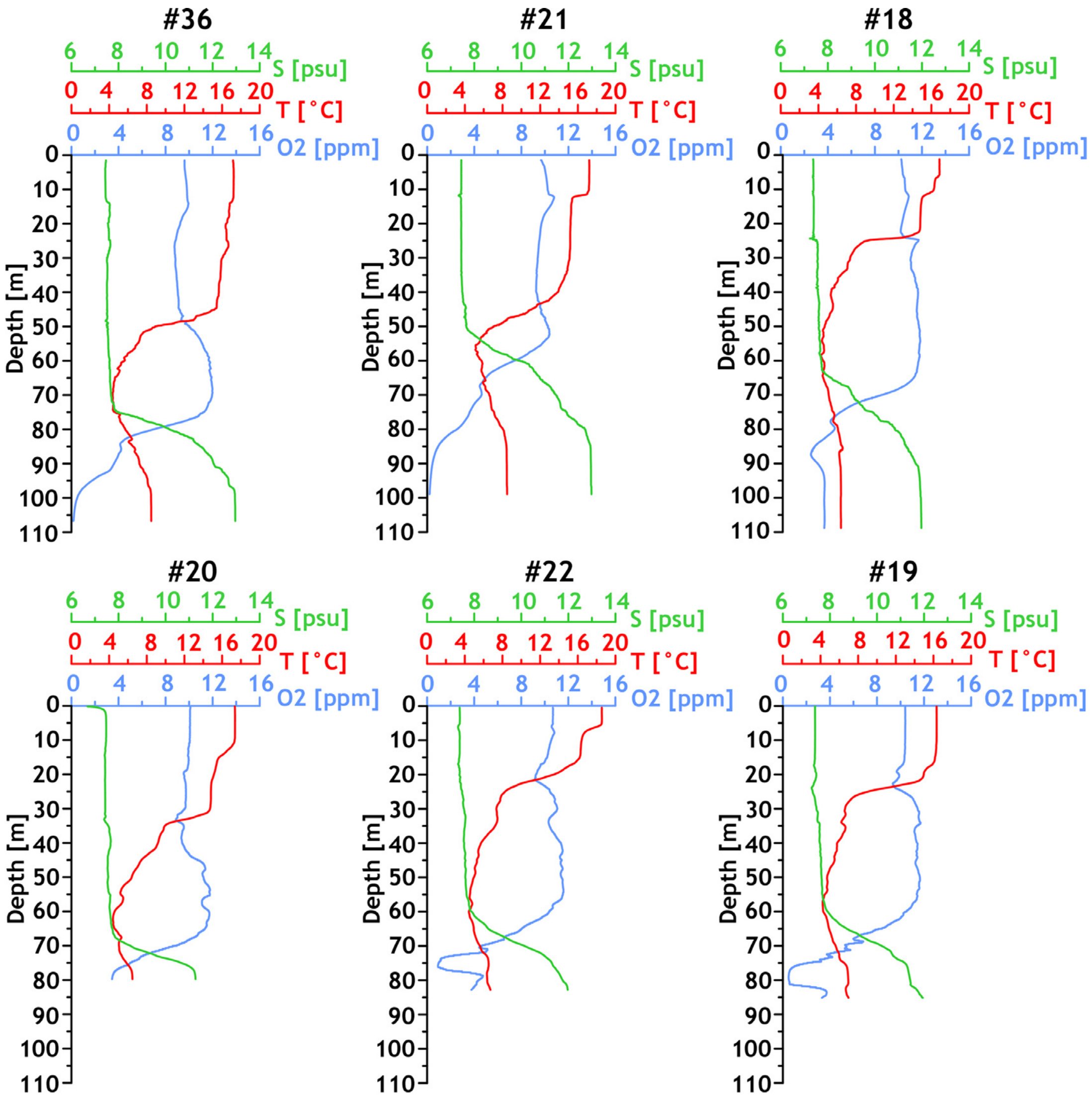

Figure 10 Vertical distribution of temperature, salinity, and dissolved oxygen in the Gdańsk Deep and on the Gdańsk-Gotland Sill.

TCM and CTD. The descending water in the erosional trench had a higher density than the water on identical horizons in the Gotland Deep.

Having filled the bottom recesses on the sill, the water from the Słupsk Furrow flows further in two main pathways (Figure 13). The first pathway passes through the southern part of the sill and leads to the Gdańsk Deep. At the same time, the reverse flow from the Gdańsk Deep in this area is improbable due to the water ponding from the Słupsk Furrow. The seabed topography of the sill and the general circulation in the Gdańsk Deep suggest that displaced bottom water flows through the north-eastern part of the sill (see Figure 13).

