nature ecology & evolution

ARTICLES

https://doi.org/10.1038/s41559-021-01628-4

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Radiocarbon dating from Yuzhniy Oleniy Ostrov cemetery reveals complex human responses to socio-ecological stress during the 8.2 ka cooling event

Rick J. Schulting[1]✉, Kristiina Mannermaa[2], Pavel E. Tarasov[3], Thomas Higham[1,4], Christopher Bronk Ramsey[1], Valeri Khartanovich[5], Vyacheslav Moiseyev[5], Dmitriy Gerasimov[5], John O'Shea[6] and Andrzej Weber[7,8,9]

Yuzhniy Oleniy Ostrov in Karelia, northwest Russia, is one of the largest Early Holocene cemeteries in northern Eurasia, with 177 burials recovered in excavations in the 1930s; originally, more than 400 graves may have been present. A new radiocarbon dating programme, taking into account a correction for freshwater reservoir effects, suggests that the main use of the cemetery spanned only some 100–300 years, centring on ca. 8250 to 8000 cal BP. This coincides remarkably closely with the 8.2 ka cooling event, the most dramatic climatic downturn in the Holocene in the northern hemisphere, inviting an interpretation in terms of human response to a climate-driven environmental change. Rather than suggesting a simple deterministic relationship, we draw on a body of anthropological and archaeological theory to argue that the burial of the dead at this location served to demarcate and negotiate rights of access to a favoured locality with particularly rich and resilient fish and game stocks during a period of regional resource depression. This resulted in increased social stress in human communities that exceeded and subverted the 'normal' commitment of many hunter-gatherers to egalitarianism and widespread resource sharing, and gave rise to greater mortuary complexity. However, this seems to have lasted only for the duration of the climate downturn. Our results have implications for understanding the context of the emergence—and dissolution—of socio-economic inequality and territoriality under conditions of socio-ecological stress.

Little is known concerning human responses to the 8.2 ka event, a major climatic cooling event with a rapid onset caused by a massive meltwater pulse from the Laurentide lakes into the North Atlantic, resulting in the collapse of the thermohaline circulation that brings warm water northwards from the Gulf of Mexico[1–6]. Early farmers may have been adversely impacted in southeastern Europe[7–11], but the majority of the Eurasian continent at this time was occupied by hunter-gatherers, who would have had considerable adaptive flexibility to respond to environmental changes[12–18], not least because of the range of options facilitated by their generally low population densities and comparatively high residential mobility[19]. However, it is likely that events of sufficient magnitude would reach a tipping point in some regions, leading to a marked response by foragers[20–22]. The challenge has been to identify evidence for such effects, particularly given the generally imprecise chronologies that, until recently, have been the norm for Early Holocene archaeology. Advances in measurement precision and greater appreciation of 'old carbon' reservoir effects, together with the application of Bayesian statistical modelling, have provided the means with which to achieve more accurate, precise and robust chronologies. Here we present such a case from Early Holocene Karelia, northwest Russia.

The Yuzhniy Oleniy Ostrov (YOO) cemetery is located on an island in Lake Onega, Karelia, some 350 km northeast of St Petersburg (Fig. 1 and Supplementary Sections 1 and 2). Excavated by Russian archaeologists in 1936–1938[23], the site has come to hold an important position in European Mesolithic studies, due both to the large number of burials recovered—177, with large areas already disturbed by quarrying, suggesting that there may originally have been over 400—and to variation in the accompanying grave offerings, ranging from graves lacking them entirely to those with abundant and elaborate offerings. This has led to debate concerning whether the cemetery should be understood as reflecting a relatively egalitarian society with achieved status, or whether the differential distribution of grave 'wealth' indicates a degree of social inequality and hierarchy[24–26]. An important aspect of choosing between these two interpretations is the cemetery's chronology, since an alternative reading could see diachronic trends in grave provisioning. Previous radiocarbon dates have confirmed that YOO belongs to the earlier part of the Mesolithic (ca. 11,500–5500 cal BP in northern Europe), but these dates are limited in number and precision[27–29] (Supplementary Section 3 and Supplementary Table 1). Taken at face value, they indicate use of the cemetery over some 800 years,

[1]School of Archaeology, University of Oxford, Oxford, UK. [2]Department of Cultures, University of Helsinki, Helsinki, Finland. [3]Institute of Geological Sciences, Palaeontology, Freie Universität Berlin, Berlin, Germany. [4]Department of Evolutionary Anthropology, University of Vienna, Vienna, Austria. [5]Peter the Great Museum of Anthropology and Ethnography (Kunstkamera), Russian Academy of Sciences, St Petersburg, Russia. [6]Museum of Anthropological Archaeology, University of Michigan, Ann Arbor, MI, USA. [7]Department of Anthropology, University of Alberta, Edmonton, Alberta, Canada. [8]Research Centre 'Baikal Region', Irkutsk State University, Irkutsk, Russia. [9]Laboratoire Méditerranéen de Préhistoire Europe Afrique (LAMPEA), Aix-Marseille Université, Aix-en-Provence, France. ✉e-mail: rick.schulting@arch.ox.ac.uk

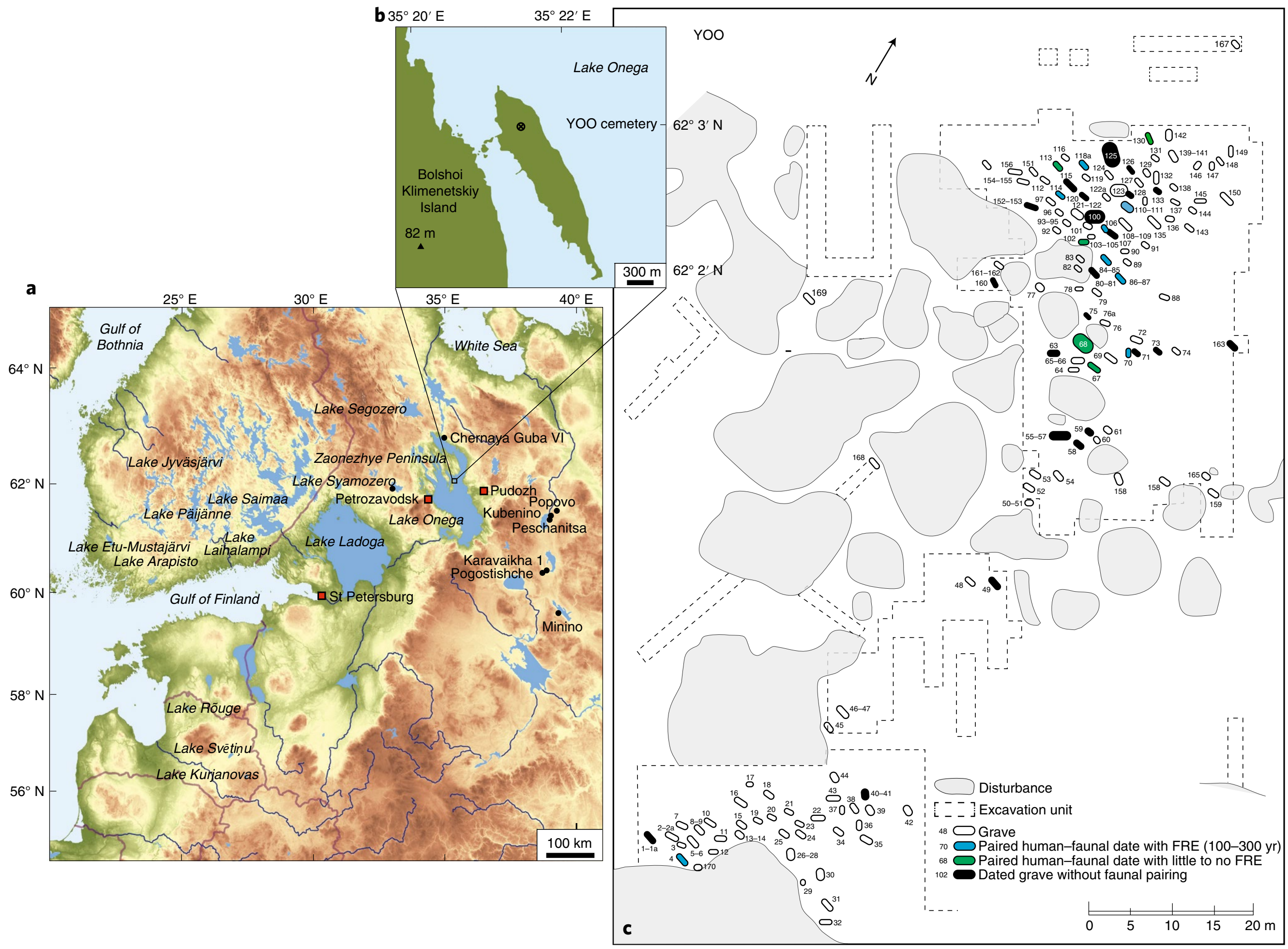

Fig. 1 | Site location and plan. a, Northeast Baltic region. The topographic map is based on 30-arc-second GTOPO30 data[101] provided by the US Geological Survey (https://lta.cr.usgs.gov/gtopo30). The water bodies are drawn based on modified Natural Earth Vector Data v.2.0 (http://www.naturalearthdata.com). **b**, Location of YOO. **c**, Site plan, showing the locations of the graves analysed in this study (after O'Shea and Zvelebil[24], Fig. 2).

