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Distribution of floating marine macro-litter in relation to oceanographic characteristics in the Russian Arctic Seas

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Abstract

The main objectives of this work were the acquisition of new data on floating marine macro litter (FMML) and natural floating objects in the Arctic seas, an initial assessment of the level of pollution by FMML and an analysis of potential sources. The results of this study present the first data on FMML distribution in Russian Arctic shelf seas in relation to oceanographic conditions (i.e. position of water masses of different origin as described by temperature, salinity, dissolved oxygen and pH). The main finding of this study is that FMML was found only in the water of Atlantic origin, inflowing from the Barents Sea, where FMML average density on the observed transects was 0.92 items/ km^2. Eastern parts of the study, Kara Sea, Laptev Sea and East Siberian Sea were practically free from FMML. No input from rivers was detected, at least in autumn, when the observations were performed.

Key words:

marine pollution, floating marine macro litter, Arctic, marine environmental monitoring

Introduction

Floating marine macro litter (FMML) represents the mobile fraction (> 2.5 cm) of litter at sea and is available for long rage transportation by currents, winds and waves (Andrady, 2015). As a direct threat to marine wildlife and a precursor of marine micro litter (Galgani et al. 2013) it is one of the most important pollution problems affecting the World Oceans nowadays. Marine litter originates from numerous land-based and at-sea sources (PAME, 2019). Besides the consequences concerning harm to marine wildlife by ingestion or entanglement, there can be other impacts, such as e.g. negative visual and aesthetic effects (NOAA MDP, 2014a) (NOAA MDP, 2014b), hazards to navigation (Johnson, 2001), acting as a pathway or vehicle for invasive species (Ruiz et al. 1997) (USEPA, 2012) or posing a chemical hazard due to the release of organic contaminants from plastic debris (Van et al. 2011) (Rochman et al. 2013). Debris may sink to the bottom, be washed up on beaches and shorelines or decompose into microplastics (< 5 mm), but a relevant fraction can remain floating at sea surface for long periods of time and could be transported over great distances (NOAA, 2016).

The Arctic Ocean is a vulnerable environment, with a unique ecosystem that is subject to increasing pressures through climate change and affected by related issues such as increased human access and reduction in ice coverage. Marine litter is also in the Arctic a topic of growing concern, but data on Arctic marine litter are scarce and do not allow an evaluation of litter pathways and sinks in the Arctic Ocean (Halsband and Herzke, 2019). The lack of data concerns also floating macrolitter and includes in particular also the coastal areas along the eastern Arctic coast and the related watersheds. Such information is needed in order to identify and implement measures for the mitigation of marine litter (PAME, 2019).

General oceanic circulation patterns, particularly surface currents, greatly affect the redistribution and accumulation of marine debris in the world's oceans (Moore et al.2001). Debris in the near-surface ocean can accumulate in so-called "great ocean garbage patches". There are five major garbage patches, one in each of the convergence zones in the five subtropical gyres (Maximenko et al., 2012) and one additional patch has been predicted for the Barents Sea (Van Sebille et al., 2012). Actually, available observations in the Arctic are limited to the Barents Sea (Grøsvik et al., 2018) and northern parts of the Siberian Seas, studied in the Tara Ocean circumpolar expedtition where it was found that plastic debris was scarce or absent in most of the studied Arctic waters (Cózar et al., 2017), except the Barents Sea. There are availailable some estimates about the microplastics in different Arctic regions (Tirelli et al., n.d.; Yakushev et al., n.d.), but no studies had so far been made for the floating litter in the Russian Siberian Seas.

The objective of this work was to assess the level of pollution by FMML in the Russian Arctic Seas: the Barents Sea, the Kara Sea, the Laptev Sea and the East Siberian Sea in order to analyse its distribution together with oceanographic parameters.

Materials and Methods

The surveys were organised during the 82d cruise of the R/V Akademik Mstislav Keldysh in September-November 2020 in the Barents, Kara, Laptev, and East-Siberian Sea (Fig. 1).

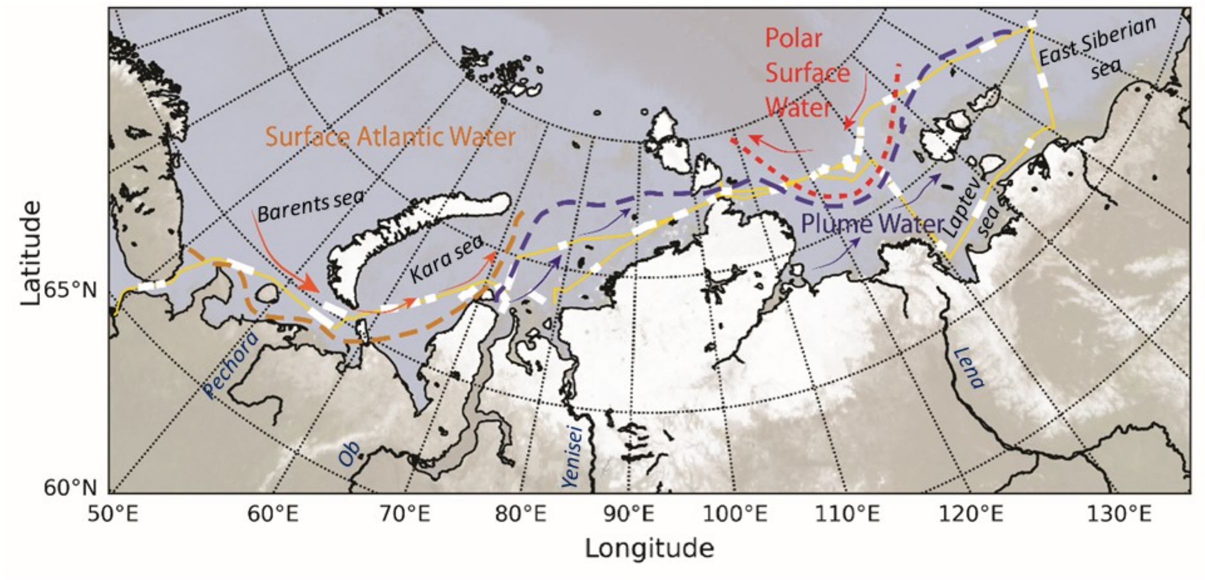
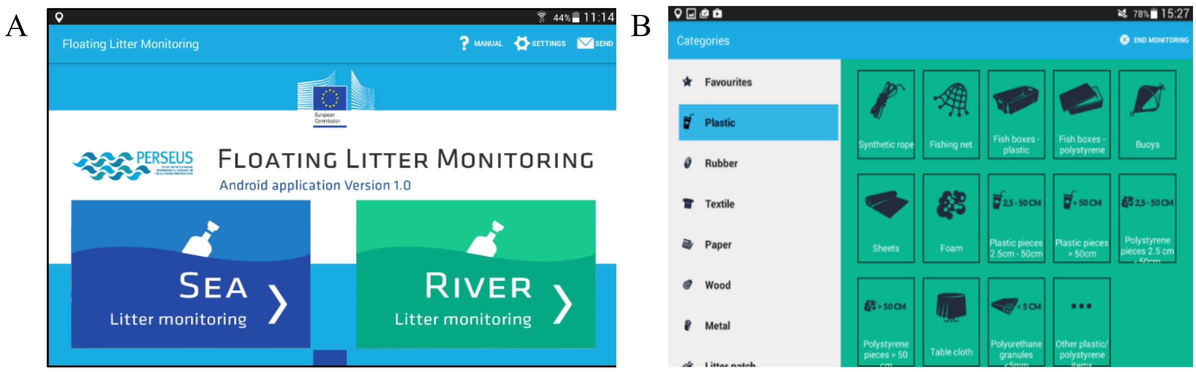


