CHAPTER NINE

A RADIOCARBON DATABASE FOR THE MESOLITHIC AND EARLY NEOLITHIC IN NORTHWEST EUROPE

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Abstract

We have collated an extensive regional radiocarbon database for the Mesolithic and Early Neolithic in Northwest Europe in the age range 10,000 to 4000 yrs ^{14}C-BP (i.e. 11.7 ka calBP to 5000 calBP). The database contains more than 4100 individual ^{14}C-ages (each defined by its specific laboratory code), and which are derived from c. 1000 different archaeological sites. The database is fully (95%) georeferenced and covers the countries Belgium, Denmark, England/Wales, Ireland, the Netherlands, and Scotland.

Résumé

Nous avons collationné une banque de données de datations au radiocarbone d'une région extensive pour le Mésolithique et le Néolithique ancien au nord-ouest de l'Europe. Il s'agit de la période de 10 000 à 4000 ^{14}C-BP (c'est-à-dire 11.7 ka cal BP à 5000 cal BP). La banque de données contient plus de 4100 datations individuelles au radiocarbone (chacune définie par son code spécifique de *laboratoire), et elles sont dérivées d'environ mille sites archéologiques différents. La banque de données est presque complètement (95%) géoréférencée et couvre la Belgique, le Danemark, l'Angleterre, le pays de Galles, l'Irlande, les Pays-Bas et l'Ecosse.*

Keywords: *Mesolithic, Early Neolithic, radiocarbon dating, database, Northwest Europe, demography*
Mots-clés: *Mésolithique, Néolithique ancien, datation au radiocarbone, banque de données, nord-ouest de l'Europe, démographie*

1. Introduction

This paper describes the design and contents of an extensive regional radiocarbon database that was collated for archaeological research on the Mesolithic and Early Neolithic of Northwest Europe. The database is fully (95%) georeferenced and covers the countries Belgium, Denmark, England/Wales, Ireland, the Netherlands and Scotland. It has been specifically constructed for research into prehistoric demography and cultural transmission. In its stand-alone version, the database (xls-format) has public access from the web. The database is also available as a component of the Cologne Radiocarbon Calibration Software 'CalPal'. In the following, we first provide a technical description of the radiometric and archaeological variables used in the database, and then describe its contents, in terms of major temporal and geographic patterns, according to the different countries. Since the database is purposely constructed for research in prehistoric demography, we undertake efforts in identifying as many as possible of the biasing factors that may, or may not, influence the demographic hypotheses that are generated from the spatio-temporal ^{14}C-distributions. As discussed below, external factors such as research goals and dating programs have considerable influence on the temporal and regional availability of ^{14}C-data for all countries under study.

2. Database variables

All dates are entered in the database (Excel-format) according to a standardised set of variables, which are described in the following. Note that during data entry a number of (optional) synonyms and translations are used, in order to reduce the number of variables. These synonyms are compiled in table 9-1 In general terms, the database is designed to exclusively cover archaeological radiocarbon data, which are defined such that for each sample, to be allowed entry, some kind of human activity may be distinguished. The requested human influence can be clearly identifiable, for example, for an age measured on charred hazelnut shells from a hearth-pit. However, the requested human influence is often less clear e.g. for peat cores with AMS-ages measured on hazelnut pollen, in which case the hu-

	Material	**Species**	**Comments**
seeds	seed		no information in plural
well preserved bones	bone		"well preserved" does not effect material
animal bone from pit	bone		superfluous information "animal" and "pit"
worked human bone	bone	human	superfluous information "worked"
charred wood	charcoal		use default material "charcoal"
charred wood and twigs	charcoal		use default (longlived) material "charcoal"
plants	organic		use default material "organic"
humic material	organic		use default material "organic"
organic residue	organic		use default material "organic"
food remains	charcoal	food crust	use species "food crust"
charred food remains	charcoal	food crust	use species "food crust"
menschlicher Schädel	bone	human	translation from German to English
potsherd residue	charcoal	food crust	use species "food crust"
bone, carbonate	carbonate		maybe defect date, use "carbonate" or delete
mud	soil		no loss of information
soil carbonate	carbonate		use default material "carbonate"
cattle	bone	*bos*	use Latin as default database language
reindeer bones and antlers	bone	*rangifer*	remove "antler"
leg bone of cow	bone	*bos*	superfluous information "leg"
reindeer bones	bone	*rangifer*	no loss of information
black horse (cave painting)	organic		use default material "organic"
charcoal and bone	charcoal		select lower information level
charred hazelnuts	charcoal	hazelnut	We differentiate for short-lived hazelnut shells
charred hazel wood	charcoal	hazel	and long-lived charred

Table 9-1: Synonyms used for MATERIAL.

