Younger Dryas *Larix* in eastern Siberia: A migrant or survivor?

Pavel Tarasov[1], S. Müller[1], A. Andreev[2], K. Werner[3] and B. Diekmann[2]

[1]Free University, Berlin, Germany; ptarasov@zedat.fu-berlin.de
[2]Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany; [3]Leibniz Institute of Marine Sciences, Kiel, Germany

Radiocarbon-dated larch cone and needles from Dyanushka Peat and pollen data from Lake Billyakh, located ~170 km south of the Arctic Circle, provide the first unequivocal evidence for larch trees growing locally prior to the Holocene and indicate reforestation of eastern Siberia by the early Holocene.

Knowledge of past forest change serves for a better understanding of the climate system, carbon cycle and genetic diversity, and can inform current predictions and conservation strategies (Prentice et al., 1992; Tarasov et al., 2007; Petit et al., 2008). Botanical records from high-latitude regions of Europe and North America indicate that boreal forests "became established during the Holocene interglacial (the past 11.6 ka) as a result of population invasion from southern glacial refugia and local expansion of small tree populations that survived the Last Glacial Maximum interval (LGM: ~25-17 ka) in cryptic refugia" (Petit et al., 2008). An extensive dataset of radiocarbon-dated macrofossils from northern Asia provides evidence that boreal trees advanced close to the current arctic coastline between 9 and 7 ka (MacDonald et al., 2000). Due to a lack of wood macrofossils older than 10 ka from the ~2000×2500 km² region of eastern Siberia between 108° and 145°E (Fig. 1a), there is no agreement on whether trees could persist there during the coldest phases of the last glacial period (Johnsen et al., 2001), including the Younger Dryas (YD: ~12.7-11.6 ka) and the LGM (Brubaker et al., 2005; Tarasov et al., 2007; Binney et al., 2009 and references therein).

