УДК 551.794:56(571.645)

ENVIRONMENTAL CHANGES ON KUNASHIR ISLAND (Kuril Archipelago) DURING THE MIDDLE AND LATE HOLOCENE

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Sea level rise during the Pleistocene-Holocene transition period caused the formation of lagoon lakes along the western and eastern coasts of the Kuril Islands. These lakes include Lake Serebryanoye, located in the northern part of the South Kuril Isthmus near the Pacific coast of Kunashir Island (44°03'21" N; 145°49'46" E). The total thickness of sediments in the lake was 367 cm. They are characterized by diatom flora (334 species), representing various ecological groups: freshwater, brackish water, marine, marsh, lacustrine, rheophilic, planktonic, benthic. The analysis of diatoms made it possible to distinguish two complexes. As shown by radiocarbon dating, in the Middle Holocene (100.5–367 cm interval) the sediments corresponded to the lagoon stage, which changed in the Late Holocene (100.5–0 cm interval) to the freshwater lake stage. Palynological analysis showed a successive change of biocenoses, reflecting the development in the Middle Holocene of birch-broadleaved forests with the participation of *Pinus koraiensis*, *Picea* sp. The most abrupt change in biocenoses is observed at the boundary of the Middle and Late Holocene. This change of biocenoses is expressed by the dominance of conifers in the vegetation cover, represented by various species of *Picea*, *Pinus*, *Abies*, *Larix*. It also shows the relative cooling of the climate in the Late Holocene.

***Keywords*: Holocene, lagoon, diatom analysis, palynology, biocenosis, radiocarbon.**

DOI: 10.34078/1814-0998-2022-2-59-70

The Kuril Archipelago is an intriguing part of the territory that spans key climatic and biogeographic links between the arctic, subarctic, temperate, and subtropical zones within the Russian Far East. In addition to the Kuril Islands, the broader region includes Northeastern Siberia (Western Beringia), the basin of the lower reaches of the Amur River, Far Eastern Primorye, and Sakhalin Island. Atmospheric general circulation models (AGCM) and/or paleobotanical data depict key climatic events that occurred over the past 21,000 years in Northeast Asia (Kutzbach et al., 1998; Binney et al., 2017). These events include: the increased impact of the East Asian monsoon system following the summer insolation maximum in the early and middle Holocene; the post-glacial thermal maximum, which occurred in the northern region (i. e., Northeastern Siberia) 2,000 years earlier than in southern areas of the Far East; and a stronger manifestation of short-term climatic events in southern as compared to northern sectors of the region. While most paleoenvironmental investigations occurred at mainland sites, the expansion of the research area to include offshore island systems certainly will contribute to a better understanding of the mechanisms responsible for the paleoclimatic patterns described for Northeast Asia during the Late Quaternary.

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Studies of Holocene deposits preserved in marine, river, and lake terraces and in peat bogs on Kunashir Island have been the primary focus of paleoenvironmental studies in the southern Kuril archipelago (Korotky et al., 2000; Anderson, Lozhkin, 2002; Razjigaeva et al., 2022). Detailed lithological, palynological, diatom, and radiocarbon analyses have documented the complex changes in climate and vegetation in this area during the middle and late Holocene. Based on section data from Kunashir Island and from nearby mainland areas, Korotky et al. (1995, 1996, 2000) proposed that the regional climate was controlled primarily by a combination of changes in sea level (warm climates indicated by marine transgressions and cool climates by regressions and formation of coastal dunes) and shifts in marine currents (particularly the Soya warm current). They concluded that the Middle and Late Holocene included three intervals of cool climates (*c*. 5400 to 5200 cal. BP, *c*. 1600 to 1200 cal. BP, Little Ice Age), a major warm, transgressive period marking the Holocene thermal maximum (*c*. 7400 to 6800 cal. BP; +2.5 to 3.0 m sea level rise), a second transgression that is only slightly cooler than during the Holocene maximum (*c*. 4500 to 3500 cal. BP; +1.25 to 2.5 m sea level rise), and two times of more modest warming/transgressions (*c.* 3100 to 2700 and *c*. 1200 to 700 cal. BP). However, the development of accurate age

models for sites with a variety of depositional conditions, as is the case for the terraces, can be a significant obstacle for obtaining an accurate documentation of the vegetation and climate histories of the archipelago. To better understand the timing and nature of environmental changes during the Holocene, a suite of lake cores was recovered from the Kuril archipelago as part of the Kuril Islands Biocomplexity Project, a joint study involving scientists from Russia, the United States, and Japan. In this paper, we discuss the results from Lake Serebryanoye), located in the east-central part of Kunashir Island (Fig. 1).

RESEARCH METHODS

The research at Lake Serebryanoye is a multidisciplinary study involving diatom, palynological, and lithological analyzes and radiocarbon dating (Figs. 2, 3, 4). A 367-cm-long core was retrieved from the western part of the lake with a modified Livingstone piston sampler (Wright et al., 1984). Sampling was done continuously along the length of the core in the laboratory at NEISRI. Chemical processing of 1 or 2 cm^3 sediment samples for palynological analysis followed standard procedures used in the study of arctic lake sediments (Anderson et al., 1994). At least 300