Fig. 1. Observation efforts during the 82d cruise of R/V Akademik Mstislav Keldysh. GPS track is shown as yellow line, the position of observed transects are shown as white lines. Dashed lines indicate boundaries between the average extention of surface water masses in the study area during the cruise (labels), arrows indicate prevailing currents.

The investigation of FMML in the current study was based on visual observations performed by 6 trained observers standing on the bow deck of the ship and documenting litter items passing by in a determined strip within a fixed distance (the width of the transect corridor) (Arcangeli et al., 2020).

Observation position (4 m height) and observed transect width (15 m) were chosen in order to ensure the detecting of minimum target size objects (larger than 2.5 cm in the longest dimension). Since harmonization of reported item classes and size information is important for comparison of results between different surveys and areas, a mobile computer app developed by the European Commission JRC was used as tool for harmonized monitoring. The Floating Litter Monitoring Application (González-Fernández and Hanke, 2017) provides a common approach for obtaining comparable results from different expeditions, regions and seas. This App facilitates the recording of metadata such as positions, transect information, ship speed, etc. This method was previously applied during a series of surveys on the Black Sea (Pogojeva et al. 2020). The application could be employed also in high latitude regions, despite low temperatures. Observation periods were limited to one hour, avoiding observer’s fatigue and due to challenging environmental conditions.



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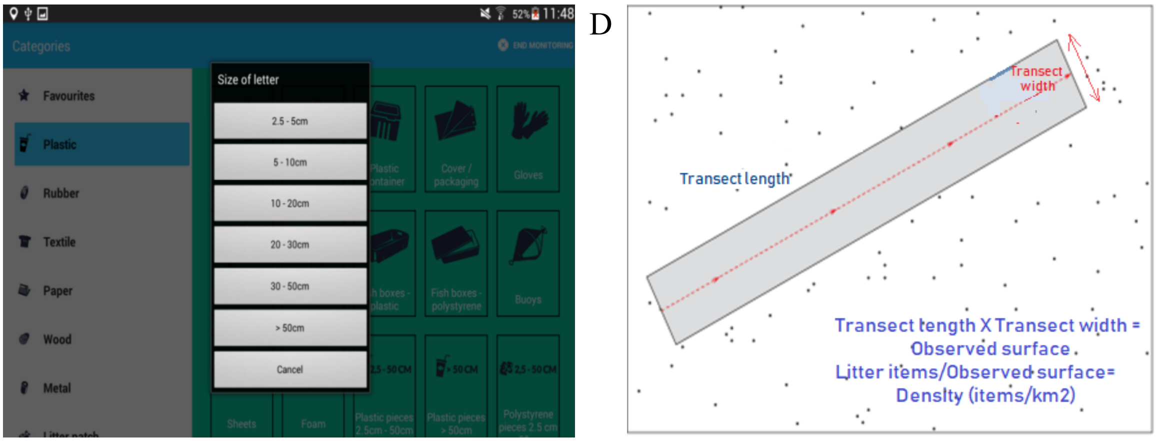

Fig. 2. JRC Floating Litter Tablet App interface (A), choosing a type of litter (B), choosing a litter size range (C), a principle of operation and estimation of litter dencity (D).

The JRC App supports surface observations both at sea and in rivers (Fig.2, A). During the monitoring sessions different litter categories/items, organized by materials, can be directly selected (Fig.2, B) and the estimated size range of litter items be recorded through a pop-up menu (Fig.2, C). Documented items include also natural objects (i.e. feathers, driftwood) as supporting information.

Data are automatically saved, together with the GPS coordinates, in the monitoring track. The track with the georeferenced litter items and the supporting metadata can then be exported as .csv file.

The identified FMML objects have been categorised according to the Joint List of Litter Categories, which enables an unambiguous identification and reporting of macro litter items across monitoring frameworks (Fleet et al. 2020). This list has been developed in the context of the implementation of the EU Marine Strategy Framework Directive in collaboration with Regional Sea Conventions in the shared marine basins.

The observation of floating marine litter is much depending on the observation conditions, in particular on the sea state and wind speed (Galgani et al 2013), which is particular relevant in Arctic in automn. In the cruise the observations were often interrupted because of the glassy foam on the seasurface which makes floating objects indistinguishable. This feature was not always connected with concrete sea state by Beaufort but could be a combination of factors. Fogs and cloudiness also often affected the observation conditions. In all cases the observations were stopped until conditions improved. It was also necessary to stop the observations during ice formation in the Enisey River estuary.

A ship-mounted pump-through system with an intake located at a depth of 2.5 m on the right side of the vessel was used to support interpretation of debris distribution data. The water flow within the pump-through system was provided by a 900-watt onboard impeller pump (3200 l/h) (Kosmach, 2015). The system was equipped with a thermosalinograph (SBE 21 SeaCAT) that was continuously recording salinity and temperature of subsurface seawater. Besides this PyroScience FireSting pro fiber-based optical T, DO and pH sensors, recording concentrations of dissolved oxygen (µM) and pH (total scale), were installed. Before the cruise and after the cruise the sensors were calibrated. The pump-through system could not be used after a collision with ice in the Enisey River estuary on a backward route, which didn't affect the collection of

FMML data but hindered the interpretation of it's distribution in correlation with oceanographic characteristics on a backward route.