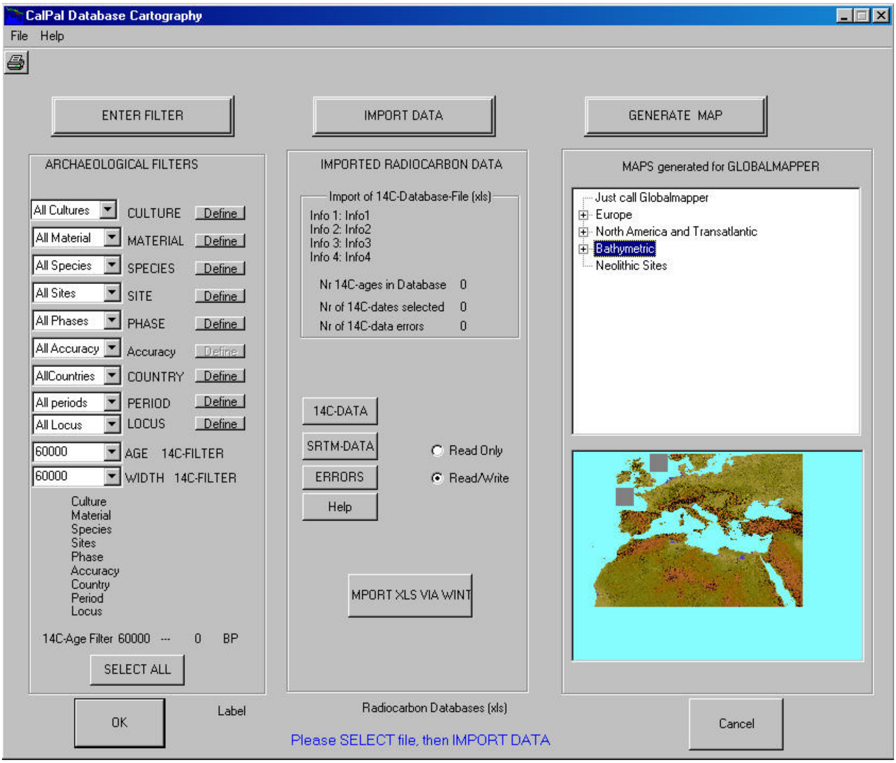

Fig. 9-1: CalPal-program dialog for radiocarbon database import.

man influence may (or may not) be the result of active Mesolithic forest management. As a rule, for all such critical cases (with indeterminate decision on human impact), the relevant radiocarbon ages would either not be included in the database, or else identified as "environmental" under the variable CULTURE (cf. below). Note that the database is designed to be open, with given restrictions, to the majority of archaeological dates. Technically defect dates are excluded from the database. The following synonyms are used to reduce the number of variables covered by Material and Species, by deleting redundant information and applying coded translations:

Laboratory Code: LABNR

A sample specific identifier, typically the code name applied to the measured ^{14}C-age by the responsible laboratory. Dates with missing laboratory code are generally not entered in the database (see below: REFERENCE).

Radiocarbon Age BP: C14AGE

Conventional Radiocarbon Age, as quoted by the laboratory, including all secondary corrections and adjustments. To simplify the ^{14}C-age calibration procedure, it is advisable to adjust all entered ^{14}C-ages on marine or lacustrine samples (e.g. shells, fish) to the atmospheric ^{14}C-level. In the case of marine samples, this will typically simply involve subtraction of 400 ^{14}C-yrs from the quoted ^{14}C-age, but in other cases (cf. Isotopic Fractionation) the exact entry of Radiocarbon Age may not be as trivial. For the purposes of using the database along with the CalPal age-calibration software, all ^{14}C-age entries should be referenced to atmospheric ^{14}C-level. In this case potential data-specific switches between atmospheric and marine radiocarbon calibration curves are automatically avoided.