spanning the 8.2 ka event without interruption (Extended Data Fig. 3) and suggesting that hunter-gatherers here were highly resilient and were not substantially affected in either their use of this location or their mortuary practices. But, as we will show, there are problems with this characterization.

A robust chronology is essential both for framing discussions of the cemetery's mortuary rites and for inferring the underlying social structure, as well as for assessing any response (or lack thereof) to the 8.2 ka event. Aside from the poor precision of the published dates, another potentially complicating factor not considered previously is the likelihood that the inclusion of freshwater fish in the diet would lead to an 'old carbon' reservoir effect, making the dates too old relative to the atmospheric ^{14}C reservoir[30–32]. To assess the impact of freshwater reservoir effects (FRE), we analysed 17 paired human and terrestrial fauna samples (mainly Eurasian elk (*Alces alces*) tooth ornaments) from the same graves. Previous research has demonstrated the utility of this approach in developing regression equations to correct for the FRE, making use of stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotopes in the human remains to estimate the contribution of fish in the diet[33]. An additional 22 humans lacking pairings with terrestrial fauna were also directly dated to provide better spatial coverage of the cemetery, including graves lacking any associated offerings (Fig. 1). With two exceptions, we make no use of previously published results[27,28] because of the lack of associated stable isotope data, and because of discrepancies observed between previous results and the new determinations when both are available for the same individual (Supplementary Table 1). The dates are modelled in OxCal v.4.4 (refs. [34,35]). The sampled materials are held in the Peter the Great Museum of Anthropology and Ethnography/Kunstkamera, Russian Academy of Sciences, St Petersburg, Russia.

Results

The results of a paired human–faunal dating programme indicate that approximately half the individuals were subject to reservoir offsets of between ca. 70 and 330 ^{14}C yr ($\bar{X} = 188 \pm 83$ ^{14}C yr), while the other half were unaffected ($\bar{X} = 0 \pm 69$ ^{14}C yr), implying the consumption of fish from different sources (other aquatic species, such as waterfowl, may also have been consumed but probably contributed far less to the diet than fish) (Supplementary Tables 2–4). There are weak but statistically significant correlations between ^{14}C offsets and both δ^{13}C ($r^2 = 0.267$, $P = 0.049$, d.f. = 14) and δ^{15}N ($r^2 = 0.311$, $P = 0.031$, d.f. = 14) values in separate linear regression models (Extended Data Fig. 6). When combined, the two stable isotopes together account for just over half of the variation in ^{14}C offsets ($r^2 = 0.525$, $P = 0.005$, d.f. = 14). However, there is a negative correlation with δ^{15}N and a positive correlation with δ^{13}C. This is unexpected, since δ^{15}N acts as a proxy for fish consumption and therefore should show a positive relationship with ^{14}C offsets. Thus, while all individuals must have consumed fish given the relatively high δ^{15}N values compared with terrestrial fauna (Fig. 2 and Supplementary

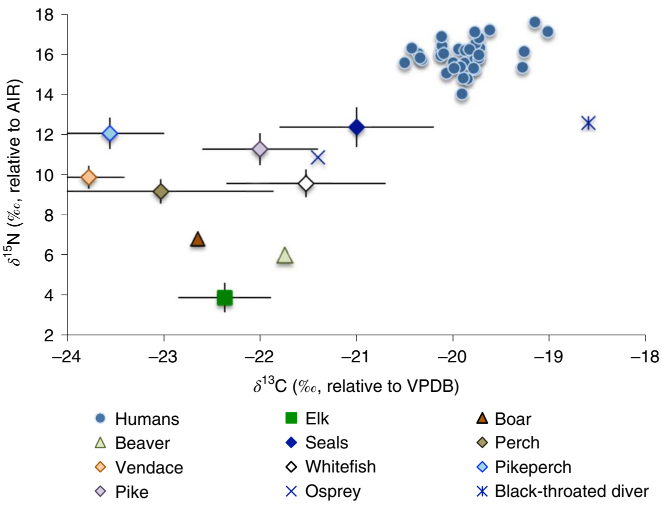

Fig. 2 | Human and comparative faunal δ^{13}C and δ^{15}N data. Plot of δ^{13}C and δ^{15}N values for prehistoric humans and terrestrial fauna (this study) and avifauna[102] from YOO and modern freshwater seals and fish from Lake Saimaa[103], adjusted to make them comparable (Supplementary Section 6 and Supplementary Table 5). The error bars are ±1 s.d.

Section 6), these fish must have derived either from different basins of Lake Onega or from surrounding lakes and rivers, which can be differentially impacted by old carbon[36]. The implication is that, within these different catchments, fish with lower δ^{15}N values would have had higher average ^{14}C offsets.

The 17 determinations made on terrestrial fauna from graves form a very tight group, Bayesian modelled as starting *8340–8190* bp and ending *8150–7945* bp (95.4% confidence) (Fig. 3 and Extended Data Fig. 8). To make use of the full dataset, radiocarbon determinations made on human bone lacking terrestrial pairings are corrected for the FRE using the stable isotope results associated with the paired dates (Supplementary Section 6). The estimated start and end dates for burials at YOO are modelled as *8340–8200* bp and *8125–7935* bp, respectively (Supplementary Section 8 and Extended Data Fig. 9). The medians of the modelled distributions show the coincidence with the 8.2 ka event even more strikingly, falling between *8240* and *8020* bp for fauna and *8250* and *7995* bp for humans. A useful way of showing the overall chronological trends for both the fauna and the humans is through kernel density estimation (KDE) plots within a Bayesian single-phase model (Fig. 3; see Supplementary Section 10 for the OxCal codes used for all models). The dates on the fauna and the humans coincide remarkably well with both the onset and the end of the 8.2 ka climatic downturn—the largest and most abrupt climatic oscillation of the past 10,000 years[37–39]. This strongly suggests a causal relationship.

Discussion

The Greenland ice core δ^{18}O records document a substantial temperature drop of 3–6 °C lasting ca. 160 yr centred on 8.2 ka, synchronous with a decrease in snow accumulation and the onset of generally dry and windy conditions, comparable in many respects to the Younger Dryas, though of a much lesser magnitude[1,3,38,40]. While in the North Atlantic region the temperature decrease is reduced to 1–3 °C, this remains the largest climate downturn in the Holocene in the northern hemisphere. Yet the details of the impact of the 8.2 ka cooling event on the environment are still debated, partly because its effects are highly dependent on the specific location and the resilience of individual ecosystems[41–48]. Simulation models strongly support an overall cooling scenario combined with greater continentality for the North Atlantic region[2,6,45]. Reconstructions for northern Europe identify distinctive changes in climate and vegetation, consistent with slightly warmer summer temperatures combined with considerably cooler winter temperatures, such that the net annual effect is negative[41,43,44,49,50] (Fig. 4). Plant models have been employed to infer a mean annual temperature decrease of ca. 1–3 °C for northeast Europe specifically[45,51,52]. Researchers analysing the spatial structure of the impact of the 8.2 ka event in northern Europe through a synthesis of palynological studies concluded that cooling took place mostly during the winter and spring, and that ecosystems responded sensitively to the cooling during the onset of the growing season, as documented in a marked decrease in temperate deciduous broadleaf trees across the region[53].