Results

Oceanographic conditions

During the cruise the ship crossed the major surface water masses of the Siberian Arctic in the ice-free season. These water masses have different thermohaline characteristics, as well as different typical concentrations of dissolved oxygen and pH (Fig. 3, 4). The Barents Sea and the western part of the Kara Sea were dominated by the saline (30-32 psu) and warm (6-10 $^{\circ}$C) Atlantic Surface Water. This water was characterized by a low concentration of oxygen (200-240 uM) and high pH (7.95-8.00). Surface water in the central and western Kara Sea, the Laptev Sea, and the East-Siberian Sea is formed by either the saline (25-30 psu) Polar Surface Water, or low-salinity (<25 psu) surface layer formed by mixing of river discharge with sea water. The surface layer with freshwater influence consists of an inner part with the lowest salinities (<15 psu) and short residence time of riverine water (order of several weeks) and outer part with intermediate salinities (15-25 psu) and a long residence time of riverine water (order of several months) (Osadchiev, 2020). The main freshwater discharge to the study area is provided by the Ob and Yenisei rivers flowing into the Kara Sea, and the Lena River flowing into the Laptev Sea.

The near river mouth parts of the Ob-Yenisei plume in the Kara Sea and of the Lena plume in the Laptev Sea were characterized by low concentrations of dissolved oxygen (260-280 µM), and a low pH (<7.8). In particular, the minimum pH value (7.50) was found in vicinity of the Lena Delta. Low pH in the freshwater is induced by large quantities of CO_2 in river water, which is the important mechanism of acidification of sea water in the Eastern Arctic (Semiletov et al., 2016). At the same time, these low pH regions could potentially contain litter that was recently (several days) brought to the Sea with the rivers. The Polar Surface Water is characterized by high concentrations of dissolved oxygen (oxygen 270-280 µM) and high pH (7.90-7-95).

Litter distributions

The main results of FMML investigations during the cruise are shown in Table 1.

Table 1. The main results of FMML investigations during the cruise.

Transects (observation sessions)	*115*
Hours of observations	87
Length of transects	2228 km
Covered observation area	33 km^2
Average transect length	15.1 km km, SD = 17.3 km
Average transect area	0.29 km^2
FMML density range	0.0-7.97 items/km^2

FMML density average West from the Gulf of Ob (57 transects)	0.92 items/km^2,
FMML density average East from the Gulf of Ob (58 transects)	0.002 items/km^2
Natural objects density range	0.0-1536 items/km^2
Natural objects average West from the Gulf of Ob (57 transects)	108.25 items/km^2,
Natural objects average East from the Gulf of Ob (58 transects)	0.29 items/km^2
Total FMML and Natural objects	634 items
Litter objects	10 Plastic pieces 2.5-50 cm 2 Plastic bottle 10-50 cm 2 Cover / packaging 10-20 cm 2 Plastic containers 20-50 cm 1 Synthetic Rope >50 cm 1 Bag 20-30 cm
Natural objects	301 Jellyfish 2.5-50 cm 223 Other natural objects (mostly seaweed) 2.5-50 cm 68 Feathers 2.5-30 cm 23 Driftwood 2.5-50 cm 3 Dead fish 2.5-10 cm
Plastic item categories percentage of total items	2.8 %

The results of the floating debris observations are shown in Fig. 3. FMML included plastic pieces, bottles, packaging material, synthetic rope and plastic containers (Table 1). The maximum density of FMML was 7.97 items/km^2 (Fig. 3) and the maximum density of natural objects was 1536 items/km^2 (Fig. 4).

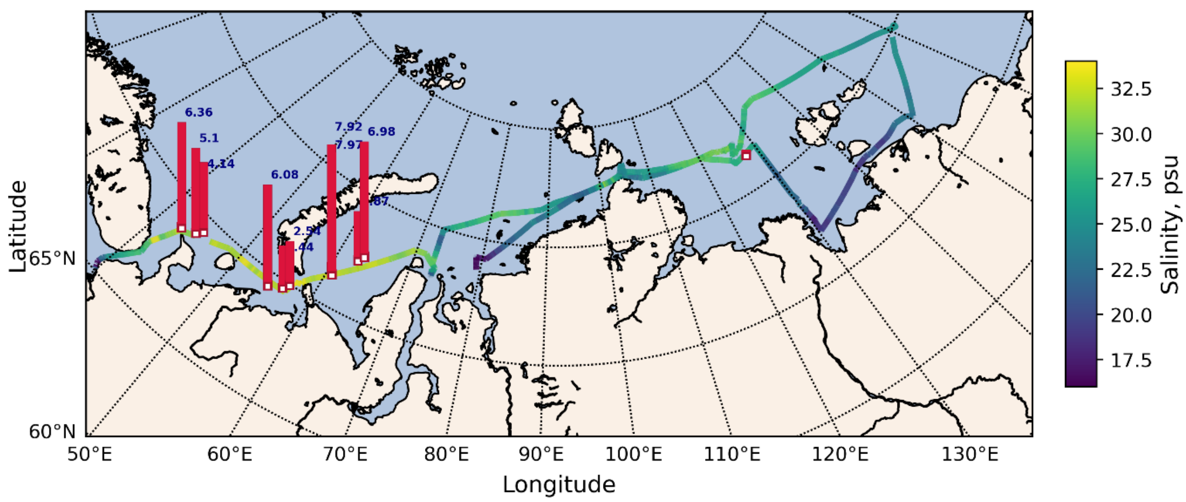

Fig. 3. Schematic map representing salinity, psu, (multicoloured line) in the surface layer along the route and abundance of FMML (items/km^2) (red bars). Red empty squares show positions of the transects with at least one FMML object. Empty transects are not shown.