Radiocarbon Error: C14STD

Error term for the Conventional Radiocarbon Age, as quoted by the laboratory, including all secondary corrections and adjustments. Dates with missing errors are generally not entered in the database (see below: REFERENCE), and cannot be processed by the CalPal-program.

Isotopic Fractionation: 13C

In calculation of conventional radiocarbon ages, allowance is made for the natural isotopic fractionation that occurs during assimilation and biochemical fixation of carbon. This fractionation is a complicated function of temperature and metabolic pathway, and mainly depends on differences in the atomic mass of the carbon isotopes involved (^{14}C, ^{13}C, ^{12}C). For simplicity, the (unknown) mass fractionation of ^{14}C in relation to ^{12}C is assumed to be twice as large as the fractionation between ^{13}C and ^{12}C, which can be measured (or at least estimated) to achieve the requested correction of the raw ^{14}C-age. Measured corrections are given in terms of the deviation of the measured sample ^{13}C/^{12}C-value in relation to the ^{13}C/^{12}C-value of a standard limestone sample known as PDB (*Belemnata americana*). Typical δ^{13}C-values range from 0‰ for marine samples (shell) to -30‰ (peat), giving an overall correction range of 480 ^{14}C-yrs. Human and animal bones have values c. -20‰. Caution is advisable for measured δ^{13}C-values on human (or animal) bone in the range -12‰ to 16‰, in which a strong marine component in diet can be assumed. The marine reservoir effect will generally have an upper value of 400 ^{14}C-yrs, as would apply to a theoretical 100% marine diet. However, especially in Mesolithic studies, we should remain aware of the fact that ^{14}C-ages on food residues (e.g pottery) can be influenced to even higher values by the freshwater reservoir effect, stemming from cooked fish and molluscs that lived in inland lakes, streams and rivers (Cook et al. 2001; Fischer and Heinemeier 2003; see also in this volume Cook et al.; Boudin, Van Strydonck and Crombé). Due to the complexity and magnitude of the freshwater correction effect, such dates require dedicated studies. Typical archaeological radiocarbon ages, as entered in the database, will have been measured on wood charcoal, with δ^{13}C-values in the range of - 25‰. When the database is used in connection with the calibration software CalPal, the entry (or omission) of this variable has no effect on numeric age-calibration results.

Material: MATERIAL (Table 9-2)

Most common sample materials in the database are charcoal, bone, wood and shell.

Species: SPECIES

The "species" variable is defined to achieve more detail than available under "material" but which can be taken as reference. Typical entries are e.g. *quercus*, *bos*, *human*, *hazelnut*. Please observe that, to support manual data entry, we purposely avoid upper-case lettering. Please also note the pairwise relationship between the MATERIAL and SPECIES data entry (e.g. wood-*quercu*s, bone-*human*, charcoal-*hazel*).

Material	**N dates**	**%**
charcoal	2092	50,4
bone	706	17
wood	277	6,6
shell	171	4,1
antler	109	2,6
soil	29	0,7
carbonate	2	0
other	396	9,5
unknown	368	8,8
Total	**4144**	**99,70%**

Table 9-2: ^{14}C-Data counted under MATERIAL .

Country	N dates	%-georef	N sites	Major Data Sources
England/ Wales	787	99%=777	219	Oxford-Lab Lists, Bayliss and Whittle (2007), CBA-Lists
Netherlands	744	84%=626	211	Niekus (2005/2006),
				Lanting and van der Plicht (1995/1996; 1997/1998; 1999/2000)
Germany	521	97%=508	67	Cologne-Lab, Furholt et al. 2002
Belgium	492	97%=479	92	Vanraes (2002), Van Strydonck and Crombé (2007), RC Journal
Scotland	475	96%=455	119	Ashmore (2004b), CBA-Lists
Denmark	471	73%=346	145	Radiocarbon Journal
Ireland	227	99%=226	59	CBA-Lists
France	226	100%=226	94	Incomplete
Sweden	161	100%=161	24	Incomplete
Luxembourg	10	40%=4	3	Ingrid Koch (Universität zu Köln)
Total	**4114**	**94,9%= 3808**	**1033**	

Table 9-3: ^{14}C-Data counted under COUNTRY.

Country: COUNTRY (Table 9-3)

Based on modern political borders.