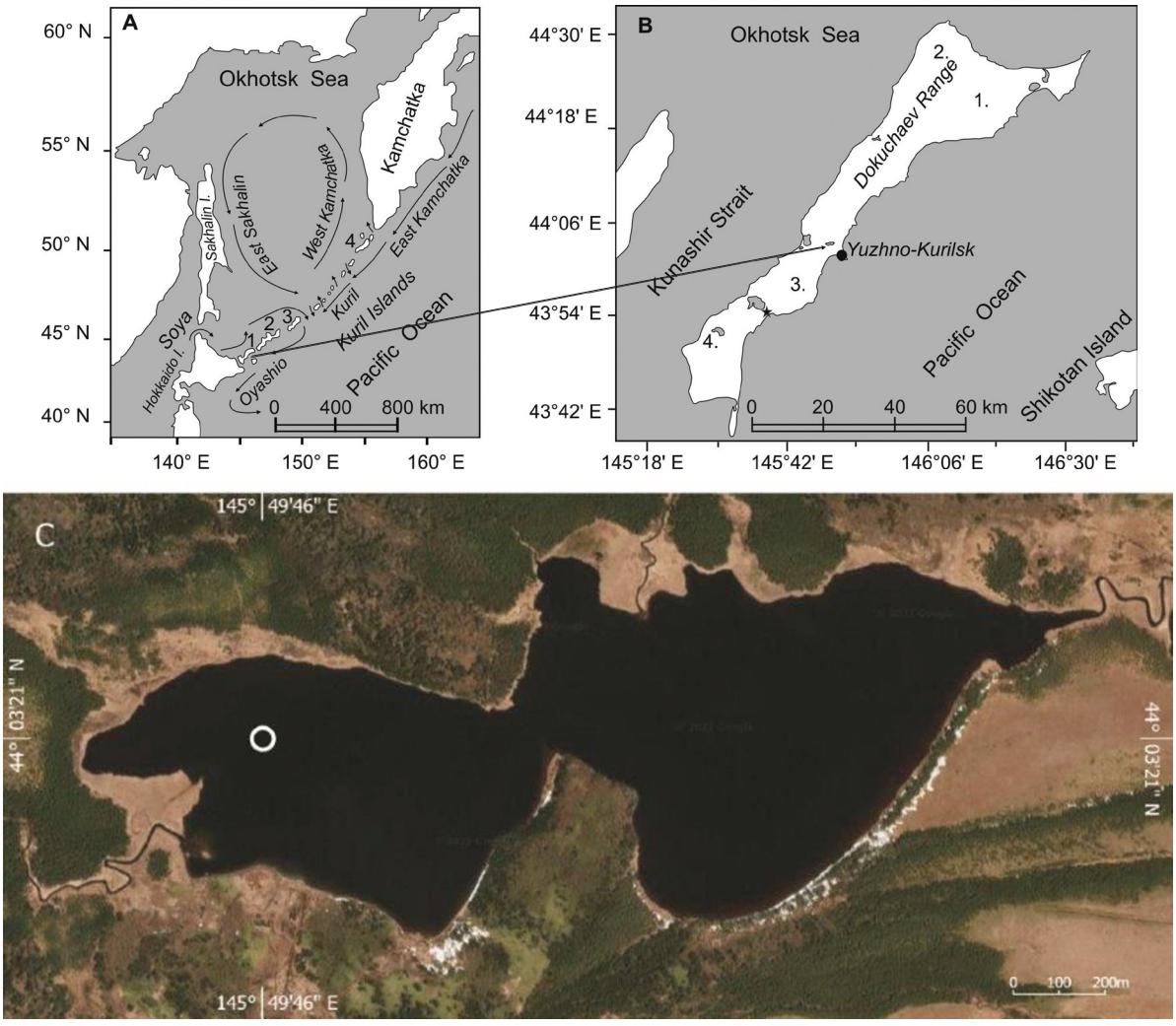

Fig. 1. Maps of the study area. A – Location of the Kuril Islands. Arrows indicate location and direction of marine currents (Gorbarenko et al., 2014). Islands mentioned in the text: 1 – Kunashir Island, 2 – Iturup Island, 3 – Urup Island, 4 – Paramushir Island. B – Kunashir Island showing locations for: 1 – Tyatya Volcano (1819 m a. s. l.); 2 – Ruruy Volcano (1485 m a. s. l.); 3 – Mendeleev Volcano (887 m a. s. l.); 4 – Golovin Volcano (541 m a. s. l.). The arrow shows the position of Lake Serebryanoye in the Yuzhno-Kurilsk region. C – Satellite view of Lake Serebryanoye; the white circle in the western part of the lake indicates the coring locale where 367 cm of lacustrine sediments were recovered

Рис. 1. Карты района исследования. А – расположение Курильских островов. Стрелки указывают местоположение и направление морских течений (Gorbarenko et al., 2014). Упомянутые в тексте острова: 1 – Кунашир, 2 – Итуруп, 3 – Уруп, 4 – Парамушир. В – о. Кунашир с указанием местонахождения: 1 – влк. Тятя (1819 м н. у. м.); 2 – влк. Руруй (1485 м н. у. м.); 3 – влк. Менделеева (887 м н. у. м.); 4 – влк. Головина (541 м н. у. м.). Стрелка показывает положение оз. Серебряное в районе Южно-Курильска. С – вид со спутника на оз. Серебряное; белый кружок в западной части озера указывает на место отбора керна, где было извлечено 367 см озерных отложений

pollen grains from terrestrial plants were counted in each sample. The calculation of pollen and spore percentages and the construction of the palynological diagrams were carried out using "Tilia" and "Tilia-graph" (http://www.tiliait.com). In addition to the individual taxa, the palynological diagrams show the ratios of three vegetation groups, i. e., pollen of trees and shrubs, herb pollen, and spores. The percentage of each pollen and spore taxon is based on the sum of all identified and unidentified terrestrial pollen grains. Four pollen zones (SE1, SE2, SE3, SE4; Fig. 3) were delimited based on the variations in the percentages of the main pollen and spore taxa. Radiocarbon dating was done at the Center for Mass Spectrometry at the Lawrence Livermore National Laboratory. Radiocarbon dates were converted to calibrated ages using the IntCal13 calibration curve in CALIB 7.1 (Stuiver et al., 2020).

Processing of samples for diatom analysis followed standard methods (Диатомовые..., 1974). Diatom counts were done with an Axioplan 40 light microscope (SM) using an immersion liquid at ×1000 magnification. More than 300 valves were counted in most samples. Diatom classification is based on AlgaeBase (http://www.algaebase.org), and the ecological and geographical characteristics of the taxa are taken from Barinova et al. (2006). For a comparative analysis of fossil and modern diatom communities, we also studied four modern samples from surface bottom sediments collected by V. S. Pushkar in the southern part of Lake Serebryanoye during the expedition of the Pacific Institute of Geography of the Far East Branch of the Russian Academy of Sciences in August 1996.

