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INFORMATION

Comprehensive Research on the Kara Sea Ecosystem (128th Cruise of Research Vessel *Professor Shtokman*)

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The Kara Sea is a key Arctic region, the study of which allows us to address not only local-basin-related but also general regional problems. The Kara Sea receives about 45% of the total freshwater runoff to the Arctic (1200 km^2). River runoff strongly freshens the surface sea layer, which significantly affects intrabasinal water exchange processes, vertical water column mixing, nturient regimes, and thus environmental conditions for. Freshwater flow carries out over 150 million tons of allochthonous materials to the Arctic shelf, including a wide range of contaminants.

The Kara region is strongly influenced by the climatic processes characteristic of the Arctic over the past decades, primarily, summer ice-cover degradation. On the shelf and in the coastal area, major gas condensate and oil reserves have been explored, and their development and transportation threaten the Kara ecosystem with very strong anthropogenic effects. Very large radioactive burial grounds in the bays of the eastern coast of Novaya Zemlya and in Novozemel'skaya Vpadina (Novaya Zemlya Trough) have made the Kara Sea a focus of colossal accumulated ecological risks.

To study the above problems, the Oceanology Institute RAS organized a Kara Sea expedition: the 128th scientific cruise of the R/V *Professor Shtokman*. The voyage was conducted from August 8 to September 11, 2014. The leader of the expedition was M.V. Flint, Dr. Sci. (Biol.) and deputy director of the Institute of Oceanology RAS (IO RAS); the vessel was under the command of master mariner A.A. Khromov. The expedition continued the IO RAS comprehensive studies of the Kara basin conducted in 2007, 2011, and 2013 and was based on the same multidisciplinary methodological approach, which made it possible to combine multiyear research data.

The main goals of the expedition studies were the following:

—to obtain the characteristics of the current state of key abiotic and biotic components of pelagic and benthic ecosystems of the Kara Sea, taking into account the current climatic condition of the Arctic region;

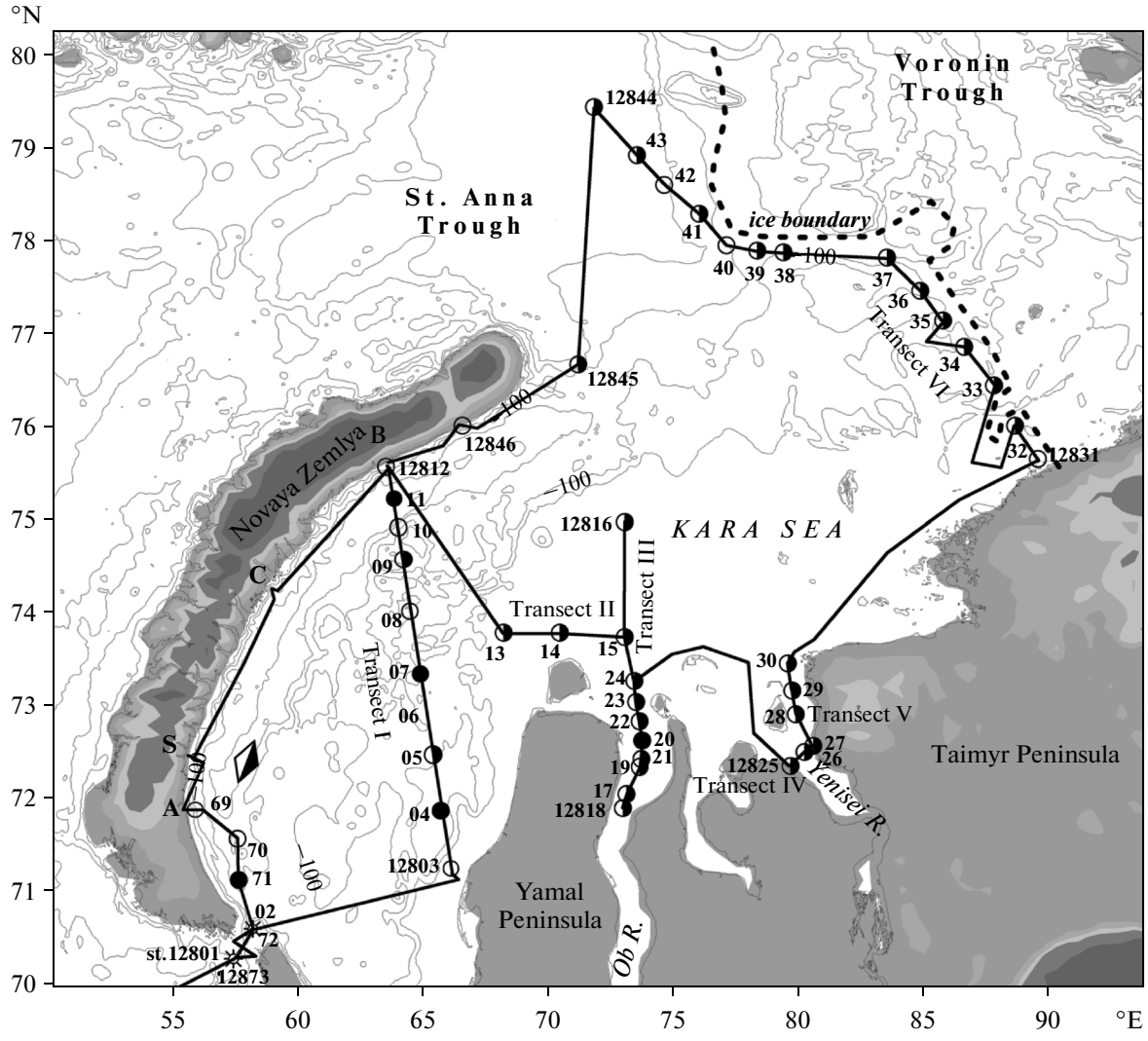
—to assess the specifics of physical, hydrochemical, biological, and geochemical processes near a large desalinated surface lens formed by the runoff of the Ob and Yenisei rivers and its role in forming biological production, as well as in the transformation and cross-shelf transfer of substances;