The second pathway passes along the sill to the north-east and further into the Gotland Deep through the erosional trench. The U-shaped form of the Gdańsk-Gotland Sill prevents the denser water from rolling into deep water basins. The water from the Słupsk Furrow is most likely to move along relatively small troughs in the sill, in a thin near-bottom layer. Moreover, the density of this water appears to be higher than the density of the water of the Gdańsk Deep and the Gotland Deep located at the same depth. Therefore, getting into the erosional trench, the water from the Słupsk Furrow is pressed to the bottom.

To the south of the erosional trench, advective water, extruded from the Gdańsk Deep, also arrives at the sill (see Figure 13). This is where the water mixing zone is located.

The increased salinity on the Gdańsk-Gotland Sill was observed by (Ponomarenko and Krechik, 2018), that indicates the frequent water exchange through the Gdańsk-Gotland Sill.

It was the periodic water supply from the Słupsk Furrow that could have led to the formation of the unique habitats. Ten macrozoobenthos species inhabited the erosional trench only (*P. ciliata, H. capuzinus, D. monacanthus, P. laevata, C. pumila, O. lacerate, M. octocostatum, A. borealis, L. ruber*, and *Cribroelphidium* spp.). These organisms are not found in the Gdańsk Deep (Dziaduch, 2007; Gusev and Rudinskaya, 2014; Mańkowski, 1961; Mulicki, 1957). Stable distribution areas of *A. borealis, D. monacanthus,*

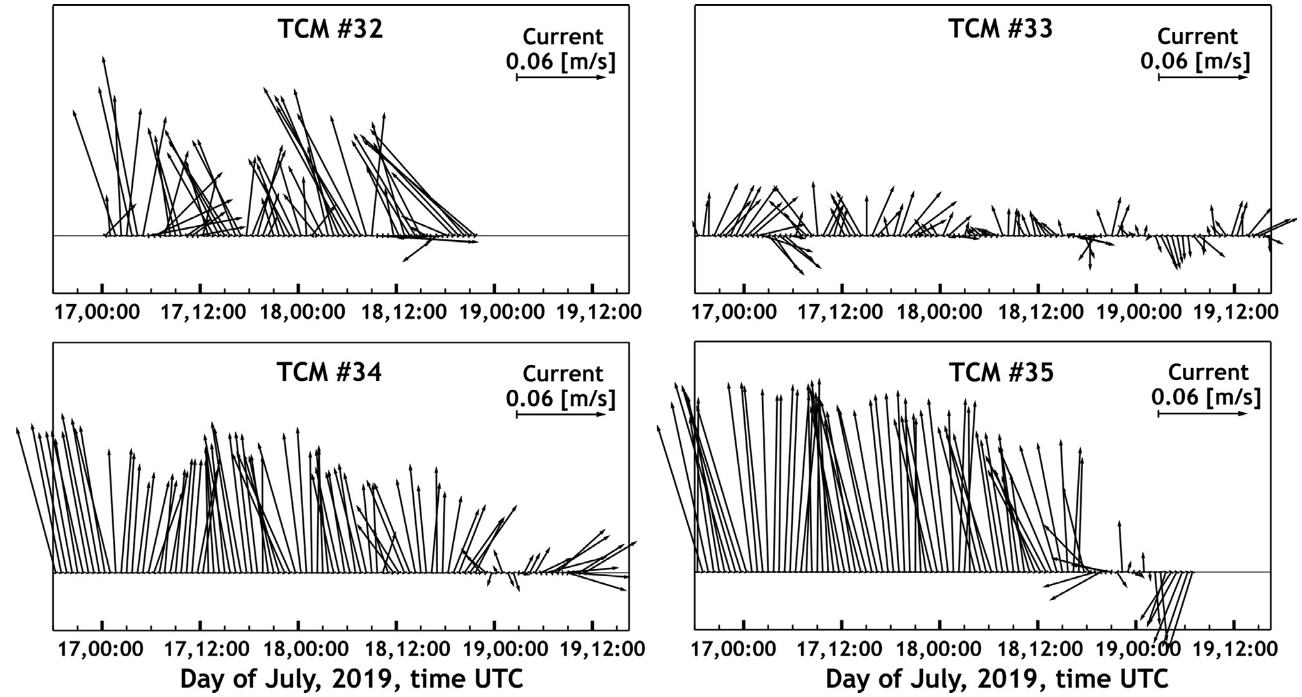

Figure 11 Results of bottom currents velocity measurements, located in the erosional trench on the Gdańsk-Gotland Sill, May 2019.