RESEARCH AREA AND OBJECTIVES

The rise in sea level during the Pleistocene to Holocene transition resulted in the formation of coastal basins along both western and eastern shores of the Kuril Islands. These basins, known as lagoon lakes, were created as seawater flooded the valleys of small streams, which flowed into the Okhotsk Sea or Pacific Ocean (Korsunskaya, 1958; Klyuchareva, 1967). Water depth and composition during the early history of lagoon lakes were strongly affected by tidal currents. These influences eventually decreased when the connection of the lagoons to the sea became restricted, either as sea level decreased during the Holocene or barrier bars were formed. The isolation of the basin from the sea reflects the interaction of various processes, such as the increased in wash of sediments to the lakes from nearby slopes and wave action parallel to the coastline, which caused the formation of coastal dunes. The lakes were gradually desalinated as freshwater input from inflowing streams became greater than the contribution of marine waters.

The first continuous lacustrine pollen record of Holocene climate and vegetation changes in the Kuril Islands was obtained from Lake Pernatoye on Paramushir Island in the northern Kuril Archipelago (Lozhkin et al., 2010). Subsequent investigations of lake sediment cores from Urup, Iturup, and Kunashir Islands further documented sea level fluctuations, as well as the changing environmental conditions during the Holocene (Lozhkin et al., 2017).

The last site to be investigated as part of the Kuril Islands Biocomplexity Project was Lake Serebryanoye (44°03'21" N; 145°49'46" E, 8 m above present sea level; Fig. 1 - B, C). The lake is in the northern part of the South Kuril Isthmus of Kunashir Island, ~ 3 km northwest of Yuzhno-Kurilsk, and is on the Pacific side of the island. Serebryanoye originated as a lagoon lake. Today the lake is elongated along an east-west axis, is ~ 2250 m long, and has a maximum width of ~ 780 m. It consists of two basins with a maximum water depth of 2 m, although depths in most of the lake vary between 1.2 and 1.4 m (Sokov, 1998). The basins are separated by a shallower area (0.5–0.6 m) that is found between two peninsulas in the central part of the lake (Fig. 1C). A small inlet enters the western part of the basin with two additional inflowing streams to the north. Lake Serebryanoye is connected to the Pacific Ocean (South Kuril Strait) by a ~ 4-m-long channel. Aquatic plants are common. *Nymphaea* is found in most areas of the lake, whereas *Potamegeton*, Lemnaceae, *Equisetum*, *Menyanthes*, and Juncaceae are restricted to near shore areas.

The vegetation surrounding Lake Serebryanoye is a mosaic of *Abies-Picea* forest (*Abies sachalinensis, Picea glehnii*), *Betula*-broadleaf-coniferous forests, and meadows. *Taxus cuspidata* also is present, but the conifer is rare. The most common deciduous tree is *Betula ermanii*, with *Betula maximowicziana* being less common. *Kalopanax* and *Acer mayrii* are present in the forest, but they are not common. *Alnus hirsuta* and *Duschekia* shrubs, which grow up to 2 m in height, are numerous near the lake shore. A mix of *Alnus* trees and tall *Salix* shrubs are typical of the shoreline communities, but in some of these areas *Picea* dominates. *Sorbus commixta* can be common in the deciduous forest, and it is found in shorter growth forms near the lake. *Actinidia* also is found in the shoreline communities, but the shrub is not common. We noted only a single *Pinus pumila* on a ridge top near the lake. However, *Pinus pumila* probably occurs in greater densities on higher elevation slopes found in this part of the island. Lianas are found sporadically wrapped around trees. The mosaic nature of the forest partially reflects slope and aspect (e. g., *Picea* and *Betula* seem to be more common on north facing slopes) and perhaps soils (e. g., *Betula* dominates on the rocky slopes of the "peninsulas" that jut out in the central part of the lake).

Meadows typify the boggy to slightly more mesic, low-lying areas that border the lake. Poaceae spp. including *Sasa kurilensis* are the most common meadow taxa. However, a variety of flowering forbs (e. g., *Aruncus dioicus*, *Iris setosa*, *Lysichiton camtschatcense*, *Lillium dahuricum*, Asteraceae, *Artemisia*), Apiaceae, Rosaceae spp. including *Rosa rugosa*, *Rumex* and other Polygonaceae) also characterize the microhabi-

tats within the meadow communities. *Sphagnum* and other green mosses are present but are relatively rare. Low growth forms of shrub *Salix* (~ 25–35 cm high) are found occasionally in these meadows.

LITHOLOGICAL CHARACTERISTICS AND DATES OF LAKE SEDIMENTS

The upper 100.5 cm of sediments in the Serebryanoye core are organic-rich, dark gray silt. Between 100.5 and 367 cm, the sediments change to dark gray, sandy silt mixed with gravel. The volume of the coarsest sediment varies in this part of the core, but it noticeably increases in the lowest 3–4 cm of the sediment column. Two radiocarbon dates were obtained from bulk sediment samples at depths of 140–141 and 300–301 cm. The upper sample yielded a radiocarbon date of 5380 ± 40 BP (median calibrated date of 6190 cal. BP; (CAMS-143087) and a date of 7640 ± 70 BP (medium calibrated date of 8440 cal. BP; (CAMS-143088) for the lower sample.