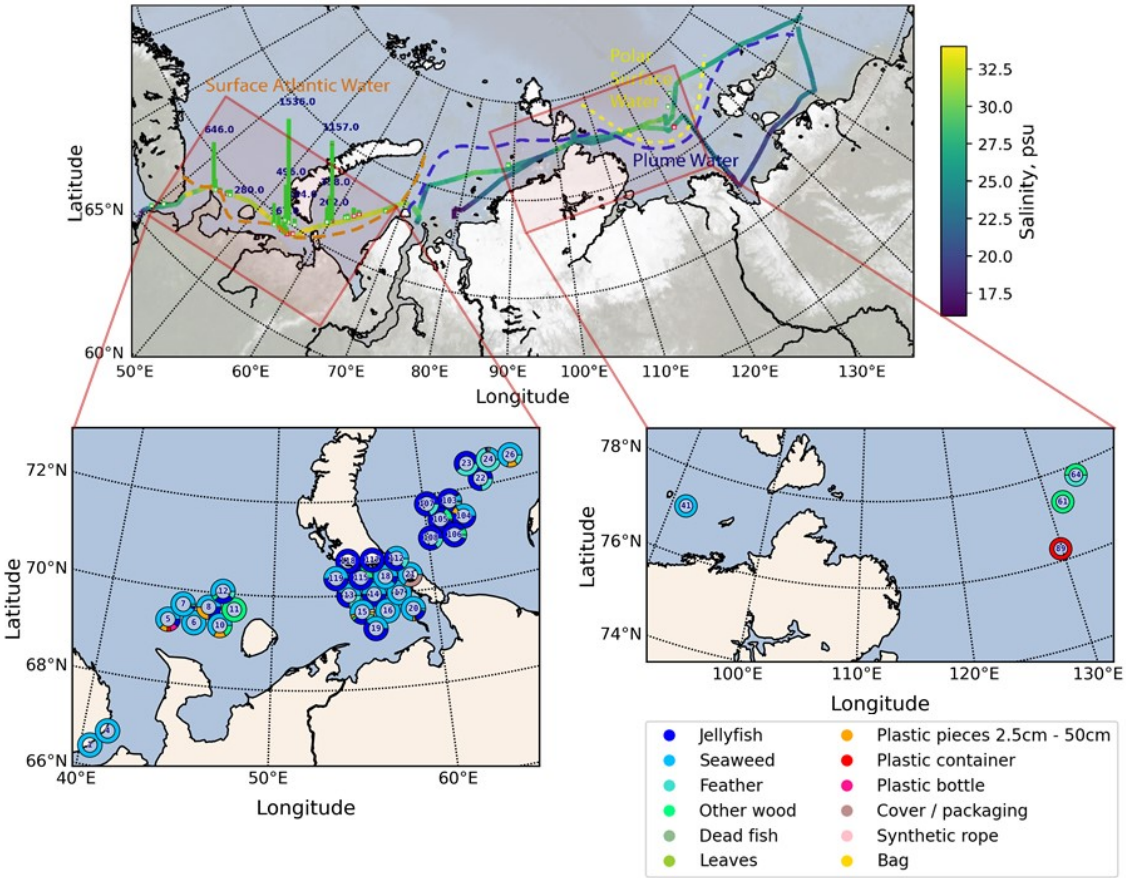

Fig. 4. Schematic map representing salinity, psu, (multicoloured line) in the surface layer along the route and abundance of the natural objects (items/km^2) (green bars). Green empty squares show position of transects with at least one natural object, red empty squares show positions of the transects with at least one FMML object. Empty transects are not shown.

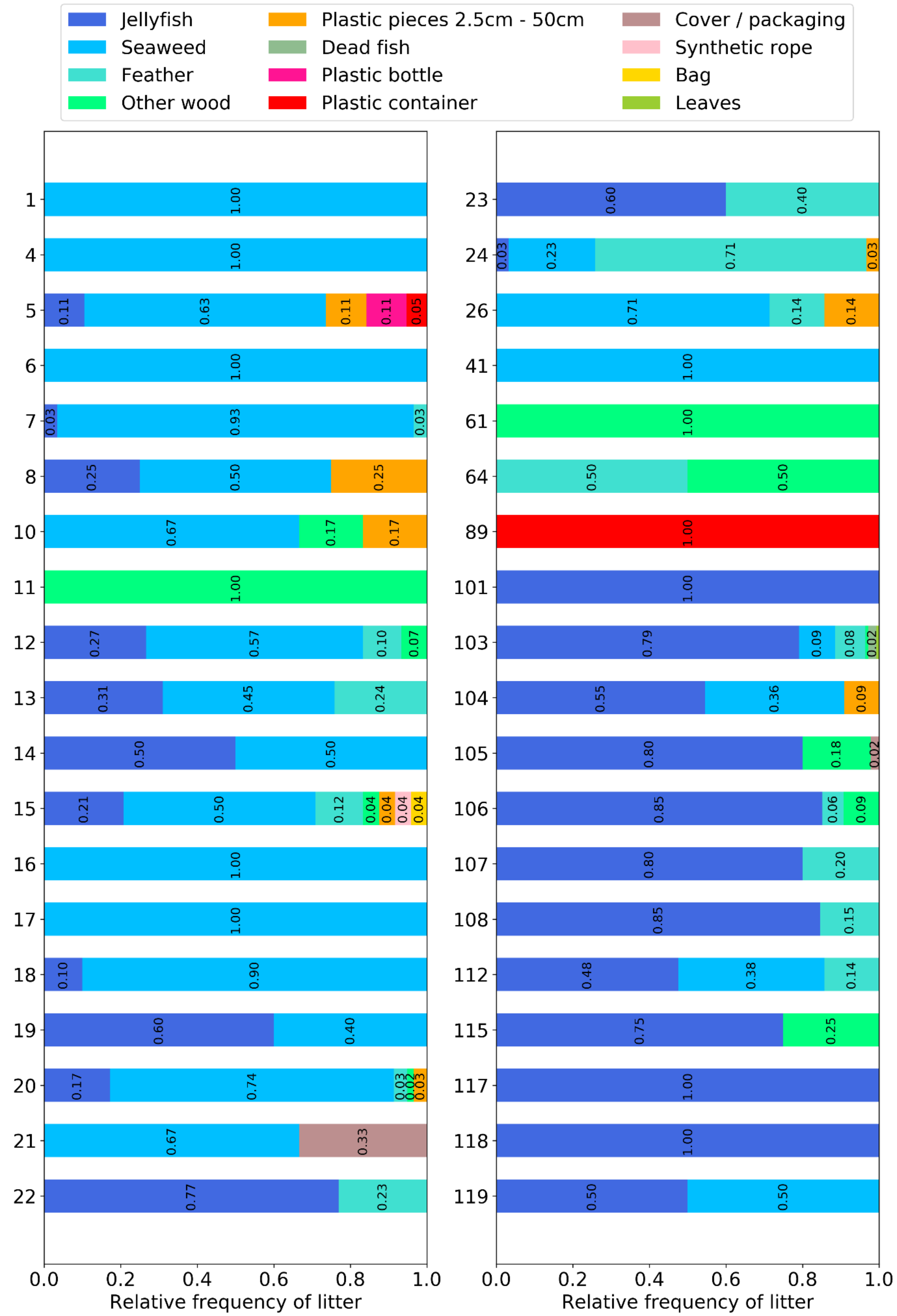

Fig. 5. Relative abundance of floating objects at the transects with data.

Discussion

FMML and natural floating objects, influence of rivers and seasonality

In this work distributions of FMML and natural objects in the Seas of the Russian Arctic in relation to the oceanographic conditions have been studied. Most of the time the distributions of FMML and natural objects (Fig. 4) were interconnected. The ratio between different types of litter found at transects with at least one observation are given in Fig. 5. The observed natural objects were dominated by jellyfishes and different organic debris, represented mainly by seaweeds, which indicates non-riverine origin of the floating debris, and potentially could be related to shallow coastal waters.

