Chapter 29. ECOSYSTEM OF THE BARENTS AND KARA SEAS, COASTAL SEGMENT (22,P)

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1. Introduction

The interest to ecosystems of the Barents and Kara seas increases recently in connection with growing anthropogenic impact. There are many investigated oil and
gas fields on the shelf of the Barents and Kara seas. However, the hard ice regime and severe natural and climatic conditions of the region to be developed put forward a number of complicated engineering problems, including the protection of biota. To solve them there is a need for reliable and complete information on the environment.

The structure and function of coastal ocean ecosystems differ greatly among continental shelves, being driven largely by differences in net primary production that are ultimately determined by the interplay of many factors such as boundary currents, shelf geometry, river runoff, upwelling and water and sediment chemistry that are unique to each shelf margin (Alongi, 2003). The shelf regions of the Barents and Kara seas are a link between the North Atlantic and the Arctic Ocean. The hydrography is characterized by frontal structures, transformation and mixing processes, resulting from the penetration of warm and saline North Atlantic Water from western boundary and abundant river runoff from east.

In Russian oceanographic and biological sciences the Barents and the Kara Seas are traditionally described separately due to significant differences of their oceanographic regime and ecosystems types. The Barents Sea is influenced by warm and saline Atlantic waters to a significantly greater extent as compared with the Kara Sea. Wide development of the polar front phenomenon and vertical water circulation are a basis of high biological productivity in the sea and high richness of its pelagic and bottom life. Biota of the Barents Sea in general is characterized by mixture of boreal and arctic elements. Quantitative variability of flora and fauna is highest in the southwestern part of the sea, and drops in significantly in the northward and eastward directions. Large quantities of heat-loving species penetrate here with warm currents from the Atlantic. Macrophytes in the coastal zone are diverse. Fishery is based mainly on cods, herrings, plaices, and capelin.

The Kara Sea is almost closed from Atlantic influence, and the biota of the sea includes much more arctic elements. Phytoplankton vegetation is almost absent about 10 months per a year, and biological productivity is low. Biodiversity in the Kara Sea is approximately twice lower as compared to the Barents Sea. Littoral and sub-littoral zones (due to rough ice conditions) are especially poor of life. Macrophyte vegetation in the coastal zone is actually absent. Large estuarine and freshened water areas are inhabited by specific complex of euryhaline organisms and are very typical for the sea. Fishery exists predominantly in the estuarine areas and is based mainly on whitefishes.

2. Oceanography

The Barents and Kara seas are semi-enclosed marginal seas of the Arctic Ocean that lie between the northern coast of Europe and four archipelagos: Svalbard, Franz Josefs Land, Novaya Zemlya and Severnaya Zemly (Fig. 29.1). According to (Gorshkov, 1980), the average depth of the Barents Sea comprises 199 m, its area is equal to 1.417 million km$^2$ and the greatest depth in the Medvezhinsky Trough is slightly more than 500 m. The average depth of the Kara Sea is 111 m and its area comprises 883 thousand km$^2$ with a maximum depth (620 m) in the northern part of St Anna Trough.
The seabed relief of the Barents Sea, which is significantly deeper than the Kara Sea, is characterized by strong dissection. Many relief features are attributed to the young age of the sea basin that has attained its modern style not more than 10 thousand years ago resulting from the ocean transgression. Large structural components of seabed relief are of tectonic origin with the relict relief forms and the ancient river network being superimposed on them.

A deep depression of the St. Anna trough separates the Barents Sea shelf from the Kara shelf. The relief of the northern Kara Sea is very irregular due to bedrock outcrops. The sea is abundant in islands. Here, in addition to St. Anna Trough, Voronin Trough and the accumulative elevations including the Central Kara Rise are distinguished.

The main features of the oceanographic regime of the Barents and Kara seas are primarily governed by its high latitude. These seas are situated completely above the Arctic Circle. Hence, during winter, solar radiation flux is absent, whereas, in summer, it is comparatively small. The polar night duration increases from 50–60 days at the southern part of the Barents Sea to 80–100 days in the northern part of the seas. The average annual air temperatures at the southwestern part of region is about 2°C. Further north, it decreases to –6 to -10°C at latitude 77° in the Barents Sea and to –11 to -14°C in the northern Kara Sea (Gorshkov, 1980).

The Barents and Kara Seas due to atmospheric circulation features are characterized by the monsoon distribution of the prevailing wind directions—south quarter in winter and north quarter in summer. The average annual speed over the seas ranges from 6 to 7 m/s and only in the vicinity of Cape Zhelaniya, it becomes higher (7.8 m/s). The maximum wind speed over a year is practically at all coastal
stations equal to or greater than 40 m/s being mainly observed in the autumn-winter period. In summer, the maximums decrease to 20 m/s in July and only near Cape Zhelaniya, they can comprise 40 m/s as in winter (Hydrometeorological conditions ..., 1985, 1986).

The Barents Sea is primarily a throughflow region for the considerable transport of water masses (about 2 Sv) from the Greenland-Norwegian Sea towards the Arctic Ocean (Blindheim, 1989; Ingvaldsen et al., 2002). An eastward going branch of the Norwegian Atlantic Current reaches the Barents Sea via the Bear Island Trough. The interference of Atlantic and Arctic water masses in the central Barents Sea leads to a pronounced Polar Front south and east of Bear Island (Fig. 29.2). In the eastern Barents Sea the water has become transformed from warm saline water to cold, less saline intermediate and bottom water. This transformation happens through mixture of cooled Atlantic Water with cold brine-enriched shelf water generated west of Novaya Zemlya, and possibly also at the Central Bank. The moderately cold, low salinity mixture continues to the Kara Sea without further change. According Schauer et al. (2003), in 1991/1992 the water transport through the northeastern Barents Sea was between 0.6 Sv in summer and 2.6 Sv in winter towards the Kara Sea and between 0.0 and 0.3 Sv towards the Barents Sea with 11-month averages of 1.5 Sv and 0.1 Sv, respectively.

River runoff into the Barents Sea is rather small. The Pechora River is the largest river of the Barents Sea basin. Its mean annual runoff is up to 134 km$^3$ (Joint US-Russian Atlas ..., 1998). The rivers of Scandinavia and the Kola Peninsula together give about 10% of the runoff. In the consideration of the continental
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runoff to the Barents Sea one should take into account its water exchange with the White Sea, into which quite large rivers Severnaya Dvina, Mezen’ and Onega fall. This aggregated annual runoff is up to 135 km$^3$. The river runoff significantly affects the hydrological conditions of the Barents Sea only in the south-eastern part of the sea.

According Hanzlick and Aagaard (1980), the importance of the Kara Sea to the Arctic Ocean derives from two features. First, it receives more than one third of the total freshwater discharged into the Polar Basin, and the conditioning and cycling of this freshwater has consequences for the salinity stratification of the Arctic Ocean (Aagard and Coachman, 1975). Second, the Kara Sea appears to be the site of significant transformation of Atlantic Water, with a large attendant vertical heat flux (Timofeyev, 1962).

The Kara Sea receives about 55% (1350 km$^3$/year) of the total river runoff discharged to the entire Siberian Arctic (Soviet Arctic, 1970, Ivanov et al., 1984, Pavlov and Pfirman, 1995). The annual discharge of the Ob’ River is 530 km$^3$, the Yenisey River, 605 km$^3$, the other rivers add up to 190 km$^3$. The continental discharge could fill the entire volume of the Kara Sea within only 73 years. The total watershed area of the Kara Sea comprises 5.57 million km$^2$ and Ob’ and Yenisey carry about 221 mill. tons of suspended matter and almost 8 mill. tons of organic matter (particulate and dissolved) per year into the Arctic Ocean (Gordeev et al., 1996).

The main feature in the sea surface temperature distributions is a general decrease in temperature from west to east (Fig. 29.3). The western region of the Barents Sea, influenced by the warm Atlantic waters, is characterized by positive temperature values in the surface layer and near the bottom. The highest temperature in the coastal zone of the western Barents Sea is up to 16° C (Hydrometeorological conditions ..., 1985). In winter, sea surface temperature is generally less then 3° C. At the same time, the northeastern part of the Kara Sea, directly influenced by the Arctic Basin, has a significantly smaller range of temperature oscillations. The sea surface temperature in this region is lower than 0° C during the whole year. Because relatively warm water of Atlantic origin penetrates into the Kara Sea through the St. Anna and Voronin troughs, water temperature increases at about 50 to 70 m water depth, reaching maximum values of 1.0 to 1.5° C (Hanzlick and Aagaard, 1980, Pavlov and Pfirman, 1995)

Figure 29.3 Mean multiyear distribution of the surface water temperature for summer (a) and winter (b).
The most prominent features of salinity distribution in the Barents Sea are its high values during the whole year (Fig. 29.4). It is most clearly defined in the Atlantic water mass (up to 35.0 ‰). Salinity values in the coastal zone are somewhat lower, and it is caused by peculiarities of freshwater balance and income of freshened waters from the White Sea.