MODERN AND FOSSIL DIATOM RESULTS

The modern diatom flora is characterized by a relatively high species richness (72 taxa), although one species, *Melosira lineata*, is dominant. This species is usually the main component of aufwuchs communities found in coastal brackish waters (Krammer and Lange-Bertalot, 1991), tolerating water salinity of up to 9.0 ‰ (van Dam et al., 1994). Its dominance at Serebryanoye is primarily the result of the shallow depth of the lake, which determines the homogeneity of the water column. The freshwater-brackish water epiphytes *Rhopalodia gibba* and *Epithemia adnata* and tychoplanktonic *Fragilaria vaucheriae* have high percentages in the modern samples. These species live in salinities of up to 0.9 ‰ The sublittoral marine taxa *Paralia sulcata* and *Diploneis smithii* occur rarely in the planktonic component of the modern samples. The composition of the present-day diatom community reflects the absence of a direct sea influence on the lake. The dominance of species tolerant of increased water salinity is most likely due to the relatively high mineralization of the lake, which is in an area of active volcanism. Additionally, onshore winds and spray from breaking waves may also have contributed to the salinization of the lake.

The fossil diatom flora of Lake Serebryanoye is rich and varied (Fig. 2). It consists of 334 taxa, which include species, varieties, and forms and represents different ecological groups (e. g., freshwater, brackish, marine, bog, lacustrine, rheophilic, planktonic, benthic). The ecological diversity of diatoms found in the Serebryanoye core reflects the variations in paleoenvironmental conditions under which the fossil diatom assemblages formed. The changes in the percentage of taxa with different tolerances in salinity, as well as the variations in the percentages of marine, sublittoral, and lacustrine species, were the basis for the identification of two main complexes within the Serebryanoye core.

The lagoon complex (385–112 cm, zone DZ1) is characterized by the dominance and high species diversity of marine and brackish-water taxa. Tychoplanktonic species (i. e., diatoms whose life cycle includes stages as bottom dwellers and as part of the planktonic community), such as *Paralia sulcata*, *Melosira discigera*, and *Odontella aurita*, and sublittoral benthic taxa (e. g., *Diploneis smithii*, *Giffenia cocconeiformis*, *Tabularia fasciculata*, and *Tryblionella granulate*) are dominant in this complex. Freshwater diatoms (e. g., planktonic *Aulacoseira italica*, tychoplanktonic *Staurosira venter*, and *S. pinnata*) also are present, but in lower percentages as compared to the marine-brackish water group. The composition of the DZ1 complex indicates the presence of a brackish lagoon.

The warm-water *Terpsinoë americana* is present consistently in the paleoassemblages of zone DZ1. The species occurs as single valves in the Serebryanoye sediments. *T. americana* is a tropical epiphyte living in saline waters from 45°N and southward (Alhonen et al., 1984). The species is not found in the modern algal communities in the study area. Alhonen et al. (1984) noted that a rise in *T. americana* indicated an increase in salinity and temperature of surface waters in lacustrine deposits on the coast of the North Sea between 9500 and 4500 cal. BP during the Littorina transgression. *T. americana* has also been found in high percentage (> 60 %) in paleoassemblages from the Tamatsu section located on the coast of Osaka Bay, western Japan (Sato et al., 1983). This latter assemblage formed during a regression *c*. 5700–4500 cal. BP, which followed the maximum Holocene transgression.

Three diatom subzones (DZ) have been identified in the lagoon sediment based on changes in the concentration of diatom valves, the composition of the prevalent ecological group, and the percentage of taxa within the different groups.

DZ 1.1 (365–258 cm) is dominated by *P. sulcata* and has relatively high percentages of sublittoral benthic *D. smithii* and *G. cocconeiformis*, which inhabit tidal shallows (Gomes et al., 2017). The lowest concentration of diatom valves and the abundance of large valve fragments are other features of this subzone.

DZ 1.2 (258–172 cm) is characterized by an increase in the percentages of brackish water taxa, such as *Cocconeis scutellum*, *M. discigera*, *O. aurita*, *Tabularia fasciculata*, and *Tryblionella granulata*, and of freshwater types, particularly *S. venter*. The disappearance of *G. cocconeiformis* from the dominant group and a slight increase in the concentration of valves also occurred. The concentration of diatom valves increases slightly from DZ 1.1.

The highest percentages of *C. scutellum* and *M. discigera* and a decrease in the percentages of *O. aurita* and *T. granulata* are recorded in DZ 1.3 (172–112 cm). Freshwater-brackish water *Thalassiosira bramaputrae*, *Melosira lineata*, and *Rhopalodia gibba* appear in the subzone. The rising trend in valve concentration continues.

