Freshwater reservoir effect and the radiocarbon chronology of the cemetery in Ząbie, Poland

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Abstract

In the 3rd millennium BC an island on the Łańskie Lake in north-eastern Poland was seasonally settled by a group of people practicing a syncretic burial ritual, exhibiting indigenous and foreign patterns. They left behind a small cemetery consisting of at least six graves. ¹⁴C dates made for samples of human bones until 2009 did not coincide with the expected age of the graves. Under a new pilot program in 2010-2013, a series of radiocarbon measurements was made for the human bones and an artefact of red deer antler, along with analyses of the stable isotopes ratios of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) in the collagen. The results indicate a significant proportion of freshwater food in the diet, which caused the radiocarbon dates to be too old due to the freshwater reservoir effect (FRE). Based on the dating of the antler, unaffected by FRE, and comparative analysis, the reservoir offset for one of the graves was estimated to 740 radiocarbon years. The results, although limited by a low number of investigated humans and animals, indicate indirectly a specialization in the exploitation of local water resources. Such an economic strategy seems to be characteristic for the societies inhabiting the coasts of the Baltic Sea and littoral zones of large lakes in the Final Neolithic and at the beginning of the Early Bronze Age.

Key words: radiocarbon dating, isotopes, freshwater reservoir effect, diet reconstruction, Final Neolithic, burial ritual, subsistence strategy

Highlights:

Final Neolithic/Early Bronze Age society follows a Sub-Neolithic subsistence strategy

Consumption of freshwater foods causes at least 740 years of radiocarbon age offset

A local burial ritual of syncretic character developed

1. Introduction

In the last decades isotopic methods, aimed at human diet reconstruction, have become increasingly common leading to a re-evaluation of the economic foundations of a number of past societies (e.g. [Lanting and van der Plicht, 1998](#); [Cook et al., 2001](#); [Lillie et al., 2009](#)). In the case of regions located to the south and east of the Baltic Sea, it was revealed that the dietary habits typical for Mesolithic people were also practiced locally in the Early and Middle Neolithic. Moreover, with the identification of freshwater food in human diets,

verification of radiocarbon chronologies became essential because human remains may have provided too-old dates due to the freshwater reservoir effect (FRE).

The reservoir effect in water occurs when the balance between dissolved ^{14}C and atmospheric $^{14}\text{CO}_2$ is disturbed (e.g. [Broecker and Walton, 1959](#); [Olsson, 1983](#)). FRE in lake waters is caused mainly by inflow of CO_2 coming from organic deposits and, to a lesser extent, inflow of groundwater leaching through deposits containing ‘old carbon’ with decreased or no radioactivity. If a given material contains carbon coming from other sources than atmospheric CO_2 then its age becomes older according to radiocarbon measurement ([Lanting and van der Plicht, 1998](#); [Keaveney and Reimer, 2012](#); [Philippsen, 2013](#)). Hard-water lakes contain dissolved ancient carbonates, usually very old compared with the half-life of ^{14}C , causing high apparent (reservoir) ages ([Deevey et al., 1954](#); [Olsson, 2009](#)).

^{14}C with decreased activity, accumulated in water reservoirs, might be transferred in food chains and incorporated into organisms consuming freshwater foods. As a consequence the radiocarbon age of their remains appears older than its true age. Consuming freshwater organisms, mainly fish and molluscs, also can lead to the accumulation of ‘old carbon’ in human bodies. The presence of this kind of food in diet can be identified by comparing the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in remains of humans and the animals consumed by them.

Well known subjects of research aimed at diet reconstruction and identification of FRE offset of radiocarbon ages are cemeteries in Ostorf in north-eastern Germany ([Olsen et al., 2010](#)) and Zvejnieki in Latvia ([Eriksson et al., 2003](#); [Larsson and Zagorska, 2006](#)). The latter together with a number of other isotopically investigated burial grounds and isolated graves scattered in the south-eastern Baltic zone demonstrate that the exploitation of lakes and rivers almost entirely ceased by the onset of the 3rd millennium BC. Thus, the diet reconstruction done for people buried at that time on the island on Łańskie Lake in north-eastern Poland (Fig. 1) appears to be noteworthy. This article presents the outcome of a pilot study aimed at the absolute chronology of the cemetery in Ząbie and to understand the observed dietary habits and burial practices in a proper historical, spatial and cultural context.

Fig. 1. Location of the sites from Mazurian Lakeland (Ząbie, Dudka, Niedrzwica) and Vistula Lagoon (Suchacz) mentioned in the text.

2. Characteristics of the site

The site no. 10 (X) in Ząbie was discovered in 1994, and excavations have been conducted since 1997 by researchers from the Institute of Archaeology at Warsaw University. It is located on Łańskie Lake's promontory (4 ha in size), which consists of two small kame hillocks separated by a marshy depression (Fig. 2: A). The larger, southern hill is ca. 4 m high, the northern is ca. 3 m high. In the past the promontory was a littoral island; at present it is linked to the lakeshore through a strip of marshland (Manasterski, 2009, p 21).

Up until 2010 a cultural layer and 650 archaeological features had been unearthed, dated to Neolithic, Early Bronze Age, Early Iron Age, Early Middle Ages and modern periods. Almost 90% of the features come from the Early Iron Age, when older deposits were disturbed, and many features were damaged or even destroyed (Waluś, 2011). Artefacts and organic remains found in the cultural layer come from all phases of site's occupation. At least 33 settlement features (almost exclusively pits) from the Late Neolithic to the Early Bronze Age (i.e. from ca. 2600 to at least ca. 1600 BC) (Manasterski, 2009, p 23) have been found. It means that one pit was dug on average every 30 years. Hence, the occupation on the site at that time had a rather seasonal character and was oriented on repeated exploitation of the surrounding lake, which is evidenced by numerous fish bones and shells of molluscs found in the cultural layer (Waluś, 2011). Other animal remains were excavated from the settlement and burial pits but intensive human activity in the Early Iron Age probably led to destruction of their upper parts and mixing of bones from different periods. Some graves could also have been re-opened and

eventually filled with younger deposits. As a result the archaeozoological calculations for later Neolithic and Early Bronze Age (92.2% of mammals were identified as domesticated) might be erroneous (cf. Manasterski, 2009, pp 111-114).

On the southern hillock a small cemetery was discovered, composed of six flat graves (Fig. 2: B). These are the main focus of this study.

Fig. 2. (A) location of the site no. 10 in Ząbie at the Łańskie Lake (based on lake's bathymetric plan after Smoter et al., 2013, modified), (B) plan of the cemetery (numbers of graves indicated), (C) grave 398 (position of T-shaped plates marked; after Manasterski 2009, modified), (D) radiocarbon dated T-shaped plate from grave 398.

2.1. Environment

The site is situated in north-eastern Poland, on Olsztyn Lakeland, a part of Mazurian Lakeland and, in a wider geographical context, of the East-Baltic Lakelands, covering also (almost entirely) the territories of Lithuania, Latvia, Estonia, northern Belarus and adjacent areas of European Russia (Kondracki, 1965).

2.1.1. The Olsztyn Lakeland

The young moraine landscape of the Olsztyn Lakeland has been formed by the Vistulian Glaciation (Weichselian), mainly in the Poznań and Pomeranian phases (ca. 20-15 ky BP). It is built by parallel W-E ranges of moraine hills reaching ca. 300 m in height a.s.l., cut by perpendicular and oblique systems of numerous ribbon lakes and rivers running to the Baltic Sea, ca. 120 km distant (Pawlikowski et al., 1982, p 88). The Quaternary surface consists of tills and sands 60 to 200 m thick. It covers older beds of Cretaceous marls and limestones or Tertiary sands and clays (ibid.).

2.1.2 The Łańskie Lake

The Łańskie Lake is a ribbon lake of glacial origins, extending longitudinally. It is a flow-through lake in connection with the Łyna River. The lake is over 10 km long, 0.5-2.2 km wide with an area of 1042.3 ha and maximum depth of 53 m. Today there are four islands in the lake, the shoreline is very well developed, there are several promontories, and the lakeshore is high and steep (Fig. 2: A). The lake's catchment is 426.4 km², and covers the entire upper part of the Łyna River's basin (Choiński, 1991, p 114; Smoter et al., 2013).

The lake belongs to α -mezotrophic freshwater lakes, with the hardness of 131-173 mg/l CaCO₃ (August-December 2012; personal communicate of Kamila Smoter from The Voivodship Inspectorate for Environmental Protection in Olsztyn). These values are typical for medium hard water and hard water (e.g. Lekang, 2007, p 38; Beran, 2011, p 250). 2.2% of the phytolittoral is built by the charophytes (Smoter et al., 2013), communities creating underwater Chara meadows, typical for hard water mezotrophic lakes (e.g. Krause, 1997).