—to study the zonal specifics of physical, hydrochemical, biological, and geochemical phenomena and processes in the eastern, practically unstudied, and the coldest and most ice-bound region of the Kara Sea;

—to investigate the hydrophysical, hydrochemical, biological, and geochemical phenomena and processes associated with the Ob estuarine frontal zone; to determine conditions of the formation and structure of the plankton "biological filter" associated with the estuarine frontal zone, as well as its role in the transformation and flows of organic matter; and

—to obtain hydrophysical and hydrochemical data, as well as biological materials for the characterization of pelagic and benthic ecosystems in large radioactive burial grounds: the bays of the eastern coast of Novaya Zemlya (Abrosimova, Stepovogo, Tsivol'ki, and Blagopoluchiya) and the Novaya Zemlya Trough.

The figure shows the route of the expedition. Study revealed the location of a surface lens freshened by the Ob and Yenisei runoff in the central and southwestern parts of the Kara Sea. In the center of the lens, with coordinates ~73°20, 20′ N and 65°40.0′ E, an area was found with a salinity of 9.2 psu, which is a record-breaking low for the open parts of the Kara Sea. A rigid pycnocline, with salinity gradients up to 5.5–6.0 psu/m, underlay the freshened lens at the surface, hindering wind-induced mixing, the flow of nutrients into the euphotic layer, and the seasonal descent of the lower boundary of the upper mixed layer. Data on localization and gradient characteristics of the frontal zones on the periphery of the freshened lens on the surface were obtained using continuous recording of hydrophysical and biophysical parameters of the surface sea layer. The boundary of the freshwater region



Route plan, position of transects and stations of the 128th cruise of the R/V *Professor Shtokman*.

(<24 psu) reached the coast of the northern island of Novaya Zemlya. Surface waters with the lowest salinity were characterized by relatively high fluorescence values of dissolved organic matter and chlorophyll. Overall, the desalinated region was significantly shifted to the west of the basin compared to our observations of 2007, 2011, and 2013.

The Ob estuarine frontal zone was characterized by the sharply expressed southern periphery (gradients 0.8–1.0 psu/km) in near-bottom salinity distribution, which lay between 72°12′ and 72°27′ N. In the northern periphery of the estuarine frontal zone (73°20′ N), near-bottom salinity reached >33 psu, which is characteristic of the Kara shelf. Salinity changes in the estuarine zone's surface water layers were much more even. For 220 km (from 71°12′ to 74°00′ N), salinity increased from 0 to 12 psu. Surface salinity reached values characteristic of the Kara shelf only at 74°50′ N; thus, the external periphery of the estuarine frontal zone within the Ob estuary was practically unexpressed. This was the consequence of an intensive (August) runoff and the effect of southward offshore winds.