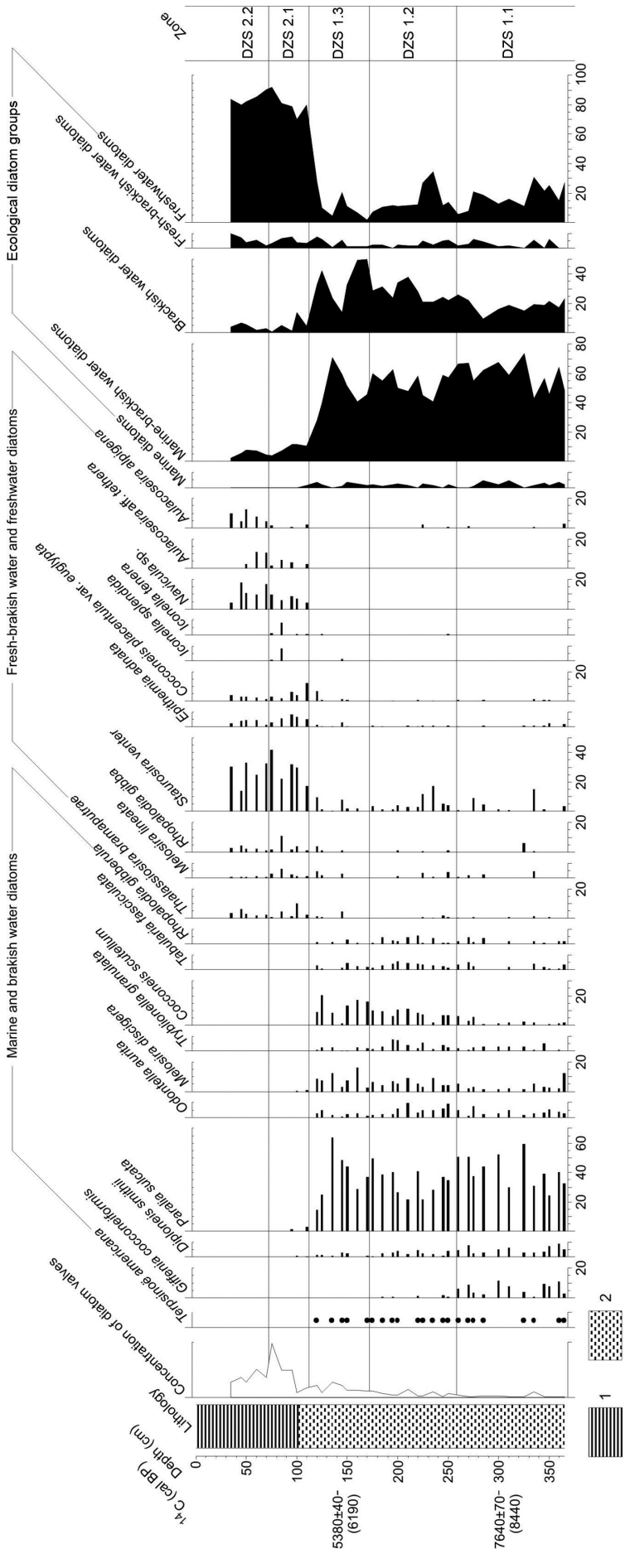

Fig. 2. Diatom data from the sediment core from Lake Serebryanoye showing: the concentration of diatom valves per 1 g of dry sediment ($\times 10^6$); percentages and the distribution of the main diatom taxa and ecological groups. Lithological characteristics: 1 – dark gray silt, with abundant organics; 2 – sandy silt mixed with gravel

Рис. 2. Данные о диатомовых водорослях из керна отложений оз. Серебряное, показывающие концентрацию створок диатомовых водорослей на 1 г сухого осадка ($\times 10^6$); процентное содержание и распределение основных таксонов диатомей и экологических групп. Литологические характеристики: 1 – темно-серый ил с обилием органики; 2 – песчаный ил с примесью гравия

The lake complex (112–35 cm, zone DZ 2) is characterized by a marked increase in freshwater taxa and species tolerant of low salinity (Michelutti et al., 2001; Weckström et al., 2003). A specific feature of this assemblage is the dominance of the tychoplanktonic *S. venter*, which lives in small, shallow lakes in forested temperate and subarctic regions Species with small valves such as *Navicula minima*, *Sellaphora seminulum*, and *S. submuralis*, also have high percentages.

Two diatom subzones are present in the lake complex: DZ 2.1 (112–71 cm) and DZ 2.2 (72–35 cm). High percentages of epiphytic *Epithemia adnata* and *Cocconeis placentula* var. *euglypta* as well as benthic *Iconella splendida* and *I. tenera* characterize DZ 2.1. Relatively high percentages of *M. lineata*, which dominates the modern diatom communities of the lake, is also present. A high concentration of diatom valves is a feature of this subzone.

The relatively cold-water *Aulacoseira subarctica* appears in DZ 2.2. The percentages of species with small valves increase, whereas the percentages of epiphytes with large valves decrease.

INTERPRETATION OF THE DIATOM RECORD

The two radiocarbon dates indicate that the sediments in the lower part of the Serebryanoye core accumulated during a Middle Holocene sea-level rise (Korotky et al., 1995, 1996, 2000). The dominance of brackish-water benthic diatoms during DZ 1.1 shows the presence of a lagoon. Poor diatom preservation, the large number of diatom valve fragments, a high percentage of benthic species, and a low concentration of valves reflect the active influence of tidal currents. Similar data from across the globe have been obtained from shallow sites (e. g., lagoons, estuaries) in coastal areas, which have been affected by strong tidal currents and/or sea level fluctuations (e. g., Katsuki et al., 2017; Gomes et al., 2017).

The gradual increase in the concentration of diatom valves in DZ 1.2 and the appearance of freshwater tychoplanktonic taxa most likely indicate the increased impact of freshwater streams flowing into the Serebryanoye basin. However, these changes also suggest that a slight weakening of wave action and/or a decreased impact of marine water in the basin possibly occurred. The shift in the lagoon's salinity could have been caused by an increase in precipitation, although the pollen data do not suggest a change in climate (Fig. 3). Alternatively, a rise in the water level in the lagoon, as suggested by an increase in the concentration of diatom valves and a decrease in mineral input, could have caused a slight increase in the base level of the inflowing streams and thus a reduction in solids carried by the stream runoff.

The continued increase in valve concentrations, a decrease in the percentages of freshwater taxa, and an increase in the percentages of marine and brackish-water species reflect a re-emergence of Pacific Ocean influences in DZ 1.3. The lagoon complex perhaps was formed during the Holocene climatic optimum, although the chronological limitations of the Serebryanoye record make this a tentative conclusion. According to Razjigaeva et al. (2004) the elevation of the Kunashir coastline was 2–2.5 m higher than present between 7400 and 6800 cal. BP. The three diatom subzones at Serebryanoye suggest an unstable position of the coastline during the Middle Holocene.

The shift from a lagoon to a freshwater lake apparently occurred relatively quickly (< 10 cm along the core) at some time after 6190 cal. BP. The lack of any transitional diatom complexes further suggests that the lagoon-lake transition was rapid. A similar shift from a lagoon to a lake at *c.* 4000 cal. BP was also observed in a core from Lake Glukhoye, southern Kunashir Island (Lozhkin et al., 2020). The change in depositional environment perhaps was caused by a decrease in sea level, which the Korotky et al. model suggests occurred *c.* 5400 to 5200 cal. BP. Alternatively, the change to the Serebryanoye basin may have been due to the formation of a sandbar, which blocked inflowing streams from the Pacific Ocean. Such a mechanism has been suggested for several other Kuril Island lakes that originated as lagoons (Lozhkin et al., 2020).