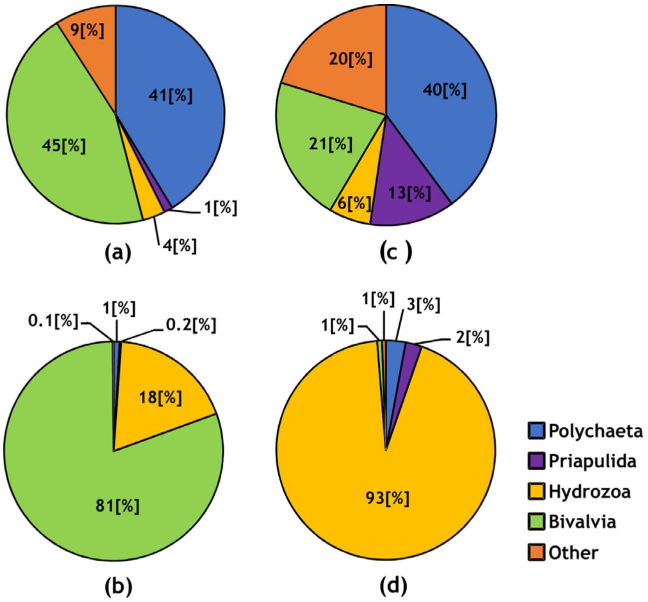

Figure 12 Relative abundance and biomass of the main macrozoobenthos groups in the erosional trench (a — abundance and b — biomass) and outside its boundaries (c — abundance and d — biomass).

and *M. octocostatum* are located along the pathway of the North Sea waters (see Figure 13) (Dziaduch, 2007; Mańkowski, 1961; Mulicki, 1957).

During periods when there is no advection through the Gdańsk Deep, the volume of the bottom layer water coming through the Gdańsk-Gotland Sill from the Słupsk Furrow is insufficient for spreading to the bottom areas adjacent to the erosional trench, that is why the water exchange occurs mainly within the erosional trench.

Sedentary bottom-dwelling organisms, such as bivalves and polychaetes, are usually more tolerant of oxygen-deficient conditions (Diaz and Rosenberg, 1995). In the Baltic Sea, the bivalve *A. borealis* is considered to be the most tolerant species of the conditions of complete oxygen absence. For these bivalves, it was shown that in the conditions of oxygen absence, 50% of individuals die (Lt_{50}) in 69 days (Janas et al., 2017), and 100% death rate (Lt_{100}) is observed in 192 days (Theede et al., 1969). It was previously shown that *A. borealis* was found under hypoxia conditions (1.921 mlO_2/l, 10.77 psu, 4.81°C and 95 m) in 2010 (Gusev and Rudinskaya, 2014).

Favorable oxygen conditions in the erosional trench exist on a fairly long basis. The bottom layers in the erosional trench are well ventilated during periods of water flow from the Słupsk Furrow along the Gdańsk-Gotland Sill. Thus, bivalve *A. borealis* were found at five stations along the most probable direction of the current (stations ##23—27). *A. borealis* was represented by juveniles as well as large individuals with shell lengths of up to 15—22 mm, which corresponds to the age of 5—9 years (Gusev and Rudinskaya, 2014). The rest of the bivalve species were represented by young or juvenile individuals. Therefore, they can be considered indicators of the recent flow along the thalweg of the erosional trench from the Słupsk Furrow, which was also shown earlier for *M. octocostatum* and *D. monacanthus* in the waters of Poland (Dziaduch, 2007; Gusev and Rudinskaya, 2014; Mańkowski, 1961; Mulicki, 1957; Ponomarenko and Krechik, 2018).

The absence of large living organisms less resistant to the development of anaerobic conditions is determined by

