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

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Abstract

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 of 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 upon 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 only appears to have lasted for the duration of the climate downturn. Our results have implications for understanding the context for the emergence—and dissolution—of socioeconomic inequality and territoriality under conditions of socio-ecological stress.

Fig. 1a) NE Baltic region; b) location of Yuzhniy Oleniy Ostrov; c) site plan, showing locations of grave analysed in this study (after O'Shea and Zvelebil[1], fig. 2).

Little is known concerning human response 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 bringing warm water northwards from the Gulf of Mexico[2-7]. Early farmers may have been adversely impacted in southeastern Europe[8-12], 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[13-19], not least because of the range of options facilitated by their generally low population densities and comparatively high residential mobility[20]. However, it is likely that in some regions events of sufficient magnitude would reach a tipping point leading to a significant response by foragers[21-23]. The challenge has been to identify such evidence, 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 (Figure 1; Supplementary Information 1, 2). Excavated by Russian archaeologists in 1936–38[24], 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 originally there may have been over 400—and to variation in the accompanying grave offerings, ranging from graves lacking these entirely, to those with abundant and elaborate offerings. This has led to debate concerning whether or not 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[1,25,26]. 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 confirmed that YOO belongs to the earlier part of the Mesolithic (ca. 11,500 – 5500 cal BP in northern Europe), but were limited in number and precision[27-29] (SI.3; Supplementary Table 1). Taken at face value, they indicate use of the cemetery over some 800 years, spanning the 8.2 ka event without interruption (Extended Data Figure 3), and suggesting that hunter-gatherers here were highly resilient, and were not significantly affected in either their use of this location or in their mortuary practices. But, as we will show, there are problems with this characterisation.

A robust chronology is essential both for framing discussions of the cemetery's mortuary rites and for inferring 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 on 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 (Figure 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 these and the new determinations when both are available for the same individual (Supplementary Table 1). The dates are modelled in OxCal 4.4[34,35]. The sampled materials are held in the Peter the Great Museum of Anthropology and Ethnography/Kunstkamera, Russian Academy of Sciences, Saint-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 ± 83 ^{14}C yr), while the other half were unaffected ($\bar{X}$ = 0 ± 69 ^{14}C yr), implying the consumption of fish from different sources (other aquatic species, e.g., waterfowl, may also have been consumed but likely 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 ($r^2 = 0.267$, $p = 0.049$, df = 14) and δ^{15}N ($r^2 = 0.311$, $p = 0.031$, df = 14) values in separate linear regression models (Extended Data Figure 6). When combined the two stable isotopes together account for just over half of the variation in ^{14}C offsets ($r^2 = 0.525$ $p = 0.005$, df = 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 to terrestrial fauna (Figure 2; SI.6), they must have derived from either 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 on average higher ^{14}C offsets.

Fig. 2. Plot of $\delta^{13}C$ and $\delta^{15}N$ values for prehistoric humans and terrestrial fauna (this study) and avifauna[37] from YOO and modern freshwater seals and fish from Lake Saimaa[38], adjusted to make them comparable (see SI.6; Supplementary Table 5). Error bars are ± 1 SD.

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) (Figure 3; Extended Data Figure 8). To make use of the full dataset, radiocarbon determinations made on human bone lacking terrestrial pairings are corrected for the freshwater reservoir effect using the stable isotope results associated with the paired dates (SI.6). The estimated start and end dates for burials at YOO are modelled as *8340–8200 BP* and *8125–7935 BP*, respectively (SI.8, Extended Data Figure 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) plot within a Bayesian single-phase model (Figure 3; see SI.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 most significant abrupt climatic oscillation of the past 10,000 years[39-41]. This strongly suggests a causal relationship.

Fig. 3. Kernel Density Estimation plots within Bayesian models for ^{14}C dates on human and faunal remains from Yuzhniy Oleniy Ostrov, plotted against three Greenland $\delta^{18}O$ records[41] and modelled air temperature (10 yr averaging) anomaly over central Greenland during the 8.2 ka event[3]. Two human dates have been excluded as outliers identified by their low indices of agreement (see SI.8). Unmodelled summed probability distributions are shown in grey.

Discussion

The Greenland ice core $\delta^{18}O$ records document a significant 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[2,4,40,42]. While in the North Atlantic region the temperature decrease is reduced to 1–3 °C, this remains the largest climate downturn in the Holocene of the northern hemisphere. Yet 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[43-50]. Simulation models strongly support an overall cooling scenario combined with greater continentality for the North Atlantic region[3,7,47]. Reconstructions for northern Europe identify distinctive changes in climate and vegetation, consistent with slightly warmer summer temperatures combined with significantly cooler winter temperatures, such that the net annual effect is negative[43,45,46,51,52] (Figure 4). Plant models have been employed to infer a mean annual temperature decrease of ca. 1–3 °C for northeast Europe specifically[47,53,54]. Analyzing spatial structure of the impact of the 8.2 ka event in northern Europe through a synthesis of palynological studies, it was 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[55].

Fig. 4. Selected environmental proxies[45,49,55] in NE Europe relating to the 8.2 ka cooling event against the Greenland δ^{18}O ice core records[41].

An important point to highlight here is that the various model outcomes demonstrate that even small changes of only 1–2 °C can be highly significant for vegetation near climatic thresholds for plant communities and ecosystems in general[17,47,48]. As an apt point of comparison, the Little Ice Age of the fifteenth to nineteenth centuries had a significant historically attested impact on human, floral and faunal populations, particularly in northern Europe, including the disappearance of roe deer from Finland[56], 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[57].