In the Kara Sea, the salinity distribution exhibits pronounced seasonality due to fluctuations in river runoff as well as ice formation and melting. In summer a strong frontal zone develops where river runoff meets the more saline shelf water. Horizontal salinity gradients can reach value 1.5 ppt per 1 km, and vertical 5 ppt per 1 m in the open sea and 8 ppt per 10 cm in the Ob' and Yenisey estuaries (Kulakov and Stanovoy, 2002). The lowest salinities (several parts per thousand) are observed in the vicinity of the Ob' and Yenisey estuaries, while salinity in the western part of the sea are greater then 32 ppt. In winter, river runoff decreases. At the same time, ice formation and consequent brine-release cause salinity to increase. In the southwest, except for regions directly adjacent to the river mouths, salinity approaches 25 to 30 ppt. To the north and near Novaya Zemlya, the salinity is generally about 34 ppt.

Due to income of warm Atlantic waters brought by the North-Atlantic current, the Barents Sea never (even in the most severe winters) is covered completely with ice (Fig. 29.5). This is its basic difference from other seas of the Arctic shelf. One of the main features of the sea is the significant interannual and seasonal variability of its ice cover extent. The greatest ice cover extent is seen usually in the middle of April; the least at the end of August, and first half of September. In the extremity of the most severe winters more than 90 % of the sea surface is covered with ice, and in especially warm winters the greatest ice cover extent even in April does not exceed 55–60 % (Hydrometeorological conditions ..., 1985).

In August–September anomalously warm years the sea completely frees from ice, and in anomalously cool years the ice cover these months is stored on 40–50 % of its area, placing mainly in northern regions. The location of the ice edge during summer can vary by hundreds of kilometers from year to year, and there is also variability on longer time scales, up to century scale, correlated with North Atlantic Oscillation (Vinje, 2001). These variations reflect the inter-annual dynamics of inflowing Atlantic Water and atmospheric forcing.
In the Barents Sea, ice formed within the limits of the sea usually predominates. But some years in a northwest part of the sea in the winter the old ice from Polar Basin through a channel between Svalbard and Franz Jozef Land enter. Quite often in a north-east part of the sea the thick ice from northern part the Kara Sea are brought. This particular ice enters in the winter from the White Sea, and also from a southwest part of the Kara Sea through Kara Gate.

Ice formation begins in the Kara Sea in September in the north and in October in the south. From October to May almost the entire sea is covered with ice of different types and ages (Soviet Arctic, 1970, Pavlov and Pfirman, 1995). Fast ice occupies the coastal zone, and its development is patchy. Typically in July, the fast-ice band breaks up and disintegrates into separate floes that sometimes persist throughout the year, in the form of Severnaya Zemlya massif. Seaward of the fast ice zone in winter is typically a region that is either ice-free or has young ice. Floe thickness of first year ice reaches maximum in May of 1.5 to 2 m.

The ice distribution in the spring and summer depends on the winds and resultant surface ocean currents. According to Zakharov (1976) the Kara Sea discharges ice to the central Arctic about 180,000 km$^2$/year (approx. equal to 170 km$^3$/year). Most of ice export from the Kara Sea to the Arctic Basin occurs in winter. According Zubakin (1987), in winter approximately 140–198 km$^3$/year of ice exported from the Kara Sea to the Barents Sea through the strait between FJL and Novaya Zemlya. The estimated net flux from the Barents to the Kara Sea through Karskiye Vorota Strait is about 16.8 km$^3$/year.
3. Sediments

Grain-size analysis of seafloor sediments of the Western Arctic Shelf shows that the occurrence of monogranular or pure deposits (containing more than 75% sand, silt or clay) does not exceed 1%, either by space or mass (Gurevich, 1995). As regards total mass, the figures for bigranular or transitionary deposits, especially those having relatively silty composition, are: sandy silt - >10%, silty sand - > 12%, silty clay - > 17%, clayey silt—nearly 47.5% (see also Figs. 29.6 and 29.7). Triangular or mixed sand-silt-clay mixtite, practically absent from the White Sea, is widespread in northern parts of the Barents Sea and the Kara Sea. Polygranular bouldery-pebbly and gravelly polymixtites are only present in appreciable quantities in the Barents Sea.

Figure 29.6  The content (%) of the sand (left, 1 - < 10; 2 – 10–25; 3 – 25–50; 4 – 50–75; 5 - > 75.) and silty (right, 1 - < 25; 2 –25–50; 3 – 50–75; 4 - > 75) fraction in the modern deposits on the Western Arctic Shelf.

Figure 29.7  The content (%) of the clay (left, 1 - < 10; 2 – 10–25; 3 – 25–50; 4 – 50–75; 5 - > 75) and biogenic components (right, 1 - < 1; 2 – 1–5; 3 – 5–10; 4 – 10–30; 5 – 30–50; 6 – 50–70; 7 - > 70) fractions in the modern deposits on the Western Arctic Shelf.
The biogenic components of modern sediments on the Western Arctic Shelf are carbonate and siliceous remains and organic material originating from animals and plants (Gurevich, 1995). The total content of biogenic components (Fig. 29.7) is usually only exceeded by the terrigenic components. A significant proportion of the organic material of deposits in near-shore areas is a humus compound of vegetal origin. There is a very high content of sapropelic components in organic material near polar fronts. The background content of chloroformic bituminoids is less than 0.007 %, but this is enriched to 0.1–0.3 % in fine-grained sediments of frontal zones. The biogenic carbonate content in the modern sediments is generally low, and carbonate sedimentation is uncommon in polar regions in general. Across 65 % of the Western Arctic Shelf it measures no more than 1 %, and in 32 % of the area it ranges 1 and 5 % (Gurevich, 1995). The biogenic siliceous components of the Western Arctic Shelf sediments are mainly represented by diatom shells and sponge spicules. White, glass-like, “thick felt” derived from spicules of siliceous sponges was noted several times in south-western areas of the Barents Sea. Increasing contents of amorphous silica reach 2–3 % or more of the total mass of modern deposits in these areas.

4. Phytoplankton

4.1. The Barents Sea

Composition. There are 308 phytoplankton species in the Barents Sea, including Bacillariophyta - 167, Dinophyta - 119, Chlorophyta - 10, Chrysophyta - 8, Xanthophyta - 3, Euglenophyta - 1 (Makarevich and Larionov, 1992).

Biogeographical structure. According to taxonomic composition and quantitative indices of phytoplankton development, the Barents Sea is divided into three provinces: Boreal Polar Province—the northern part of the sea (the Arctic waters), Atlantic Subarctic Province—the southern part affected by the Atlantic water bodies, and Novaya Zemlya Province—south-eastern shallow part of the sea (the Pechora Sea; Longhurst, 1998; Druzhkov and Makarevich, 1999). Arcto-boreal and cosmopolitan species make up 70–80 % of the phytoplankton species in the all provinces; the warmest years are marked with entering of boreal and even tropical-boreal species.

Seasonal dynamics. Seasonal development of the Barents Sea phytoplankton is thoroughly studied for the Atlantic Subarctic Province, only, and is characterized by the all principal features which are typical for boreal marine ecosystems (Fig. 29.8). There are the following features of the seasonal succession of the Barents Sea phytoplankton: (i) very low number in winter; (ii) predomination of Bacillariophyta representatives in spring; (iii) unobligatory (facultative) autumn peak. The start of the phytoplankton development depends on the rate of insolation and water column stabilization (Druzhkov et al., 1997). At first phytoplankton develops in the region of the ice edges (Polar front) and in the coastal zone, and only then the development is recorded in the open sea (Slagstad and Støle-Hansen, 1991). In the Novaya Zemlya Province the spring phytoplankton development also begins under ice at water temperature below 0° C in April, and is associated with polynyas (Pautova, Vinogradov, 2001).
Long-term dynamics. Long-term phytoplankton dynamics depends on climate dynamics. In warm years the delay of phytoplankton development is recorded in the Atlantic waters (Atlantic Subarctic Province); the colder years are characterized with more early development; the shift in maximal phytoplankton development can make 2–3 weeks (Rey et al., 1987). Abundance and biodiversity of the phytoplankton in warm years can be twice more than in cold years (Matishov et al., 2000).

Sedimentation. In spring phytoplankton makes up about a half of all sediments from the euphotic zone. At this time the rate of sedimentation (due to phytoplankton, only) is similar in the Atlantic and Arctic waters, and makes up about 200 mgC m$^{-2}$ per day (Olli et al., 2002).

### 4.2. The Kara Sea

Composition. There are 264 phytoplankton species in the Kara Sea, including Bacillariophyta – 148, Dinophyta – 89, Chrysophyta – 9, Cyanophyta – 9, Chlorophyta – 7, Xanthophyta – 1 and Haptophyta – 1 (Makarevich and Koltsova, 1989; Druzhkov and Makarevich, 1999; Druzhkov et al., 2001).

Biogeographical structure. In respect to taxonomic composition and quantitative indices of phytoplankton development the Kara Sea is divided into 5 regions or provinces (Usachev, 1968): (i) high latitude Arctic – north-eastern part of the sea; (ii) central – affected by the Barents Sea; (iii) Novaya Zemlya Province – practically the whole south-west region of the sea (Druzhkov, Makarevich, 1999); (iv) the region affected by the Ob-Yenisey river system (estuary Arctic interzonal province; Skarlato and Golikov, 1985); (v) the sea region adjacent to the western coast of the Severnaya Zemlya archipelago.