2.1.3. Vegetation history in the vicinity of the site

In the pollen profile taken from the bottom of Łańskie Lake the changes in vegetation are recorded since the end of Atlantic period, ca. 4800 cal. BC (Madeja, 2013, pp 246, 257). What is crucial for this paper is the observation made for a vegetation development stage dominated by pine forests and mixed multispecies forest with hornbeam (*Carpinus*) and alder (*Alnus*), dated to ca. 3400-1350 cal. BC. The lower boundary for the earliest phase of human impacts on vegetation is fixed chiefly at the first appearance of *Triticum t.* pollen around 1900 cal. BC and the rise of *Artemisia* curve. Because ruderal plants like *Artemisia*, *Chenopodiaceae*, *Rumex acetosella* and *Urtica* were already present below this level, the lower boundary of this phase might fall at ca. 2600 cal. BC or even earlier (Madeja, 2013, pp 249-251).

2.2. The cemetery

The cemetery in Ząbie consists of 6 graves nos. 78, 120a, 120b, 192, 360 and 398. They are concentrated in the north-eastern part of the hillock, the nearest burials were 14-18 m apart (Fig. 2: B). Human bones were also found in cultural layer and settlement features, perhaps they are remains of destroyed graves or other ritual practices. A simplified description of the graves is provided in Table 1.

grave no.	burial pit	deceased	body arrangement	grave goods	other finds
78	partly destroyed, rectangular outline with rounded corners	male, aged 20-25 years	partly preserved anatomical order, probably laid in a crouched position on left side with head to east and face to south	large fragments of a beaker (Fig 3: 1); L-shaped pendants of deer antler (Fig. 3: 2-5) on the chest and around the head;	flint artefacts, remains of fish and molluscs, small fragments of vessels from the turn of Neolithic and Bronze Age
120a	oval outline, oriented along E-W line; under the cultural layer and above burial 120b	incomplete remains of male and female, both aged 20-25 years	skulls placed next to each other, facing east and bottom of the pit; long bones of arms placed parallel on E-W line and on skulls	none	animal remains, fragments of vessels and flint artefacts from the turn of Neolithic and Bronze Age
120b	oval, slightly trapezoidal outline	male, aged 40-50 years	slightly crouched position, on left side, along E-W line, with head to east and face to south	50 amber ornaments, scraper of Baltic erratic flint, remains of a single fish	none
192	almost oval outline	unknown	bones of a hand in anatomical order	none	none
360	irregular or trapezoidal outline	male aged 35-40 years	strongly crouched position, on right side, along E-W line, with head to east and face to north	none	small object made of bronze above the clavicle, fragments of vessels, flint flakes, fragment of a stone axe, fragments of bones of wild and domesticated animals, fish vertebrae, shells of molluscs
398	almost oval outline, partly destroyed in Iron Age	child aged 2-3 years	crouched position on left side (?), along E-W line, with head to east and face to south	two T-shaped plates of deer antler on the pelvis; two pendants made of dog teeth and two of wolf teeth – three of them were laying in their original position around the neck and trunk of the deceased (possibly parts of a necklace)	remains of culture layer in upper part of the pit, containing flint flakes, small animal bones and fragments of vessels from the turn of Neolithic and Bronze Age

Table 1. General characteristics of the burials found at the cemetery in Ząbie (based on Kałwak and Karczmarek, 2000; [Waluś and Manasterski, 2004](#); [Manasterski et al., 2001](#); Manasterski, 2009).

2.2.1. Relative chronology

The child from grave 398 (Fig. 2: C) was equipped with a necklace made of canine teeth and a pair of ornamented T-shaped antler plates (Fig. 2: D). The latter, described also as belt buckles, occur exclusively in Corded Ware grave assemblages in Central and Eastern Europe and in the Złota group/culture in Little Poland (Peška, 2002). Artefacts resembling in form

and decoration the specimens from Ząbie were discovered *inter alia* in four Corded Ware graves, for which ^{14}C dates are also available (Table 2). They place this type of artefact in the early Corded Ware period, i.e. 1st half of the 3rd millennium BC.

site	feature	lab code	^{14}C age (BP)	cal. BC (68.2%)	cal. BC (95.4%)	literature
Sarkani/Lake Sedzers, Latvia	grave 1	Ua-19801	4285 $\pm$ 75	3022-2760	3264-2630	Eriksson et al., 2003 p 11, Table 3
Zvejnieki, Latvia	grave 186	Ua-15545	4190 $\pm$ 90	2893-2636	3011-2492	Zagorska, 2006
Nohra, Germany	grave 6	KIA-32304	4135 $\pm$ 28	2861-2632	2873-2620	Schmidt-Thielbeer, 1955; Schwarz in press; cf. Müller, 2000
Żerniki, Poland		Ki-6330	4120 $\pm$ 45	2859-2588	2874-2576	Czebreszuk and Łoś, 1999
Żerniki, Poland		Ki-6331	4170 $\pm$ 70	2880-2667	2904-2574	Czebreszuk and Łoś, 1999

Table 2. Radiocarbon dates from sites with similar artefacts to grave 398, Ząbie. All dates in this paper calibrated with OxCal 4.2 (Bronk Ramsey, 2009) using IntCal 13 (Reimer et al., 2014).

Pendants made of drilled teeth, mostly belonging to wolf, are common artefacts in Mesolithic and Neolithic. In the Corded Ware culture they are particularly numerous in graves from today's Central Germany (e.g. Clason, 1969, p 174; Petzold, 2005, p 4) and the Czech Republic (e.g. Havel, 1981, p 70). However, the nearest radiocarbon-dated grave assemblage containing this type of pendant comes from Krusza Zamkowa in Kujawy region of Central Poland. Its age was 4175 $\pm$ 35 BP (Poz-24848) and 4150 $\pm$ 35 BP (Poz-23886) (Golsar and Kośko, 2011). After combined calibration its age falls into a range from 2878 to 2640 cal. BC, 68.2% probability. In the larger area of the East-Baltic Lakelands one absolutely dated Corded Ware burial containing pendants made of perforated animal teeth has been discovered. It was a destroyed grave (no. 137) of an adult individual at the cemetery in Zvejnieki in Latvia. A human bone yielded a date 4280 $\pm$ 60 BP (Ua-19811), 3011-2779 cal. BC, 68.2% probability. (Zagorska, 2006, pp 103-105).

Fig. 3. Selection of finds from graves 78 (1-5) and 120b (6-14) in Ząbie (after Kałwak and Karczmarek, 2000, and Manasterski et al., 2001, modified). 1 – beaker, 2-5 – L-shaped pendants of deer antler, 6-14 – amber beads.

L-shaped pendants (known also as wing-shaped) known from grave 78 (Fig. 3: 2-5) are found mainly in burials of the Złota culture/group (e.g. Krzak, 1976; Furholt, 2008). A good example are the specimens from grave no. 12 at the cemetery in Samborzec, radiocarbon-dated to 4170 ± 35 BP (Poz-34687), 2877-2695 cal. BC, 68.2% probability (Burchard and Włodarczak, 2012).

Grave 120b should be linked with a later stage of the cemetery. Amber ornaments found in the burial pit, especially V-perforated buttons (Fig. 3: 6-8), resemble in many respects the specimens known first of all from the Rzućewo and Bell Beaker cultures (Kwiatkowska, 1996, pp 80-81). The chronology of Rzućewo is unclear (e.g. Machnik, 1997; cf. Piliciauskas et al., 2011) but in the Bell Beaker period the amber was in use only after 2500 cal. BC (Czebreszuk, 2011, p 43). Hence, this grave can be cautiously situated in the 2nd half of the 3rd millennium BC as earliest, and grave 120a, dug into it, could be of the same or slightly younger age.

