

## Vegetation response in the surrounding area of Zarya Bay (the Sea of Japan) to multidecadal climatic variations over the past 5500 years

✉ Razjigaeva, Nadezhda G., <https://orcid.org/0000-0001-7936-1797>, [nadyar@tigdvo.ru](mailto:nadyar@tigdvo.ru)

Ganzev, Larisa A., <https://orcid.org/0000-0002-2538-6603>, [lganzev@mail.ru](mailto:lganzev@mail.ru)

Mokhova. Ludmila M., <https://orcid.org/0000-0003-0396-4756>

*Pacific Geographical Institute of the Far Eastern Branch, Russian Academy of Sciences, Vladivostok, Russia*

Abstract

[PDF RUS](#)

[PDF ENG](#)

[Full text](#)

[PDF RUS](#)

**Abstract.** The development of vegetation on the eastern coast of Primorye in the low and middle mountains of the eastern macro-slope of Sikhote-Alin over the past 5500 years was reconstructed based on the pollen analysis of lacustrine and bog sediments. The temporal resolution of the reconstructions is 30–88 years. Twenty phases of vegetation development, lasting from 670 to 120 years, were identified, amidst which the multidecadal variations took place. The transport of pollen and spores played a certain role in the variability of pollen spectra. Short-term hydroclimatic changes are reflected in the structure of the pollen spectra as changes in the ratio of broadleaf to dark coniferous pollen, the peaks of which are consistent with solar activity variations. A long phase of stable development of Korean pine-broadleaf forests was noted at the end of the Middle Holocene (5050–4380 yr BP). Vegetation changes were recorded during the 4.2 ka event, characterized by cool climatic conditions and low humidity. Korean pine generally expanded in cooler and more humid conditions, and its presence declined during the periods of low humidity. The biggest distribution of Korean pine forests was recorded during 2820–2640 yr BP cooling. Dark coniferous forests became widespread at the beginning of the Little Ice Age. The role of birch trees increased in the late Holocene and modern conditions. Alder thickets spread along the swampy shores of the lake during decreased humidity. Slopewash, which intensified during the periods of high typhoon frequency, played a significant role in spore transport. Allochthonous pollen (*Cryptomeria*, *Fagus*) transported in bioaerosols from remote areas, possibly from the Japanese Islands, was found. *Ephedra* pollen might have been carried by dust storms from the continental interiors. Signals of anthropogenic influence on the landscape have been noted since the Bronze Age. The most significant human impact to forests occurred in the late 19th and early 20th centuries, before the establishment of a nature reserve.

### **Keywords:**

**pollen analysis, Holocene, warming, cold events, moisture, monsoon, flash wash, human impact, Far East, Eastern Primorye**

**For citation:** Razjigaeva N.G., Ganzev L.A., Mokhova L.M. Vegetation response in the surrounding area of Zarya Bay (the Sea of Japan) to multidecadal climatic variations over the past 5500 years. *Geosistemy perhodnykh zon = Geosystems of Transition Zones*, 2026, vol. 10, No. 1, p. 33–56. (In Russ.). <https://doi.org/10.30730/gtr.2026.10.1.033-056>; <https://www.elibrary.ru/bcixwr>

**Для цитирования:** Разжигеева Н.Г., Ганзей Л.А., Мохова Л.М. Реакция растительности обрамления бухты Заря (Японское море) на мультидекадные климатические вариации за последние 5500 лет. *Геосистемы переходных зон*, 2026, т. 10, № 1, с. 33–56. <https://doi.org/10.30730/gtr.2026.10.1.033-056>; <https://www.elibrary.ru/bcixwr>