Generally, an evident correlation between the FMML and natural objects (Appendix, Table A1) testifys a similarity of the mechanism of their maxima formation, i.e. local convergence and accumulation at multiple internal frontal zones formed within the river plumes (Osadchiev et al. 2017, 2019). Both of them (Fig. 3, 4) were present in the high salinity Surface Atlantic Water, occupying the Barents Sea and the Eastern part of the Kara Sea to the outer boundary of the Ob-Yenisei plume. Few natural objects and one plastic object were found in saline Polar Surface Water detected in the central part of the Laptev Sea. No items have been found close to the river mouths.

On the contrary, during microplastis studies made in 2019 (Yakushev et al., n.d.), an increase of microplastics in the outer plumes relative to the inner plumes was found. The current study took place in late autumn, when all river-origin plastic could be transported very far (to the outer boundary of rivers plumes), but no floating items were observed there as well.

We suggest, that the absence of floating litter in this period of time could be connected with intra-seasonal features of the Siberian rivers runoff: the majority of freshwater runoff from the Siberian rivers inflows to the sea in June-July. Then river runoff steadily decreases till September and is very low in late autumn, winter, and spring.

Comparison with other regions

Comparisons of mean and maximum litter densities with other regions are shown in Table 2.

Table 2. FMML densities in items per km^2 in different areas.

Region	*Mean density, item/km^2*	*Max density, item/km^2*
Barents Sea and Kara Sea West from the Gulf of Ob, FMML (this study)	0.92	7.97
Kara Sea East from the Gulf of Ob, Laptev Sea, East Siberian Sea, FMML (this study)	0.002	0.002
Black Sea (Kerch Strait)(BSC, 2007)	66	-
Northeastern Black Sea (Suaria et al., 2015)	30.9	
Black Sea (Slobodník et al., 2017)	90.5	800
Mediterranean Sea (Suaria and Aliani, 2014)	10.9-52	194.6
Mediterranean Sea (Constantino et al., 2019)	232	1593
North Sea (Herr, 2009)	2	1-6
North Sea (Thiel et al., 2011)	25-38	-
Chile (Hinojosa and Thiel, 2009)	10-50	250
South China Sea (Zhou et al., 2011)	4.9	16.9

North Pacific (Titmus and David Hyrenbach, 2011)	459	
Strait of Malacca (Ryan, 2013)	579	
Bay of Bengal (Ryan, 2013)	8.8	
Southern Ocean (Ryan et al., 2014)	0.0032-6	
Southern Ocean (Suaria et al., 2020)	0.02-0.03	7
British Columbia (Williams et al., 2011)	1.48	2,3
West of Hawaii (Matsumura and Nasu, 1997)	0.5	
Barents Sea (Pogojeva et al. 2021, in press)	3.5	

FMML and natural objects have been found only in the Atlantic water of the Barents Sea and the Kara Sea. In the expedition the FMML concentrations averaged at 0.92 items/km^2 (mean) with a maximum of 7,97 items/km^2. This is lower than in all the regions listed in Table 2, with the exception of Southern Ocean (Ryan et al., 2014) (Suaria et al., 2020), the observations West of Hawaii (Matsumura and Nasu, 1997) and also lower than found in the Central Barents Sea, 3.5 items/ km^2 found in 2018 (Pogojeva et al. 2021, submitted).

All the other parts of the Russian Arctic Seas East from the Gulf of Ob were free from FMML and floating natural items, with the exeption of a single observation in the saline waters of Atlantic Origin.

Possible fate of FMML in the Arctic and it's correlation with oceanographic characteristics

This occurrence of FMML in the Atlantic surface water can be clearly illustrated by the distribution of plastic litter plotted on the surface layer temperature-salinity diagram (Fig. 6). The river plume water, with the formal boundary of 25 psu is free of plastic litter. Warm and saline Atlantic surface water contains plastic litter, also detected in the cold and saline water of the central Kara Sea. Similar tendencies are demonstrated by the temperature-oxygen, pH-salinity and oxygen-pH diagrams (Appendix, Supplementary figure 5, 6, 7). Statistical analysis shows the best correlation for FMML and salinity (0.627, Appendix, Table A1), re-confirming the occurrence of plastic litter only in the waters of Atlantic origin.

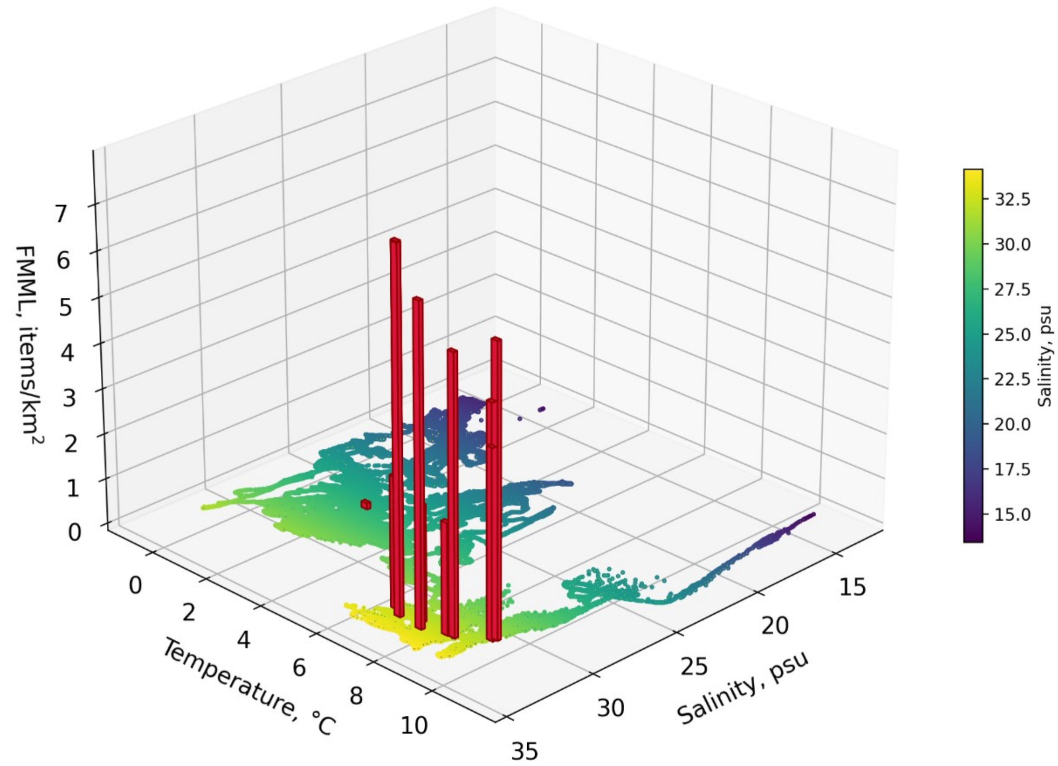

Fig. 6. Surface layer temperature-salinity diagram and distribution of plastic litter, items/km^2.