A relatively shallow lake was present by DZ 2.1. This freshwater basin had a rich aquatic macrovegetation on which diatom epiphytes attached. The presence of *Iconella* species may indicate a warming of the basin's waters caused by shallowing lake levels. Changes occurred in the lake ecosystem (DZ 2.2) probably at some time during the Late Holocene. The appearance of relatively cold-water taxa (e. g., *A. subarctica*) possibly was associated with a decrease in air temperature or effective moisture. The percentages of diatom epiphytes with large valves decrease, whereas the abundance of species with small valves increases. These features may reflect calm hydrological conditions, which in turn suggest a decrease in storminess and/or a better sheltering of the lake by the surrounding forest. The disappearance during DZ 2.2 of *M. lineata,* which is dominant in the modern lake, suggest that environmental conditions differed from those of the present day.

PALYNOLOGICAL RESULTS

The pollen diagram has been divided into four zones based on changes in percentages of major pollen and spore taxa (Fig. 3). Zones SE1 through SE3 are dominated by *Quercus* and *Betula* pollen. These zones contain the greatest number of temperate broadleaf trees (e. g., *Ulmus, Juglans, Fagus*). Conifer pollen is < 1 % with the lowest values occurring in zone SE2. Herb pollen is dominated by Poaceae and Cyperaceae, and these zones show the most diversity of minor taxa.

Polypodiaceae and Osmundaceae represent the main spore taxa, with percentages decreasing from zones SE1 to SE3.

Zone SE4 is marked by a sharp change in the pollen assemblage. Conifer pollen dominates, particularly that of *Picea*, and percentages of broadleaf tree pollen are reduced. In the case of *Quercus*, this taxon decreases from maximum percentages in zone SE3 to < 5 % at core top.

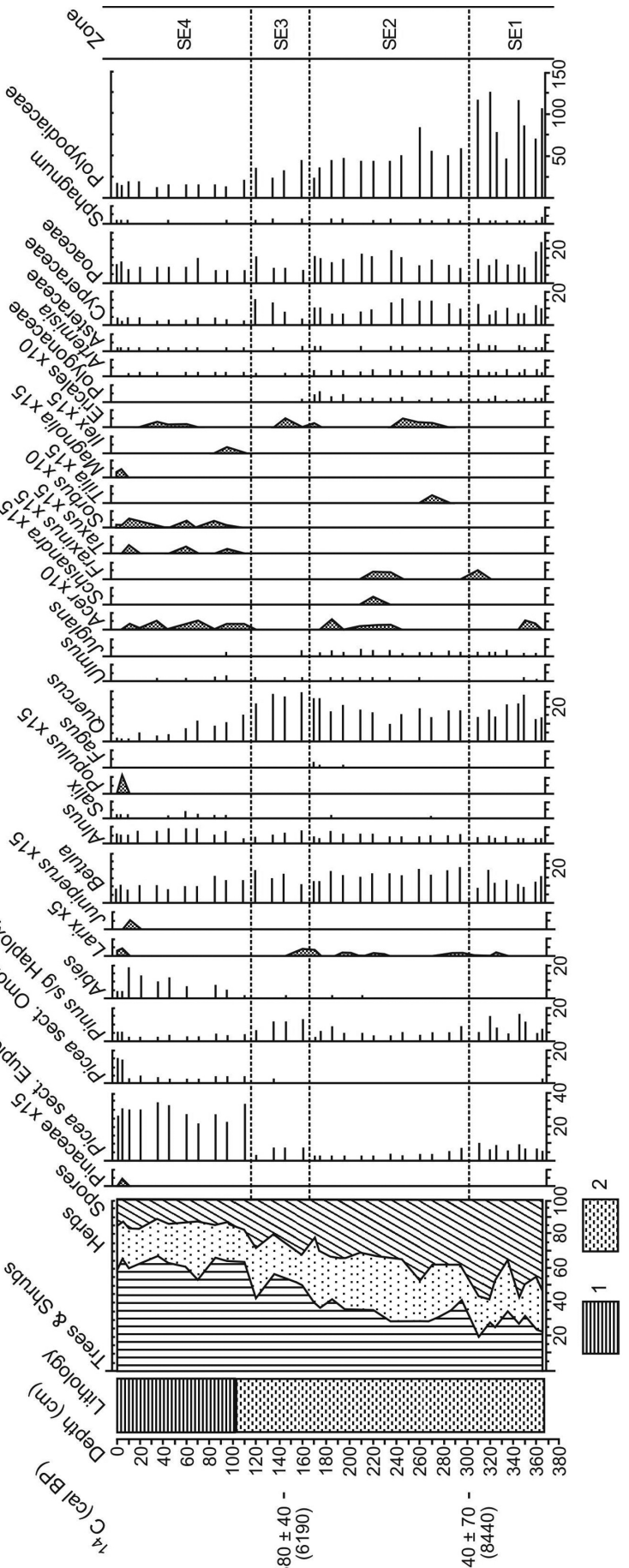

Fig. 3. Percentages of vegetation groups and of the main pollen and spore taxa in sediments from Lake Serebryanoye. Lithological characteristics: 1 – dark gray silt, with abundant organics; 2 – sandy silt mixed with gravel

Рис. 3. Соотношение групп растительности, основных пыльцевых и споровых таксонов в осадках оз. Серебряное. Литологическая характеристика: 1 – алеврит темно-серый, обогащенный органикой; 2 – песчаный алеврит с примесью гравия

Percentages of Polypodiaceae and Osmundaceae spores also decrease dramatically. The two uppermost samples in zone SE4 show abrupt increases in *Picea* sect. Omorica pollen and decreased percentages of *Abies*.