### **References**

1. Kiselev A.A., Makhotkina E.L., Pavlova T.V. (eds) [*The Third assessment report on climate change and its impacts on the territory of the Russian Federation*]. St.-Petersburg: Naukoemkie Tekhnologii [High-Tech Publ.], 2022, 124 p. (In Russ.).
2. Li C., Wu Ya., Hou X. Holocene vegetation and climate in Northeast China revealed from Jingbo Lake sediment. *Quaternary International*. 2011, 229:67–73. <https://doi.org/10.1016/j.quaint.2009.12.015>
3. Chu G., Sun Q., Xie M., Lin Y., Shang W., Zhu Q., Shan Y., Xu D., Rioual P., Wang L., Liu J. Holocene cyclic climatic variations and the role of the Pacific Ocean as recorded in varved sediments from northeastern China. *Quaternary Science Reviews*. 2014, 102:85–95. <https://doi.org/10.1016/j.quascirev.2014.08.008>

4. Stebich M., Rehfeld K., Schlutz F., Tarasov P.E., Liu J., Mingram J. Holocene vegetation and climate dynamic of NE China based on the pollen record from Sihailongwan Maar Lake. *Quaternary Science Reviews*. 2015,124:275–289. <https://doi.org/10.1016/J.QUASCIREV.2015.07.021>
5. Zhang M., Bu Z., Jiang M., Wang S., Liu S., Jin Q., Shi P. Mid-late Holocene maar lake-mire transition in northeast China triggered by hydroclimatic variability. *Quaternary Science Reviews*. 2019,220:215–229. <https://doi.org/10.1016/j.quascirev.2015.07.021>
6. Zhang M., Bu Z., Wang S., Jiange M. Moisture changes in Northeast China since the last deglaciation: Spatiotemporal out-of-phase patterns and possible forcing mechanisms. *Earth-Science Reviews*. 2020,201:102984. <https://doi.org/10.1016/j.earscirev.2019.102984>
7. Park J., Bahk J., Park J., Kim H., Choi J. Mid-to-late Holocene climate variability in coastal East Asia and its impact on ancient Korean societies. *Scientific Report*. 2023,13:15379. <https://doi.org/10.1038/s41598-023-42551-x>
8. Lobanov V.B., Danchenkov M.A., Luchin E.V., Mesentseva L.I., Ponomarev V.I., Sokolov O.V., et al. Far East Seas of Russia. In: Yasyukevich V.V., Govorkova V.A., Korneva I.A., et al. (eds) [*Roshydromet's second assessment report on climate change and its impacts on the territory of the Russian Federation*]. Moscow: Rosgidromet, 2014, Chapter 5.4, p. 684–743. (In Russ.).
9. Mezentseva M.I., Grishina M.A., Kondrat'ev I.I. Trajectories and depth of cyclones entering the territory of Primorsky Krai. *Vestnik of the FEB RAS*. 2019,4:29–38. (In Russ.).
10. Byshev V.I., Neiman V.G., Ponomarev V.I., Romanov Y.A., Serykh I.V., Tsurikova T.V. The influence of global atmospheric oscillation on formation of climate anomalies in the Russian Far East. *Doklady Earth Sciences*. 2014,458(1):1116–1120. <https://doi.org/10.1134/S1028334X14090025>
11. Byshev V.I., Gusev A.V., Sidorova A.N. Conceptual foundations of an alternative physical model of modern climate. *Journal of Oceanological Research*. 2024,52(1):5–33. [https://doi.org/10.29006/1564-2291.JOR-2024.52\(1\).1](https://doi.org/10.29006/1564-2291.JOR-2024.52(1).1) (In Russ.).
12. Ponomarev V.I., Trusenkov O.O., Trousenkov S.T., Ustinova E.I., Kaplunenko D.D., Polyakova A.M. The ENSO signal in the Northwest Pacific. *PICES Scientific Report*. 1999,10:9–31.
13. Park J., Park J., Yi S., Kim J.C., Lee E., Choi J. Abrupt Holocene climate shifts in coastal East Asia, including the 8.2 ka, 4.2 ka, and 2.8 ka BP events, and societal responses on the Korean Peninsula. *Scientific Reports*. 2019,9:10806. <https://doi.org/10.1038/s41598-019-47264-8>