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’[58], and involving both its terrestrial and aquatic resources. The palaeoenvironmental data document the spread of pine at the expense of broadleaved trees during the 8.2 ka event[49,55] (Figure 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 (SI.1). In addition, lower precipitation and warm summer temperatures would have potentially 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[59]. 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[60,61]. 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[62-65]. 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[66]. It has been observed in recent decades in lakes in northern Europe[67-69]. 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 (SI.1).

When a lake undergoes a significant overwinter fish kill event, it can take years to rebuild its fish populations to previous levels[70]; 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 last century lasts on average approximately four to five months of the year[71,72], and would have been longer during the 8.2 ka cooling event. Given their volume, depth and oligotrophic status, large lakes like 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 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[73] (SI.2). Clearly, the site reflects a novel development in the broader region. Archaeologists have long made use of the proposition that formal cemeteries are one means of laying (or attempting to do so) exclusive claim to some important but limited resource[74]. This link has been repeatedly tested against both the ethnographic and archaeological records and found to be broadly valid[75-79]. However, it should be emphasised that this relationship is complex, and may play out in various ways in individual cases[80]. 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 sociopolitical 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 of may be underpinned by origin myths and cosmologies[81-83]. In the absence of written documents of ownership, formal cemeteries become one way of negotiating social access through defining group membership. The need to emphasise 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[84].

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 (Lakes Ladoga and Onega are the two largest lakes in Europe), which would have had their own microclimates[85]. 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[1,24]. There are indications of horizontal social distinctions marked by location within the cemetery and by types of effigy carvings: elk effigies predominating in the north cluster and snake and human effigies in the south[1,86]. 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 (see SI.2). This is consistent with recent genetic evidence indicating the presence of a surprisingly diverse range of mitochondrial haplogroups at YOO[87]. Hunter-gatherer groups are likely to have been seasonally mobile, aggregating at the lake in summer and dispersing in winter—that the burials were made exclusively in the summer half of the year is highly likely given that the ground would be frozen solid in winter.

Thus, access to the lake's resources during the summer fishing season potentially would 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[88]. This option, however, would have been curtailed in 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 over-wintering. This is attested both for the northern forest steppe specifically[89], as well as more generally[20,90,91]. 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 their 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 to explain 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[73] (see SI.2). This is consistent with the account offered here, suggesting a reduction in the scale and/or importance of the dead/ancestors in the negotiation of relationships amongst the living. Thus, whatever 'complexity' we see at YOO was situational and reversible; it did not form part of any evolutionary trend towards increasing social differentiation (as one aspect of complexity)[92].

Our study reinforces Yuzhniy Oleniy Ostrov'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[93]. 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'[94]). With the application of additional proxies (e.g., other isotope systems, single amino acids) and 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, Yuzhniy Oleniy Ostrov currently presents the most striking case of a socio-cultural response to this climatic event by hunter-gatherers in northern Eurasia. Yet 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[95,96]. 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[97]. Dates are calibrated and modelled in OxCal 4.4[35] using the new IntCal20 atmospheric curve for the northern hemisphere[98].

Modelling of radiocarbon dates

Bayesian modelling provides a statistical approach to incorporating additional information into the interpretation of a series of radiocarbon dates[34,99]. In the case of YOO, the dates were analysed using a single-phase model with no inherent internal ordering, i.e., the phase constitutes an 'uninformative' prior. Models were run with both uniform and trapezium boundaries[100]. Outliers are identified in OxCal[35] using the index of agreement; those falling well below the accepted threshold of 60% are removed and the model re-run. Following convention, modelled dates are italicised and referred to as 'BP' rather than 'cal BP' since the date ranges are not solely based on the calibration curve (though they nevertheless still refer to calibrated years). All dates ranges are presented at 95.4% confidence and rounded to nearest half-decade, since modelled results vary from run to run. Since the resulting probability distributions may be highly asymmetrical, the median is used when summarising the central tendencies of 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 kernel density estimation (KDE), either on its own (KDE_Model) or as a plot (KDE_Plot) in combination with a Bayesian phase model[101]. Here, we take the latter approach as a robust and effective means of visualising the overall shape of the distribution of radiocarbon dates (Figure 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 δ^{13}C and δ^{15}N, respectively) and in-house cow (−

24.30‰ and 7.86‰) and seal (−12.54‰ and 16.14‰) bone collagen standards. Samples were analysed in duplicate on a Sercon 20/22 isotope ratio mass spectrometer (IRMS) 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 bone collagen standards in a three-point regression equation to calibrate the drift-corrected target samples[102]. Reported values are the mean of the two individually calibrated measurements, relative to the international standards VPDB and AIR for δ^{13}C and δ^{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 and so separate stable isotope measurements could not be obtained.

Results were assessed for normality using the Shapiro-Wilk test, and then tested with either parametric (e.g., Student's *t*-test) or non-parametric (e.g., Mann-Whitney *U*-test) as appropriate. In all cases two-sided tests were employed, with $\alpha = 0.5$.

Data availability

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

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Author Contributions

R.J.S., C.B.R. and A.W. designed the study. T.H. oversaw radiocarbon measurements. R.J.S. and C.B.R. performed Bayesian modelling. R.J.S. analysed the stable isotope results and calculated the reservoir effects. P.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 statement

The authors have no competing interests.

Figure Captions

Fig. 1a) NE Baltic region; b) location of Yuzhniy Oleniy Ostrov; c) site plan, showing locations of grave analysed in this study (after O'Shea and Zvelebil[1], fig. 2).

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