3. Summary of previous findings

Since the moment of discovery assessing the age of the burials and assigning them to a particular archaeological culture has been highly problematic (cf. Manasterski, 2009). Based mainly on ^{14}C dates the use life of the cemetery was calculated to at least 1500 years, covering the Final Neolithic and entire Bronze Age (Waluś and Manasterski, 2004; Manasterski, 2009), according to the periodization system for the area of the Polish Lowland,

including the Mazurian Lakeland (see Table 3), i.e., northern part of Poland. However, the radiocarbon chronology of the cemetery is highly problematic.

period	approximate time interval (BC)
Late Neolithic	3650/3450-2750
Final Neolithic	2750-2250
Early Bronze Age	2250-1550

Table 3. Periodization of the later Neolithic and beginning of the Bronze Age in the Polish Lowland

3.1. Absolute chronology

By 2009 every grave at the site was radiocarbon dated. Only samples of human bones were used for that purpose. The measurements were done at the Gliwice Absolute Dating Methods Centre, with the use of gas proportional counters (GPC) and accelerator mass spectrometry (AMS) techniques (lab codes Gd and GdA respectively), and with liquid scintillation counting (LSC) technique at both the Institute of Geochemistry and Geophysics of the National Academy of Sciences of Belarus in Minsk (lab code IGSB) and at the Conventional Carbon Dating Laboratory in Kiev (lab code Ki). The reported data comes entirely from the literature (Table 4), and no information about the quality of the samples is available.

feature	lab code	¹⁴ C dating technique	¹⁴ C age (BP)	cal. BC (68.2%)	cal. BC (95.4%)
78	IGSB-669	LSC	2480 ± 70	764-517	778-411
78	Ki-9772	LSC	4370 ± 70	3091-2906	3331-2885
78	Gd-17305	GPC	5087 ± 200	4222-3653	4343-3384
120a	Gd-30076	GPC	4920 ± 170	3947-3528	4226-3349
120b	GdA-438	AMS	2865 ± 35	1114-981	1189-922
192	GdA-480	AMS	3660 ± 60	2135-1953	2201-1889
360	Gd-30075	GPC	4990 ± 230	4046-3521	4346-3127
398	GdA-481	AMS	5100 ± 70	3968-3800	4041-3712

Table 4. Radiocarbon dates for the graves from Ząbie until 2009 (based on Waluś and Manasterski, 2004, and Manasterski, 2009).

Fig. 4. Probability distribution of calibrated radiocarbon dates received for the graves from Ząbie until 2009.

These radiocarbon dates are surprising for several reasons (Fig. 4). Firstly, there are striking differences between results of dating three samples from grave 78. Moreover, none of these dates fits the expected age of the burial, based on typological dating. Secondly, the date obtained in Minsk (IGSB-669, 778-411 cal. BC, i.e., Hallstatt C-D) falls in the Early Iron Age. A comparably late result was received for grave 120b (GdA-438, 1189-922 cal. BC, i.e., Montelius' Bronze Age Period III to IV or Hallstatt A1-B1). Finally, four of the remaining five dates done in Gliwice (Gd-17305, Gd-30076, GdA-480, Gd-30075, GdA-481) are convergent, but too early, if one assumes that the cemetery was mostly used in 3rd millennium BC. With such an assumption only the radiocarbon age of the bones from grave 192 (GdA-480) seems correct, a point already noted (Manasterski, 2009, p 27).

As yet there have been no significant attempts to explain the controversial results from the absolute dating. One idea was that the samples used for ¹⁴C dating did not belong to the buried individuals but were later intrusions linked to grave re-opening or settlement activity. This would explain the too young dates falling into Late Bronze Age and Early Iron Age. Also in this way a small bronze object could have been deposited above the skeleton in grave 360 (Manasterski, 2009, pp 27, 109) which might be plausible. However, such a scenario does not explain the extremely early dates, ranging roughly from 4000 to 3000 cal. BC. It has already been noted that graves 78 and 398 are several centuries older than the oldest known Corded Ware burials (Manasterski, 2009, p 27).

4. Methods and results

Between 2010 and 2013 a new series of AMS radiocarbon dating and stable isotopes measurements ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) were obtained as a part of a pilot study. Their aim was to explain why the previously obtained radiocarbon dates did not fit the expected ages of the burials. Initially it was assumed that some of the dates might be erroneous due to poor preservation of collagen, contamination or accidental exchange of samples in the laboratories. Hence, a sample from grave 120b was given to Poznań Radiocarbon Laboratory in 2010. As an extraordinary early date was received again, it was proposed that this and other old dates could have been caused by FRE. However, at that time the Poznań Radiocarbon Laboratory did not offer nitrogen and carbon stable isotope measurements which could be useful in identifying freshwater food consumption by studied individuals. The collagen left after radiocarbon dating of sample from grave 120b was sent for isotopic analyses to the Isotope Dating and Environment Research Laboratory at the Institute of Geological Sciences of the Polish Academy of Sciences in Warsaw. In case of grave 360, radiocarbon dated in Gliwice, a new sample was taken for the purpose of isotopic analyses. Collagen extraction was done in Poznań, stable isotope measurements were performed in Warsaw. Samples from graves 78 and 398 were sent to the ^{14}C HRONO Centre for Climate, the Environment, and Chronology at the Queen's University in Belfast for both radiocarbon dating and stable isotopes measurements. Additionally, one of the T-shaped antler plates from grave 398 (Fig. 2: D) was submitted to the Oxford Radiocarbon Accelerator Unit, which was able to take a relatively small sample to minimise the destruction of the artefact.

4.1. Radiocarbon dating

In the first stage of the new research, a re-dating of human remains from three graves (78, 120b, 398), was conducted in laboratories in Poznań and Belfast using AMS, following the samples pre-treatment method as described in [Brock et al. \(2010\)](#). The same procedure was followed in Oxford for the plate from grave 398. However, as the sample has been impregnated with polyvinyl acetate it also had an initial solvent wash consisting of sequential hour-long rinses with water, acetone, water and methanol at 45° C. The sample gave a yield of 3.44 mg of collagen from a starting weight of 150 mg. The small sampled weight was low due to the precious nature of the artefact. While small, proportionally the collagen yield comprises 2.7% weight of collagen, which indicates good preservation of the bone.

feature	sample	lab code	^{14}C age (BP)	C:N	cal. BC (68.2%)	cal. BC (95.4%)	$\delta^{13}\text{C}$ VPDB (‰)	$\delta^{15}\text{N}$ AIR (‰)
78	human maxilla	UBA-15680	5024 ± 36	3.22	3938-3717	3944-3711	-21.7 ± 0.22	13.5 ± 0.15
120b	human metatarsal	Poz-36253	5210 ± 40	2.5	4042-3974	4226-3954	-23.5 ± 0.3	12.5 ± 0.3
398	human femur	UBA-15658	4927 ± 35	3.14	3757-3654	3776-3646	-21.4 ± 0.22	15.5 ± 0.15

360	human metatarsal			2.92			-20.5 ± 0.3	12.1 ± 0.3
398	deer antler	OxA-X-2417-15	4187 ± 31	3.3	2881-2701	2890-2668	-22.5 ± 0.3	5.6 ± 0.4
44	<i>Cyprinidae</i> vertebra			2.4			-24.7 ± 0.3	5.8 ± 0.3

Table 5. Results of AMS radiocarbon dating and isotopic measurements done for humans and animals from Ząbie between 2010 and 2013.

Fig. 5. Probability distribution of calibrated radiocarbon dates received for the graves from Ząbie between 2010 and 2013.

Taking into consideration the proportions of carbon and nitrogen in collagen from the dated samples, their preservation state can be described as good. Only the sample from grave 120b had a C:N value slightly lower than the conventional range 2.9-3.5 (van Klinken, 1999; [Bronk Ramsey et al., 2004](#)) so the result of ^{14}C dating (Poz-36253) might be inaccurate. The standard deviation for all four dates is relatively small when compared to previous dates.

The radiocarbon age of three of the new samples for graves 78, 120b and 398 (UBA-15680, Poz-36253, UBA-15658) and the earlier results from the laboratory in Gliwice for graves 78 and 398 (Gd-17305 and GdA-481) falls into the range 5210-4920 BP. The difference between the age of 'old' and 'new' samples from graves 78 (Gd-17305 and UBA-15680) and 398 (GdA-481 and UBA-15658), determined by independent measurements is equal to 63 ± 203 and 173 ± 78 radiocarbon years respectively. In both cases the older dates come from the laboratory in Gliwice, associated with AMS and GPC techniques.

In total the two series of human bone measurements provided 12 radiocarbon dates of which 7 (including new age determination for grave 120b) fall into the range 5210-4920 BP. Hence, it can be assumed, that this is the most probable radiocarbon age for the majority of graves at the cemetery. The date from grave 120b from the laboratory in Gliwice (GdA-438) must be erroneous. At the same time it is difficult to determine what caused the error. Perhaps a contaminated sample or sample with poorly preserved collagen was submitted for dating. The

radiocarbon date received for the antler plate from grave 398 (OxA-X-2417-15) is 740 ± 47 radiocarbon years younger than date (UBA-15658) received for a human bone from the same feature. After calibration it falls between ca. 2880-2700 cal. BC and is consistent with the expected age of the grave, based on comparative analysis. A summed age of graves 78, 120b and 398 falls into a wide time span (Fig. 5) and differs significantly from the assumed range (ca. 2900-2000 cal. BC, see above). Taking into account (1) the too old radiocarbon age of human remains from graves 78, 120b and 398, (2) the correct age of the antler plate from grave 398, (3) the difference between the age of the human bone and antler plate from grave 398, (4) the environmental setting of Ząbie, and (5) the character of animal remains found at the site (the abundance of fish and molluscs) it can be assumed that the too early radiocarbon dates for human bone was caused by FRE.