Surface Atlantic water detected in this study is originated from the Barents Sea, that is hypothesized to be the location of the 6th great ocean garbage patch gyre (Van Sebille et al., 2012). While finding low litter concentrations, our study demonstrates the transport of floating litter from the Barents Sea to the Western Kara Sea with Atlantic Surface water, potentially then accumulating in the Arctic.

The occurrence of litter only in the Atlantic water, demonstrates litter import into the Siberian Arctic from other areas. This is supported by modelling which showed that the main influx of microplastics into the Arctic region within sea water is from the North Atlantic, with plastics transported along the Norwegian coastline and entering through the Norwegian and Barents seas (Mountford and Maqueda, 2020). In the Northern Barents Sea the Surface Atlantic water submerges below the Polar surface water mass (Aksenov et al. 2010) and its circulation no longer influences the fate of floating litter. The FMML as well as floating microplastics can then be trapped (Obbard et al., 2014) and transported with ice (Peeken et al., 2018). Terrestrial microplastics sources in these sparsely populated high-latitude regions seem to have a negligible contribution to the microplastics load of Arctic waters. In contrast to other coastal (and more densely populated) areas, which are known to be much more contaminated with microplastics (Lusher 2015), emissions from Arctic terrestrial sources may be considered to be low. In this work we see the fate of FMML outflowing from the Barents Sea through the Kara Gate strait to the Kara Sea. As shown, the region of its distribution is limited by the frontal zone between the high saline Surface Atlantic water and the fresher Ob-Enisey Plume water. We can hypothesise that FMML as well as the floating microplastics accumulate at this frontal zone and transport the litter North with the plume water and finally reach the regions of the ice formation in the Northern Kara Sea. This is also supported by previous study suggesting that some regions of the Barents Sea are coming close to being as polluted by microplastics as the most contaminated subtropical zones (Tošić et al.2020). The samples collected during the 82d research cruise of the R/V Akademik Mstislav Keldysh 2020 expedition for the surface microplastics, subsurface microplastics and microplastic in the sediments will give an additional information about the microplastics fate in the Arctic after they will be processed.

Using oceanographic (hydrophysical and hydrochemical) information for analyzing macro litter distribution appears to be very useful. First of all, this approach allows to distinguish different water masses, that can have different FMML content (using the data of salinity, temperature, dissolved oxygen, pH). It also allows to detect different zones inside the water masses, like, for example, to use pH distributions to map river water that was recently discharged to the sea. And from the other side, plastic is a unique tracer that provides an opportunity to learn more about the physics and dynamics of the ocean across multiple scales (van Sebille et al. 2020) and as we showed for microplastics for the water masses propagation studies (Yakushev et al., n.d.). In our case it was possible to show, that in the autumn period the river discharge is free from FMML. This is in agreement with the findings for the microplastics distributions in the Siberian Arctic area in October 2019.

Conclusion

Based on hydrophysical (temperature, salinity) and biogeochemical (dissolved oxygen, pH) parameters distributions it was possible to distinguish the water masses in the surface layer of the investigated regions of the Eurasian Arctic in relation to floating macro litter objects and natural objects. It was found that the Atlantic Surface water is providing import of floating plastic litter to the Arctic, while the eastern part of the Eurasian Arctic is free from floating objects. This study presents first observations in areas without any previous surveys for floating objects. The outcome implies low input of litter from Siberian river systems in autumn, and thus can contribute to the prioritization of efforts in Arctic marine litter management.

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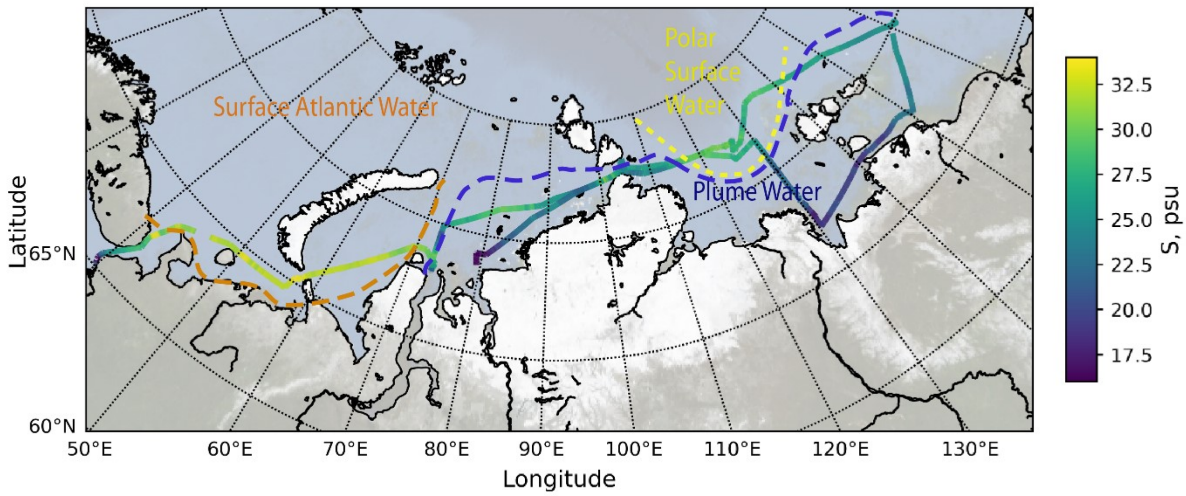
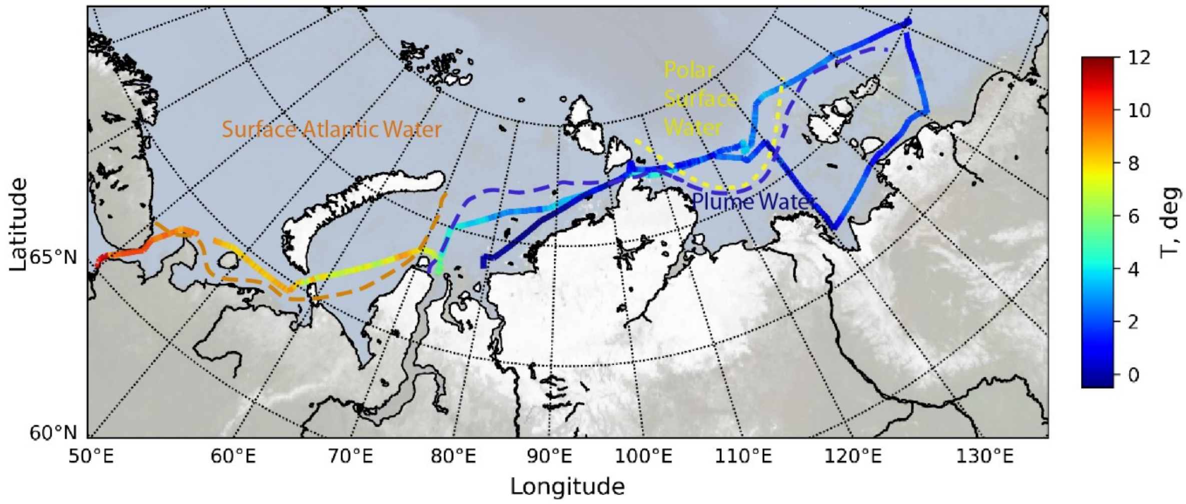
Appendix