Site Name: SITE

This entry contains the name of the archaeological site, or other description (e.g. town) allowing the geographic position of the dated sample to be identified.

Period: PERIOD

Typical archaeological periods, as contained in the database, are Palaeolithic, Mesolithic and Neolithic.

Culture: CULTURE

Typical archaeological cultures, as contained in the database, are Maglemose, Ertebølle, Michelsberg, Swifterbant and Linearbandkeramik. Certain dates may be assigned as "environmental".

Phase: PHASE

The majority of entries for this variable remain under construction, but its intent is to allow the more detailed study of "culture-specific" entities, in which case typical entries would be e.g. Early, Middle, Late, Michelsberg III and Troy VI.

Locus: LOCUS

The majority of entries for this variable remain under construction, but its intent is to allow the more detailed study of "site-specific and/or architectural" entities, in which case typical entries would be e.g. hearth, pit , grave, living floor, building construction, fill, hoard, enclosure, without context. When used in context with the CalPal software, the requested data would be available by applying a double SQL-filter. The first filter would select all dates from the requested e.g. Troia). The second filter would then select on the reduced number of dates, from this site, with requested LOCUS.

Latitude: LATITUDE

Geographic site coordinates are entered for in WGS84 (World Geodetic System) with four significant figures. Typical entries have a geographic resolution of 3km.

Longitude: LONGITUDE

Geographic site coordinates are entered in WGS84 (World Geodetic System) with four significant figures. In this reference system, archaeological sites situated East of the Greenwich meridian have positive WGS84 longitude values. Sites to the West of Greenwich have negative longitude. Typical entries have a geographic resolution of 3km.

Reference: REFERENCE

This variable contains only the main bibliographic reference for each radiocarbon date. For simplicity we avoid multiple citations and cross-references.

First preference is given to the original (earliest) publication, if available, otherwise we quote the actual data source. In an ideal case, this entry will cover the sample submitter, as well as the scientific journal in which the date was first published. Many dates, however, are not formally published, and there exist many cases when secondary (or higher order) references e.g. "personal communication" are necessary. The minimal required reference for any data entry is its actual source. Due to the large amount of data under study, our preferred minimal reference is an external database. We enforce the view that data with missing laboratory codes and/or missing references have non-scientific character, similar to radiocarbon ages with missing standard errors (which cannot be processed in the CalPal-program package, due to division by 0). Such "dates" should not be included in the database. There are exceptions to this rule.

3. Radiocarbon data processing

A description of the methods used in radiocarbon processing, for which we use the CalPal Radiocarbon Calibration Program, is given in Weninger (1986) and Weninger and Jöris (2004). For the purposes of the present studies we have reworked the dialog for database import and site mapping. The revised dialog for import of radiocarbon data stored in xls-format data is shown in figure 1. During import, filters can be applied on the text variables as defined above (Material, Species, Country, Site, Period, Phase, Locus), as well as on numeric variables (Radiocarbon Age, Radiocarbon Error). The filtered data are stored to file for further processing. This will typically include the construction of cumulative calibrated probability distributions, as well as mapping. The possibility of quick import and efficient processing of large numbers of ^{14}C-ages from an external database, as supported by the new dialog, is associated with a significant geographic widening of research possibilities. Consequently, we have equipped CalPal with a new interface for data-output to the external commercial cartographic software Globalmapper, and have integrated a large number of prefabricated high-resolution 3D-SRTM maps both for the NW-European countries under study, as well as for other European, Mediterranean and Near Eastern regions. The availability of these maps, and the possibility of rapid cartographic radiocarbon data processing, is crucial for demographic and cultural studies with the large numbers of available high-quality radiocarbon data. The amounts of radiocarbon data are likely to undergo further major if not dramatic increases, in the near future, due to prevailing multi-year backlogs in data publication and the increasingly widespread application of ^{14}C-AMS technology in archaeology, during these recent years.