INTERPRETATION OF THE POLLEN RECORD

The continuous pollen record from Lake Serebryanoye (Figs. 3, 4), the discussion of which concludes this article, shows two major changes in biocenoses dating to the Middle and Late Holocene, respectively. Zones SE1 through SE3 (approximating the Middle Holocene) show a marked similarity. The only exception is a slight increase in *Pinus* s/g Haploxylon (*Pinus koraiensis*, *P. pumila*) and *Picea* sect. Eupicea in pollen in zones SE1 and SE3 as compared to zone SE2. Temperate, thermophilous species played a significant role in the vegetation during the Middle Holocene. The diversity in the forest community is highlighted by the presence of such pollen taxa as *Fagus*, *Quercus*, *Ulmus*, *Juglans*, *Acer*, *Fraxinus*, *Tilia*, and *Magnolia*. Of these taxa, *Quercus* is the most abundant, which indicates that the tree was one of the main forest-forming species, perhaps reaching its widest distribution *c*. 6000 cal. BP (zone SE3). The high percentages of *Betula* pollen in the spectra, which is often comparable with that of *Quercus* (especially in zone SE2), indicate the dominance of *Betula*-broadleaf forests. In addition to *Quercus*, *Juglans* and *Ulmus* were important components of these temperate communities. The consistence presence of *Alnus* pollen in the Middle Holocene spectra may reflect the occurrence of both shrub and tree forms of the taxon, the latter perhaps forming gallery forests within floodplains.

The percentages of Poaceae and Cyperaceae pollen are sufficiently high in all zones to indicate the presence of open meadow communities near the lake throughout the Middle and Late Holocene. As seen today, the most common taxa were probably members of the Poaceae family, including *Sasa kurilensis*. Flowering forbs of Rosaceae (e. g., *Aruncus dioicus*, *Rosa rugosa*), Liliaceae, (e. g., *Lillium dahuricum*), *Iris* (e. g., *Iris setosa*), Primulaceae, Polygonaceae, and Asteraceae (e. g., *Artemisia*, *Petasites amplus*) were also typical of these meadow communities.

In addition, the Middle Holocene pollen assemblages are characterized by high percentages of spores, particularly Polypodiaceae (Fig. 3) and Osmundaceae (Fig. 4), with zone SE1 registeringthe greatest values (e. g., Polypodiaceae reaches 125 % of the pollen sum). The widespread appearance of Polypodiaceae in the Kuril archipelago is typically associated with tall thickets of *Pinus pumila* and *Duschekia fruticosa*. Dense thickets of these shrubs are found today both on the mountain slopes and in the lowlands near the lake. A sharp increase in the number of Polypodiaceae spores in zone SE1 indicates the drying of the substrate near the site. A noticeably smaller number of spores of Polypodiaceae and Osmundaceae occur in zones SE2 and SE3. The decrease in the role of spore-bearing plants in the Serebryanoye record quite likely indicates an increase in the density of trees and a closing of the forest canopy.

A significant restructuring of the vegetation in the Lake Serebryanoye area occurred during zone SE4 and possibly approximates the boundary between the Middle and Late Holocene. A major change in the core lithology coincides with the zone SE3-SE4 boundary and indicates the shift from a lagoon to a freshwater lake. The main feature of the SE4 pollen zone is the dominance of coniferous pollen, which reflects the replacement of *Betula*-broadleaf forests with evergreen communities. Such a shift in biocenoses suggests climate was cooler and effective moisture was greater as compared to the Middle Holocene. Conifer forest was not only present along the shores of the Lake Serebryanoye, but it also expanded to dominate the regional vegetation during the Late Holocene. Although *Abies-Picea* forests were the prevalent vegetation, areas of *Betula*-broadleaf forest persisted as did *Pinus pumila* thickets and meadows. This Late Holocene vegetation was generally like that seen today on Kunashir Island. It should also be noted that the present-day forests of Kunashir Island primarily consist of two *Picea* species (*Picea ajanensis* and less commonly *Picea glehnii*), as well as *Abies sachalinensis*. The shrub *Pinus pumila* is found throughout the modern forest zone. The uppermost samples in the core suggest a recent decline in *Abies* and an increase in *Picea*, possibly related to a slight climatic cooling.

PALEOCLIMATE IMPLICATIONS OF THE SEREBRYANOYE RECORD

Although the sediment core from Lake Serebryanoye lacks sufficient chronological control for a detailed assessment of the Korotky et al. (1995, 1996, 2000) paleoclimate-sea level model, some general comparisons can be made. In terms of the palynological data, the shift from *Betula*-broadleaf (zones SE1 to SE3) to conifer (zone SE4) forest suggests that climate was cooler and effective moisture was greater during the Late Holocene as compared to the Middle Holocene. These results are consistent with the occurrence of the Holocene thermal maximum (HTM) during the Middle Holocene (*c.* 7400 to 6800 cal. BP) as proposed by Korotky et al. Furthermore, they associate the HTM with higher than present sea levels, which also is consistent with the presence of a brackish lagoon in the Serebryanoye basin (DZ 1). However, the shorter-term climate fluctuations described in the model, except for a recent cooling noted at the core top, are not supported by the palynological data. Even though variations in the DZ 1 diatom complex indicate shifts in the basin's hydrology, such changes do not appear to be linked to variations in sea levels. Comparisons to a second, better-dated lake record from Kunashir Island shows a similar vegetation history as documented at Lake Serebryanoye, although the palynological data suggest a gradual rather than an abrupt cooling from the HTM.