Abundance and production. In spring-summer phytoplankton biomass varies in superficial water layer from 6.8 g m$^{-3}$ in the north (high latitude Arctic and central provinces) (Usachev, 1968; Druzhkov et al., 2001) up to 1.2–1.4 g m$^{-3}$ (Ilyash, Koltsova, 1981; Matishov et al., 2001a) and even 5.5 g m$^{-3}$ (Usachev, 1968) in the
zone of the rivers Ob and Yenisey confluence. Phytoplankton biomass in the Novaya Zemlya Province can reach 24 g m\(^{-2}\) (in the layer 0–100 m; Druzhkov et al., 2001). The phytoplankton production (primary production) differs in different regions (provinces; Vedernikov et al., 1994): 39–359 (104 at an average) mgC m\(^{-2}\) per day in the south-western region of the sea (the Novaya Zemlya province), 29–147 (64, on average) mgC m\(^{-2}\) per day in the central shallow region, 25–63 (47, on average) mgC m\(^{-2}\) per day in the Ob estuary and 107–312 (224, on average) mgC m\(^{-2}\) per day in the Yenisey Bay (estuary Arctic interzonal province). The annual phytoplankton production for the whole sea is 133.5–160.2 mgC m\(^{-2}\) (Galkina et al., 1994), or 14 × 10\(^6\) t C (Romankevich and Vetrov, 2001).

Seasonal dynamics. The Kara Sea is covered with ice for many months in year. Hence phytoplankton seasonal dynamics still remains unstudied. Earlier phytoplankton development was considered to start in June (Usachev, 1968), but the data obtained in February-May, 1996–1997 (during expeditions on board the nuclear ice-breakers) demonstrated that vegetation season in the Kara Sea starts in April (phytoplankton biomass makes up 218 mg m\(^{-3}\); Makarevich, 1998).

Long-term dynamics. We have no enough data to make conclusions about long-term phytoplankton dynamics in the Kara Sea. It should be noted, however, that during “warming” of the Arctic (in 1934) the focus of maximal phytoplankton development in August-September was situated in the more northern region (about 80° N, 75° E), than in 1945 (76° N, 80° E), 1981 (75–76° N, 65° E) and 1991 (71° N, 60° E; Usachev, 1968; Matishov et al., 2000).

5 Zooplankton

5.1. The Barents Sea

Composition. About 200 zooplankton taxa are recorded in the Barents Sea. Biodiversity of the zooplankton varies in different regions of the sea (Fig. 29.9): 180 taxa in Atlantic waters, 64 in Arctic waters, 100 – in the south-eastern shallow part of the sea (Pechora Sea; Timofeev, 2000; Troshkov and Gnetneva, 2000).

![Number of zooplankton species in different parts of the Barents Sea. BPR – Boreal Polar Province, ASP – Atlantic Subarctic Province, NZP – Novaya Zemlya Province. 1 – Copepoda, 2 – Coelenterata, 3 – Decapoda (larvae), 4 – Rotatoria, 5 – Cirripedia (larvae), 6 – Euphausiacea, 7 – Hyperiidae, 8 – Ctenophora, 9 – Polychaeta, 10 – Mysidacea, 11 – Gastropoda, 12 – Appendicularia, 13 – Ostracoda, 14 – Chaetognatha, 15 – Cladocera.](image)
Biogeographical structure. In respect to biogeographical composition of the zooplankton and level of the species predomination over the Barents Sea, three regions may be identified; their boundaries coincide with those of the biogeographical provinces for phytoplankton. Boreal oceanic species *Calanus finmarchicus* predominates in the Atlantic Subarctic Province; *Calanus glacialis* inhabiting Arctic shelf predominates in the Boreal Polar Province, and widespread coastal species *Pseudocalanus minutus*, *Oithona similis* and larvae of benthic invertebrates (especially of Bivalvia) predominate in the Pechora Sea. Increase in input of Atlantic waters (for example, during “warming” of the Arctic in 1930s) may be marked with occurrence of some subtropical zooplankton species (for example, euphausiids *Stylocheiron maximum*).

Abundance. The level of zooplankton biomass in the Barents Sea is determined with the two factors: temperature regime and press from planktonophagous fishes). In the western region of the sea (Atlantic Subarctic Province) during the spring-summer period the average zooplankton biomass in the water layer 0–50 m makes up about 100–200 mg m$^{-3}$ during cold years, and 200–400 mg m$^{-3}$ in warm years. In the northern region of the Barents Sea (Boreal Polar Province) in summer zooplankton biomass in the same water layer doesn’t exceed 50–100 mg m$^{-3}$ (Nesterova, 1990; Tereschenko et al., 1994). In the south-eastern region of the Barents Sea (Pechora Sea) zooplankton biomass varies from 100 to 300 mg m$^{-3}$ during ice-free period (June-August) (Troshkov, Gnetneva, 2000).

Communities and trophic structure. In the Atlantic waters (Atlantic Subarctic Province) 75–90 % of spring-summer zooplankton biomass consist of herbivorous *Calanus finmarchicus*, in the Arctic waters - of herbivorous *Calanus glacialis*. In the coastal waters and in the Pechora Sea the great role is played with herbivorous planktonic larvae of benthic invertebrates (which constitute up to 50 % of zooplankton biomass in some regions). There are following carnivorous among zooplankton species: chaetognaths (Chaeognatha), hydromedusae (Coelenterata) and pelagic amphipods (Amphipoda, Hyperiidea; Timofeev, 2000).

![Figure 29.10](image)

Figure 29.10 Seasonal dynamic of zooplankton biomass in the southern part of the Barents Sea (Atlantic Subarctic Province; by Zelikman, 1977).
Seasonal dynamics. The Barents Sea is a reservoir with pronounced seasonal cycles in production of organic matter in pelagic zone. The seasonal cycles in the zooplankton biomass are mainly caused by oceanographical regime of the sea and trophic factors (occurrence of food – phytoplankton, and press by consumers; Manteufel, 1941; Zelikman, 1977). Seasonal dynamics of zooplankton is only studied for the regions affected by Atlantic water bodies (ice-free in winter; Fig. 29.10). Decrease in biomass, which begins in summer, is connected with press from consumers of the primary zooplankton species *Calanus finmarchicus*, by ctenophores, jellyfishes, chaetognaths and planktonophagous fishes, and with transfer of the crustaceans into eastern and northern regions of the sea.

![Temperature](image1)

![Zooplankton](image2)

![Planktivorous fish](image3)

Figure 29.11 Long-term dynamic of zooplankton biomass in the south-western part of the Barents Sea (Atlantic Subarctic Province; by Timofeev, 1997, 2001). 1 – cold year, 2 – “normal” year, 3 – warm year, 4 – collapse of the herring stock, 5 – collapse of the capelin stock. III – transect from the Nord Cape to open sea, VI – Kola transect (along 33°30’ E).
Long-term dynamics of zooplankton biomass in the western part of the sea (Atlantic Subarctic Province) depends on the two processes (Timofeev, 1997, 2001): (i) intensity in inflow of Atlantic water (it determines the amount of crustaceans *Calanus finmarchicus* transported with these water bodies); and (ii) press from planktonophagous fishes (Fig. 29.11).

5.2. The Kara Sea

Composition. Eighty zooplankton taxa (with exception of Protozoa and planktonic larvae of benthic animals) have been recorded in the Kara Sea. Taxonomic diversity in different regions of the Kara Sea is very similar: south-western region – 43, south-eastern region – 44 and northern region – 40 species (Timofeev, 1989; Halsband and Hirche, 1999; Fetzer *et al.*, 2002). In the south-eastern, shallow and freshened region of the Kara Sea the central role is played by freshwater Cladocera and Copepoda, and larvae of benthic invertebrates.

Biogeographical structure. In respect to biogeographical composition of zooplankton and species predomination the Kara Sea may be divided into three regions: (i) south-western, where *Calanus glacialis* inhabiting Arctic shelf predominates; (ii) south-eastern, where the central role is played by the Arctic endemic, neritic and brackish-water species *Drepanopus bungei*; (iii) northern, predominated by representatives of genus *Calanus* (*C. glacialis, C. finnarchicus* – boreal North-Atlantic species, *C. hyperboreus* - Arctic oceanic species).

Abundance. During ice-free season distribution of zooplankton abundance and biomass is determined by oceanographic conditions. Zooplankton biomass in the south-western region of the Kara Sea varies from 50 to 300 mg m$^{-3}$ (Ponomareva, 1957; Fomin and Petrov, 1985; Vinogradov, M.E. *et al.*, 1994 a), in the south-eastern region (Ob-Yenisey shallow) – 100–1000 mg m$^{-3}$ (Ponomareva, 1957; Vinogradov *et al.*, 1994 b). There are no data on zooplankton biomass for the northern region of the Kara Sea.

Communities and trophic structure. In the south-western and northern regions of the Kara Sea zooplankton is predominated by genus *Calanus*, typical herbivorous species which fattening seasons fall on spring-summer phytoplankton development. In these regions carnivorous are mainly represented with Chaetognatha and Coelenterata (Timofeev, 1989). In the south-eastern part of the Kara Sea omnivorous species predominate; their diet consists of phytoplankton and suspended organic matter transported with flow of rivers Ob and Yenisey.