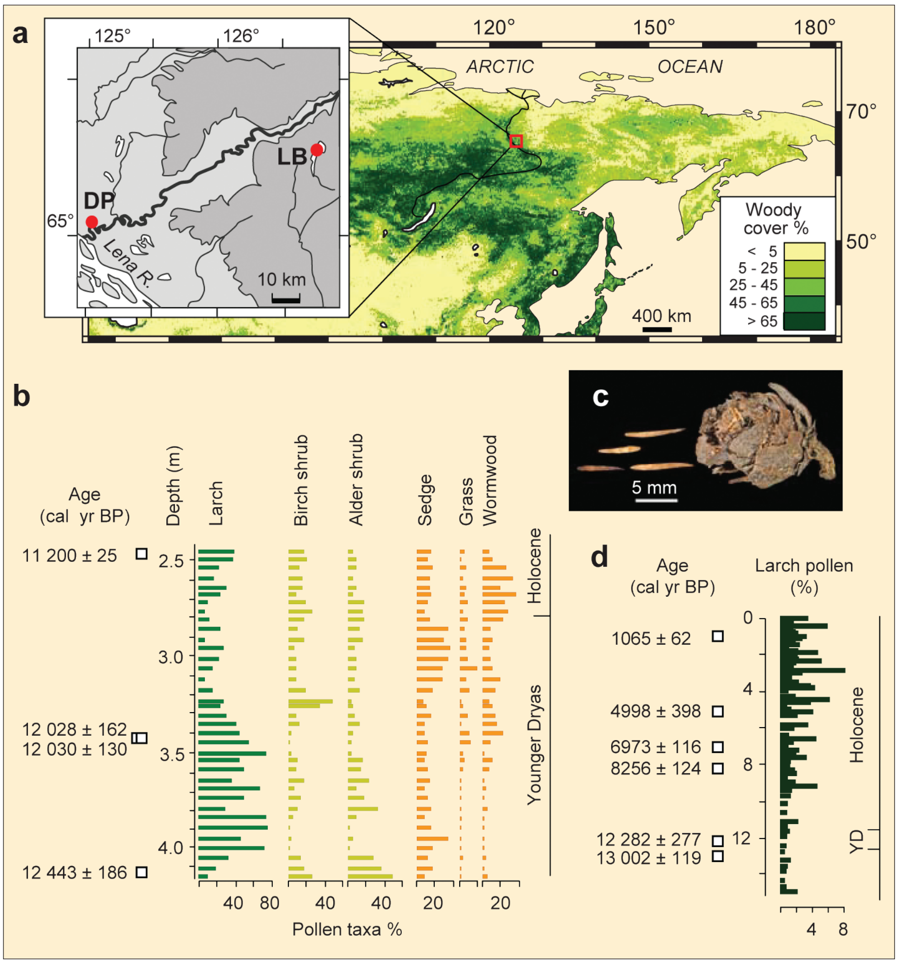

*Figure 1: **a**) Location of Dyanushka Peat (DP) and Lake Billyakh (LB) study sites (left) in the boreal forest belt of eastern Siberia (right, modified from Tarasov et al., 2007); **b**) Pollen diagram of the lowest part of the DP section, showing percentages of selected tree, shrub and herbaceous taxa and the calibrated radiocarbon ages (68% range); **c**) Photo of larch cone and needles from 340-345 cm depth in DP, dated to 12,030±130 (Poz-28087) and to 12,028 ± 162 cal yr BP (KIA26015), respectively (after Werner et al., 2009); and **d**) Chart showing the occurrence of larch pollen during ~15 ka in the short core from LB (after Müller et al., 2009). Radiocarbon years before present were converted to calendar years using the CalPal program (Danzeglocke et al., 2008).*

Results and discussion

Here we present unequivocal evidence from Dyanushka Peat (123 m asl), located in the western foreland of the Verkhoyansk Mountains, ~170 km south of the Arctic Circle (Fig. 1a), for larch trees (most probably *Larix cajanderi* Mayr) growing locally prior to the Holocene. Modern climate is extremely continental, with a mean temperature of around -40°C in January and about 15-19°C in July (Werner et al., 2009). Annual precipitation of 300-400 mm is relatively low but humidity is relatively high due to low evaporation. In addition, summer melting of the active permafrost layer provides a considerable amount of plant-available water. Cold deciduous forest dominated by larch, with shrubs growing in the understorey, occupies lower elevations, while tundra occurs above 700-1200 m asl. Dyanushka Peat reveals organic material accumulated in a former oxbow-lake exposed by the erosion of the Dyanushka River running from the Verkhoyansk Mountains to the Lena River (Werner et al., 2009). Analysis of pollen in the peat (Fig. 1b) demonstrates that larch trees and abundant birch and alder shrubs grew near the site between 12.5 and 11.2 ka, spanning the YD and early Holocene. The calibrated AMS radiocarbon dates on fossil wood (12,443 ± 186 cal a BP), cone (12,030 ± 130 cal a BP) and needles (12,028 ± 162 cal a BP) also identified within the peat (Fig. 1b-c) support the reconstruction of locally growing larch trees during the mid- and late YD. The herbaceous cover was mainly represented by sedges, with grasses and wormwood species becoming more abundant during the later phase of the YD after ~12 ka, likely indicating increasingly dry conditions (Fig. 1b). Recorded decrease in percentages of tree and shrub pollen corroborates such an interpretation. However, both pollen and macrofossil records indicate that this climatic change was not strong enough to destroy local larch stands.

Recently, Müller et al. (2009) published a radiocarbon-dated late glacial-Holocene pollen record from Lake Billyakh (340 m asl), situated in the western part of the Verkhoyansk Mountains, ~80 km from Dyanushka Peat (Fig. 1a). This publication demonstrated the continuous presence of larch pollen in the lake sediment during the past 15 ka (Fig. 1d). Larch pollen is known for its short-distance dispersal from the pollen-producing tree and generally poor preservation (Gunin et al., 1999; MacDonald, 2001 and references therein). This fact may explain its low percentages in the late glacial but also in many of the mid- and late Holocene pollen spectra from Lake Billyakh (Fig. 1d). The pollen data from Lake Billyakh, viewed together with the pollen and plant macrofossil records from Dyanushka Peat, strongly support our interpretation that local populations of larch persisted in the western foreland of the Verkhoyansk Mountains throughout the last 15 ka and survived the YD cold episode. The question, whether larch could survive the much longer, cold and dry LGM interval in situ or migrated into the study region as the result of the late glacial climate amelioration, needs more careful investigation.

The 9.36 m sediment core PG1755 recovered from the central part of Lake Billyakh provides for the first time in the study region a detailed pollen and vegetation record covering the past 50 ka (Müller et al., in prep.), as suggested by the age model (Fig. 2b) based on 6 bulk radiocarbon dates from the core PG1755 (Fig. 2a) and on 6 dates from the shorter core PG1756 (Fig. 1d). The correlation between the two cores was performed using pollen and magnetic susceptibility records.