4.2. Reconstruction of human diet

Ratios of stable isotopes of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) in bone collagen are linked with protein content of food. The $\delta^{13}\text{C}$ value in large herbivores is 4-6‰ more positive than in their food (Ambrose and Norr, 1993, pp 27-28; [Jim et al., 2004](#)). In higher levels of the trophic web the increase of $\delta^{13}\text{C}$ is smaller and equals ca. 1‰ (Schoeninger and DeNiro, 1984, p 625; Schoeninger, 1989). $\delta^{15}\text{N}$ reflects trophic level and increases 3-5‰ at each stage of food chain ([Hedges and Reynard 2007, p 1241](#)). Hence, to reconstruct past human diet it is necessary to know the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in remains of animals representing the species consumed daily in studied population. Today there are no such data for the site in Ząbie, except a single sample of deer antler and freshwater fish (*Cyprinidae*) vertebra (Table 4: 5, 6). Attempts of analysing a larger number of fish remains was unsuccessful due to poor collagen preservation. Hence, results for Neolithic animal remains from other parts of the East-Baltic Lakelands (Eriksson and Zagorska, 2003; [Antanaitis-Jacobs et al., 2009](#)) were used as a reference. Information about $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios in human remains is available for four individuals from Ząbie (Table 4).

Fig. 6. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for humans from Żąbie (numbers of graves indicated) and animals from Neolithic East-Baltic Lakelands (Eriksson and Zagorska, 2003; Antanaitis-Jacobs et al., 2009) and Medieval north Poland (Reitsema et al., 2013). The black boxes mark the isotopic ranges for terrestrial and freshwater animals. The grey boxes indicate the isotopic ranges for animals displaced to the equivalent consumer values by 1‰ for $\delta^{13}\text{C}$ and 3.5‰ for $\delta^{15}\text{N}$ to illustrate the diet-to-consumer shift.

Figure 6 presents the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for Neolithic wild animals from the East-Baltic Lakelands. As there is a shortage of samples, especially for fish, data from the medieval site of Kaldus in north Poland (Reitsema et al., 2013) was added to the plot. Two boxes with black lines on the plot mark the ranges of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for the two main sources of protein in human diet, i.e., terrestrial herbivores and omnivores, and freshwater fish. Two other boxes, marked with grey line, indicate the ranges of isotopic values assumed for people consuming food exclusively from one of these sources. These boxes are shifted in relation to the two previous ones, 1‰ for $\delta^{13}\text{C}$ and 3.5‰ for $\delta^{15}\text{N}$, to illustrate the diet-to-consumer shift, in other words, to illustrate the change in trophic level (Olsen et al., 2010, pp 637-640). Individuals from Żąbie present elevated $\delta^{15}\text{N}$ values, and it seems likely that the diet of these humans was based largely on freshwater food. $\delta^{13}\text{C}$ values suggest an admixture of terrestrial animals in the diet although some contribution of marine sources of protein cannot be excluded, too (cf. Fischer et al., 2007).

$\delta^{15}\text{N}$ values for adults from graves 78, 120b and 360 fall into the range 12.1-13.54‰, but in case of child from grave 398 the value is 15.51‰ – the difference ranges from 2 to nearly 4‰ and indicates an increase of one trophic level. In case of the child it is probably due to breast-feeding (e.g. Tsutaya and Yoneda, 2013). The lowest $\delta^{15}\text{N}$ was found for the individual from

grave 360. At the same time this sample has the highest $\delta^{13}\text{C}$ ratio, of -20.5‰ , while the other humans exhibited values from -23.5 to -21.48‰ . In the case of that individual a more diverse diet can be assumed, with smaller contribution of freshwater food.

Fig. 7. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for humans from Ząbie (numbers of graves indicated) and, as reference, for selected Corded Ware populations from Bavaria (Asam et al., 2006), Latvia and Lithuania (Antanaitis-Jacobs et al., 2009; Eriksson et al., 2003), Scania (Fornander, 2013) and Mesolithic to Early-Middle Neolithic populations from Zvejnieki, Latvia (Eriksson et al., 2003).

Figure 7 shows the results for the people from cemetery in Ząbie on a background of data for other Mesolithic and Neolithic populations from Scania in south Sweden and East-Baltic Lakelands, and Corded Ware individuals from graves in Kruszyn (Pospieszny et al., in preparation) and Niedrzwica (Reitsema, 2012), located in Polish Lowland. Additionally, results of isotopic analyses for Corded Ware populations from the Alpine Foreland were plotted, which is one of the largest series of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements for the whole Corded Ware culture (Asam et al., 2006). What is remarkable is the discrepancy between values for majority of the individuals from Ząbie compared to two Corded Ware burials from the Polish Lowland and Corded Ware populations from Lithuania, Latvia and partly also from Bavaria. The values obtained for the most of Corded Ware people concentrate in the range typical for terrestrial diet or in an area representing a diet with small proportion of freshwater organisms. In case of the Lithuanian and Latvian Corded Ware populations, fairly consistent results from the isotopic analyses are interpreted as an expression of a ‘standardized diet’.

based mainly on animal proteins such as meat and milk, without a significant share of freshwater fish (Antanaitis-Jacobs et al., 2009, p 23; Eriksson et al., 2003, pp 17, 20). Authors of the study in Bavaria came to similar conclusions. The diet of individuals representing the Corded Ware (or Battle Axe) populations from Scania ranged from terrestrial protein intake to a mixture of marine fish/mammals and terrestrial protein sources which challenges the notion of a farming/pastoralist economy (Fornander 2013, p 24).

From the perspective of isotopic analyses, individuals from graves 78 and 120b resemble the Mesolithic and Early-Middle Neolithic populations from the cemetery in Zvejnieki (Eriksson et al., 2003). The child from grave 398 has an unusually high $\delta^{15}\text{N}$ value when compared to all individuals from Zvejnieki, 1.9‰ higher than the individual of the highest value, representing a Middle Neolithic population, but this is probably due to breast-feeding. There is a lack for good analogies for the man from grave 360 in the East-Baltic Lakelands, but similar values were obtained for two individuals associated with Bavarian Corded Ware culture. They stand out in terms of diet from the majority of that population because of relatively high ratios of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ (from -20.2‰ to -20.4‰ and from 11.0‰ to 11.4‰ respectively). Similar results were obtained for the Bavarian Bell Beaker population, explained by an increase of freshwater food in human diet at the beginning of the Early Bronze Age (Asam et al., 2006).

The diet of the three individuals from graves 78, 120b and 398 in Ząbie (buried according to ritual rules of the Corded Ware or Bell Beaker culture) is completely different from the “normal” diet of representative Corded Ware populations. Similar dietary habits were present in the Mesolithic and Early-Middle Neolithic populations at Zvejnieki.

Grave 78, thanks to a radiocarbon-dated analogy, can be safely situated around 2750 cal. BC, and the reservoir offset is about 1080 years. Analogies for amber artefacts from the grave 120b come from a period after ca. 2500 cal. BC hence the reservoir offset of radiocarbon age in this case may be from at least 1000 to around 1500 years.

5. Discussion

In the light of comparative study and isotopic analyses the cemetery in Ząbie, specifically the part not destroyed during the Iron Age, was used for approximately 1000 years. The oldest graves (398 and 78) belonged to a child and male who died between 2900 and 2700 cal. BC, i.e., at the transition from the Late to the Final Neolithic. The other burials come from 2nd half of the 3rd millennium BC and fall on the transition from the Final Neolithic to the Early Bronze Age. Almost all the investigated humans had similar eating habits. Their diet was plausibly based to large extent on freshwater foods. Judging by animal remains found on the site these were mostly fish and molluscs but it must be stressed that no systematic isotopic data for local food web reconstruction is available.

One consequence of establishing the absolute chronology of the cemetery, narrowing the period of its use largely to the 3rd millennium BC, and identifying a significant proportion of freshwater food in the human diet, is the need to answer two basic questions.

First, what does the burial rite tell us about the identity of the population of Ząbie in the context of these kind of practices in other societies from the transitional period between the Neolithic and the Bronze Age?

Second, how should we understand the dietary habits of the population from Ząbie in the context of other subsistence strategies during the same period?