The position and intensity in the salinity and temperature field of the frontal zone over the continental slope in the St. Anna Trough, which separates the relatively warm low-salinity waters of the Kara Shelf from the cold and saline Arctic waters, were identical to those recorded during our studies of 2007 and 2011, which made it possible to confirm the stability of this important ecological boundary.

The assessments of hydrochemical parameters in various sea areas showed that the contents of oxygen and main nutrients did not go beyond the limits of average multiyear values for the summer season. Phosphate and nitrate–nitrogen concentrations in the euphotic layer did not drop to the analytical zero everywhere, and their concentrations could not serve as a factor limiting phytoplankton development.

The primary production of the Kara Sea was measured in situ for the first time in waters with various trophic statuses during the active period of the seasonal succession of phytoplankton (August) in situ, which allows us to calculate the total values of primary production in the water column. Characteristic dependences of the assimilation number on underwater irradiance in waters of various optical types and productivity were obtained. For the first time, the spatial variability of the light-curve parameters of the Kara Sea phytoplankton's photosynthesis was studied the maximum assimilation number, photosynthesis efficiency, light saturation levels (photoadaptation parameter), optimal illuminance, and light inhibition of photosynthesis.

Phytoplankton bloom was detected only in the southern periphery of the estuarine front (freshwater phytoplankton, 4 g/m^3) and in the central part of the freshened surface lens of waters in the western part of the basin (marine types of phytoplankton, 500 mg/m^3). In the eastern regions of the sea near the seasonal ice edge and in the northern regions (north of 78° N), despite recent ice melting, the phytocene was at a late-winter stage of seasonal succession and was characterized by a very low level of biomass, <100 mg/m^3. The values of chlorophyll a in all the regions of the Kara Sea investigated, even in the layer of maximum fluorescence, did not exceed 1 μg/L, which also indicated low phytoplankton biomass. An exception was the estuarine areas of the Ob and Yenisei rivers, where average chlorophyll-a concentrations were 4–6 μg/L, reaching 17 μg/L in the freshwater part of the Ob estuary.

Quantitative estimates of dissolved organic carbon produced by phytoplankton during photosynthesis were obtained for the first time in the region. The production values of organic carbon dissolved by phytoplankton changed from 25 to 62% of the total primary production assessed by ^{14}C fixation. The share of organic matter newly synthesized by phytoplankton and fixed by plankton bacteria varied from 1 to 15% of primary production.

For the first time, data were obtained on the quantitative distribution of zooplankton and its trophodynamic parameters in the region where the surface freshened layer of the Kara Sea had been localized. In the estuarine frontal zone of the Ob, the trophic characteristics of mass zooplankton species were determined on the basis of daily observations, and this will allow us to assess the role of the estuarine "biofilter" in the transformation of allochthonous and autochthonous organic matter and in vertical organic matter flows. Material that allows us to characterize the structural and functional parameters of the zooplankton community near the ice boundary in the eastern part of the basin was obtained for the first time for the Kara Sea. Mass zooplankton species from various biotopes of the Kara Sea were collected, and this will allow us to assess the genetic distances of populations different in their origin.

Studies on benthic fauna made it possible to distinguish a successive latitudinal change in biocoenoses that corresponded to the pattern given in the work by Z.A. Filatova and L.A. Zenkevich based on the 1945 materials. This indicates the large temporal stability of the structure of benthic biocoenoses in the western part of the Kara basin, where the largest licensed sites for shelf hydrocarbon production are located.

We have obtained samples of benthic sediments, zoobenthos, and zooplankton that will make it possible to measure mercury contents in components of the Kara Sea ecosystem and to determine mercury bioaccumulation ratios and transfer mechanisms. The materials were collected to assess the radiation condition of benthic sediments in various regions of the Kara Sea, including the Ob and Yenisei estuaries.

Hydrophysical, hydrochemical, and biooceanological studies of Blagopoluchiya, Tsivol'ki, Stepovogo, and Abrosimova bays of the Novaya Zemlya Archipelago, which differ in morphology, hydrodynamics, climatic conditions, runoff, and volumes of radioactive burials, were carried out, making it possible to characterize local ecosystems in detail and to assess the level of their isolation from the main basin. It was shown that the benthic communities of the bays were mainly formed by Arctic species and individual representatives of Arctic–boreal species.

For the first time, materials were obtained to characterize the radioactive contamination of soil and plant components of landscape–geochemical ecosystems and coastal bottom sediments in the four bays of Novaya Zemlya. Ice samples were obtained from the Rose and Serp i Molot outlet glaciers, and this will make it possible to assess their radiation condition for the first time.

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