Seasonal dynamics. Zooplankton seasonal dynamics has only been studied in the southern region of the Kara Sea (the Dikson harbor, 1955–1956; Chislenko, 1972). From November till May-June zooplankton biomass is very little and doesn’t exceed 30 mg m$^{-3}$. June is marked with drastic increase, annual maximum is recorded in August-September (up to 375 mg m$^{-3}$), whereas October is characterized with dramatic decrease in biomass (Fig. 29.12). In the south-western region of the Kara Sea zooplankton biomass in winter doesn’t exceed 30–40 mg m$^{-3}$ (Vinogradov *et al.*, 2001).

Long-term dynamics. We have no enough data on the zooplankton long-term dynamics in the Kara Sea. It should only be noted that in 1936 (during “warming” of the Arctic) occurrence of indicator species of Arctic water bodies was significantly less than in 1981 (Matishov *et al.*, 2000).
6. Bottom algae and invertebrates

6.1. Biological diversity, biomass and structure

The number of known species of benthic invertebrates decreases from west to east: Barents Sea—2499 species; Kara Sea—1580 species (Northern Sea Route, 1998). The highest benthic biodiversity in the Barents Sea is observed on shoal and hard bottom near the coast of Kola Peninsula and archipelagos, the lowest is in its south-west deepwater part. In the Kara Sea the highest species diversity is registered on hard bottoms and small depths along the Novaya Zemlya coast, in Karskiye Vorota and Yugorskiy Shar Straits. The lowest biodiversity is typical for regions influenced by the Ob and Yenisey River discharge. It is also rather low in northern (deepwater) regions of the Novaya Zemlya Trough.

Distribution of bottom organism biomass (Fig. 29.13) is similar to that of biodiversity. In absolute expression, macrobenthos biomass varies from 0.1 g m\(^{-2}\) up to 12 kg m\(^{-2}\) in the Barents Sea and from 1.5 up to 400 and more g m\(^{-2}\) - in the Kara Sea (Kiyko and Pogrebov, 1997 a). The highest values of biomass as those of species diversity correspond to shallow depths along the coast. Thus, near Svalbard and in the southeast part of Spitsbergen Bank the biomass ordinary exceed 1.5–2 kg m\(^{-2}\), with main contribution made by sponges and bivalves. Average biomass up to 300 g m\(^{-2}\) on the Central Bank in the Barents Sea is determined by high density of sea urchins of the *Strongylocentrotus* sp. and, on some sites, by sea cucumbers of *Trochostoma* sp. In the southern part of the Barents Sea, on the Murman, Geese, Kanin Banks, Kolguiev Island and Pechora Sea shoals the biomass averages 100–300 g m\(^{-2}\). Bivalves and barnacles form its base here. The maximum biomasses for the Murman slope, exceeding 1.5 g m\(^{-2}\), are obtained near the offshore Seven Islands owing to aggregations of mollusks of *Chlamys islandica* and *Modiolus modiolus*. From the Barents Sea side of Novaya Zemlya, benthic biomass on some sites also exceeds 1 kg m\(^{-2}\). Bivalves, hydroids and barnacles play the main role here. The highest biomass is registered in the Karskiye Vorota and Yugorskiy Shar Straits where, due to mussels and red algae, the total benthic biomass reaches 10–12 g m\(^{-2}\). The Kara Sea side of Novaya Zemlya is characterized by biomass 200–400 g m\(^{-2}\). The main roles here are played by sea urchins of *Strongylocentrotus* sp. and...
mollusks of *Astartidae spp.* Biomasses up to 300 g m\(^{-2}\) are observed in the Kara Sea as well in the region of the Baydaratskaya Inlet. Mainly they are formed by mollusks of *Serripes groenlandicus, Ciliatocardium ciliatum* and *Astartidae spp.*

Figure 29.13  Distribution of total benthic biomass (g m\(^{-2}\)) on the Russian West Arctic shelf according to the result of 1991–1994 cruises. 1 – less than 10; 2 – 10–25; 3 – 25–50; 4 – 50–100; 5 – 100–300; 6 – 300–500; 7 – more than 500.

Regions with especially low biomass (no more than 25 g m\(^{-2}\)) enter the Barents Sea from the west, occupying the Bear Island Trough and the north-western part of the Norwegian Trough. Regions with reduced biomass are located also in the central deepwater part of the Barents Sea: Central and Northeastern Deeps and, partly, on the Central Plateau. In the Kara Sea the minimum biomasses (no more than 10 g m\(^{-2}\)) are registered in the deepest parts of the Novaya Zemlya Trough and the Saint Anna Trough. The maps of biomass, to a great extent, may be interpreted by bathymetry and bottom sediment maps: regions of increased biomass correspond to the bottom relief rise and mainly coincide with regions of hard bottom and strong current. The opposite environment would characterize the biomass minimum.

A decisive influence on the results of division of the studied area into trophic zones (Figs. 29.14 and 29.15) is rendered by morphological, lythological and hydrodynamic peculiarities of areas. Areas with abundance of sessile and motile filter-feeders (SFF and MFF) usually coincide with the largest relief bulgings while those with prevailing surface and subsurface deposit-feeders or burrowing (SDF and BDF) are typical for the largest flexures and depressions. The greatest part of the Barents Sea central regions is occupied by BDF zone (Fig. 29.14). Regions of SFF and MFF prevailing are found off Svalbard, Franz Josef Land, Novaya Zemlya and Murman, as well as on the Spitsbergen and Kanin Banks and the Kolguev
Island and Pechora Sea shoals. The largest SDF zone in area is registered on the northeast of the Barents Sea. In the Kara Sea the largest area is occupied by SDF zone (Fig. 29.15). Zone of BDF prevailing is situated mainly in deepwater regions of the Novaya Zemlya Trough. Areas with SFF prevailing enveloped by a narrow band the Novaya Zemlya coast, occupies the Karskiye Vorota and Yugorskiy Shar Straits. MFF zone is observed along the Novaya Zemlya coast, occupying the Baydaratskaya Inlet, spreading along the west and north coasts of Yamal and wedging north-ward.

Autotrophs (AT) are prevailing at small depths in the straits, off the mainland and island. It may be assumed that the areas where AT are prevailing are more numerous but they are located on shoals that are rather difficult for studying aboard a large vessel. Sites with carnivores and herbivores prevailing are dispersed in patches all over the investigated area. This group is not represented at our scheme since it is considered to be a migration component of fauna and depends in its distribution upon distribution of other benthic groups (Kuznetsov, 1970).

On the whole, trophic zonality of the Kara Sea is less patchy in comparison with that of the Barents Sea, which may be due to the more simple morphology of the
Kara Sea bottom. Most distinctly trophic zonality is observed in western part of the Kara Sea where regular interchange of AT-SFF-MFF-SDF-BDF belts may be seen clearly along the depth gradient.

By analyzing the community structure of the Barents and Kara Seas it is shown that dominating species biodiversity here is comparatively high while the area of communities, formed by them, as well as their share in total benthic biomass, varies in a wide range. The most diverse forms among them are bivalves, echinoderms and polychaetes. A large area in the central part of the Barents Sea is occupied by communities of worms (polychaetes and sipunculides Golfingia sp.) and sea cucumber Trochostoma sp. (Fig. 29.16). In the southern part of the Barents Sea, on Kanin Bank, the Kolguyev Island and Pechora Sea shoals the community of bivalves is a typical one. Such clam species as Tridonta borealis, Serripes groenlandicus, Ciliatocardium ciliatum and Macoma calcarea prevail here. Communities of Strongylocentrotus sp., Chlamis islandica, Balanus sp., Lithothamnion sp. are found usually near the coasts of Svalbard, Novaya Zemlya, Kola Peninsula, Vaygach Island and on the shoals of Geese and Central Banks. The largest areas in the Kara Sea are occupied by the brittlestar community: Ophiopleura
borealis, Ophiocten sericeum, and bivalves: Tridonta borealis, Portlandia arctica, and P. aestuariorum (Fig. 29.15).

Figure 29.16 Bottom communities, singled out on the Barents Sea shelf according to the results of cluster analysis. 1 – Ophiopleura borealis + Hormosina globulifera; 2 – Polychaeta + Sipunculoidea (Golfingia sp.); 3 – Trochostoma sp.; 4 – Elliptica elliptica + Astarte crenata; 5 – Brisaster fragilis; 6 – soft bottom community adjacent to Svalbard; 7 – community of Saint Anna Trough slopes; 8 – Strongylocentrotus sp. + Ophiopholis aculeata; 9 – shoal community of sessile filter-feeders adjacent to Svalbard; 10 – shoal community of sessile filter-feeders on Lithothamnion sp.; 11 – shoal community adjacent to western coast of Novaya Zemlya and Vise Island; 12 – Tridonta borealis; 13 – Ciliatocardium ciliatum; Macoma calcarea + Serripes groenlandicus; 14 – Bivalvia; 15 – Macoma fusca.