An important point to highlight here is that the various model outcomes demonstrate that even small changes of only 1–2 °C can be critical for vegetation near climatic thresholds for plant communities and ecosystems in general[16,45,46]. As an apt point of comparison, the Little Ice Age of the fifteenth to nineteenth centuries had a substantial historically attested impact on human, floral and faunal populations, particularly in northern Europe (including the disappearance of roe deer from Finland[54]), yet its magnitude was far less, and more variable, than that of the 8.2 ka event, being on average cooler by only ca. 0.6 °C (ref. [55]).

There are two ways in which this regional climate scenario may have affected human communities, both seeing Lake Onega as the epicentre of a regional 'basin of attraction'[56] and involving both its terrestrial and aquatic resources. The palaeoenvironmental data document the spread of pine at the expense of broadleaf trees during the 8.2 ka event[47,53] (Fig. 4). This change in regional vegetation could have caused a concentration of big game such as elk closer to the microenvironment created by Lake Onega, where the onset of spring growth would have been earlier (Supplementary Section 1). In addition, lower precipitation and warm summer temperatures could have increased the risk of fires in the region, as supported empirically by charcoal peaks at ca. 8.2 ka in lake sediments from northern Europe[57]. This may have been another factor encouraging people and animals to stay closer to large lakes.

There may have also been an important impact on aquatic habitats. The dramatic decrease in winter temperatures and snow accumulation during the 8.2 ka event occurred during the regionally relatively dry Early Holocene interval characterized by low lake levels[58,59]. The extended duration and thickness of ice cover could have threatened fish populations in shallower lakes, as they would be more vulnerable to winter fish kills as the sub-ice oxygen levels became progressively depleted by microbial decomposition of organic matter[60–63]. This effect is very well known in shallow eutrophic lakes today, to the extent that oxygen pumps may be used in an attempt to maintain fish stocks[64]. It has been observed in recent decades in lakes in northern Europe[65–67]. A less obvious consequence of the aforementioned higher incidence of forest fires would have been an increased nutrient (P and NO_3^-) load into streams and lakes, affecting their trophic status and making them more susceptible to eutrophication and hence to winter fish kills (Supplementary Section 1).

When a lake undergoes a major overwinter fish kill event, it can take years to rebuild its fish populations to previous levels[68]; thus, the phenomenon need not happen every winter to result in severely depleted fish stocks in shallow lakes. Given that the largest and most predictable fisheries in the region's rivers and streams would relate to spawning runs from lakes, these fish populations would also be severely affected. Ice cover in Karelian lakes over the past century has lasted on average approximately four to five months of the year[69,70] and would have lasted longer during the 8.2 ka cooling event. Given their volume, depth and oligotrophic status, large lakes such as Ladoga and Onega would not experience winter fish kills regardless of the duration of ice cover. They would thus become correspondingly more important fisheries regionally. The third-largest lake in Karelia, Lake Syamozero, is over an order of magnitude less

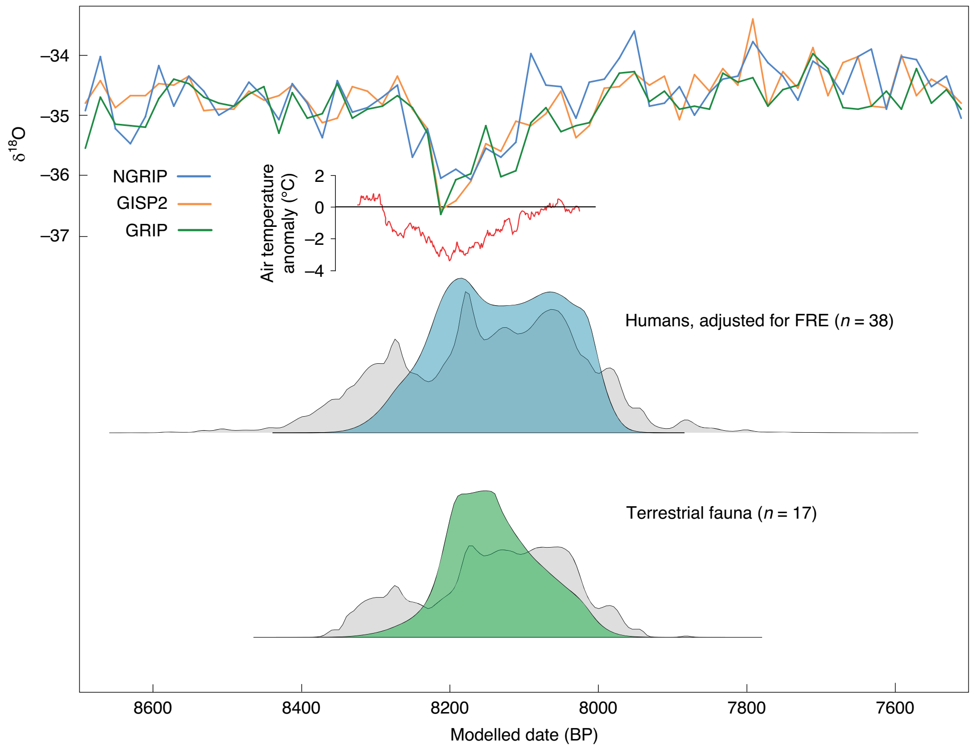

Fig. 3 | Human and faunal dates plotted against climate record. KDE plots within Bayesian models for ^{14}C dates on human and faunal remains from YOO, plotted against three Greenland δ^{18}O records[39] and modelled air temperature (10 yr averaging) anomaly over central Greenland during the 8.2 ka event[2]. Two human dates have been excluded as outliers identified by their low indices of agreement (Supplementary Section 8). The unmodelled summed probability distributions are shown in grey. The models were run in OxCal v.4.4.1 (ref. [35]) using IntCal20 (ref. [96]).

in volume than Onega. While it seems a plausible scenario, further research is required to confirm the presence and timing of periodic anoxic conditions in the region's small lakes.

But why should the proposed shifts in the spatial abundance of resources elicit a human response in the form of a formal burial ground? The region saw human occupation soon after deglaciation, and indeed a number of earlier small burial grounds are known, none of which approach the size of YOO[71] (Supplementary Section 2). Clearly, the site reflects a novel development in the broader region. Archaeologists have long used the proposition that formal cemeteries are one means of laying (or attempting to lay) exclusive claim to some important but limited resource[72]. This link has been repeatedly tested against both the ethnographic and archaeological records and found to be broadly valid[73–77]. However, it should be emphasized that this relationship is complex and may play out in various ways in individual cases[78]. It is not suggested that the use of cemeteries in this way is necessarily a conscious behaviour. Rather, it is an empirically observed phenomenon, underpinned by an appreciation of the emotional and socio-political importance of the ancestral dead in terms of creating and maintaining an attachment to place and to its associated resources. This attachment to place and the attendant shaping of social structures may be underpinned by origin myths and cosmologies[79–81]. In the absence of written documents of ownership, formal cemeteries become one way of negotiating social access through defining group membership. The need to emphasize this sense of belonging, always exclusive to some degree, emerges most strongly when there is a particularly important resource, the perceived or actual demand for which exceeds supply and thus becomes contested. This is one aspect of territoriality conceived as spatial behaviour employed strategically to control the movement of people and things[82].

In the context of Karelia, it is likely that the 8.2 ka downturn resulted in an increased concentration of game around the region's large lakes (Ladoga and Onega are the two largest lakes in Europe), which would have had their own microclimates[83]. Perhaps more importantly, the fish and aquatic bird resources of Lake Onega itself would have provided an important buffer against the periodic failure of terrestrial resources as fauna responded to a decrease in the length of the growing season and to increased continentality. Both processes would have led to the lake becoming a focal point for hunter-gatherers regionally. It has long been suggested that the cemetery at YOO holds the dead from a number of distinct communities[23,24]. There are indications of horizontal social distinctions marked by location within the cemetery and by types of effigy carvings, with elk effigies predominating in the north cluster and snake and human effigies in the south[24,84]. The presence of both flint and slate artefacts in the cemetery—unusual in the wider region—could also imply the coming together of bands from the east and west, where these raw materials dominate (Supplementary Section 2). This is consistent with recent genetic evidence indicating the presence of a surprisingly diverse range of mitochondrial haplogroups at YOO[85]. Hunter-gatherer groups are likely to have been seasonally mobile, aggregating at the lake in summer and dispersing in winter. It is highly likely that the burials were made exclusively in the summer half of the year, given that the ground would be frozen solid in winter.