14. Ding X., Hu B., Li J., Lan J., Zgeb X., Yi L. Late Holocene orbital forcing and solar activity on the Kuroshio Current of subtropical north Pacific at different timescales. *Frontiers of Earth Science*. 2022,10:845228. <https://doi.org/10.3389/feart.2022.845228>
15. Lim J., Matsumoto E. Fine aeolian quartz records in Cheju Island, Korea, during the Last 6500 years and pathway change of the westerlies over East Asia. *J. of Geophysical Research: Atmospheres*. 2008,113:D08106. <http://dx.doi.org/10.1029/2007JD008501>
16. Nagashima K., Tada R., Toyoda S. Westerly Jet – East Asian summer monsoon connection during the Holocene. *Geochemistry, Geophysics, Geosystems*. 2013,14:5041–5053. <https://doi.org/10.1002/2013GC004931>
17. Bezrukova E.V., Reshetova S.A., Kulagina N.V., Shchetnikov A.A., Filinov I.A., Kuzmin M.I. Vegetation and climate in the north of the Minusinsk basin in the late Holocene: a record from shira lake resolved by decade. *Doklady Earth Sciences*. 2024,518(2):1755–1760. <https://doi.org/10.1134/S1028334X2460316X>
18. Novenko E.Yu., Mazei N.G., Kupriyanov D.A., Babeshko K.V., Kusilman M.V., Zyuganova I.S., Tsyganov A.N., Mazei Yu.A., Phelps L.N., Davis B.As. A 1300-year multi-proxy palaeoecological record from the northwest Putorana Plateau (Russian Subarctic): environmental changes, vegetation dynamics and fire history. *The Holocene*. 2023,33(2):181–193. <https://doi.org/10.1177/09596836221131693>
19. Nazarova L.B., Razjigaeva N.G., Golovatyuk L.V., Biskaborn B.K., Grebennikova T.A., Ganzey L.A., Mokhova L.M., Diekmann B. Reconstruction of environmental conditions in the Eastern Part of Primorsky Krai (Russian Far East) in the Late Holocene. *Contemporary Problems of Ecology*. 2021,14:218–230. <https://doi.org/10.1134/S1995425521030094>
20. Lyashchevskaya M.S., Bazarova V.B., Makarova T.R. Environment development and the evolution of Gniloe Lake (south-eastern Primorye) during the last 3300 years. *Geomorphology and Paleogeography*. 2023,54(3):108–123. (In Russ.). <https://doi.org/10.31857/S2949178923030064>
21. Razjigaeva N.G., Ganzey L.A., Grebennikova T.A., Kopoteva T.A., Klimin M.A., Arslanov Kh.A., et al. Atmospheric anomaly bioindicators in peat sections on the eastern macroslope of the Sikhote-Alin Range in the Late Holocene. *Russian Journal of Pacific Geology*. 2023,17(1):41–53. <https://doi.org/10.1134/S1819714023010086>
22. Razjigaeva N.G., Ganzey L.A., Grebennikova T.A., Mokhova L.M., Chakov V.V., Klimin M.A., Simonova G.V. Global cooling events of the Late Holocene preserved in the coastal sediments in the southern Far East of Russia. *Geomorphology and Paleogeography*. 2023,54(1):112–130. <https://doi.org/10.31857/S0435428123010115>
23. Razjigaeva N.G., Ganzey L.A., Grebennikova T.A., Mokhova L.M., Arslanov Kh.A. Lacustrine paleoarchives of environmental changes of Peschany Peninsula, Sea of Japan (South Primorye). *Geosistemy perehodnykh zon = Geosystems of Transition Zones*. 2023,7(4):375–404. (In Russ.). <https://doi.org/10.30730/gtr.2023.7.4.375-404>
24. Razjigaeva N.G., Ganzey L.A., Grebennikova T.A., Mokhova L.M., Belyanin P.S., Kuddryavtseva E.P., Shekman E.A., Kopoteva T.A., Klimin M.A. Vaskovskoye Peatland as a natural archive of environmental