6.2. Long-term benthic population changes

A general review of obtained data had not shown any striking abnormalities in benthos status and was mainly indicative of normal natural features of its over the Barents and Kara Seas area. At almost all studied sites of the Kara Sea, composition, abundance and bottom population structure were just the same as described earlier. In any case data for their statistical analysis appeared to be unavailable.
For the Barents Sea the results of our survey and of ones carried out earlier some differences, which were statistically significant, were observed. The results of the statistical assessment of long-term changes in the bottom communities of the Barents Sea fulfilled on the basis of three-way ANOVA show that the total benthic biomass value has no significant differences compared to that registered in 1920–1930ies (Brotskaya and Zenkevich, 1939; Kiyko and Pogrebov, 1997a). Negligible distinction, observed at some sites, most likely should be regarded as being engendered by natural fluctuations of benthic species population density (if they are also not caused by the errors of random sampling, what is rather probable). The total biomass values, obtained during the surveys of the end of 1960ies (Antipova, 1975), significantly differ both from the values of 1920–1930ies and from our values of 1991–1994ies (for 1968–1970ies notes significant reduction in benthic biomass all over the Barents Sea; Antipova, 1975; Kiyko and Pogrebov, 1997a). Biomass lowering on the south has reached 50–70% of the previous values and in the richest southeastern part of the Barents Sea – 40–60%. Decrease in abundance has affected primarily arctic-boreal species, which from the base of the Barents Sea bottom dwellers (Zenkevich, 1963).

According to Yu.I. Galkin (1987) opinion to which we also subscribe, the decrease in biomass, registered in collection of 1968–1970ies, is the result of prolonged rise of temperature which was observed in the Barents Sea in 1940–1960ies and had told on arctic-boreal species especially negatively.

Further studies fulfilled in the southeastern segment of the Barents Sea in 2000–2002 had revealed decrease in the benthic biomass as compared to the 1991–1994 data. The average biomass decrease was two-fold and in some areas 3–5-fold (Kiyko et al., 2002). At the same time, benthos composition and structure of both survey periods were quite similar. Statistical analysis of data has shown that significant lowering of benthic organism size took place. That caused decrease in total biomass while the community structure remained the same. The revealed long-term dynamic could be caused by climatic changes, natural fluctuations of the population abundance, geochemical processes or man-induced impacts. However, definite knowledge of real causes of these changes may be obtained only after additional studies.

Summarizing all the result obtained during the study of north-western shelf of Russian arctic in 1991–1994, we can regard contemporary ecological state of the Barents and Kara Sea benthos (except some coastal regions) as being close to the average long-term norm.

Considerable man-induced disturbances of macrobenthic structure (in comparison with biological norm for studied abiotic environments) on trans-regional level were discovered only in rare cases in the Kola Bay and in the vicinity of the Novaya Zemlya coasts. First of all, they manifested themselves in a decrease in biodiversity and biomass of bottom dwellers. However, confirmation of cause-and-effect relationships between disturbances of the benthic structure and level of human impact in particular regions needs more thorough research.

### 6.3. Pollutant concentrations in bottom organisms

The comparative estimate of persistent organic pollutant (POP), trace metal (TM) and radionuclide (RN) concentrations in benthic invertebrates and algae of vari-
ous region of the Barents and Kara Seas shelf did not reveal any meaningful anomalies (Kiyko and Pogrebov, 1997 b). Their variation was only dependent on taxonomic classification and was practically unaffected by the location of sampling site in the water basin.

POP concentrations (ng g\(^{-1}\) wet weight) in benthic organisms of the Barents Sea are as follows: alpha-HCH – 0–32.4; gamma-HCH – 0–39.0; DDT – 0–23.3; PCB – 0–11.4. TM concentrations (mg g\(^{-1}\) dry weight) in benthic organisms of the Barents Sea varies within the following limits: Zn – 10–173; Fe – 11–663; Sn – 0.2–2.8; Mn – 0.4–44.3; Ni – 0.4–2.9; Cu – 0.3–2.1; Cd – 0.1–2.2; Pb – 0.2–2.0; Co – 0.1–1.1 (Kiyko and Pogrebov, 1997 b). No present of gamma-emitting man-made RN has been registered in any one sample at any one station in 1992 (Kiyko and Pogrebov, 1997 b). The results of sample radiometric analysis are indicative of the background content of gamma-emitting RN (on the level of 10 Bq kg\(^{-1}\) of dry weight), and correlation between the registered rate of count of beta-particles and K-40 content in the preparations indicates that it is particularly this RN which is responsible for basic contribution into the total beta-activity. Gamma-active K-40 (Bq kg\(^{-1}\) dry weight) and beta-activity in benthic specimens of the Barents Sea are as follows: K-40 – 1–114; beta particles counting fate (l/S) <0.2–1.43 (Kiyko and Pogrebov, 1997 b). Measurements of radionuclide concentrations in biological specimen from Chernaya Inlet (where nuclear tests took place) testified to absence of their significant bioaccumulation by benthic and invertebrates (Pogrebov et al., 1997). On the whole, the results of radionuclide concentration measurements were in the limits of their variability known from literature (Matishov et al., 1994).

The comparison between the pollutant concentration in the benthic organisms of the Barents Sea and the literature data on other areas may suggest that in our studies the POP and TM concentrations are basically much lower and are only comparable to similar concentrations in areas referred to as background. On the other hand, according some published data (Moore and Ramamurti, 1987), the levels of zinc and cadmium in the bottom dweller tissues are close to these from the impacted areas.

7. **Fishes**

7.1. *The Barents Sea*

Ichthyofauna of the Barents Sea counts not less than 150 species of fishes and fish-like vertebrates (Andriashev, 1954), which belong to 53 families. The most species are families Gadidae (18 species), Zoarcidae (13), Cottidae (12), Pleuronectidae (9), and Salmonidae (7). Approximately a third of total number of species are rare or threatened species. About 90–95 species occur permanently, and 30–35 of them is used commercially (Rass, 1993).

Vast estuarine areas are not typical for the Barents Sea, with exception of the south-eastern part, which is freshened by the Pechora River outflow. Thus, a brackish-water complex of fish species is represented in the sea insignificantly. Only a few freshwater species coming into the brackish waters near mouths of rivers occur (burbot, pike, ide, whitefish).

Some anadromous fish species also present, life cycle of which is related partly with fresh waters. They reproduce in fresh waters but feed in the sea. They are valuable salmonids (Atlantic salmon, sea trout, Arctic char, introduced pink
Ecosystem of the Barents and Kara Seas, Coastal Segment

salmon) and also whitefish and sea lamprey. Anadromous fishes are fished mainly in rivers during their spawning migrations. At present the most important is salmon fishery. Sea trout, Arctic char, and whitefish are listed practically in all rivers where fishery control exists, but they are collected as by-catch only. Knowledge about sea period of life of sea trout, Arctic char, and whitefish in the Barents Sea is poor. Sea trout and whitefish make short migrations into the sea, whereas the Arctic char make much longer sea migrations, almost similar with the Atlantic salmon.

Majority of fishes of the Barents Sea are marine species, which spend the whole life in salt water and reproduce here. Types of their life cycles are connected with their relations to temperature conditions. Three types of species can be distinguished. Many warm-loving boreal species come into the Barents Sea sporadically, in “warm” periods and when inflow of warm Atlantic waters enlarges (blue whiting, whiting, Atlantic argentine and others). Fishes of this group do not make large schools in the Barents Sea and are not commercial here. Group of boreal-arctic species reproduce mainly in more southern areas (coast of northern Norway, Lofoten Islands), and use highly productive areas of the Barents Sea as feeding grounds (Atlantic cod, haddock, pollack, Atlantic herring, capelin, red-fishes). They reach northern and easternmost areas of the sea during feeding migrations. The size of their feeding grounds and prolongation of migrations depend greatly from temperature conditions. For example, in “warm” and “normal” years (1993–1996) Atlantic cod make its main summer-autumn feeding migration into southern and eastern parts of the Sea but in “cold” years (1997–1998) they migrate into the area of the Bear Island and Spitsbergen. Species of Arctic fauna (Arctic cod, *Eleginus navaga*, some *Lycodes*) are related in their distribution with arctic cold waters. In periods of cold snap the area of their distribution in the Barents Sea greatly enlarges.

In relation to habitat preference the following groups can be distinguished: pelagic, which live in mid-water (capelin, Atlantic herring, Arctic herring *Clupea pallasii suworovi*) and benthic or benthico-pelagic, which live on bottom or near bottom (Atlantic cod, pollack, haddock, wolf-fishes, plaices, halibut, red-fishes). Polar cod living among arctic ice is called kryopelagic species. Pelagic capelin, Polar cod are abundant fishes and play a large role in the ecosystem, as many carnivorous fishes, sea birds and marine mammals prey on them.