Access to the lake's resources during the summer fishing season could thus have been a source of considerable social stress and tension between these groups, who would have maintained contacts and no doubt intermarried, but would not have co-habited for much of the year. The classic hunter-gatherer response to disputes arising in periodic large gatherings is to 'vote with one's feet' and simply move away[86]. This option, however, would have been curtailed in

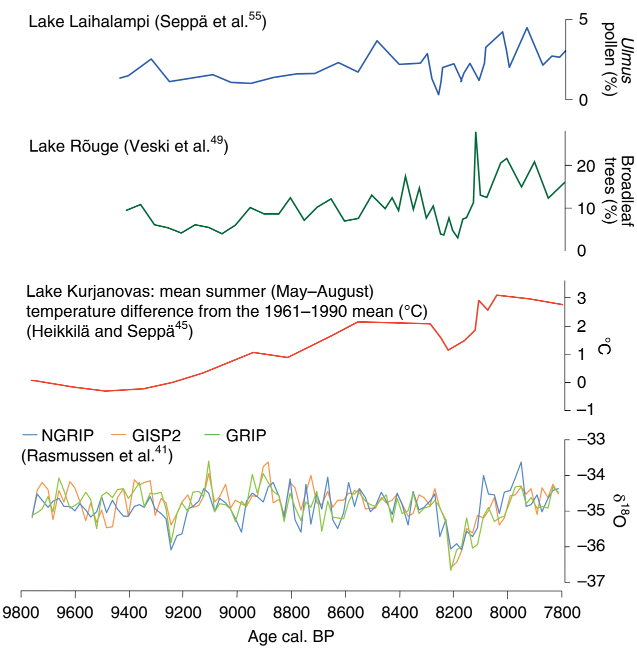

Fig. 4 | Palaeoenvironmental data. Selected environmental proxies[43,47,53] in northeast Europe relating to the 8.2 ka cooling event against the Greenland $\delta^{18}O$ ice core records[39].

proportion to the importance and seasonality of the fishery, not just in terms of immediate consumption but also—through drying, smoking, freezing and possibly fermenting—in providing a storable resource for overwintering. This is attested for the northern forest steppe specifically[87] as well as more generally[19,88,89]. Burial in the cemetery of a selection of those who died at this time (or in previous years, the memory of which would be retained and strategically recalled) could have helped diffuse these tensions through reaffirming joint use-rights, and may have also been used to establish seniority in the allocation and management of the fishery and other key resources. This could account for some of the burials with particularly abundant grave inclusions, perhaps signalling these people's importance as past decision makers and helping confirm this role for their successors—whether defined in terms of kinship or through some other means—in the next generation. An important aspect of our account is the rapidity with which climate changed at ca. 8.2 ka BP, such that gradual adjustments to livelihood strategies were a less viable option.

It remains unknown why the cemetery apparently went out of use, or at least saw much reduced use, after ca. 8.0 ka BP. It may be that over some two centuries of burial at YOO, representing some ten human generations, the use-rights of various bands across the region became sufficiently firmly established in tradition and in social memory to obviate the need for the physical presencing of the ancestral dead. But perhaps more importantly, the rapid return to warmer winter temperatures after 8.0 ka may have reduced the value of the Lake Onega fishery, as the region's surrounding shallower lake systems recovered. The result may have been a return to a pre-8.2 ka pattern of more scattered bands of hunter-gatherers. The mortuary evidence for this period is limited, as bone preservation is generally very poor—YOO is situated on a rare limestone outcrop, which preserves bone well—but where burials can be inferred from grave cuts and the presence of ochre, they form far smaller cemeteries. Chernaya Guba VI is a potential example, located on the northeastern shore of Lake Onega, with eight pits of an appropriate size for graves but with no bone preservation and no stone artefacts, provisionally dated to the sixth millennium BP[71] (Supplementary Section 2). This is consistent with the account offered here, suggesting a reduction in the scale and/or importance of the dead or ancestors in the negotiation of relationships among the living. Whatever 'complexity' we see at YOO was thus situational and reversible; it did not form part of any evolutionary trend towards increasing social differentiation (as one aspect of complexity)[90].

Our study reinforces YOO's exceptional position and the need for an explanation that integrates social and, in the light of the remarkable coincidence with the 8.2 ka event, environmental considerations[91]. It also highlights the situational and mutable nature of increased social complexity. The support for a comparatively 'short chronology' of one to three centuries for the cemetery's main period of use confirms its potential to address broadly synchronic social differentiation and inequality (recently identified as one of archaeology's "grand challenges"[92]). With the application of additional proxies (for example, other isotope systems and single amino acid analysis) and further radiocarbon dating, it may be possible to further improve the site's chronology; nevertheless, its association with the 8.2 ka downturn seems robust. While further research is required to confirm and refine the details of the explanation proposed here, YOO currently presents the most striking case of a socio-cultural response to this climatic event by hunter-gatherers in northern Eurasia. It is not a simple case of abandonment but rather one of resilience mediated through a complex social response involving a renegotiation of rights of access to crucial resources through the medium of the dead.

Methods

Radiocarbon dating. Samples were prepared for radiocarbon dating following the standard protocols in place at the Oxford Radiocarbon Accelerator Unit, School of Archaeology, University of Oxford. This involves an acid–base–acid pre-treatment and a 30 kD ultrafiltration step[93,94]. When duplicate determinations were made as part of the system of random quality control checks in the laboratory, the results were combined using the R_combine function in OxCal[95]. The dates were calibrated and modelled in OxCal v.4.4 (ref. [35]) using the new IntCal20 atmospheric curve for the northern hemisphere[96].

Modelling of radiocarbon dates. Bayesian modelling provides a statistical approach to incorporating additional information into the interpretation of a series of radiocarbon dates[34,97]. In the case of YOO, the dates were analysed using a single-phase model with no inherent internal ordering—that is, the phase constitutes an uninformative prior. Models were run with both uniform and trapezium boundaries[98]. Outliers were identified in OxCal[35] using the index of agreement; those falling well below the accepted threshold of 60% were removed and the model rerun. Following convention, modelled dates are italicized and referred to as 'BP' rather than 'cal BP' since the date ranges are not solely based on the calibration curve (though they nevertheless refer to calibrated years). All date ranges are presented at 95.4% confidence and rounded to the nearest half-decade, since the modelled results vary from run to run. Since the resulting probability distributions may be highly asymmetrical, the median is used when summarizing the central tendencies of the modelled dates.

A series of radiocarbon dates is sometimes combined using a summed probability distribution. However, this can be strongly influenced by the shape of the calibration curve. An alternative approach is to apply KDE, either on its own (KDE_Model) or as a plot (KDE_Plot) in combination with a Bayesian phase model[99]. Here we take the latter approach as a robust and effective means of visualizing the overall shape of the distribution of radiocarbon dates (Fig. 3).

Stable isotope analysis. The same collagen prepared for the radiocarbon dating process was used for stable isotope analysis. Samples weighing approximately 1 mg were placed into tin capsules along with alanine (−27.11‰ and −1.56‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively) and in-house cow (−24.30‰ and 7.86‰) and seal (−12.54‰ and 16.14‰) bone collagen standards. The samples were analysed in duplicate on a Sercon 20/22 isotope ratio mass spectrometer in the stable isotope laboratory of the School of Archaeology, University of Oxford. Half the alanine standards were used to correct for machine drift, with the remainder used together with the cow and seal bone collagen standards in a three-point regression equation to calibrate the drift-corrected target samples[100]. The reported values are the mean of the two individually calibrated measurements, relative to the international standards VPDB and AIR for $\delta^{13}C$ and $\delta^{15}N$, respectively. Instrument precision based on repeated measurements of the standards over multiple runs is on the order of ±0.2‰ for both isotopes. In three cases (Graves 56, 59 and 81), no collagen remained after the dating process, so separate stable isotope measurements could not be obtained.

The results were assessed for normality using the Shapiro–Wilk test and were then tested with either parametric (for example, Student's *t*-test) or non-parametric (for example, Mann–Whitney *U*-test) methods as appropriate. In all cases, two-sided tests were employed, with $\alpha = 0.05$.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

All of the data used in this paper are included in the Supplementary Tables. The OxCal codes used for the Bayesian modelling are provided in the Supplementary Information.