Table A1 Correlation matrix for the parameters measured.

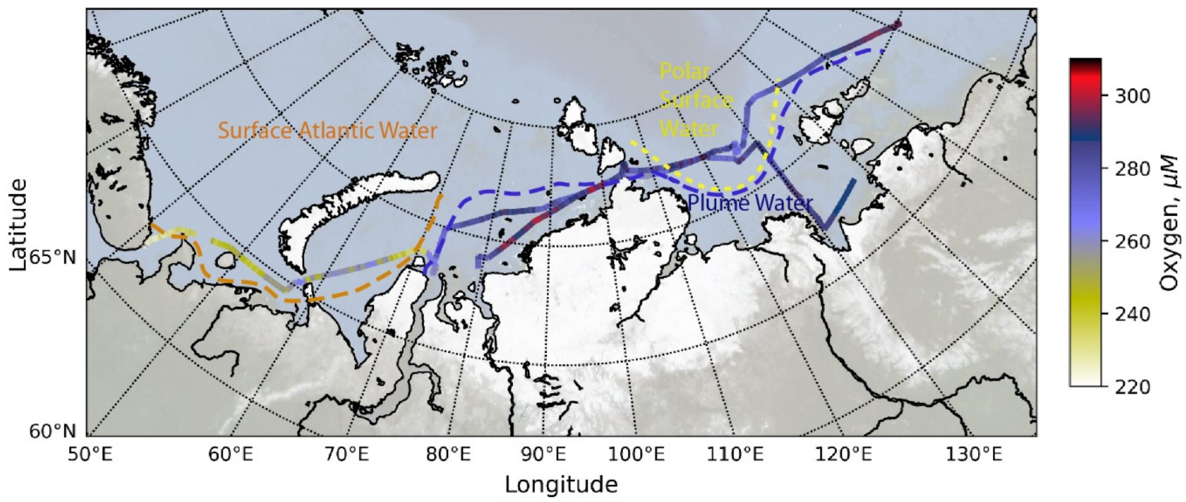
	FMML	Natural Objects	Total floating items	T	S	O_2	pH	lat	lon
FMML	1,000								
Natural Objects	0,523	1,000							
Total floating items	0,529	1,000	1,000						
T	0,475	-0,119	-0,115	1,000					
S	0,627	0,279	0,282	0,685	1,000				
O_2	-0,360	0,239	0,235	-0,828	-0,252	1,000			
pH	0,131	0,234	0,234	0,189	0,699	0,325	1,000		
lat	-0,362	0,087	0,084	-0,951	-0,639	0,713	-0,293	1,000	
lon	-0,540	-0,034	-0,038	-0,964	-0,801	0,718	-0,371	0,941	1,000



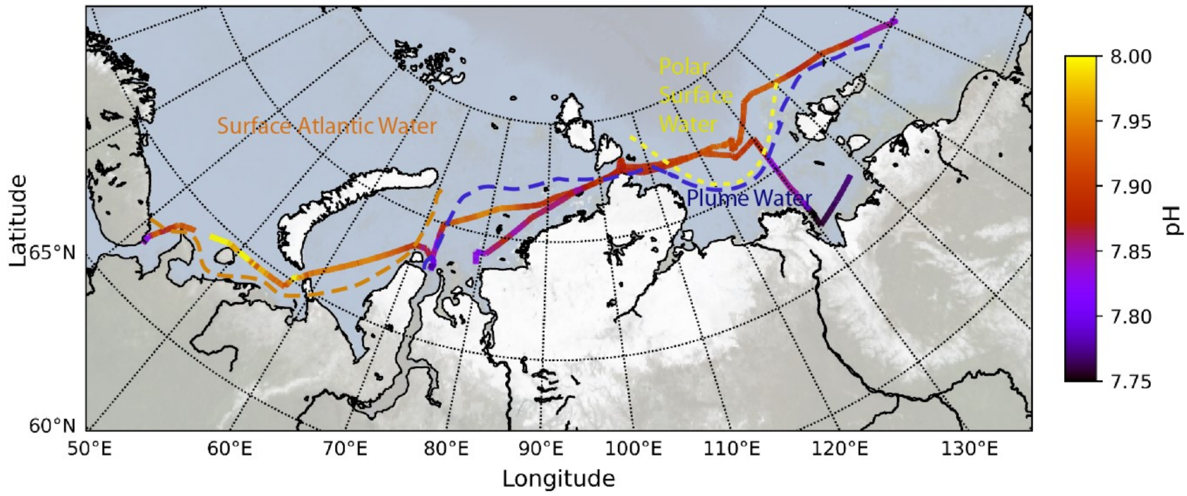
Supplementary Fig. 1. Schematic map representing salinity, psu, (multicoloured line) in the surface water layer along the route of the 82d cruise of RV Akademik Mstislav Keldysh.