5.1. Burial ritual

The cultural situation in north-eastern Poland in the 3rd millennium BC was quite complex. In the Final (ca. 2750-2250 cal. BC, see Table 3), or perhaps already in the Late Neolithic, the south-eastern coast of Baltic was occupied by the Rzucewo culture (also *Haffküstenkultur* or *Pamarių*). In Lithuanian archaeology the Rzucewo culture or its zone of influence also covers sites located further in the hinterland, including the Mazurian Lakeland (Grasis, 2007, p 41, Fig. 1, cf. Girininkas 2006). However, in Polish archaeology a distinct group of early Corded Ware sites is recognized there (Machnik, 1979). At the same time communities of Globular Amphora culture (Szmyt, 1999) and groups of people with a predominantly hunter-gatherer economy were present in that area. The latter include mainly the representatives of the Neman culture (e.g. Piliciauskas, 2002). At the beginning of the Early Bronze Age influences of the Iwno culture from the south-west and, to a lesser extent, of the Mierzanowice culture from Little Poland became visible (Manasterski, 2010).

Determining the identity of the society burying their dead at the cemetery in Ząbie is complex due to the variety of characteristics of burial ritual from different cultural contexts. Some features are, however, exceptional, or repeated often enough that one can talk about the creation of local burial tradition.

First of all, in four graves (78, 120b, 360 and 398) human remains were buried and preserved in almost anatomical order. The child from grave 398 was buried in a contracted position on the left side. This arrangement of the body was typical for the Corded Ware culture. Furnishing the burial with T-shaped antler plates and placing them in the pelvic area of the body is also a typical practice for Corded Ware culture (Peška, 2002). It can therefore be assumed that the burial in grave 398 was made in accordance with the ritual of this culture.

The position of the body of a man in grave 78 can also be seen as compatible with burial ritual of the Corded Ware culture. Placement on the right side (usually restricted for males) with bent legs has been found, e.g., in graves of juvenile males from Niedrzwica in Mazurian Lakeland (Fig. 1; Reitsema, 2012) and from Kuczkowo in Kujawy (Czebreszuk, 2000, pp 427-431; Pospieszny et al., in preparation), and a juvenile individual at Zvejnieki (grave 186) in Latvia (Zagorska, 2006, p 103).

The male buried in the grave 120b was arranged in a contracted position, but on his left side. Taking into account the amber ornaments primarily resembling a Bell Beaker style, it can be assumed that the principle of burying males on left side and females on right side, typical for Bell Beaker and opposed to Corded Ware culture, was decisive in this case. It must be stressed, however, that the nearest Bell Beakers graves are found in distant regions of Little Poland (Budziszewski and Włodarczak, 2010) and Central Germany (Hille, 2012). The number of anthropologically investigated skeletons from nearer Iwno culture (a syncretic entity that combines features of Bell Beakers and Corded Ware culture) is too low to confirm

the existence of such principle in the Polish Lowland (Makarowicz, 2005). Burials equipped with numerous amber artefacts are also known from Rzucewo culture, although they usually contain disarticulated human bones. In Suchacz site 1 (Fig. 1) a pit was found at the entrance to one of the huts containing fragments of a human skull and a necklace made of 25 amber beads (Ehrlich, 1936, p 62). In another pit on that settlement bones of the skull of the child and a preserved *in situ* necklace consisting of 67 amber ornaments was found (Mazurowski, 1987, p 155).

Burial 360 is distinguished by highly contracted position of the corpse, placed on the right side. Pulling up legs to the chest, possibly due to undercutting ligaments and restraining the body, was practiced mainly in the aforementioned Iwno culture (Makarowicz, 2005).

Exceptions to the rule of burying the dead in anatomical position are burials 120a and 192. The man whose hand was buried in grave 192 could have been in some way different than the others. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for this individual are unknown but his radiocarbon age seems not be shifted by FRE. This speaks for a diet to a large extent free of freshwater food and unusual for the rest of the population in Ząbie.

Grave 120a contained a secondary burial. This conclusion is based on the incompleteness of the skeleton buried in it, and the disarticulated, but non-random, arrangement of bones. Analogous practices are known from another site in the Masurian Lakeland – Dudka (Fig. 1), located on a former island, primarily surrounded by waters of a dried-up lake (Gumiński, 2003). In the habitation area of the site a small cavity (VI-1) was found, containing the incomplete, mixed and compressed skeletons of three adults from the Globular Amphora culture (Gumiński, 1997, p 96; 1999, pp 54, 56). Two ^{14}C dates were obtained from human bones, 4690 ± 40 BP (Ki-5718) and 4730 ± 40 BP (Ki-5720), i.e., 3623-3380 cal. BC, 68.2% probability, after the combined calibration (Gumiński, 1999, p 38, Table 1: 6, 7). At the site a zone was identified where most likely the decomposition of soft tissues of dead bodies took place. Evidence for this process are fragments of human skeletons and pendants of animal teeth, and bone and amber with broken holes, originally parts of necklaces. This form of burial could have local roots, reaching back to the Mesolithic (Gumiński, 1999, p 56). Perhaps similar practices are reflected in the loose human bones found outside the burial pits in Ząbie, although some of them probably come from graves destroyed by the subsequent occupation of the island.

What is also interesting in the case of grave 120a is its incorporation into the burial pit of an older grave. The absolute age of the latter is unknown, but because of its stratigraphic relationship with grave 120b it may be assumed that it comes, at the earliest, from the end of 3rd millennium BC, perhaps already from the Early Bronze Age. It is important because in Central Europe placing burial pits in the older graves is known mainly from that period. One example is the grave of proto-Únětice culture no. 32A in Bożejewice in Kujawy, dug into a Final Neolithic grave (Koško, 1991).

What is striking in the structure of the entire cemetery in Ząbie is the identical orientation of all but one grave. Individuals in graves 78, 120b, 360 and 398 rested on W-E line, along the longer axis of the burial pits. All the dead were also oriented with their heads to the east. Orienting burial pits along the W-E axis was rarely practiced among later Neolithic societies in Central Europe. This is demonstrated by analogies of early Corded Ware burials in Kujawy, Little Poland and Central Germany. In the case of a grave at Niedrzwica in the Masurian

Lakeland, a rare example of a recently discovered and well preserved early Corded Ware inhumation from that region, the burial pit was oriented obliquely, i.e. along the SW-NE axis, with head to the south-west. Oblique orientation was also observed in the above mentioned early Corded Ware grave 186 in Zvejnieki, except that the skull of the deceased pointed to the north-west.

In the area of Mazurian Lakeland there are no well-preserved graves that could be clearly associated with the late Corded Ware period, i.e., the 2nd half of the 3rd millennium BC. The equipment of a child grave from Dudka is atypical hence its relationship with the Corded Ware is not certain (cf. Gumiński, 1997, p 98). Nevertheless it should be noted that the deceased was laid N-S on the back with head to the south, the legs bent and folded to the left side of the body. A ¹⁴C date 3775 ± 40 BP (Ki-5717), 2281-2139 cal. BC, 68.2% probability, was obtained from its bone (Gumiński, 1999, p 38, Table 1: 1). The nearest, although relatively small, concentration of late Corded Ware graves is in Kujawy. In case of the three best preserved examples (Ciechrz, Kościelna Wieś and Podgaj), the graves were oriented along the N-S axis, and the heads of the dead were directed to the north (Pospieszny, 2009). The principle of the orientation of graves on a N-S line was continued in Iwno culture, which is illustrated by completely preserved graves from Łojewo, Łysinin, Siniarzewo and Żegotki, all in Kujawy (Makarowicz, 2005). The N-S orientation of bodies, common in Central Europe in the last centuries of the 3rd millennium BC, including the Bell Beaker, has not become a part of the burial ritual in Ząbie.

5.2. Diet and economy

The specific diet of the population represented in the cemetery in Ząbie testifies indirectly to a specific subsistence strategy. In the 1st half of the 3rd millennium BC large parts of Central Europe were dominated by the Corded Ware and Globular Amphora cultures (e.g. Szmyt, 1999; Furholt, 2003). Their economies were based largely on agriculture, with more or less mobile animal husbandry playing an important role. In peripheral areas some other societies developed, closely adapted to local environmental conditions. The most widely discussed example is the Rzucewo culture, whose representatives exploited coastal waters of the Baltic Sea and gathered amber on the coast and inland (Mazurowski, 1984; 2014; Makowiecki and Van Neer, 1996; Lasota-Moskalewska, 1997).