Received: 11 September 2020; Accepted: 11 November 2021; Published online: 27 January 2022

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Acknowledgements
The radiocarbon dates reported here were funded by the Natural Environment Research Council's (UK) NRCF programme (grant no. NF/2016/1/5 to R.J.S.) and by the Baikal-Hokkaido Archaeology Project and the Baikal Archaeology Project, funded by the Social Science and Humanities Research Council of Canada (grant nos 412-2011-1001 and 895-2018-1004 to A.W.). We thank the Peter the Great Museum of Anthropology and Ethnography/Kunstkamera, St Petersburg, for permitting sampling of the YOO materials, and the crew of the Посейдон (Poseidon) for a most interesting journey to YOO and for supplying modern fish from Lake Onega. We also thank C. Leipe for drafting the maps used in Fig. 1 and Ilkka Matero for providing data used in Fig. 3.

Author contributions
R.J.S., C.B.R. and A.W. designed the study. T.H. oversaw the radiocarbon measurements. R.J.S. and C.B.R. performed the Bayesian modelling. R.J.S. analysed the stable isotope results and calculated the reservoir effects. D.G., K.M. and J.O. provided

the wider archaeological context. P.E.T. led the palaeoenvironmental overview. D.G., V.K., K.M. and V.M. contributed resources. R.J.S. led the writing of the paper, to which all authors contributed. All authors discussed the results and commented on the manuscript.

Competing interests

The authors declare no competing interests.

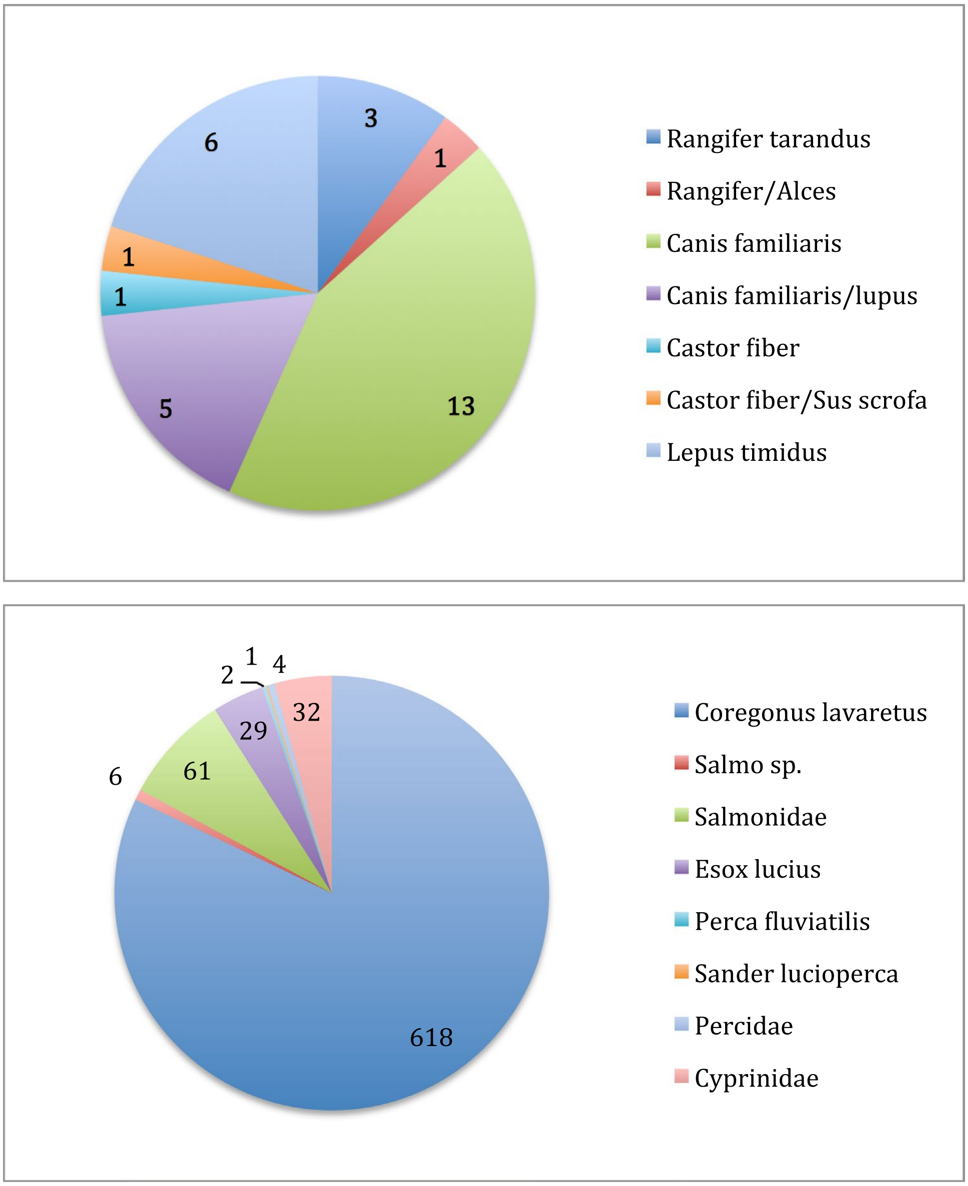
Additional information

Extended data is available for this paper at https://doi.org/10.1038/s41559-021-01628-4.

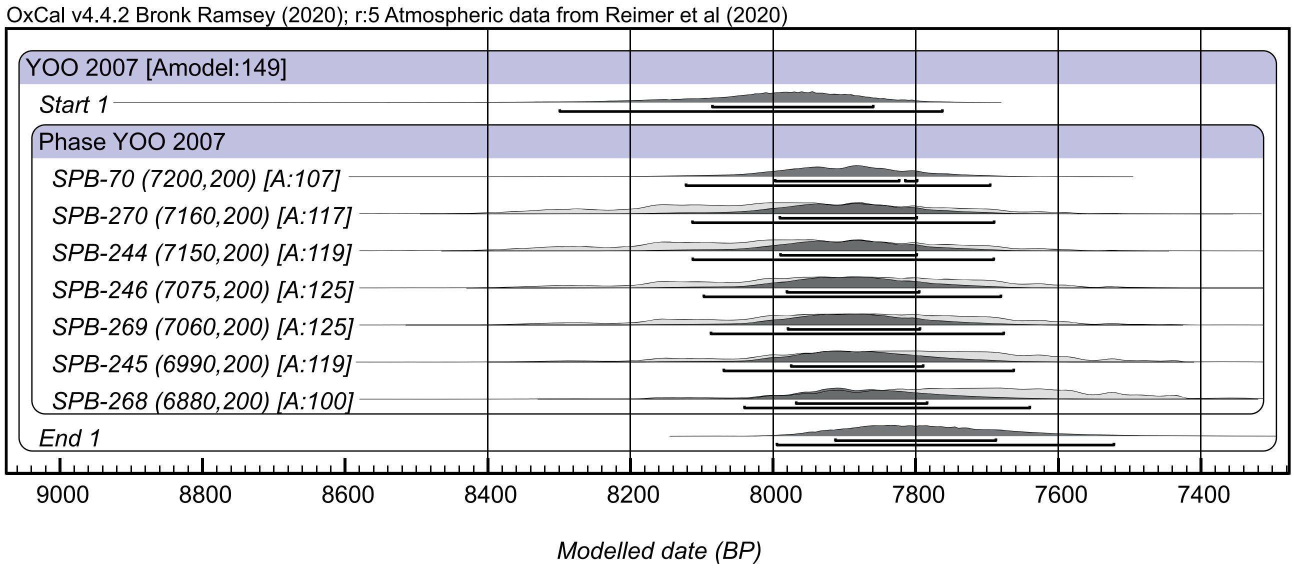
Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41559-021-01628-4.

Correspondence and requests for materials should be addressed to Rick J. Schulting.