Strong fishery exists mainly in the southern, western and central parts of the sea. About 40 fish species regularly occur in trawl catches (Karamushko et al., 2001), among them 7 species of Pleuronectidae, 6 species of Gadidae, 4 species of Rajidae. Pelagic species comprise about 19.5%, benthic and benthico-pelagic comprise 80.5%. Fishery is based on Atlantic cod *Gadus morhua*, capelin *Mallotus villosus*, haddock *Melanogrammus aeglefinus*, Polar cod *Boreogadus saida* and plaice *Pleuronectes platessa*. Pollack *Pollachius virens*, Atlantic herring *Clupea harengus*, red-fishes (*Sebastes marinus* and *S. mentella*), three species of wolf-fishes (*Anarhichas denticulatus*, *A. lupus* and *A. minor*), European plaice *Hippoglossoides platessoides limandoides* are also important. At present stocks of all commercially used fishes subjected to over-fishing. Fishery statistic of the International Council for the Exploration of the Sea (ICES) is carried on for the Barents Region, which includes besides the Barents Sea itself also the northeastern part of the Norwegian Sea and West Spitsbergen. In the Barents Region the fishery was most
intensive in 1960–1970ies. The total catches of fish increased from 2.3–2.8 to 4.3–4.6 million tons per year, what comprised about 5% of the total world catches. Then fish catches decreased significantly. In 1997–1998 about 2.3–2.7 million tons of fishes per year was caught in the Barents Region (Borisov et al., 2001). Accounting stock of all biological resources (invertebrates inclusive) in the Barents Region is estimated at approximate level of 28 million tons, with variations from 33–35 million tons (in 1950 and 1954) to 5.6–8 million tons (1986 and 1989; Borisov et al., 2001). Content of pollutants and radionuclides in fishes caught in the Barents Sea at present is significantly lower than the levels of maximum allowable concentration (Ilyin, 2001; Matishov et al., 2001b).

7.2. The Kara Sea

Fish fauna of the Kara Sea (including bays, inlets and mouth areas of numerous rivers) counts about 83 species of fishes and fish-like vertebrates (Esipov, 1952; Andriashev, 1954; Andriashev and Chernova, 1994), which belong to 28 families. The most specious are families Zoarcidae (14 species), Cottidae (12), Coregonidae (9). Among them 54 species (or 62.1%) are marine, 14 (16.1%) are semi-anadromous, 1 euryhaline, 18 (20.7%) are freshwater species which occur in deltas of Kara, Ob, Yenisey, Pyasina rivers and brackish water areas nears other streams entering the sea.

Distinguishing feature of the Kara Sea fish fauna as compared with the Barents Sea is quite large number of freshwater fishes, which occur offshore. This is due to much larger influence of freshened waters from outflow of numerous rivers. Characteristic is also a small number of “guest” warm-loving species coming from the Barents Sea (Atlantic cod, Atlantic herring, haddock, lump-sucker Cyclopterus lumpus).

Biology of anadromous and semi-anadromous fishes during marine period of their life is purely studied in the area. It is known that Siberian sturgeon Acipenser baeri stenorrhynchus, whitefishes Coregonus nasus, C. sardinella, C. muksun and Stenodus leucichthys nelma feed inside bays and inlets. Only C. autumnalis spread more wide in the coastal zone of the sea.

Marine fishes belong to 15 families: Squalidae (1 species), Rajidae (1), Clupeidae (1), Osmeridae (1), Myctophidae (1), Cottidae (11), Cottunculidae (1), Agonidae (2), Cyclopteridae (3), Liparidae (6), Lumpenidae (3), Zoarcidae (14), Ammodytidae (1), Gadidae (5), Pleuronectidae (3), total number is 54 species. The most specious are families Zoarcidae and Cottidae, which count 25 species (or 46.3%).

Arctic species predominate, which permanently live and reproduce in water with negative temperatures (to −1.96°C; Gymnelus esipovi, G. andersoni and other). Some of these species are distributed circumpolarly in the Arctic (Lycodes polaris, Triglopsis quadricornis polaris, Aspidophoroides olriki, Liopsetta glacialis, Boreogadus saida, Leptagonus decagonus). Endemic species in the sea are absent.

Benthic and near-bottom species predominate. The Polar cod is cryopelagic abundant species which play important role in food webs. In relation to vertical distribution three categories of fishes can be distinguished. Fishes of coastal shallow waters occur at a depth less than 50 meters (Myoxocephalus scorpius, Triglopsis quadricornis polaris, Artediellus scaber, Liparis tunicatus). Next group of
species occur at a depth of a few meters to 400–500 meters (Icelus bicornis, Liparis fabricii, Lygodes rossi, L. pallidus, Gymnelus andersoni, Boreogadus saida). Deepwater species occur at a depth from 100–250 to 700 m (Triglops pingelii, Careproctus reinhardtii, Cottunculus sadko, Leptagonus decagonus, Lycenchelys sarsi, Lygodes seminudus). Fishes of two latter groups predominate. Shallow water coastal zone is poorly inhabited by fishes due to heavy ices present here permanently during almost the whole year. So conditions for fishes are adverse. Reach fish population in coastal zone occur only in summer time in warm parts of bays near mouths of rivers (Ob, Yenisey Rivers and other).

In relation to salinity three categories of fishes can be distinguished. Highly-stenohaline species live in water under salinity from 33.3–34.5 to about 35‰ (Triglops pingelii, Cottunculus sadko, Leptagonus decagonus, Lygodes seminudus, L. rossi, L. pallidus, Gymnelus esipovi, G. andersoni). Moderately-stenohaline species occur under salinity from 29 to 35‰ (Myoxocephalus scorpius, Triglopsis quadricornis polaris, Artediellus scaber, Gymnelus knipowitschi), e.g. all coastal forms belong to this group. Euryhaline species occur under salinity from 29 to 35‰ (Gymnocanthus tricuspidis, Icelus bicornis, I. spatula, Lygodes agnostus, Boreogadus saida).

Quantitative studies of the Kara Sea fish fauna are absent. The following species are numerous in trawl catches made in the offshore shelf areas: Icelus bicornis, Boreogadus saida, Gymnelus andersoni, Gymnelus knipowitschi, Lygodes pallidus, Artediellus scaber, Triglops pingelii, Gymnocanthus tricuspidis. In the coastal zone Triglopsis quadricornis polaris is common. Food of Coregonus autumnalis in the Ob Bay consists mainly from this species. The most important item in the food webs in the open sea is Polar cod.

In general, the level of knowledge on the Kara Sea fish is many times less than that of the neighboring Barents Sea. It depends on the lesser fishery importance of the region and its more unfavorable ice conditions. Ichthyological studies have been conducted here mainly incidentally together with hydrobiological or other researches. The fishes of estuarine areas are better known. Offshore fauna is studied better than in the coastal zone, where trawling is not possible. Eastern coast of Novaya Zemlya ichthyologically is almost unstudied. Reproduction of fishes in the Kara Sea and other aspects of their biology are fragmentary, eggs and larvae for 18 species are only known.

Commercially valuable in the sea are semi-anadromous and anadromous species fished in estuarine waters. They are Siberian sturgeon, and several forms of whitefishes.

8. Food webs

8.1. The Barents Sea

The Barents Sea ecosystem is characterized by branchy interactions between pelagic, bottom and terrestrial communities. Main processes are realized in the water column (Zenkevich, 1963; Marti and Martinsen, 1969). Major part of organic compounds is produced here and is consumed by bottom communities, fishes and birds. Due to that, food webs of the water column are studied better as compared to the seabed communities.
Food webs of the Barents Sea pelagic system are comparatively short and simple. In general, trophic structure of the pelagic community in the Atlantic Subarctic Province may be described as follows: phytoplankton – zooplankton (Calanus and krill) – capelin (herring) – cod (Fig. 29.17). Attempts to evaluate the energy flow in the pelagic food webs quantitatively were made more than once (Marti and Martinsen, 1969; Timofeev, 1990, 1996; Nöthig et al., 1994; Sakshaug et al., 1994). However, due to considerable long-term variability of the plankton and fish production, intensity of fishery and other factors, this evaluation should be considered to be only of historic value (as old photos). For example, up to 1980ies, cod was feeding mainly on capelin but in 1980ies (due to collapse of the capelin stock caused by over-fishing) it was forced to feed on krill and its own fry (cannibalism; Orlova and Matishov, 1993). In its turn, decrease in the capelin resources caused increase in the large plankton species abundance (e.g. Temisto sp.; Dalpadado et al., 2002), which feed on Calanus. As a result, redistribution of the energy flows occurred and trophic structure changed leading to the strengthening of the levels nearest to the phytoplankton.

Figure 29.17  The food pathways in Balsfjord, Northern Norway (by Falk-Petersen et al., 1990)

Capelin Mallotus villosus, Polar cod Boreogadus saida, Atlantic herring Clupea harengus and also young of many other Barents-sea fishes are zooplankton feeders. Predominanting benthic and near-bottom fishes feed mainly on benthic and
near-bottom organisms. Wolf-fishes (Anarhichas denticulatus, A. lupus and A. minor) prey predominantly on echinoderms, mollusks, crustaceans and fishes (Orlova et al., 1989). European plaice Hippoglossoides platessoides limandoides and other pleuronectids feed usually on polychets, echinoderms and mollusks (Berestovsky, 1989). Haddock Melanogrammus aeglefinus used more often krill and shrimps, in lesser extent polychets, echinoderms and bivalves, also capelin and other fishes (Kovtsova et al., 1989). Cod Gadus morhua prefer to eat various fishes (herring, capelin, young cod and haddock, polar cod, young places, Lumpenus, Lycodes, Cottidae), and big crustaceans, but use totally about 200 feeding objects (Treska…, 1996). Red-fishes prey mainly on herring, capelin, young cod-fishes, also as on crustaceans Euphausiidae, Hyperiidae, Pandalus sp. (Barsukov et al., 1986).