A simplified pollen diagram (Fig. 2c) shows the predominance of herbaceous pollen during the last glacial, suggesting greater landscape openness compared with the Holocene. The quasi-continuous presence of larch, together with shrubby birch and alder pollen, throughout the whole record is the most striking feature of the core. The percentages of larch pollen reached high Holocene levels during the middle part of the last glacial (~40-30 ka), indicating growth of the larch trees around the lake at that time. The almost continuous record of larch pollen is difficult to explain by a long distance migration. The refugia hypothesis, which involves expansion of trees from local cryptic refugia, appears more plausible. The absence of larch in the pollen spectra from the early LGM (~25-22 ka) could indicate the disappearance of larch from the local vegetation. However, this is not likely to have been a large-scale disappearance, due to the re-appearance of larch pollen after ~22 ka without any significant changes in the pollen spectra, and thus in the glacial climate and environments. Further study, including counting of greater amounts of pollen, search for larch stomata and biomarker analysis, may help to resolve this problem.

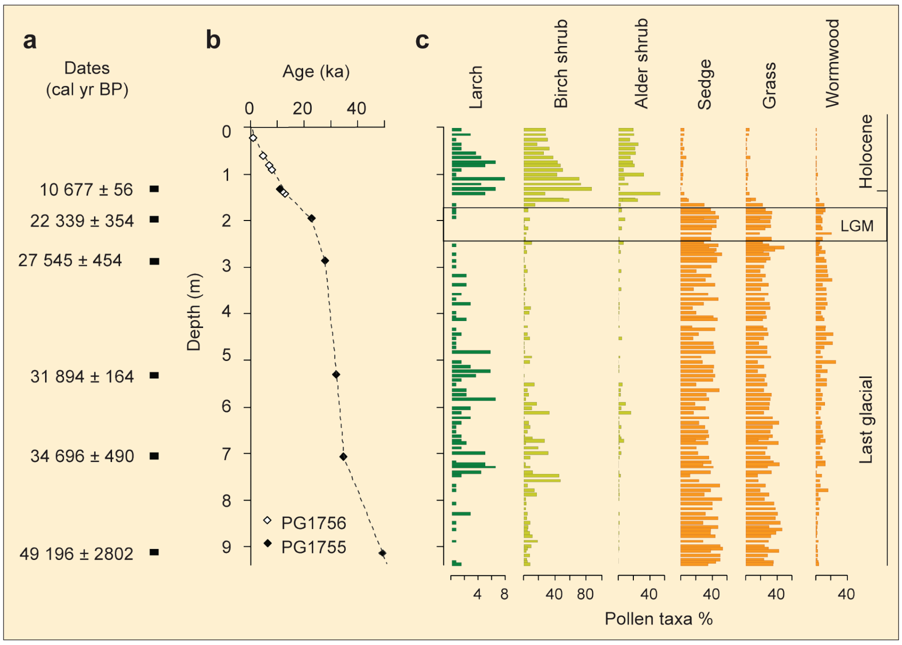

*Figure 2: **a**) The calibrated radiocarbon ages (68% range) from the long Lake Billyakh core used to construct **b**) The age-depth model; and **c**) Simplified pollen diagram showing percentages of selected tree, shrub and herbaceous taxa (Müller et al., in prep.).*

Conclusion

Present-day extension of larch in the Arctic is limited mainly by the mean July isotherm of 10-12°C (MacDonald et al., 2000). It is plausible that the western foreland of the Verkhoyansk Mountains, the area where the Dyanushka Peat and Lake Billyakh are located, with its numerous lake and river valleys provided enough moisture and warm microhabitats to buffer larch trees against climatic extremes. The presence of larch populations during the late glacial and YD likely explains the quick reforestation of eastern Siberia by the early Holocene, and supports the molecular-based hypothesis suggesting the existence of high-latitude plant refugia during past glaciations (Abbott et al., 2000).

Data

All data from Lake Billyakh (PG1756 core) and from Dyanushka Peat used in Fig. 1 are available in the PANGAEA data information system (see http://doi.pangaea.de/10.1594/PANGAEA.708170 and http://doi.pangaea.de/10.1594/PANGAEA.716835).

Acknowledgements

We would like to acknowledge financial and technical support from AWI Potsdam and via the DFG Projects HU 378/12, ZE 154/52, RI 809/17 and TA 540/1, as well as Russian and German colleagues, who helped with the field work in Yakutia, and T. Goslar for radiocarbon dating of the larch cone.

References

Abbott, R.J., Smith, L.C., Milne, R.I., Crawford, R.M.M., Wolff, K. and Balfour, J., 2000: Molecular analysis of plant migration and refugia in the Arctic, *Science*, **289**: 1343-1346.

MacDonald, G.M. et al. 2000: Holocene treeline history and climate change across Northern Eurasia, *Quaternary Research*, **53**: 302–311.