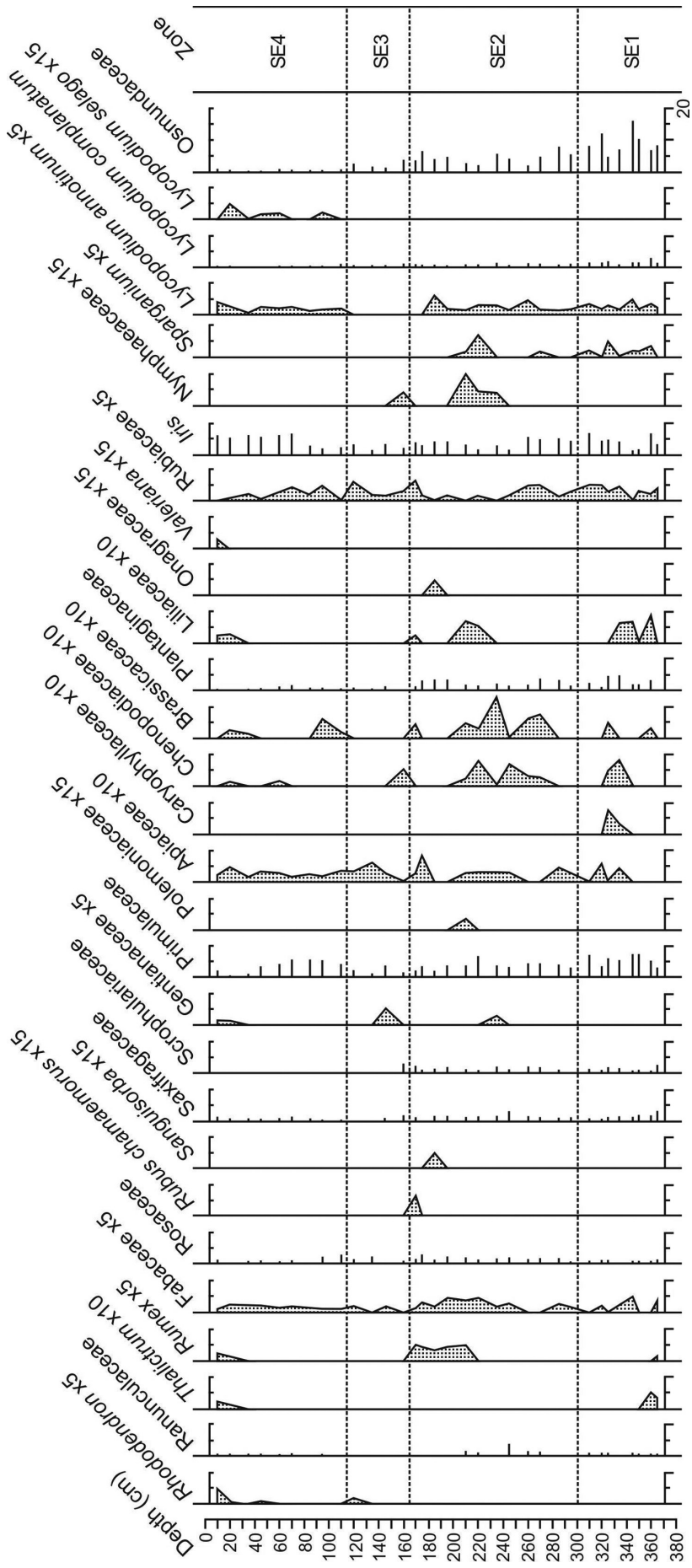

Fig. 4. Minor pollen and spore taxa in sediments from Lake Serebryanoye
Рис. 4. Второстепенные пыльцевые и споровые таксоны в осадках оз. Серебряное

The diatom record from this other site also indicates a more complex basin history as compared to that described for Serebryanoye, strengthening the conclusions of Lozhkin et al. (2017, 2020) that local processes, rather than regional sea levels, are the primary factors affecting the depositional paleoenvironments of these coastal basins. Even with the chronological limitations, the palynological, diatom, and lithological data from Lake Serebryanoye do not support the occurrence of numerous cooling/warming intervals associated with variations in sea level during the Holocene. Rather the Serebryanoye data, like other lake records from the Kuril Islands, reflect a complex interaction of atmospheric, marine, and terrestrial factors operating on local to regional scales.

ACKNOWLEDGEMENTS

Primary support for this research was provided by the National Science Foundation (ARC-0508109). Additional funding was supplied by a Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) research infrastructure grant (R24 HD042828) to the University of Washington Center for the Study of Demography and Ecology. We thank Ben Fitzhugh for overseeing the logistical support for the lake coring and for his scientific overview of the multidisciplinary study of the Kuril Islands. We greatly appreciate discussions with Tom Brown concerning radiocarbon dating. We also thank L. N. Kotova and T. B. Solomatkina for the preparation and counting of the pollen samples.

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Received 18.04.2022
Received after revision 27.04.2022

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ИЗМЕНЕНИЯ ПРИРОДНОЙ СРЕДЫ НА ОСТРОВЕ КУНАШИР (Курильский архипелаг) В СРЕДНЕМ И ПОЗДНЕМ ГОЛОЦЕНЕ

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Повышение уровня моря в переходный от плейстоцена к голоцену период вызвало формирование лагунных озер вдоль западных и восточных побережий островов Курильской гряды. К таким озерам относится оз. Серебряное, находящееся в северной части Южно-Курильского перешейка вблизи тихоокеанского побережья о. Кунашир (44°03'21" с. ш., 145°49'46" в. д.). Общая мощность осадков в озере составила 367 см. Они охарактеризованы диатомовой флорой (334 вида), представляющей различные экологические группы: пресноводные, солоноватоводные, морские, болотные, озерные, реофильные, планктонные, бентосные. Анализ диатомей позволил выделить два комплекса. Как показали радиоуглеродные датировки, в среднем голоцене (интервал 100.5–367 см) осадки соответствовали лагунной стадии, сменяющейся в позднем голоцене (интервал 100.5–0 см) стадией пресноводного озера. Палинологический анализ показал последовательную смену биоценозов, отражающую развитие в среднем голоцене березово-широколиственных лесов с участием *Pinus koraiensis*, *Picea* sp. Наиболее резкая смена биоценозов наблюдается на границе среднего и позднего голоцена. Эта смена биоценозов выражена доминированием в растительном покрове хвойных, представленных различными видами *Picea*, *Pinus*, *Abies*, *Larix*. Она также показывает относительное похолодание климата в позднем голоцене.

***Ключевые слова*: голоцен, лагуна, диатомовый анализ, палинология, биоценоз, радиоуглерод.**

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