Many of sea birds species (Fratercula arctica, Rissa tridactyla, Cepphus grille, Uria lomvia and others) feed on school pelagic fishes (capelin, herring, polar cod), also they prey on many near-bottom fish species living in sublittoral zone and shallow shelf water (young cod-fishes, wolf-fishes, Lumpenus sp., Cottidae sp., Liparis sp., Lycodes sp. et al.). Some other species of sea birds prey mainly on benthic invertebrates (Krasnov et al., 1995).

Bearded seal Erignathus barbatus feeds usually on big marine invertebrates. Ringed seal Phoca hispida consumes mainly fish and shrimps. Harp seal Histrpophoca groenlandica, Common seal Phoca vitulina, Grey seal Halichoerus grypus, Hooded seal Cystophora cristata also used fishes and big invertebrates. Walrus Odobenus rosmarus which still inhabit the Frantz Joseph Land, Spitsbergen and Novaya Zemlya areas, prefers big forms of the bivalve mollusks (Atlas…, 1980). The ringed seals and young walruses are important as the main food for polar bears Ursus maritimus.

Whales of the Subordo Mustacoceti (baleen whales) feeds mainly on zooplankton. From this group, the Blue Whale Balaenoptera musculus, Fin Whale Balaenoptera physalus, Seiwal Balaenoptera borealis, Minke Whale Balaenoptera acutorostrata, Humpbacked whale Megaptera novaeangliae and Bowhead whale Balaena mysticetus occur sporadically in the Barents Sea (Atlas…, 1980).

Bottle-nosed dolphin Tursiops truncates feed mainly on benthic invertebrates and fishes. Atlantic White-sided Dolphin Lagenorhynchus acutus preys usually on school pelagic fishes (herring, salmon) and squids. White-beaked dolphin Lagenorhynchus albirostris catch usually cod, capelin, navaga, herring, squids. Carnivorous Killer whale Orcinus orca kill seals, walruses, whales, but feeds also on fishes (cod, capelin, salmons, skates, halibuts) and squids. Long-finned Pilot Whale Globicephala melaena, Harbour Porpoise Phocoena phocoena, Giant sperm whale Physeter catodon, Beluga Whale Delphinapterus leucas, Narval Whale Monodon monoceros feed usually on fish (herring, navaga, Atlantic cod, polar cod, places, skates and others) and squids (Atlas…, 1980).

8.2. The Kara Sea

Food webs in the Kara Sea Region are well studied mainly for the Ob and Yenisey estuaries. Feeding preferences of the most abundant species leaving here are as follows (Pogrebov et al., 2001; see also Fig. 29.18). The Siberian sturgeon is a benthos-eating fish. Its main food is tendipedid larvae and larvae of Mayflies and
buffalo gnats. It also feeds on amphipods, oligochaetes, and isopods. Isopods *Saduria entomon* comprise up to 90% of its total food in the Yenisey Bay.

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**Figure 29.18** Main food webs in the Yenisey Estuary (by Pogrebov et al., 2001)

The vendace and pelyad preys mainly on zooplankton. Mysidaceans, cladocerans, and copepods are prevailing in the vendace food in the bays, whereas in delta tendipedid larvae and amphipods are leading. Crustaceans, mainly cladocerans, and, to a lesser degree, insect larvae, are predominating in the pelyad food during summer, though benthic invertebrates may be found in stomachs of this species in winter time and fish eggs in autumn. The whitefish and omul preys both on zooplankton and benthos. Young whitefish is feeding mainly on cladocerans and copepods, while adults, besides above-mentioned tendipedid larvae and amphipods, —on small mollusks and adult insects. Amphipods and mysidaceans comprise the main food of adult omul. Copepods and cladocerans are important only for the young of this species. The muksun and chir are mainly benthos-eating fishes. During summer, muksun feeds on amphipods and isopods *Saduria entomon*, and, to a lesser degree, on diatom algae. Its fry also uses cladocerans, copepods, tendipedid larvae, and amphipods in the course of migration in the deltas. The chir food comprises tendipedid larvae, small mollusks, and near-bottom crustaceans. Its fry feeds on plankton in the first months of life but by the autumn time bottom dwellers begin to prevail in its ration. The nelma is typical predator, though its young are preying on zooplankton, benthos, and adult insects during the first three yours of life. From an age of 4 to 5 years, main food of nelma comprises the fry of whitefish, muksun, burbot and own fry, as well as adult tugun, vendace, grayling, and nine-spined stickleback. From the other fish inhabiting estuaries, the smelt feeds on zooplankton (cladocerans and copepods) at the early stages of development, and on amphipods and especially mysidaceans, being adult. Role of fry in feeding is
also significant. The burbot and pike are mainly predators. The majority of other fish species feeds on both plankton and benthos. In general, the proportion of benthos-eating fishes estimated for the study area is 43% of the total fish fauna, of plankton-eating fishes 18%, whereas predators compose 20% of the fish fauna.

In offshore areas the Polar cod and Liparis cf. fabricii are the main cryopelagic abundant species, which play important role in food webs as zooplankton feeders. Cottid, zoarcid and agonid fishes consume mainly benthic and near-bottom organisms.

The role of fish is significant in seabird diets. Such true marine birds as guillemots and seagulls are among the most significant fish consumers, whereas birds of other orders (e.g., waterfowl and water birds) prey mainly on benthic algae and invertebrates.

In addition to fish, some marine mammal species also inhabit the bays. The white whale is the most abundant among the cetaceans, whereas the widely distributed ringed seal is the most common species among the pinnipeds. Polar bears may be observed in the study area on rare occasions. The white whales are usually seen in the near-shore waters during the ice-free period. In some areas these whales undertake extensive seasonal migrations. The white whale feeds on squid, benthic crustaceans and fish, in particular Arctic cod. They are important for ecology of the area as a primary marine predator. The circumpolar ringed seal is inhabitant of the permanent pack ice but congregate on landfast ice for breeding. Fish, pelagic amphipods, shrimps and other crustaceans make up the bulk of the diet. The ringed seal is important as a predator and as the main food for polar bears. The polar bear visits the bays in winter. The polar bear lives mainly on ringed seals and partly on bearded seals. They also feed on other seals, walruses, white whales, carcasses and whatever they find of birds, eggs, etc. The polar bear is at the top of the Arctic marine food chain. The size of the population has an effect on the size of the population of ringed and bearded seals.

9. **Radioactive contamination of seabed sediments and biota’s reply**

Considerable concern, not only of specialists, but of all the world community in the recent past was connected with the environmental state of the nuclear test sites and sites of radioactive waste (RAW) disposal off Novaya Zemlya. Novaya Zemlya Test Site experienced 132 nuclear explosions (Adushkin and Krasilov, 1993), and RAW of the total radioactivity 2400 kCi was damped here on shelf eastwards archipelago (Facts, 1993; see also Fig. 29.19).

9.1. **The Barents Sea**

Underwater nuclear explosions in Chernaya Inlet (see Fig. 29.19) were conducted in 1955, 1957 and 1961 (the first of them at a depth of 50 m). Measurements taken in 1992 had shown that Cs-137 concentration in the inlet bottom sediments was 80 Bq kg\(^{-1}\) while the average value all over the Barents Sea was less than 5 Bq kg\(^{-1}\) (Smith *et al.*, 1995). Radioactivity of Pu-239, 240 made up 2500–11000 Bq kg\(^{-1}\) against background level 0–3 Bq kg\(^{-1}\). Co-60 (140 Bq kg\(^{-1}\)) was also registered.
According to the results of sampling provided in Chernaya Inlet in recent decade (Pogrebov et al., 1997), the macrobenthos biodiversity at investigated sites was rather high and comprised 34 species per single quantitative sample while the biomass averaged 245.8 g m\(^{-2}\). By species diversity the first places belonged to Polychaeta and Bivalvia. Along the depth gradient, the total benthic biomass decreased from 384 g m\(^{-2}\) at 31 m to 106 g m\(^{-2}\) at 58–69 m. By prevailing trophic group the community belonged to subsurface deposit-feeder zone (60% of total biomass). In general, no deviation from statistically averaged state of bottom dwellers in Chernaya Inlet as compared to the adjacent areas of the Barents Sea could be noted.