Müller, S., Tarasov, P.E., Diekmann, B. and Andreev, A.A., 2009: Late Glacial to Holocene environments in the present-day coldest region of the Northern Hemisphere inferred from a pollen record of Lake Billyakh, Verkhoyansk Mts, NE Siberia, *Climate of the Past*, **5**: 73-84.

Petit, R.J., Hu, F.S. and Dick, C.W., 2008: Forests of the Past: A Window to Future Changes, *Science*, **320**: 1450-1452.

Tarasov, P., et al. 2007: Satellite- and pollen-based quantitative woody cover reconstructions for northern Asia: verification and application to late-Quaternary pollen data, *Earth and Planetary Science Letters*, **264**: 284–298.

For full references please consult:
www.pages-igbp.org/products/newsletters/ref2009_3.html

Full Reference List:

Abbott, R.J., Smith, L.C., Milne, R.I., Crawford, R.M.M., Wolff, K. and Balfour, J., 2000: Molecular analysis of plant migration and refugia in the Arctic, *Science*, **289**: 1343-1346.

Binney, H.A., Willis, K.J., Edwards, M.E., Bhagwat, S.A., Anderson, P.M., Andreev, A.A., Blaauw, M., Damblon, F., Haesaerts, P. Kienast, F., Kremenetski, K.V., Krivonogov, S.K., Lozhkin, A.V., MacDonald, G.M., Novenko, E.Y., Oksanen, P., Sapelko, N.V., Väliranta, M. and Vazhenina, L., 2009: The distribution of late-Quaternary woody taxa in northern Eurasia: evidence from a new macrofossil database, *Quaternary Science Reviews*, **28**: 2445–2464.

Brubaker, L.B., Anderson, P.M., Edwards, M.E. and Lozhkin, A.V., 2005: Beringia as a glacial refugium for boreal trees and shrubs: new perspectives from mapped pollen data, *Journal of Biogeography*, **32**: 833–848.

Danzeglocke, U., Jöris, O. and Weninger, B., 2008: CalPal-2007online. http://www.calpal-online.de.

Johnsen, S.J., Dahl-Jensen, D., Gundestrup, N., Steffensen, J.P., Clausen, H.B., Miller, H., Masson-Delmotte, V., Sveinbjörnsdottir, A.E. and White, J., 2001: Oxygen isotope and palaeotemperature records from six Greenland ice-core stations: Camp Century, Dye-3, GRIP, GISP2, Renland and NorthGRIP, *Journal of Quaternary Science*, **16**: 299-307.

MacDonald G.M., 2001: Conifer stomata. In: Smol J.P., Birks H.J.B. and Last W.M. (eds), Tracking Environmental Change Using Lake Sediments. Vol. 3: Terrestrial, Algal and Siliceous Indicators. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 33–47.

MacDonald, G.M., Velichko, A.A., Kremenetski, C.V., Borisova, O.K., Goleva, A.A., Andreev, A.A., Cwynar, L.C., Riding, R.T., Forman, S.L., Edwards, T.W.D., Aravena, R., Hammarlund, D., Szeicz, J.M. and Gattaulin, V.N., 2000: Holocene treeline history and climate change across Northern Eurasia, *Quaternary Research*, **53**: 302–311.

Müller, S., Tarasov, P.E., Diekmann, B. and Andreev, A.A., 2009: Late Glacial to Holocene environments in the present-day coldest region of the Northern Hemisphere inferred from a pollen record of Lake Billyakh, Verkhoyansk Mts, NE Siberia, *Climate of the Past*, **5**: 73-84.

Petit, R.J., Hu, F.S. and Dick, C.W., 2008: Forests of the Past: A Window to Future Changes, *Science*, **320**: 1450-1452.

Prentice, I.C., Crameer, W., Harrison, S.P., Leemans, R., Monserud, R.A. and Solomon, A.M., 1992: A global biome model based on plant physiology and dominance, soil properties, and climate, *Journal of Biogeography*, **19**: 117–134.

Tarasov, P., Williams, J.W., Andreev, A., Nakagawa, T., Bezrukova, E., Herzschuh, U., Igarashi, Y., Müller, S., Werner, K. and Zheng, Z., 2007: Satellite- and pollen-based quantitative woody cover reconstructions for northern Asia: verification and application to late-Quaternary pollen data, *Earth and Planetary Science Letters*, **264**: 284–298.

Werner, K., Tarasov, P.E., Andreev, A.A., Müller, S., Kienast, F., Zech, M., Zech, W. and Diekmann, B., 2009: A 12.5-kyr history of vegetation dynamics and mire development with evidence of Younger Dryas larch presence in the Verkhoyansk Mountains, East Siberia, Russia, *Boreas*, published online.