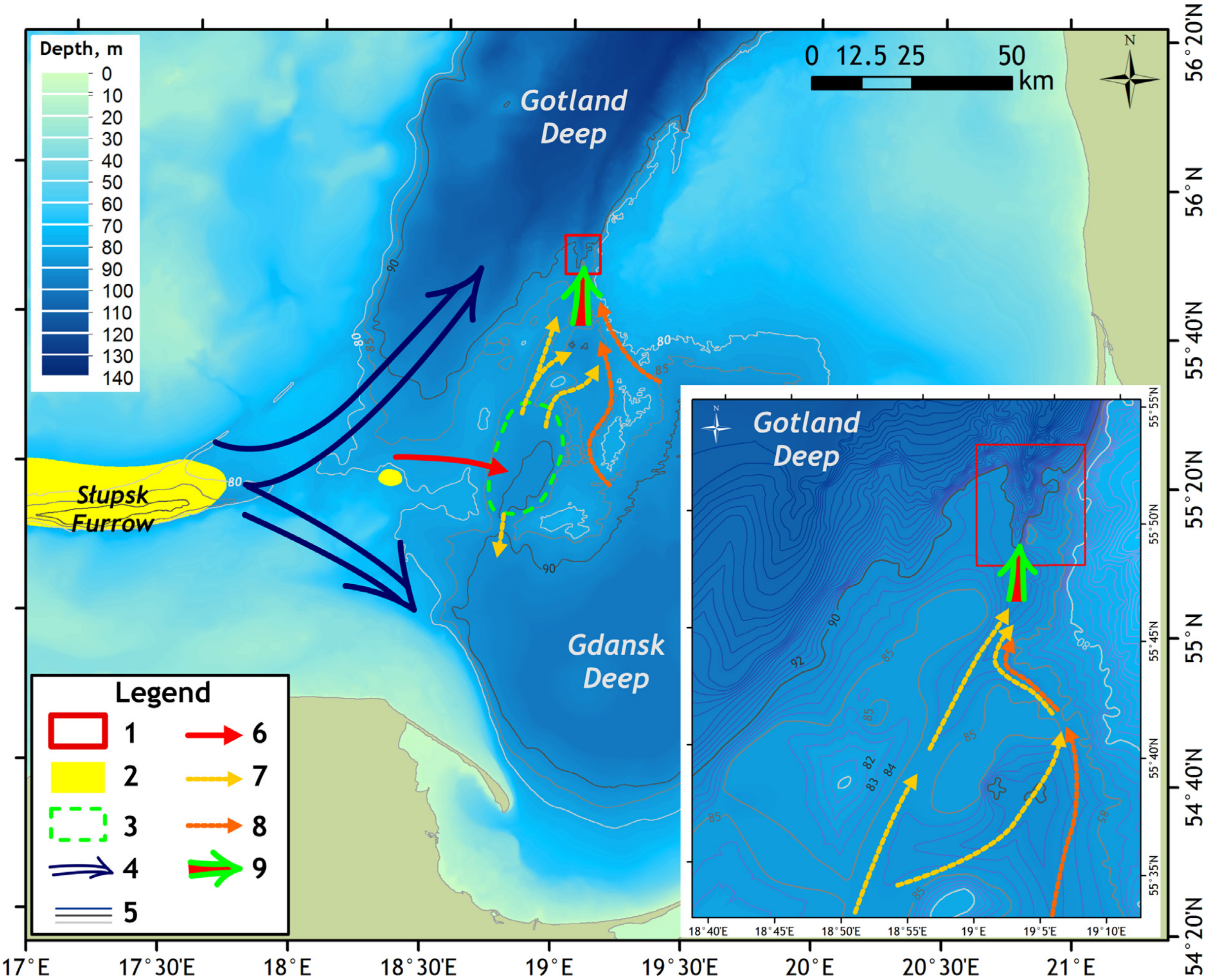

Figure 13 Water exchange pattern over the Gdańsk-Gotland Sill. Legend: 1 — Study area; 2 — Distribution areas of *Astarte borealis, Dyopedos monacanthus, Melicertum octocostatum* according to Dziaduch (2007), Mańkowski (1961), Mulicki (1957); 3 — Zone of water inflow and accumulation from the Słupsk Furrow; 4 — Main distribution routes of the North Sea waters; 5 — Isobaths [m]; 6 — The most probable pathway of advective water distribution from the Słupsk Furrow; 7 — One of the probable pathways of spreading advective water from the Słupsk Furrow; 8 — Probable pathways of water distribution from the Gdańsk Deep; 9 — Flow pathway through the erosional trench. The inset shows the detailed probable pathways of the bottom water flow through the erosional trench. (Seabed relief: Gelumbauskaite et al., 1999.)

episodic (pulse) penetration of the water from the Słupsk Furrow. The change of aerobic conditions to anaerobic ones is likely to occur under the negative influence of the waters of the Gdańsk Deep during the advection development.

6. Conclusion

The orientation of the erosional trench together with the absence of recent sediments, the development of the recent erosional surface and the biodiversity of benthic organisms suggest the additional, poorly studied, water exchange pathway through the Gdańsk-Gotland Sill. In the absence of the MBIs events, the advective water exchange determines the formation of bottom conditions and the occurrence of bottom organisms in the erosional trench. The features of the seabed topography lead to the fact that during periods of advection development through the Słupsk Furrow, the water partly enters the Gdańsk Deep and partly continues to move along the Gdańsk-Gotland Sill. The waters, coming through the Gdańsk-Gotland Sill directly from the Słupsk Furrow, and the waters, impounded from the Gdańsk Deep, interact at the base of the “bottle neck” after which they move along the erosional trench into the Gotland Deep. Oxygen-free conditions occur during periods of advection development to the Gdańsk Deep. The existing water exchange conditions made it possible for communities of benthic organisms to form and live for a long time in the erosional trench, tracing the main pathway of inflow waters to the Baltic Sea sub-basins.

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