In meiofauna of the studied area representatives of all the main taxa of this group were found. Meiobenthos abundance varied within 108–5426 thousand individuals m\(^{-2}\), biomass—within 2–112 g m\(^{-2}\). Foraminifera dominated. Minimum values of meiobenthos abundance were observed on stations, located in the center of the inlet, on silty and clayey seabed sediments. Averaged characteristics of the nearest offshore differed from those of the inlet: (i) meiobenthos density here was three times lower and biomass—five times lower than in Chernaya Inlet; (ii) dominating species and community structure were different; (iii) community variability turned out to be smaller. However, we are far from taking responsibility to correlate the revealed differences with the consequences of nuclear tests, particularly as no abnormalities in the meiobenthic organism morphology could be found.
Microbenthic fauna of Chernaya Inlet was not found to be poor. However it was difficult to overlook pauperisation of the inlet Ciliophora, both by the species number and frequency of occurrence. Thus, on the same number of stations, at similar depth and seabed sediments in the adjacent areas of the Barents Sea, no less than 10 species of these ciliate with 100% occurrence were recorded. At the same time in Chernaya Inlet only 4 species were recorded with occurrence rate of 40%. In the inlet itself infusorians were discovered only on the shallowest station located at its top. Morphology of Ciliophora individuals, belonging to gen. *Euplotes*, which were met here (5 specimens), was strongly changed: form of their body and basal granules had significant divergence from norm. As a result, movement of animals in water also differed from normal. According to the results of laboratory measurements, content of Cs-137 in seabed sediments of Chernaya Inlet on shallow-water stations in the inlet and deep-water stations in the vicinity of the inlet was similar to the background level (6 Bq kg$^{-1}$ of air-dry sediment). On the deep-water stations of the inlet content of Cs-137 in sediments increased more than 50 times (up to 328 Bq kg$^{-1}$). It is another matter that Cs-137 concentration even as much as 328 Bq kg$^{-1}$ cannot be considered high enough for the explanation of revealed phenomenon. However, if one would: (i) consider radio-caesium as a marker of all anthropogenic radionuclides; (ii) high concentration of Pu-239, 240, measured here earlier (it exceeds the background level by three-four orders of magnitude); (iii) take into account its high toxicity (10 thousand times as high as that of arsenic), then the possible cause of the infusorians state in Chernaya Inlet may be linked with the increase of man-made radionuclide concentrations in the inlet sediments with high probability. So, interpretation of their absence on deep-water stations, and especially of their morphological changes on shallow-water stations, by specific hydrological and hydrochemical regime of the inlet may hardly be regarded as logical. It is interesting to note that in the flagellate fauna of Chernaya Inlet no disturbances were found.

### 9.2. The Kara Sea

The largest in total activity RAW disposals in the Kara Sea were conducted in the Novaya Zemlya Trough, Abrosimov and Stepovogo Fjords (see Fig. 29.19). Named areas represent sites of RAW disposal with radioactivity more than 90% of total for the whole Kara Sea. According to the computations of the Livermore Laboratory scientists (Mount and Sheaffer, 1994), radionuclide inventories of dumped objects in the Novaya Zemlya Trough, Abrosimov and Stepovogo Fjords for the time of disposal are estimated at 213–811, 663–2300 and 187–191 kCi respectively.

According to the results of sampling provided in the Novaya Zemlya Trough (Pogrebov et al., 1997), Polychaeta here were predominant by species diversity and abundance. By dominating trophic group community belonged to the subsurface deposit-feeder zone (51% of total biomass). Comparison of our data with those of previous (Filatova and Zenkevich, 1957; Antipova and Semenov, 1989) revealed similarity between the results of the 1927–1945 and 1993 surveys, and their dissimilarity with the results with the results of 1975 survey. Thus, average biomasses of the 1927–1945 and 1993 surveys were equal to 13 and 16 g m$^{-2}$ respectively, while biomass of the 1975 survey averaged only 2 g m$^{-2}$. Dissimilarity of dominating spe-
cies and benthic structure could also be considered as “high”. We explain differences as sampling errors (small number of replicates in all studies) rather than fluctuation of benthic species populations. We have no evidence that the observed differences were caused by changes of radiological situation.

Taxonomic composition of meiofauna was typical for the region. Abundance of meiobenthic organisms varied from 15 to 948 thousand individuals m$^{-2}$, biomass – from 0.2 to 9.4 g m$^{-2}$. At two stations Nematoda were prevailing by abundance; in other cases Foraminifera were dominating by abundance. The same Foraminifera were prevailing on such stations by biomass too. Facts testifying to possible impact of RAW disposal on the meiofauna of the studied area were not revealed.

Microbenthic communities of the Novaya Zemlya Trough were the richest from all studied. No abnormalities in the organism state were revealed.

Along the Novaya Zemlya eastern coast, first place with respect to the species number belonged to Polychaeta and Bivalvia, with respect to biomass – to Rhodophyta and Bivalvia. On stations with a large share of hard substratum: (i) flora and fauna composition was more diverse; (ii) total benthic biomass was higher (up to 399 g m$^{-2}$); (iii) dominating of Lithothamnion sp. was more pronounced; (iv) abundance of other red algae increased; (v) in trophic structure autotrophs were leading. On silt and silty sand: (i) species diversity was lower; (ii) biomass decreased (up to 14 g m$^{-2}$); (iii) Astarte crenata were dominating; (iv) role of other bivalves increased; (v) in trophic structure motile filter-feeders and surface deposit-feeders were prevailing.

Meiobenthic composition of sites along the Novaya Zemlya eastern coast was similar to that described for the two previous sites. Organism abundance varied from 184 to 3095 thousand individuals m$^{-2}$ and biomass varied from 2.3 to 62.3 g m$^{-2}$. On the majority of stations Foraminifera prevailed. On two stations nematodes were highest in abundance. On one of the stations turbellarians were highest in biomass. Along the depth gradient, quantity of meiothos decreased: from 40 to 70 m by 0.6 million individuals m$^{-2}$ and by 13 g m$^{-2}$ on each 10 m of depth. Abnormal individuals in meiobenthic samples from the Novaya Zemlya shoal were not recorded.

Analysis of Protozoa distribution along the Novaya Zemlya eastern coast revealed no ecological peculiarities. Composition and number of species per sample of both infusorians and flagellates varied insignificantly. Appreciable correlation of these indices with depth or seabed sediment composition was not observed. No morphological abnormalities of individuals or their behavioral changes were noted.

### 10. Issues perspective for further studies

Taking into account the development of oil and gas extraction and transportation in the Barents and the Kara Sea coastal and offshore regions in the nearest future, one should consider the following issues to be the most perspective for further biological studies (Kiyko and Pogrebov, 1999): (i) study of biological effects caused by low environment contamination (in nature); (ii) elaboration of a concept of the marine ecosystem adaptation syndrome caused by natural and man-made impacts; (iii) prognostic modeling of biota changes caused by the changes in environment;
(iv) study of biological effects caused by oil pollution and subsequent rehabilita-
tion succession in typical cases.

Figure 29.20  Potential sensitivity of the Pechora Sea to accidental oil spills by the integral biological characteristics in spring (late April–June: development of plankton communities, spawning of herring, spring migration of fish, spring migration and pre- and nesting concentrations of birds, pupping and molting of seals) and autumn (September-October: autumn migration of fishes, birds and mammals to the wintering grounds)

Practically significant are the studies connected with the integral assessment of sensitivity of marine and coastal biota to the offshore oil-field development operations (Pogrebov and Puzachenko, 2001, 2003). This GIS-based technology of mapping uses ranked input data on seasonal distribution of main marine and coastal ecosys-
tem components (plankton, benthos, fishes, birds and marine mammals) and as an output one may get integral seasonal maps showing comparative spatial and tem-
poral sensitivity of the study area. A preference is usually given to quantitative data, and high attention is paid to the seasonal dynamics. Data on the distribution of organisms presented in the form of by-season maps for each species or a group of organisms are used as a basis. The maps are digitized and presented as individ-
ual GIS "layers". As an individual "layer", a regular grid is constructed whose cell size is determined based on the minimum contour size on the maps. Data on the object presence or the indicators characterizing its abundance are written at the table margins. Data on the object distribution are multiplied by the sensitivity coefficients and summed up for all objects. For compiling the end maps the sensitivity values are ranked according to a 5-point scale (from green to red, the latter characterizing the highest sensitivity). Ranking is made simultaneously for all seasons so that the assessment scale took into account the indicator variability over the year. The results of such an approach usage for the southeastern Barents Sea are presented in Fig. 29.20 (the analysis includes evidence on the distribution of about 30 species and groups of organisms for the water area considered).

As a result, it is shown that the so-called Pechora Sea is the most sensitive area of the region to the accidental oil spills in all seasons. The least sensitive period is spring with winter being the least sensitive. The potential sensitivity zone occupies the maximum area in the winter-spring period and the minimum area in spring. The most sensitive locations are in the vicinity of Gulyayevskiy Koshki, Dolgy, Bolshoy and Maly Zelentsy and Matveyev Islands and in the western part of the Pechora Sea coast. On the Kola Peninsula, the sensitive water areas are in the vicinity of bird colonies. The especially valuable objects also include Kildin Island, Motovskoy Bay, archipelagos of Seven Islands and the Ainovy Islands.

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Bibliography


Makarevich, P.R., 1998. The vernal state of the microphytoplankton community in the ice-covered areas of the south-eastern Barents and the south-western Kara Seas. In *Biology and oceanography of the Kara and Barents Seas (along the Northern Marine Route).* Kola Science Center AS USSR, Apatity, 138–149. (In Russian).


Soviet Arctic, 1970, Seas and islands of the Arctic Ocean, Moscow, Nauka, 526.