The results of dietary reconstruction for several individuals from Ząbie revealed that the population visiting the island also specialized in getting food from the richest local source, which was the lake water. Palynological data indicate that during the life of the cemetery its surroundings were forested and agriculture, if practiced at all, did not play much of a role in the local subsistence strategies which, therefore, can be called Sub-Neolithic or post-Mesolithic (cf. Józwiak, 2003; Iversen, 2010, pp. 29-30).

It is worth noting that at the aforementioned site of Dudka the proportion of fish among the bone remains from the later Neolithic was 10%, while at the beginning of the Neolithic it was 40% (Gumiński, 1997, p 99). Moreover, from the beginning of the Mesolithic to the end of the Neolithic the proportion of consumed wild animals remained the same. The percentage of the bones of domesticated animals in the later Neolithic was only 9% (Gumiński, 1999, pp.

56-57). Although the ratios of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in radiocarbon-dated human remains from Globular Amphora and Corded Ware graves in Dudka (see above) are unknown, the ^{14}C dates seem to be correct and unchanged by FRE. This may indirectly indicate a lack of a significant proportion of fish in the diet of later Neolithic Dudka.

What differentiates Ząbie from Dudka is the occurrence of numerous remains of consumed molluscs. The ^{14}C ratios in the soft tissues of these animals are usually very low due to the accumulation of 'old carbon' in their tissues. As a result, the consumption of molluscs can result in false radiocarbon dates. At the same time the molluscs have relatively low $\delta^{15}\text{N}$ values so that their role in the human diet may be masked by other types of food. It cannot be excluded that some marine foods were consumed by the population from Ząbie as suggested by relatively high $\delta^{13}\text{C}$ values for humans. This stays unclear as fish remains have not been studied in detail yet. Moreover, one can assume that products like seal fat were exchanged or brought inland together with amber (cf. Girininkas, 2004). The links with shores of the Baltic Sea are also evidenced by element of the burial ritual (see above). However, looking at the $\delta^{13}\text{C}$ values for humans from Scania indicates, that mixed terrestrial-marine diet would cause much higher signal. Hence, future isotopic analyses of fish remains from Ząbie could reveal that that predicted range for human diet based purely on freshwater fisher is wider than assumed and could include the highest value received for humans.

Isotopic data for fish from Kaldus, confirming a single measurement for Ząbie, showed that there is much higher variability of their $\delta^{15}\text{N}$ values compared to results received for few specimens from East-Baltic Lakelands. This is probably linked to trophic position of different species. As a consequence, the lowest value for human diet exclusively based on freshwater food, or more specially fish, is much lower than previously assumed for Lithuania or Latvia. Therefore the estimations of minor or no role of fish as a source of protein in Corded Ware population should be viewed with more caution.

6. Conclusions

Re-dating selected human and animal remains from the cemetery in Ząbie, and analysis of their $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, provides a number of interesting conclusions.

For all the graves exhibiting a burial ritual typical for the end the Neolithic and beginning of the Bronze Age, very early ^{14}C dates are characteristic. There is no way to reconcile these dates with the existing chronology of the cemetery based on typological and comparative studies. The very early dates seem to be the norm for these human remains.

The discrepancies in these radiocarbon dates were probably caused by FRE, as the people buried in Ząbie consumed a high proportion of freshwater organisms containing 'old carbon'. This old carbon comes from calcium carbonate dissolved in the hard water lake and probably originates in Cretaceous deposits of limestone, and perhaps from CO_2 from organic deposits as well. Dating two samples from grave 398, human bone (affected by FRE) and an artefact made of antler (not affected by FRE) allows an estimate of the FRE offset of about 740 years. For graves 78 and 120b the reservoir offset may have been around 1200 or even 1500 years which is much greater than in case of grave 398. For other human individuals this value may be different due to the chronological span of the cemetery and associated changes in

subsistence strategies, and individual differences in diet due to age, sex, social position, etc. This is supported by comparison of their apparent ages and the absolute ages of similar finds throughout Central Europe.

At the same time ^{14}C dates obtained before 2009, situating some of graves in the Late Bronze Age or Early Iron Age, must be considered incorrect. However, it is difficult to assess the cause of these divergent results.

Compared to burial ritual patterns in neighbouring, contemporary populations the cemetery in Ząbie stands out in the specific orientation of burial pits, although their low number must be kept in mind. The ways of disposing the dead, arranging and equipping their bodies indicate a combination of patterns of ritual practices from diverse societies from the Final Neolithic and Early Bronze Age, as well as elements of a post-Mesolithic tradition.

The most striking feature of the society burying the dead on the island at Ząbie is their focus on the exploitation of local natural resources. This subsistence strategy can be defined as Sub-Neolithic as one cannot exclude the possibility that animal husbandry had some economic importance. So far, such an advanced adaptation to local ecological conditions in the Final Neolithic, supplemented by stock keeping, was observed almost exclusively in the Rzucewo culture. In both cases, the common element is the occupation of areas highlighted by a richness of aquatic environments.

What seriously limits the interpretation of the results of isotopic analyses of human remains is a lack of data on the food web in the catchment of Łańskie Lake over the time span of the cemetery in Ząbie. Particularly noticeable is the lack of data on the values for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in local fish and molluscs which are strongly determined by particular water geochemistry. An additional difficulty in the reconstruction of dietary habits and subsistence strategy is the lack of detailed data on the structure of animal remains found at the site, contemporary with the cemetery.

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References

- Ambrose, S. H., Norr, L., 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate, In: Lambert, J. B., Grupe, G. (Eds.), *Prehistoric Human Bone: Archaeology at the Molecular Level*. Springer, Berlin, 1-37.
- Antanaitis-Jacobs, I., Richards, M., Daugnora, L., Jankauskas, R., Ogrinc, N., 2009. Diet in Early Lithuanian Prehistory and the New Stable Isotope Evidence. *Archaeologia Baltica* 12, 12-30.
- Asam, T., Grupe, G., Peters, J., 2006. Menschliche Subsistenzstrategien im Neolithikum: Eine Isotopenanalyse bayerischer Skelettfunde. *Anthropologischer Anzeiger* 64(1), 1-23.
- Beran, J. A., 2011. Laboratory manual for principles of general chemistry. Wiley, Chichester.
- Brock, F., Higham, T., Ditchfield, P., Bronk Ramsey, C., 2010. Current pretreatment methods for AMS radiocarbon dating at the Oxford Radiocarbon Accelerator Unit (ORAU). *Radiocarbon* 52(1), 103-112.
- Broecker, W. S., Walton, A., 1959. The geochemistry of ^{14}C in fresh-water systems. *Geochimica et Cosmochimica Acta* 16(1-3), 15-38.
- Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1), 337-360.
- Bronk Ramsey, C., Higham, T., Bowles, A., Hedges, R., 2004. Improvements to the pretreatment of bone at Oxford, *Radiocarbon* 46, 155-163.
- Budziszewski, J., Włodarczak, P., 2010. Kultura pucharów dzwonowatych na Wyżynie Małopolskiej. Wydawnictwo Instytutu Archeologii i Etnologii Polskiej Akademii Nauk, Kraków.
- Burchard, B., Włodarczak, P., 2012. Złota culture graves at site 1 in Samborzec, Sandomierz District, *Sprawozdania Archeologiczne* 64, 269-310.
- Choiński, A., 1991. Pojezierze Mazurskie. Wydawnictwo Naukowe UAM, Poznań.
- Clason, A. T., 1969. Einige Bemerkung über Viehzucht, Jagd und Knochenbearbeitung bei der mitteldeutschen Schnurkeramik, In: Behrens, H., Schlette, F. (Eds.), *Die neolithischen Becherkulturen im Gebiet der DDR und ihre europäischen Beziehungen*. VEB Deutscher Verlag der Wissenschaften, Berlin, 173-195.
- Cook, G. T., Bonsall, C., Hedges, R. E. M., McSweeney, K., Boroneant, V., Pettitt, P. B., 2001. A freshwater diet-derived ^{14}C reservoir effect at the Stone Age sites in the Iron Gates Gorge. *Radiocarbon* 43(2), 453-460.
- Czebreszuk, J., 1996. Społeczności Kujaw w początkach epoki brązu. PSO, Poznań.
- Czebreszuk, J., 2000. Osadnictwo społeczności kultury ceramiki sznurowej, In: Koško, A. (Ed.), *Archeologiczne badania ratownicze wzdłuż trasy Gazociągu Tranzytowego*, t. III Kujawy, cz. 4, Osadnictwo kultur późnoneolitycznych oraz interstadium epok neolitu i brązu: 3900 – 1400/1300 przed Chr. Wydawnictwo Poznańskie, Poznań, 424-454.
- Czebreszuk, J., 2011. Bursztyn w kulturze mykańskiej. Wydawnictwo Poznańskie, Poznań.
- Czebreszuk, J., Łoś, J., 1999. Grób kultury ceramiki sznurowej w Żernikach, gm. Kruszwica, pow. Inowrocław, woj. kujawsko-pomorskie, stanowisko 27. *Sprawozdania Archeologiczne* 51, 97-113.
- Deevey, E. S., Gross, M. S., Hutchinson, G. E., Kraybill, H. L., 1954. The natural C^{14} contents of materials from hard-water lakes. *Proceedings of the National Academy of Sciences* 40, 285-288.