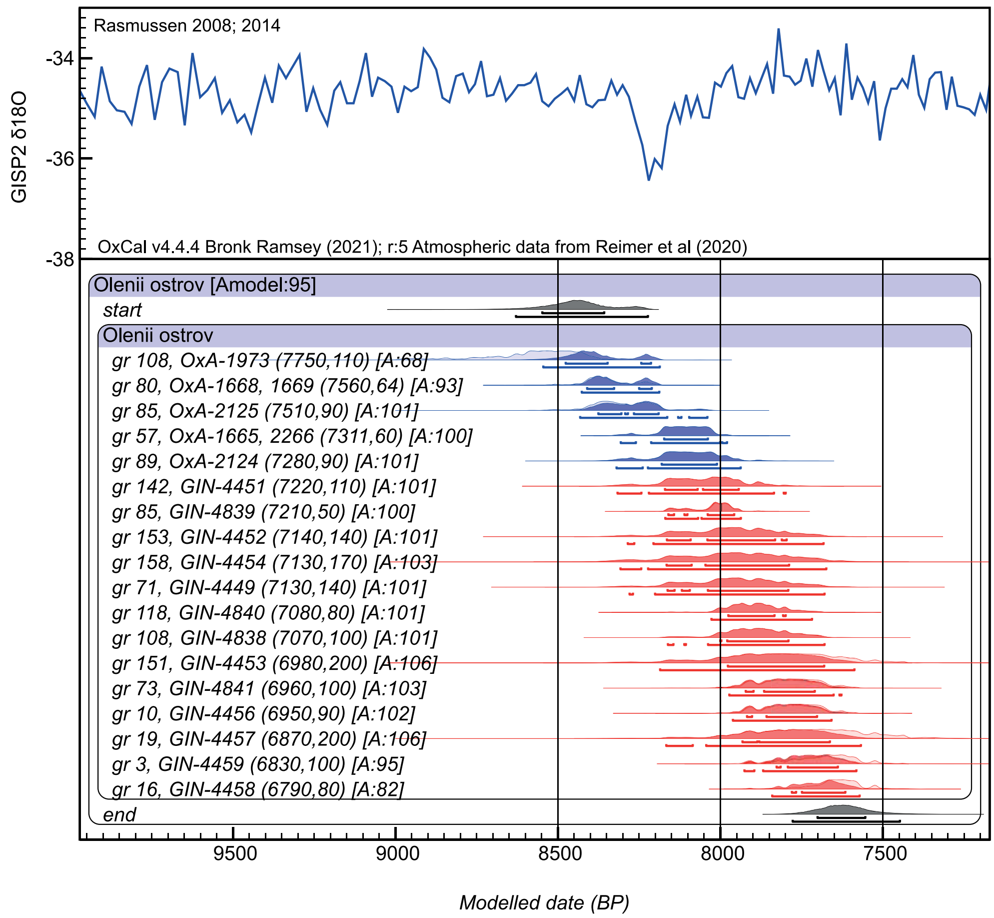
Peer review information *Nature Ecology & Evolution* thanks Henny Piezonka, Seren Griffiths and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.



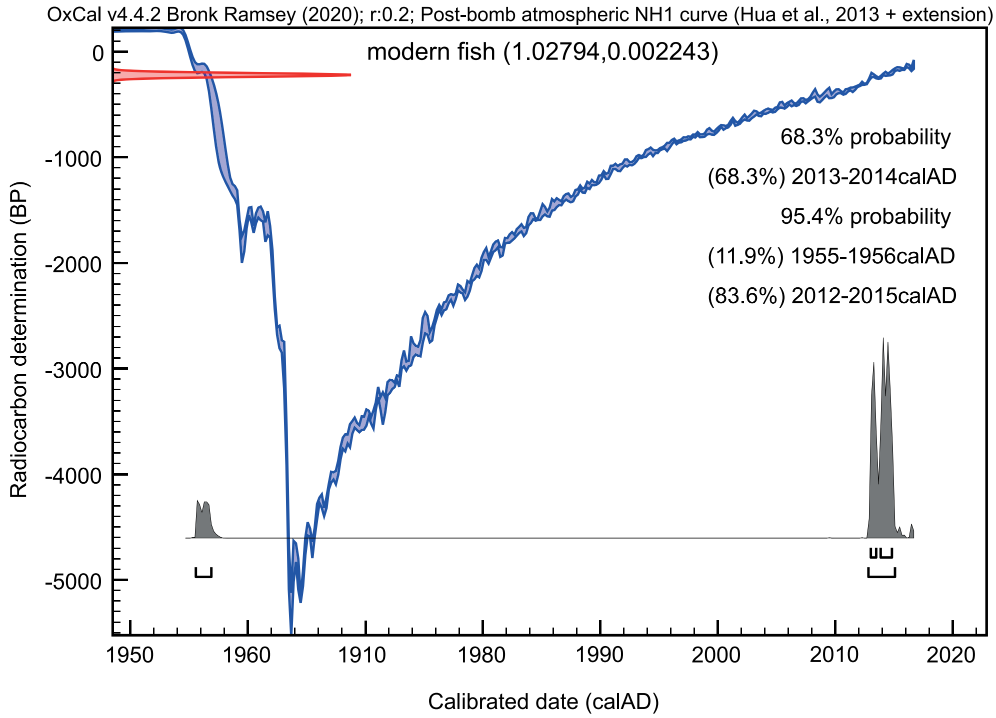
Extended Data Fig. 1 | YOO faunal remains. Identified mammalian remains from YOO 2007 (total Mammalia n = 1190)); 1b. Identified fish remains from YOO 2007 (total Teleostei n = 753) (Murashkin et al.[104] tab. 2).



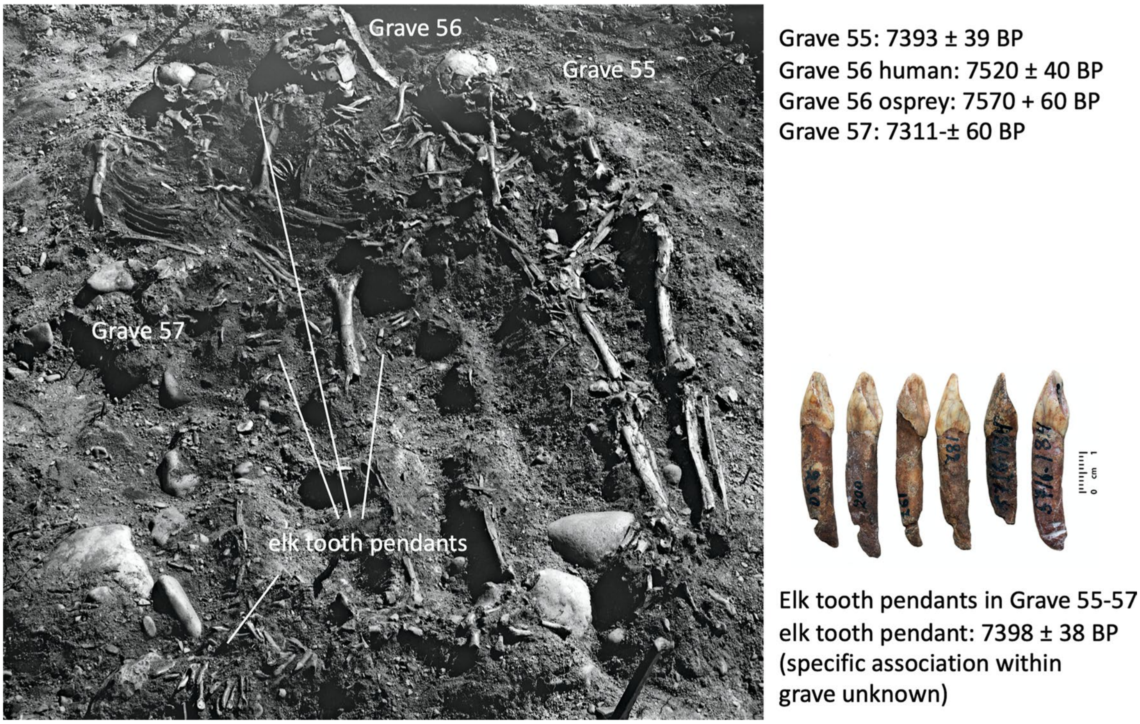
Extended Data Fig. 2 | Modelled non-cemetery radiocarbon dates from YOO. Bayesian model of radiocarbon dated calcined bone from 2007 excavations at Yuzhniy Oleniy Ostrov (data from Murashkin et al.[104], tab. 3).