- changes in the Sikhote-Alin Biosphere Region in the late Holocene. *Pacific Geography*. 2025,3:44–64. (In Russ.). [https://doi.org/10.35735/26870509\\_2025\\_23\\_4](https://doi.org/10.35735/26870509_2025_23_4)
25. Lozhkin A.V., Anderson P.M., Brown T.A., Grebennikova T.A., Korzun J.A., Tsigankova V.I. Lake development and vegetation history in coastal Primor'ye: implications for Holocene climate of the southeastern Russian Far East. *Boreas*. 2021,50:983–997. <https://doi.org/10.1111/bor.12477>
  26. Lozhkin A.V., Cherepanova M.V., Grebennikova T.A., Anderson P.M., Brown T., Korzun J.A., Tsigankova V.I. Middle and late-Holocene coastal environments of far southeastern Russia as inferred from palynological and diatom data. *The Holocene*. 2026,36(2):223–233. <https://doi.org/10.1177/09596836251387251>
  27. Zhudova P.P. [Vegetation and flora of Sudzukhinsky State Reserve of Primorye]. Vladivostok: Far East Publ., 1967, 245 p. (Bull. of Sikhote-Alin State Reserve; Issue 4). (In Russ.).
  28. [Lazovsky Reserve]. Moskow: Agropromisdat, 1989, 206 p. (In Russ.).
  29. Laptev L.A. Physical and geographical characteristics. In: Azbukina Z.M. (ed) *Flora, micro- and lichen biota of the Lazovskiy Reserve (Primorye)*. Vladivostok: Far East Branch of USSR Academy of Sciences, 1990, p. 4–9. (In Russ.).
  30. Krestov P.V., Verkholat V.P. *Rare plant communities of Amur region*. Vladivostok: FEB RAS, 2003, 200 p. (In Russ.).
  31. Pshennikova L.M. *Aquatic plants of Russian Far East*. Vladivostok: Dalnauka, 2005, 106 p. (In Russ.).
  32. Krasnopeev S.P., Rozenberg V.A. (eds) *Atlas of forests of Primorye*. Vladivostok: FEB RAS, 2005, 76 p. (In Russ.).
  33. Pokrovskaya I.M. A technique of cameral works. In: *Paleopalynology*. Leningrad: Nedra, 1966, vol. 1, p. 32–61. (Trudy VSEGEI; 141). (In Russ.).
  34. Grimm E. *Tilia software 2.0.2*. Illinois State Museum Research and Collection Center, Springfield, 2004.
  35. Blaauw M., Christen J.A. Flexible paleoclimate age-depth models using an autoregressive gamma process. *Bayesian Analysis*. 2011,6(3):457–474.
  36. Ganzey L.A., Razjigaeva N.G., Nishimura Yu., Grebennikova T.A., Kaistrenko V.M., Gorbunov A.O., Arslanov Kh.A., Chernov S.B., Naumov Yu.A. Deposits of historical and paleotsunamis on the Coast of Eastern Primorye. *Russian Journal of Pacific Geology*. 2015,9(1):64–79. <https://doi.org/10.1134/S1819714015010029>
  37. Korotkii A.M., Karaulova L.P., Troitskaya T.S. *Quaternary deposits of Primorye. Stratigraphy and paleogeography*. Novosibirsk: Nauka, 1980, 234 p. (In Russ.).
  38. Urusov V.M., Lobanova I.I., Varchenko L.I. [Conifers of Russian Far East – valuable object of the study, protection, breeding and use]. Vladivostok: Dalnauka, 2007, 440 p. (In Russ.).