- Ehrlich, B., 1936. Succase. Eine Siedlung der jungsteinzeitlichen Schnurkeramiker im Kreise Elbing. *Elbinger Jahrbuch* 12/13, 41-98.
- Eriksson, G., Lõugas, L., Zagorska, I., 2003. Stone Age hunter-fisher-gatherers at Zvejnieki, northern Latvia: radiocarbon, stable isotope and archaeozoology data. *Before Farming* 1(2), 1-26.
- Eriksson, G., Zagorska, I., 2003. Do dogs eat like humans? Marine stable isotope signal in dog teeth from inland Zvejnieki. In: Larsson, L., Kindgren, H., Knutson, K., Loeffler, D., Åkerlund, A. (Eds.), *Mesolithic on the Move: Papers presented at the Sixth International Conference on The Mesolithic in Europe, Stockholm 2000*. Oxbow, Oxford, 160-168.
- Fischer, A., Olsen, J., Richards, M. P., Heinemeier, J., Sveinbjörnsdóttir, Á. E., Bennike, P., 2007. Coast-inland mobility and diet in the Danish Mesolithic and Neolithic: evidence from stable isotope values of humans and dogs. *Journal of Archaeological Science* 34(12), 2125-2150.
- Fonander, E., 2013. Dietary diversity and moderate mobility – isotope evidence from Scanian Battle Axe Culture burials. *Journal of Nordic Archaeological Science* 18, 13-29.
- Furholt, M., 2003. Die absolutchronologische Datierung der Schnurkeramik in Mitteleuropa und Südkandinavien, UPA 101. Habelt, Bonn.
- Furholt, M., 2008. Die Złota-Gruppe in Klempolen: Ein Beispiel für die Transformation eines Zeichensystems? *Germania* 86(1), 1-28.
- Girininkas, A., 2004. Pamarių kultūros bendruomenių ūkininkavimo ypatumai. *Istorija. Lietuvos aukštųjų mokyklų mokslo darbai* 61, 3-9.
- Girininkas, A., 2006. Ar Pamarių kultūra priklausė virvelinės keramikos kultūros ratui? *Lituanistica* 4(68), 36-46.
- Goslar, T., Koško, A., 2011. Z badań nad chronologią i topogenezą kujawskich kurhanów starosnurowych. Krusza Zamkowa, powiat Inowrocław, stanowisko 3, In: Kowalewska-Marszałek, H., Włodarczak, P. (Eds.), *Kurhany i obrządek pogrzebowy w IV-II tysiącleciu p. n. e.* Instytut Archeologii i Etnologii Polskiej Akademii Nauk, Instytut Archeologii Uniwersytetu Warszawskiego, Kraków/Warszawa, 407-415.
- Grasis, N., 2007. The Skaistkalnes Selgas double burial and the Corded Ware/Rzucewo culture: a model of the culture and the development of burial practices. *Lietuvos archeologija* 31, 39-70.
- Gumiński, W., 1997. Corded Ware at the Dudka peat-bog site, NE Poland. A case of migration or local development, In: Siemen, P. (Ed.), *Early Corded Ware Culture. The A-Horizon - fiction or fact?* Arkæologiske Rapporter 2. Esbjerg Museum, Esbjerg, 93-103.
- Gumiński, W., 1999. Środowisko przyrodnicze a tryb gospodarki i osadnictwa w mezolicie i paraneolicie na stanowisku Dudka w Krainie Wielkich Jezior Mazurskich. *Archeologia Polski* 44, 31-74.
- Gumiński, W., 2003. Scattered human bones on prehistoric camp site Dudka, NE-Poland, as indication of peculiar burial rite, In: Derwich, E. (Ed.), *Préhistoire des Pratiques Mortuaires. Paléolithique - Mésolithique - Néolithique*, ERAUL 102. Université de Liège. Service de Préhistoire, Liège, 111-120.
- Havel, J., 1981. Hrob kultury se šňůrovou keramikou v Praze 8-Čimicích. *Das schnurkeramische Grab in Praha 8-Čimice*. *Praehistorica* 8, *Varia Archaeologica* 2, 67-71.

- Hedges, R. E. M., Reynard, L. M., 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *Journal of Archaeological Science* 34, 1240-1251.
- Hille, A., 2012. Die Glockenbecherkultur in Mitteldeutschland, Veröffentlichungen des Landesamtes für Denkmalpflege und Archäologie Sachsen-Anhalt - Landesmuseum für Vorgeschichte 66. Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, Halle.
- Iversen, R., 2010. In a world of worlds: The Pitted Ware complex in a large scale perspective. *Acta Archaeologica* 81, 5-43.
- Jim, S., Ambrose, S. H., Evershed, R. P., 2004. Stable carbon isotopic evidence for differences in the dietary origin of bone cholesterol, collagen and apatite: implications for their use in palaeodietary reconstruction, *Geochimica et Cosmochimica Acta* 68(1), 61-72.
- Józwiak, B., 2003. Społeczności subneolitu wschodnioeuropejskiego na Nizinie Polskiej w międzyrzeczu Odry i Wisły. Instytut Prahistorii UAM, Poznań.
- Kaławak, G., Karczmarek, P., 2000. Schyłkowoneolityczny pochówek na stanowisku X w Ząbiu gm. Stawiguda, pow. Olsztyn, woj. warmińsko-mazurskie. *Światowit* II (XLIII), 86-89.
- Keaveney, E. M., Reimer, P. J., 2012. Understanding the variability in freshwater radiocarbon reservoir offsets: a cautionary tale. *Journal of Archaeological Science* 39, 1306-1316.
- Kondracki, J. A., 1965. W sprawie fizycznogeograficznego podziału Europy w klasyfikacji dziesiętnej. *Przegląd Geograficzny* XXXVII(3), 539-547.
- Kośko, A., 1991. Ze studiów nad kujawską enklawą naddunajskiej cywilizacji wczesnobrązowej. *Cmentarzysko grupy Dobrego w Bożejewicach woj. Bydgoszcz, stanowisko 8*. UAM, Poznań/Inowrocław.
- Krause, W., 1997. Charales (Charophyceae). *Süßwasserflora von Mitteleuropa* 18. Spektrum Akademischer Verlag, Stuttgart.
- Krzak, Z., 1976. The Złota Culture. Zakład Narodowy im. Ossolińskich, Wrocław/Warszawa/Kraków/Gdańsk.
- Kwiatkowska, K., 1996. Bursztynowe ozdoby pradziejowe i wczesnośredniowieczne w zbiorach Muzeum Ziemi PAN w Warszawie (z katalogiem). *Prace Muzeum Ziemi* 44, 77-126.
- Lanting, J. N., van der Plicht, J., 1998. Reservoir effects and apparent ^{14}C -ages. *The Journal of Irish Archaeology* IX, 151-64.
- Larsson, L., Zagorska, I. (Eds.), 2006. Back to the origin: new research in the Mesolithic-Neolithic Zvejnieki cemetery and environment, northern Latvia. Almqvist & Wiksell International, Stockholm.
- Lasota-Moskalewska, A., 1997. Animal remains from the Neolithic settlement at Rzućewo. In: Król, D. (Ed.), *The built environment of coast areas during the Stone Age*. Regional Centre for Studies and preservation of Built Environment, Gdańsk, 162-166.
- Lekang, O.-I., 2007. *Aquaculture Engineering*. Wiley, Oxford.
- Lillie, M., Budd, C., Potekhina, I., Hedges, R., 2009. The radiocarbon reservoir effect: new evidence from the cemeteries of the middle and lower Dnieper basin, Ukraine. *Journal of Archaeological Science* 36(2), 256-264.
- Machnik, J., 1979. Krąg kulturowy ceramiki sznurowej. In: Hensel, W., Wiślański, T. (Eds.), *Prahistoria ziem polskich, t. II, Neolit*. Zakład Narodowy im. Ossolińskich, Wrocław/Warszawa/Kraków/Gdańsk, 337-411.