4. The database: general description

It is instructive to begin by viewing the database-inventory according to Country. This variable holds promise to give the most immediate insight into the factors that have influence on data availability. As shown in table 9-2, the largest amount of data is available for England (N=787), closely followed by the Netherlands (N=744). This is clearly the impact of the two major laboratories operating in these countries (GB-Oxford with Lab-code OxA; NL-Groningen with Lab-codes GrN and GrA). For the other countries (Belgium, Denmark, Germany, Scotland) there are less data available, although nevertheless in the range N=500. For Ireland (N=227) there are somewhat fewer dates available, but with an active major laboratory at Belfast (Lab code UB), this is likely to be the result of the presently still incomplete data collection. Another relevant factor is that Belfast until recently ran high-precision conventional dates, with correspondingly limited sample throughput. This situation is set to change with the opening in 2006 of the new ^{14}CHRONO AMS facility. We judge that the overall degree of database completeness, for all these countries (Belgium, Denmark, England/Wales, Ireland, the Netherlands, and Scotland) is compatible. In comparison, the small amount of data from Sweden (N=161) and France (N=226) is readily explained by our present incomplete work. This also applies to Germany (N=521), for which country the present database essentially only covers dates run at the Cologne radiocarbon laboratory (Lab code KN). Larger amounts of data can be expected for Germany, when more results of the laboratories at Berlin (Lab code Bln), Hannover (Lab code Hv), Heidelberg (Lab code Hd), and Kiel (Lab Code Ki) become available.

Material	Dk	G	GB	Scot	Eire	NL	B	Total
charcoal	194	159	215	291	162	611	334	1966
bone	68	80	312	67	30	29	44	630
wood	68	104	32	13	5	25	19	266
shell	104	0	4	40	4	1	0	153
antler	2	2	54	9	0	4	35	106
soil	0	0	4	40	5	0	0	49
carbonate	0	1	17	1	0	0	1	20
other	24	80	146	3	14	26	55	348
unknown	13	95	3	17	7	48	4	187 (4.5%)
Total	**471**	**521**	**787**	**475**	**227**	**744**	**492**	**3717**

Table 9-4: ^{14}C-Data counted under COUNTRY AND MATERIAL.

Species	Dk	G	GB	Scot	Eire	NL	B	Total
charcoal/wood								
quercus	34	6	22	53	0	23	5	**143**
pinus	15	0	11	5	0	49	23	**103**
alnus	8	0	1	2	1	3	0	**15**
salix	1	0	2	0	1	0	0	**4**
bone								
red deer	3	8	60	17	0	7	0	**95**
aurochs	1	0	1	0	0	7	0	**9**
rangifer	0	1	2	0	0	0	0	**3**
human	10	14	206	23	20	2	23	**298**
bos	0	0	26	1	1	0	0	**28**
Species known	72	29	331	101	23	91	51	**698 (18,78%)**
Species unknown	221	478	107	145	194	629	303	**3019 (81.22 %)**
Total	**293**	**507**	**438**	**246**	**217**	**720**	**354**	**3717 (100%)**

Table 9-5: ^{14}C-Data counted under SPECIES.

The available data is further arranged according to Country/Material (Table 9-4) and Country/Species (Table 9-5). From table 9-4 it becomes clear that the majority of dates are measured on (longlived) charcoal samples, as can be expected. The exception is for Great Britain, where there is a clear preference to process (shortlived) bone dates. It is further interesting to note that the majority of dates on marine and terrestrial shells, as contained in the database (N=171), are from Denmark (N=104) and Scotland (N=40). This is a natural result, since, in both countries such dates derive from the omnipresent coastal shell middens. In contrast, we would not expect any large number of dates on marine shells from the Netherlands and Belgium, and the database statistics confirms this expectation. By the same token, shell dates from Ireland would appear to be underrepresented. In part this may be due to the general wide availability of alternative sample materials, and is likely also due to concerns over reliability for shell dates, and the corrections needed for reservoir effects. An interesting example for such sampling focus is given by Ashmore (2004a), who mentions that - in Scotland - it is quite common for archaeologists to choose (shortlived) hazelnut shells in the 5th millennium calBC and earlier sites, but barley for dates in the 4th and later millennia (for comparable examples, see Crombé, Van Strydonck and Boudin, this volume). Ultimately, this sample selection is caused by the efforts undertaken in education of archaeologists, to provide single entity dates (Ashmore 2004b). In consequence, we must be cautious in the interpretation even of large datasets, for which we might expect the statistical laws of "large numbers" to be applicable. Such a widespread sampling bias may be most effective in producing large interpretational mistakes.