  39. Bazarova V.B., Lyashchevskaya M.S., Kudryavtseva E.P., Piskareva Y.V., Astashenkova Y.V. Holocene population of Ambrosia on South of Russian Far East. *Geography, Environment, Sustainability*. 2023,16(1):16–25. <https://doi.org/10.24057/2071-9388-2022-123>
  40. Zhou X., Liu X., Zhan T., Oyebanji D.B., Zhang J., Tu L., Jiang S. Low-latitude forcing on 4.2 ka event indicated by records in the Asian monsoon region. *Global and Planetary Change*. 2024,235:104401. <https://doi.org/10.1016/j.gloplacha.2024.104401>
  41. Steinhilber F., Beer J., Fröhlich C. Total solar irradiance during the Holocene. *Geophysics Research Letters*. 2009,36:L19704. <https://doi.org/10.1029/2009GL040142>
  42. Stott L., Cannariato K., Thunell R., Haug G.H., Koutavas A., Lund S. Decline of surface temperature and salinity in the western tropical Pacific Ocean in the Holocene epoch. *Nature*. 2004,431:56–59. <https://doi.org/10.1038/nature02903>
  43. Mayewski P.A., Rohling E.E., Stager J.C., Karle W., Maasch K.A., Meeker L.D., et al. Holocene climate variability. *Quaternary Research*. 2004,62:243–255.
  44. Conroy J.L., Overpeck J.T., Cole J.E., Shanahan T., Steinitz-Kannan M. Holocene changes in eastern tropical Pacific climate inferred from a Galapagos lake sediment record. *Quaternary Science Review*. 2008,27:1166–1180. <https://doi.org/10.1016/j.quascirev.2008.02.015>
  45. Sakaguchi Y. Warm and cold stages in the past 7600 years in Japan and their global correlation. *Bulletin of the Department of Geography University of Tokyo*. 1983,15:1–31.
  46. Razjigaeva N.G., Ganzey L.A., Mokhova L.M., Makarova T.R., Kudryavtseva E.P., Panichev A.M., Arslanov Kh.A. Climate and human impact on vegetation in the upper part of the Ussuri River basin in late Holocene, Russian Far East. *Geography, Environment, Sustainability*. 2019,2(12):162–172.
  47. Wanner H., Solomina O., Grosjean M., Ritz S.P., Jetel M. Structure and origin of Holocene cold events. *Quaternary Science Review*. 2011,30:3109–3123. <https://doi.org/10.1016/J.QUASCIREV.2011.07.010>
  48. Gorbarenko S.A., Shi X., Liu Y., Bosin A.A., Vasilenko Y.P., Artemova A.V., Yanchenko E.A., Zou J., Yao Z., Kirichenko I.S. Reconstructing Holocene centennial cooling events: synthesized temperature changes, chronology, and forcing in the Northern Hemisphere. *Frontiers of Earth Science*. 2024,12:1415180. <https://doi.org/10.3389/feart.2024.1415180>
  49. Lozhkin A., Minyuk P., Cherepanova M., Anderson P., Finney B. Holocene environments of central Iturup Island, southern Kuril archipelago, Russian Far East. *Quaternary Research*. 2017,88:23–38. <https://doi.org/10.1017/qua.2017.21>
  50. Razjigaeva N.G., Ganzey L.A., Grebennikova T.A., Mokhova L.M., Kudryavtseva E.P., Arslanov Kh.A., Maksimov F.E., Starikova A.A. Landscape and environmental changes of Eastern Primorye coast at middle–late Holocene: climatic changes and human impact effects. *Journal of Asian Earth Sciences*. 2018,158:160–172. <https://doi.org/10.1016/j.jseaes.2018.02.013>