- Machnik, J., 1997. „Rzucewo culture” and Early Horizon of the Corded Ware. In: Król, D. (Ed.), *The built environment of coast areas during the Stone Age. Regional Centre for Studies and preservation of Built Environment*, Gdańsk, 128-134.
- Madeja, J., 2013. *Vegetation changes and human activity around Lake Łańskie (Olsztyn Lake District, NE Poland) from the mid Holocene, based on palynological study. Acta Palaeobotanica* 53(2), 235-261.
- Makarowicz, P., 2003. *The Construction of Social Structure: Bell Beakers and Trzciniec Complex in North-Eastern Part of Central Europe. Przegląd Archeologiczny* 51, 123-158.
- Makowiecki D., Van Neer W., 1996. Fish remains from the Late Neolithic site of Rzucewo (Baltic Coast, Poland). *Archaeofauna* 5, 111-119.
- Manasterski, D., 2009. *Pojezierze Mazurskie u schyłku neolitu i na początku epoki brązu w świetle zespołów typu Ząbie-Szeszno. Instytut Archeologii Uniwersytetu Warszawskiego, Warszawa.*
- Manasterski, D., 2010. *Exchanges between Syncretic Groups from the Mazury Lake District in Northeast Poland and Early Bronze Age Communities in Central Europe. Archaeologia Baltica* 13, 126-139.
- Manasterski, D., Piasecki, K., Waluś, A., 2001. *Schyłkowoneolityczny grób szkieletowy z ozdobami bursztynowymi ze stanowiska X w Ząbiu, woj. warmińsko-mazurskie. Światowit III (XLIV)*, 145-166.
- Mazurowski, R. F., 1984. *Amber treatment workshops of the Rzucewo Culture in Żuławy. Przegląd Archeologiczny* 32, 5-60.
- Mazurowski, R. F., 1987. *Nowe badania nad osadnictwem ludności kultury rzucewskiej w Suchaczu, woj. elbląskie. In: Pawłowski, A. (Ed.), Badania archeologiczne w woj. elbląskim w latach 1980-1983. Muzeum Zamkowe w Malborku, Malbork*, 141-163.
- Mazurowski, R. F., 2014. *Prahistoryczne bursztyniarstwo na Żuławach Wiślanych. Późnoneolityczne centrum pozyskiwania i obróbki bursztynu w niedźwiedziówce mikrореgionie osadniczym (3300 – 2400 l. p.n.e.). Muzeum Zamkowe w Malborku, Malbork.*
- Müller, J., 2000. *Zur Radiokarbondatierung des Jung- bis Endneolithikums und der Frühbronzezeit im Mittel-Elbe-Saale-Gebiet (4100-1500 v.Chr.). Bericht der Römisch-Germanischen Kommission* 80, 31-90.
- Olsen, J., Heinemeier, J., Lübke, H., Lüth, F., Terberger, T., 2010. *Dietary habits and freshwater reservoir effects in bones from a Neolithic NE German cemetery. Radiocarbon* 52(2), 635-644.
- Olsson, I. U., 1983. *Dating of non-terrestrial materials. In: Mook, W. G., Waterbolk, H. T. (Eds.), Proceedings of the Groningen Symposium “14C and Archaeology”. PACT 8. Rixensart, Strasbourg*, 277-294.
- Olsson, I. U. 2009. *Radiocarbon Dating History: Early Days, Questions, and Problems Met. Radiocarbon* 51(1), 1-43.
- Pawlikowski, M., Ralska-Jasiewiczowa, M., Schönborn, W., Stupnicka, E., Szeroczyńska, K., 1982. *Woryty near Gietrzwałd, Olsztyn Lake District, NE Poland – Vegetational history and lake development during the last 12 000 years. Acta Palaeobotanica* XXII(1), 85-116.
- Peška, J., 2002. *Vybrané formy eneolitických pásových zápon v Evropě. In: Cheben, I., Kuzma, I. (Eds.), Otázky neolitu a eneolitu našich krajín. Archeologický ústav Slovenskej Akadémie Vied, Nitra*, 259-281.

- Petzold, U., 2005. Artefakte aus organischem Hartmaterial aus mitteldeutschen schnurkeramischen Gräbern. Leipziger online-Beiträge zur ur- und frühgeschichtlichen Archäologie, Leipzig.
- Philippson, B., 2013. The freshwater reservoir effect in radiocarbon dating. *Heritage Science* 1(24), 1-19.
- Piliciauskas, G., 2002. Dubičių tipo gyvenvietės ir neolitinė Nemuno kultūra Pietų Lietuvoje. *Lietuvos archeologija* 23, 107-136.
- Piliciauskas, G., Lavento, M., Oinonen, M., Grizas, G., 2011. New 14C dates and early metal period ceramics in Lithuania. *Radiocarbon* 53, 629-643.
- Pospieszny, Ł., 2009. Zwyczaje pogrzebowe społeczności kultury ceramiki sznurowej w Wielkopolsce i na Kujawach. Wydawnictwo Poznańskie, Poznań.
- Pospieszny, Ł., Sobkowiak-Tabaka, I., Price, T. D., Frei, K. M., Hildebrandt-Radke, I., Kowalewska-Marszałek, H., Krenz-Niedbała, M., Osypińska, M., Stróżyk, M., Winiarska-Kabacińska, M., in preparation. Remains of a late Neolithic barrow at Kruszyn. A glimpse of ritual and everyday life in early Corded Ware societies of the Polish Lowland.
- Reitsema, L. J., 2012. Stable Carbon and Nitrogen Isotope Analysis of Human Diet Change in Prehistoric and Historic Poland. PhD thesis. Ohio State University, Columbus. Permalink: http://rave.ohiolink.edu/etdc/view?acc_num=osu1330969837
- Reitsema, L. J., Kozłowski, T., Makowiecki, D., 2013. Human–environment interactions in medieval Poland: a perspective from the analysis of faunal stable isotope ratios. *Journal of Archaeological Science* 40, 3636-3646.
- Schmidt-Thielbeer E., 1955. Ein Friedhof der frühen Bronzezeit bei Nohra, Kr. Nordhausen, *Jahresschrift für mitteldeutsche Vorgeschichte* 39, 93-114.
- Schoeninger, M. J., 1989. Prehistoric Human Diet. In: Price, T. D. (Ed.), *Chemistry of Prehistoric Human Bone*. Cambridge University Press, Cambridge, 38-67.
- Schoeninger, M. J., DeNiro, M. J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 48, 625-639.
- Schwarz, R. in press. Chronologie und Verbreitung schnurkeramischer Gruppen in Sachsen-Anhalt. In: Włodarczak, P. (Ed.), *Cordé World. Proceedings of the international conference "Cordé Days in Kraków" 1st-3rd December 2011*. Instytut Archeologii i Etnologii PAN - Komisja Prehistorii Karpát, Kraków.
- Smoter, K., Krawczewska, E., Gębka, W., Wróblewska, H., 2013. Monitoring jezior. In: Budzyńska, D. (Ed.), *Raport o stanie środowiska województwa warmińsko-mazurskiego w 2012 roku*. Wojewódzki Inspektorat Ochrony Środowiska w Olsztynie, Olsztyn, 31-61.
- Szmyt, M., 1999. Between West and East. People of the Globular Amphora Culture in Eastern Europe. *Baltic-Pontic Studies* 8. UAM, Poznań.
- Tsutaya, T., Yoneda, M., 2013. Quantitative Reconstruction of Weaning Ages in Archaeological Human Populations Using Bone Collagen Nitrogen Isotope Ratios and Approximate Bayesian Computation. *PLoS ONE* 8(8): e72327.
- van Klinken, G. J., 1999. Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. *Journal of Archaeological Science* 26(6), 687-695.
- Waluś, A., 2011. Ząbie, st. X, woj. warmińsko-mazurskie. Badania w roku 2010. *Światowit VIII (XLIX)*, 283-284.

Waluś, A., Manasterski, D., 2004. Schyłek epoki kamienia i początek epoki brązu na Warmii i Mazurach w świetle prac wykopaliskowych prowadzonych na stanowisku X w Ząbiu, gm. Stawiguda, woj. warmińsko-mazurskie. In: Hoffmann, M. J., Sobieraj, J. (Eds.), Pruthenia Antiqua. Studia do pradziejów i wczesnej historii ziem pruskich, vol. I. Człowiek a środowisko w epoce brązu i wczesnej epoce żelaza u południowo-wschodnich pobrzeży Bałtyku. SNAP, Olsztyn, 33-54.

Zagorska, I., 2006. Radiocarbon chronology of the Zvejnieki burials. In: Larsson, L., Zagorska, I. (Eds.), Back to the origin: new research in the Mesolithic-Neolithic Zvejnieki locumetery and environment, northern Latvia. Almqvist & Wiksell International, Stockholm, 91-113.