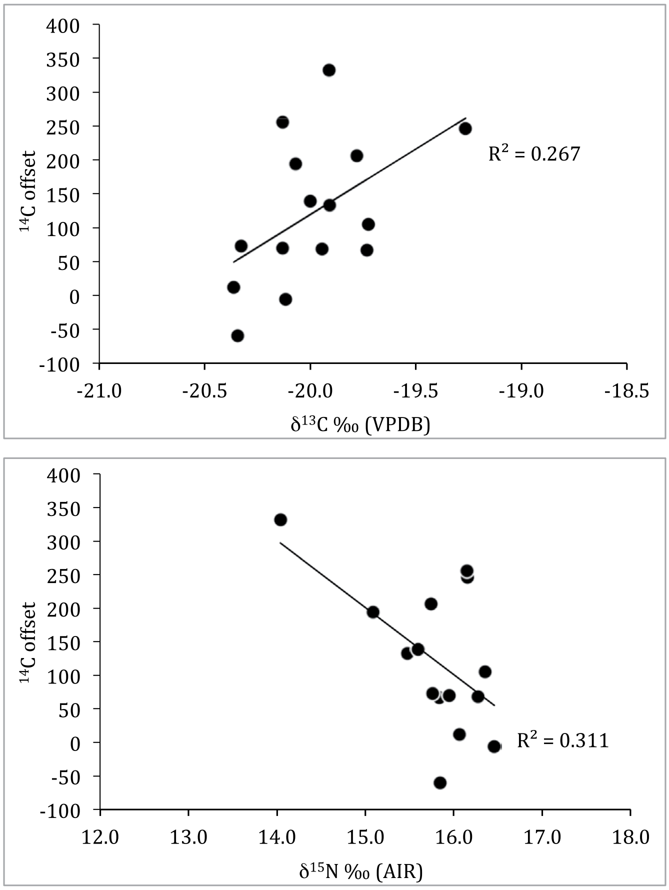
Extended Data Fig. 3 | Bayesian model of previously published human bone dates from YOO. Bayesian model of previously published radiocarbon dates on human remains from Yuzhniy Oleniy Ostrov[27,28], unadjusted for freshwater reservoir effects, plotted alongside the NGRIP $\delta^{18}O$ record[39].



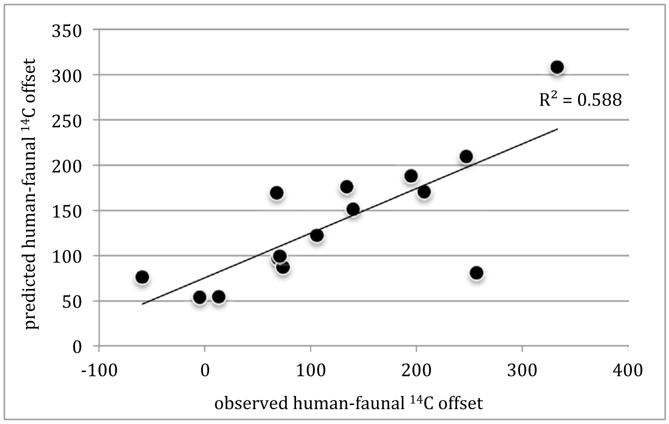
Extended Data Fig. 4 | Radiocarbon dates for modern fish from Lake Omega. Calibration of the average age for three modern fish live-collected at YOO in 2019. The calibration makes use of an unpublished extended NH1 post-bomb dataset (Hua pers. comm.).



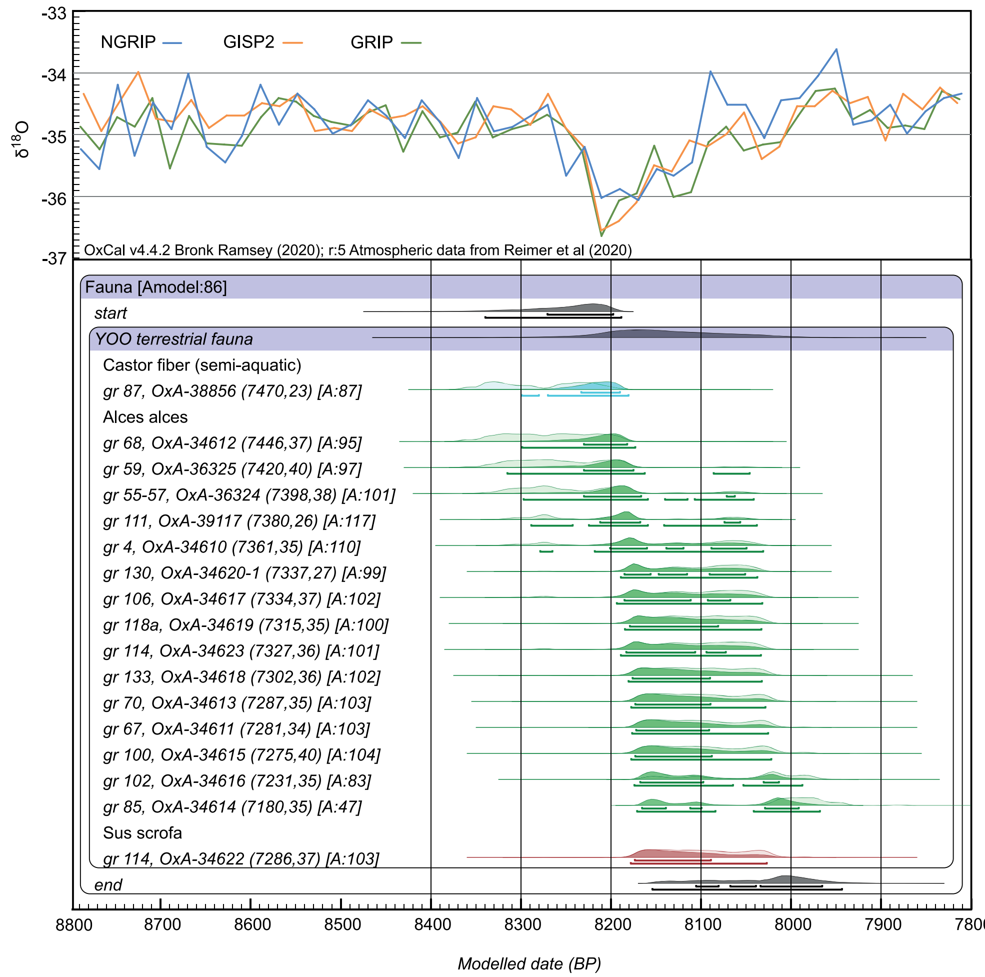
Extended Data Fig. 5 | Photograph of multiple Graves 55–57. Multiple Grave 55 (right), 56 (middle) and 57 (left). Glass negative MAE I 1886-46: From the collection of the Peter the Great Museum of Anthropology and Ethnography (Kunstkamera), Russian Academy of Sciences © MAE RAS 2021. Photo of elk teeth by K. Mannermaa.