51. Razzhigaeva N.G., Ganzey L.A., Mokhova L.M., Makarova T.R., Panichev A.M., Kudryavtseva E.P., Arslanov Kh.A., Maksimov F.E., Starikoiva A.A. The development of landscapes of the Shkotovo Plateau of Sikhote-Alin in the Late Holocene. *Izvestiya Rossiiskoi Akademii Nauk. Seriya Geograficheskaya*. 2016,3:65–80. (In Russ.). <https://doi.org/10.15356/0373-2444-2016-3-65-80>
52. Razjigaeva N., Ganzey L., Grebennikova T., Ponomarev V. “Cold-Dry” and “Cold-Wet” events in the Late Holocene, Southern Russian Far East. *Climate*. 2023,11:91. <https://doi.org/10.3390/cli11040091>
53. Park J., Park J., Yi S., Lim J., Kim J.C., Jin Q., Choi J. Holocene hydroclimate reconstruction based on pollen, XRF, and grain-size analysis and its implications for past societies of the Korean Peninsula. *The Holocene*. 2021,31(9):1489–1500. <https://doi.org/10.1177/09596836211019115>
54. Wanner H., Pfister C., Neukom R. The variable European Little Ice Age. *Quaternary Science Reviews*. 2022,287:107531. <https://doi.org/10.1016/j.quascirev.2022.107531>
55. Bazarova V.B., Makarova T.R., Lyashchevskaya M.S., Makarevich R.A., Razzhigaeva N.G., Gelman E.I., Piskareva Ya.E., Astashenkova E.V. Environmental conditions of floodplain sedimentation during the Little Ice Age in the deltaic zone of the Tsukanovka River (Southwestern Primorye). *Russian Journal of Pacific Geology*. 2025,19(3):284–300. <https://doi.org/10.1134/S181971402570006X>
56. Park J., Han J., Jin Q., Bahk J., Yi S. The link between ENSO-like forcing and hydroclimate variability of coastal East Asia during the Last Millennium. *Scientific Reports*. 2017,7:8166. <https://doi.org/10.1038/s41598-017-08538-1>
57. Dziziuropa V.D., Korznikov K.A., Petrenko T.Y., Dudov S.V., Krestov P.V. Assessment of the mixed coniferous broadleaved forest canopy disturbance induced by typhoon Maysak (2020) using drone-borne images near Vladivostok, Russia. *Botanica Pacifica*. 2022,11(2):81–87. <https://doi.org/10.17581/bp.2022.11214>
58. Usoskin I.G., Solanki S.K., Kovaltsov G.A. Grand minima and maxima of solar activity: New observational constraints. *Astronomy & Astrophysics*. 2007,471(1):301–309. <https://doi.org/10.1051/0004-6361:20077704>
59. Razjigaeva N.G., Ganzey L.A., Ponomarev V.I., Mokhova L.M., Grebennikova T.A. Application bioaerosol records for recovery of atmospheric circulation anomalies over the Kuril Islands in the Late Glacial-Holocene. *Quaternary Science Review*. 2025,353:109222. <https://doi.org/10.1016/j.quascirev.2025.109222>
60. Mokhova L.M. [Features of pollen rain composition during dust storms on Southern Far East]. In: Afonin S.A., Tokarev P.I. (eds) *Proceeding of XI Russian Pollen Conference*. Moscow: PI RAN, 2005, p. 173–174. (In Russ.).
61. Kuzmin Ya.V., Boldin V.I., Nikitin Yu.G. [Chronology of cultured of Early Iron Age and Medieval Time of Primorye]. *Russia and ATR*. 2005,4:44–53. (In Russ.).
62. Andreeva Zh.V., Garkovik A.V., Zhuschikovskaya I.S., Kononenko N.A. (eds) [*Valentin-Peresheek – the settlement of ancient miners*]. Moscow: Nauka, 1987, 248 p. (In Russ.).
63. Baklanov P.Ya., Bersenev Yu.I. (eds) *National Park «Zov tигра»*. Vladivostok: Dalnauka, 2014, 147 p. (In Russ.).