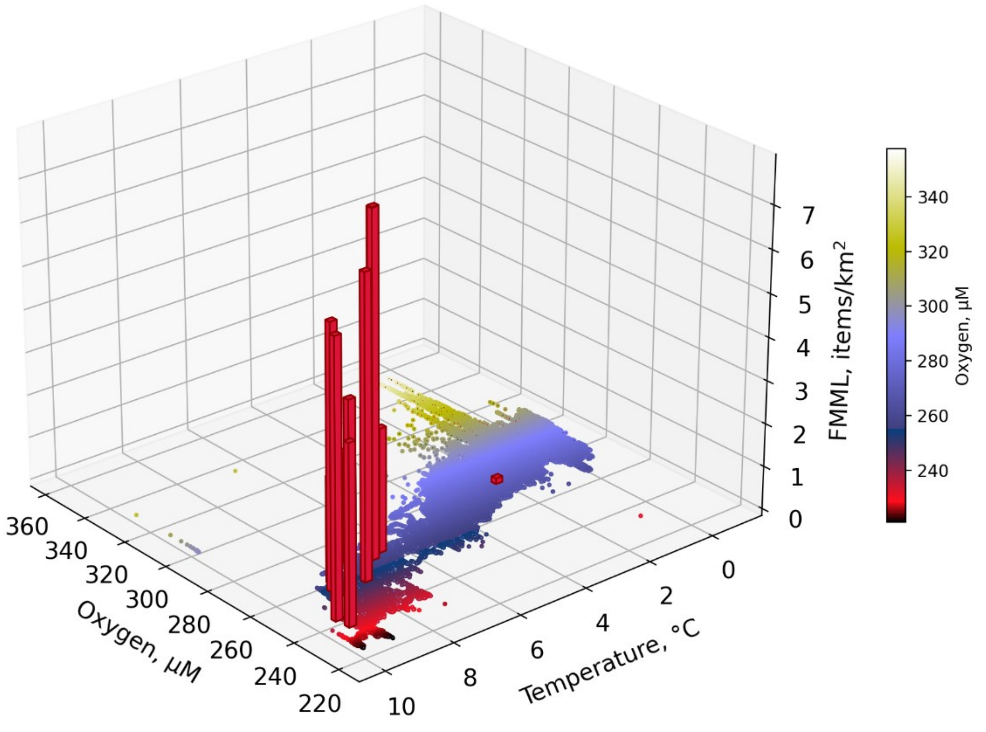
Supplementary Fig. 2. Schematic map representing temperature, ºC, (multicoloured line) in the surface water layer along the route of the 82d cruise of RV Akademik Mstislav Keldysh.



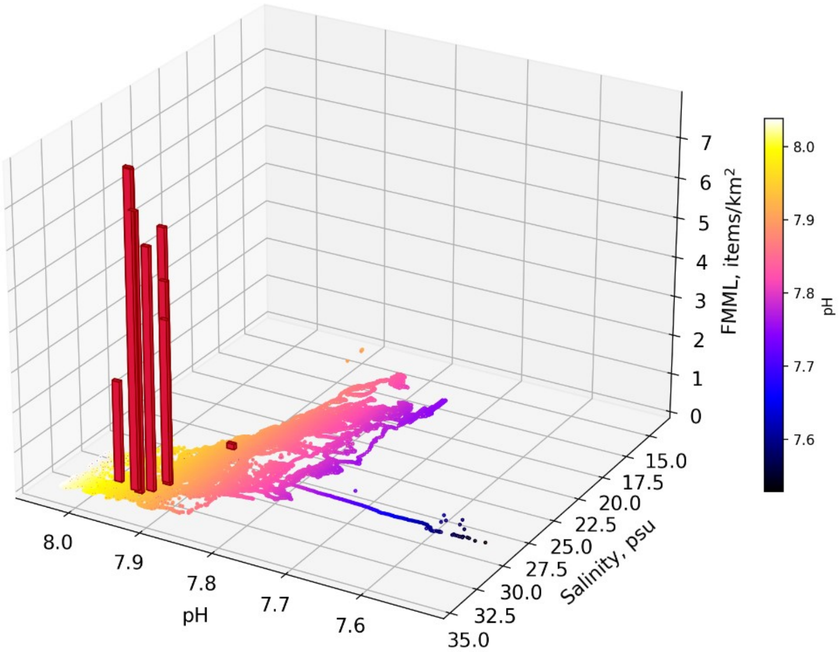
Supplementary Fig. 3. Schematic map representing dissoved oxygen, μM, (multicoloured line) in the surface water layer along the route of the 82d cruise of RV Akademik Mstislav Keldysh.



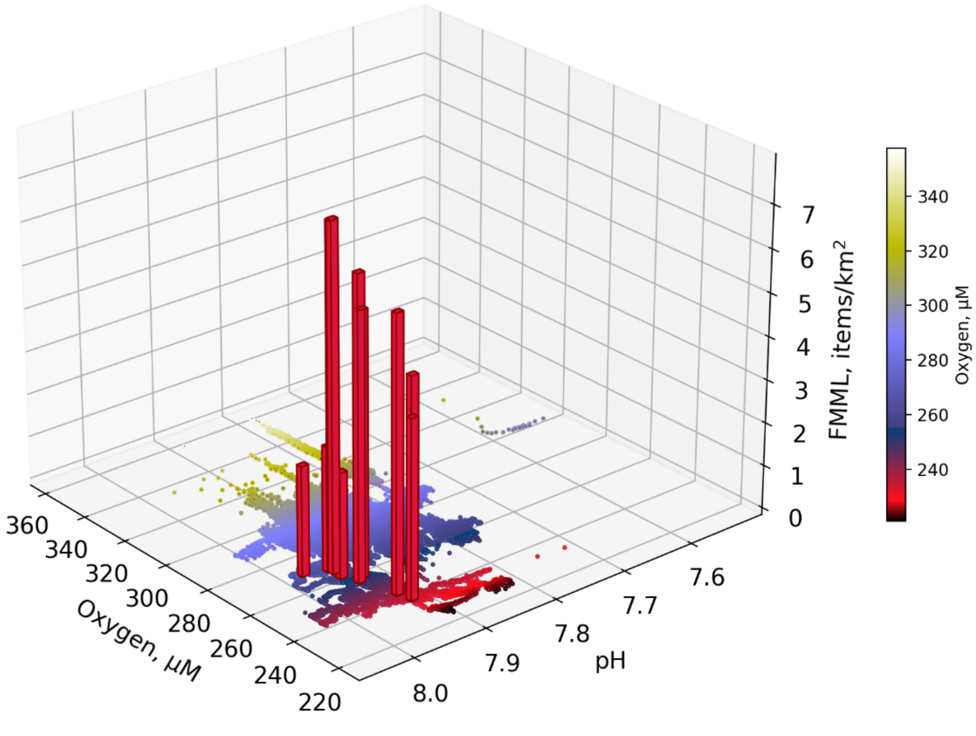
Supplementary Fig. 4. Schematic map representing dissoved pH, total scale, (multicoloured line) in the surface water layer along the route of the 82d cruise of RV Akademik Mstislav Keldysh.



Supplementary Fig. 5. Surface layer temperature-oxygen diagram and distribution of FMML, item/km^2.



Supplementary Fig. 6. Surface layer pH-salinity diagram and distribution of FMML, item/km^2.



Supplementary Fig. 7. Surface layer pH-oxygen diagram and distribution of FMML, item/km^2.