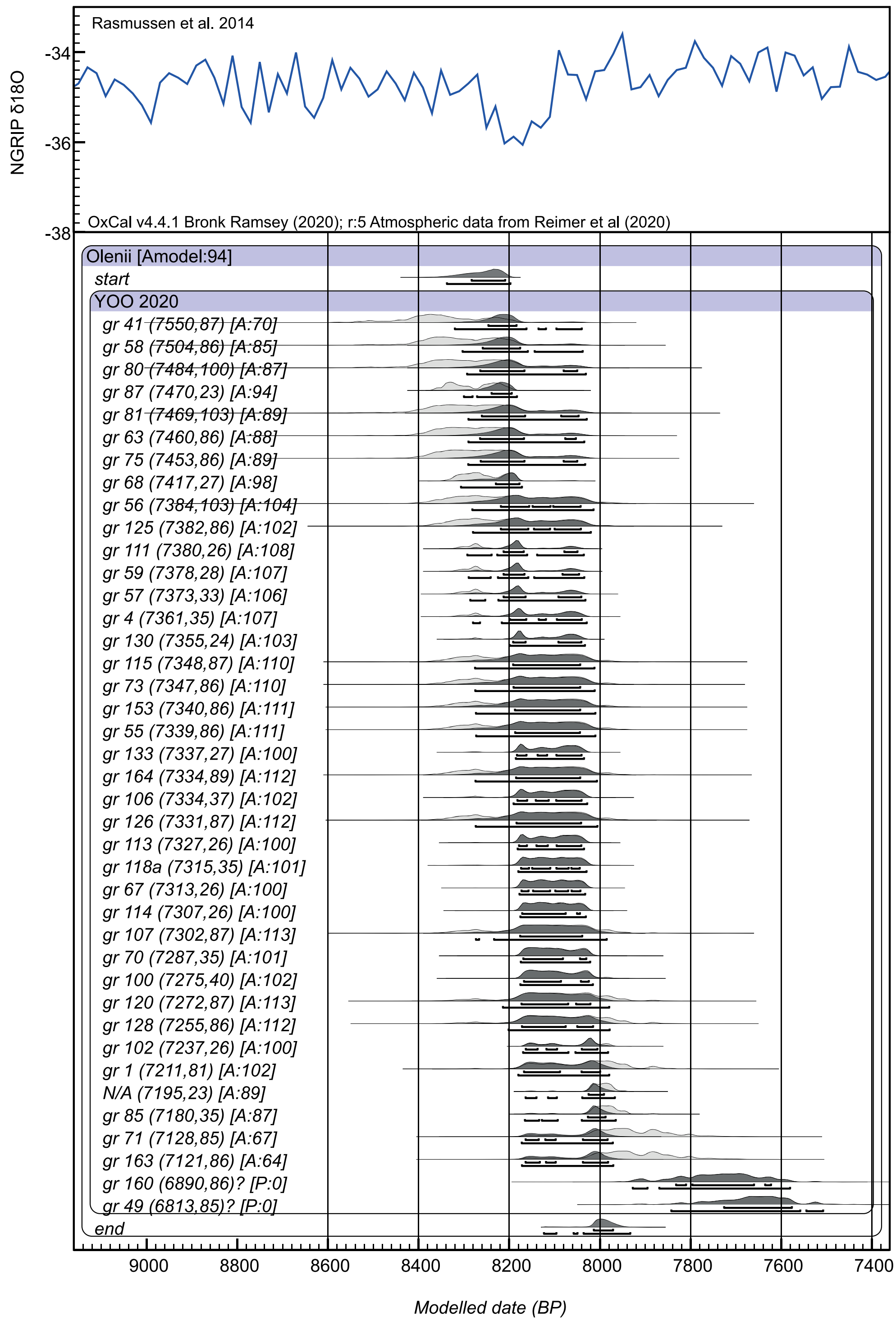
Extended Data Fig. 6 | Plot of ^{14}C offsets versus human stable carbon and nitrogen isotope values. 6a. The relationship between the ^{14}C offset in human and faunal determinations and human δ^{13}C values ($r^2 = 0.267$, $p = 0.049$, n = 15); 6b. The relationship between the ^{14}C offset in human and faunal determinations and human δ^{15}N values ($r^2 = 0.311$, $p = 0.031$, n = 15) (see Supplementary Table 4).



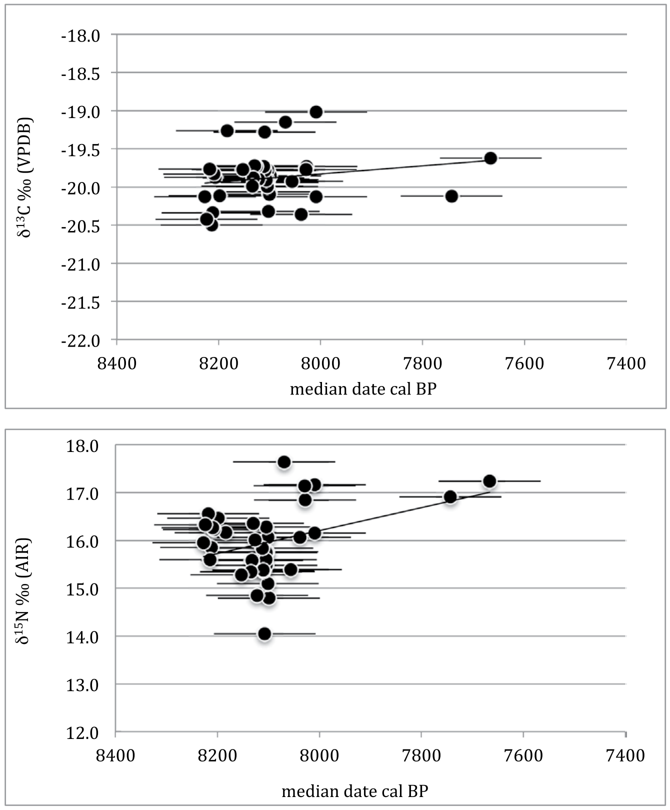
Extended Data Fig. 7 | Plot of predicted versus observed human-faunal ^{14}C offsets. A comparison of the predicted and observed human-faunal ^{14}C offsets (r^2 = 0.588, p = 0.001, n = 15) (see Supplementary Table 7).



Extended Data Fig. 8 | Bayesian model of YOO faunal dates. Bayesian model of the radiocarbon-dated fauna from Yuzhniy Oleniy Ostrov plotted against the Greenland ice core $\delta^{18}O$ records[39].



Extended Data Fig. 9 | Bayesian model of YOO human dates. Bayesian model of the FRE-corrected radiocarbon-dated humans from Yuzhniy Oleniy Ostrov plotted against the GISP2 ice core temperature record[39]. Graves 160 and 49 are shown but excluded from the model as outliers.



Extended Data Fig. 10 | Median calibrated date versus human stable carbon and nitrogen isotope values. 10a. Median calibrated date against δ^{13}C values (Spearman's rho = −0.120, $p = 0.353$, n = 36); 10b. Median calibrated date against δ^{15}N values (Spearman's rho = −0.188 $p = 0.272$, n = 36). Error bars approximate a 95% confidence interval.

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March 2021

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Study description	Radiocarbon dating and stable (carbon and nitrogen) isotopic analyses of human and animal remains from the middle Holocene cemetery of Yuzhniy Olenii Ostrov, Karelia, Russian Federation.
Research sample	Prehistoric (ca. 8.2yr BP) human and animal (European elk, boar) skeletal remains from the cemetery of Yuzhniy Olenii Ostrov, Karelia, Russian Federation.
Sampling strategy	No formal random sampling strategy was applied, but there is nevertheless a strong element of randomness as one of the main criterion was the presence of a broken animal tooth pendant in the grave, allowing the paired dating of human and faunal remains that underpins the paper. There is not reason to suspect that whether or not a broken pendant was present would bias the results in terms of the aims of the paper. Additionally, a number of individuals lacking pendants altogether were selected for dating in order to check for any chronological trends in the provisioning of grave goods.
Data collection	Samples were provided by colleagues (V.M., V.K., D.G.) at the Peter the Great Museum of Anthropology and Ethnography/ Kunstkamera. Several faunal samples were collected from the same Museum by K.M.
Timing and spatial scale	The first dates for the project were obtained in 2016 with a small number of results obtained in 2019 when additional samples became available.
Data exclusions	No new data meeting all quality control criteria were excluded from the analyses. Some older data were excluded for reasons given in the text.
Reproducibility	A number of random duplicate dates were run as per standard procedure at the Oxford Radiocarbon Accelerator Unit. Stable carbon and nitrogen isotopes were analysed separately (i.e., separate from the isotopic measurements produced as part of the radiocarbon dating process) in duplicate.
Randomization	Not relevant. No samples were assigned to groups.
Blinding	Lab codes were assigned to the samples which were then analysed with no link to their identity.

Did the study involve field work? ☐ Yes ☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study	
☒	☐	Antibodies
☒	☐	Eukaryotic cell lines
☐	☒	Palaeontology and archaeology
☒	☐	Animals and other organisms
☒	☐	Human research participants
☒	☐	Clinical data
☒	☐	Dual use research of concern

Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging

Palaeontology and Archaeology

Specimen provenance	Permission for the study was given by the Director of the Peter the Great Museum of Anthropology and Ethnography/Kunstkamera, St. Petersburg.
Specimen deposition	Specimens used in the study are held in the Peter the Great Museum of Anthropology and Ethnography/

Specimen deposition	Kunstkamera, St. Petersburg. They are not, however, freely available to other researchers and permission must be sought through the Museum.
Dating methods	Information on dating methods is provided in the paper.

☒ Tick this box to confirm that the raw and calibrated dates are available in the paper or in Supplementary Information.

Ethics oversight	No ethical approval was required for this study on prehistoric human remains, beyond the normal care and respect given to any study involving human skeletal remains.

Note that full information on the approval of the study protocol must also be provided in the manuscript.