Further information on the influence of dedicated research, as well as research preferences, can be extracted from table 9-5, where the data are arranged according to Country/Species. The main conclusion, now, is that only a very small proportion of all dated materials (charcoal, bone, shell, wood etc) has been further analysed onto species-level (e.g. wood species, animal species), prior to ^{14}C-measurement. This shows up in the general statistics as well as in many details. For example, whereas the dated sample material is known for over c. 90% of all dates (Table 9-3), the species level is only reached for c. 40% of the dates (Table 9-5). As a rule, it is for dates from the British Isles that we have the overall best knowledge of the properties of individual samples, on all levels.

5. The database: description by country

In figures 9-2 and 9-3 we focus on the temporal distribution of the ^{14}C-ages, arranged by country. Figure 9-2 shows more or less the entire database (excluding the incomplete data from Germany, Sweden and France), according to country (from top to bottom): Denmark (N=471 dates), the Netherlands (N=744), Belgium (N=492), Ireland (N=227), Scotland (N=475), and England (N=787) in the age-range 11-4 ka calBP. Figure 9-3 shows the same data, with ages younger than 7 ka calBP now omitted, and with different Y-scaling, purposely chosen in order to zoom closer onto the Mesolithic component of the database.

5.1 England/Wales

England/Wales provides the largest dataset, with 787 ^{14}C determinations. There has been a strong excavation and dating bias towards the various monuments of the Early Neolithic (long barrows, chambered tombs, causewayed enclosures – these site-types are also highly visible archaeologically) such that this period, c. 6000-5000 calBP, is very well-represented. The initial appearance of the Neolithic at c. 6000 calBP is followed by a marked increase in the number of dates, many of which are new high-quality dates on human bone from mortuary monuments, taken for the purposes of Bayesian modelling (Bayliss and Whittle 2007). Mesolithic sites are often surface flint scatters that do not lend themselves to dating programmes, and most coastal sites of the period have been inundated by rising sea levels. As with Belgium, there is a broad peak in the earlier Mesolithic (Fig. 9-3, c. 11-9 ka calBP), that is partly the result of a focus of research interest, combined with particularly well-studied sites (e.g. Star Carr: Mellars and Dark 1998), and partly the result of the presence of human remains from caves that have been a preferred dating material (Schulting 2005; Schulting and Richards 2002). An earlier period of rapidly rising sea levels has been postulated to be a possible cause of the presence of a number of burial sites in the Mendip Hills of southwest England, an area that would have been affected by land loss across what became the Bristol Channel (Schulting 2005). In terms of the 8.2 ka climate event, there seems little to indicate its impact at present, though Barton and Roberts (2004) note a sudden shift to very small microliths near this juncture. But, given the scale of the loss of land in the North Sea, and the probability of the rapid nature of the inundation, it is reasonable to expect a significant re-distribution of population. What is required is a dedicated programme of research within the most affected area, i.e. the stretch of eastern coastline from Humberside to Kent. Much of this area has low archaeological visibility due to the burial of the mid-Holocene land surfaces, e.g. by peats and alluvium.

5.2 Ireland

The database for Ireland comprises a relatively small number of determinations (227), though some 30 new dates from the Neolithic passage tomb at Tara are not yet included (Brindley, Lanting and van der Plicht 2005). The inclusion of the Tara data, as well as other as yet unpublished determinations from a number of court tombs (Schulting et al., in prep.), would result in a pattern more similar to that seen for England/Wales, of an increase at c. 6000 calBP, coterminous with the onset of the Neolithic. Again, however, the interpretation of this in terms of population demographics is made difficult by the far higher archaeological visibility of Neolithic monuments, and the research attention that they have received. It should also be noted here that a number of the dates in the range c. 6700-6000 calBP are problematic and do not appear to date the human activity represented by these (Neolithic) sites, particularly those from Ballynagilly and Carrowmore. But a strong Late Mesolithic presence at this time is indicated by good series of dates from other sites (e.g. Ferriter's Cove, Newferry) (Woodman and Andersen 1990). Nevertheless, overall, it is possible that population densities in Ireland were comparatively low in the Mesolithic, due to the impoverished fauna there (Woodman, McCarthy and Monaghan 1997; see also Woodman, this volume). As a result of the deeper waters around the coast of much of Ireland, land losses would have been experienced at a significantly earlier date than the inundation of Doggerland, and given its distance from the North Sea, this event would not be expected to have any direct impact.

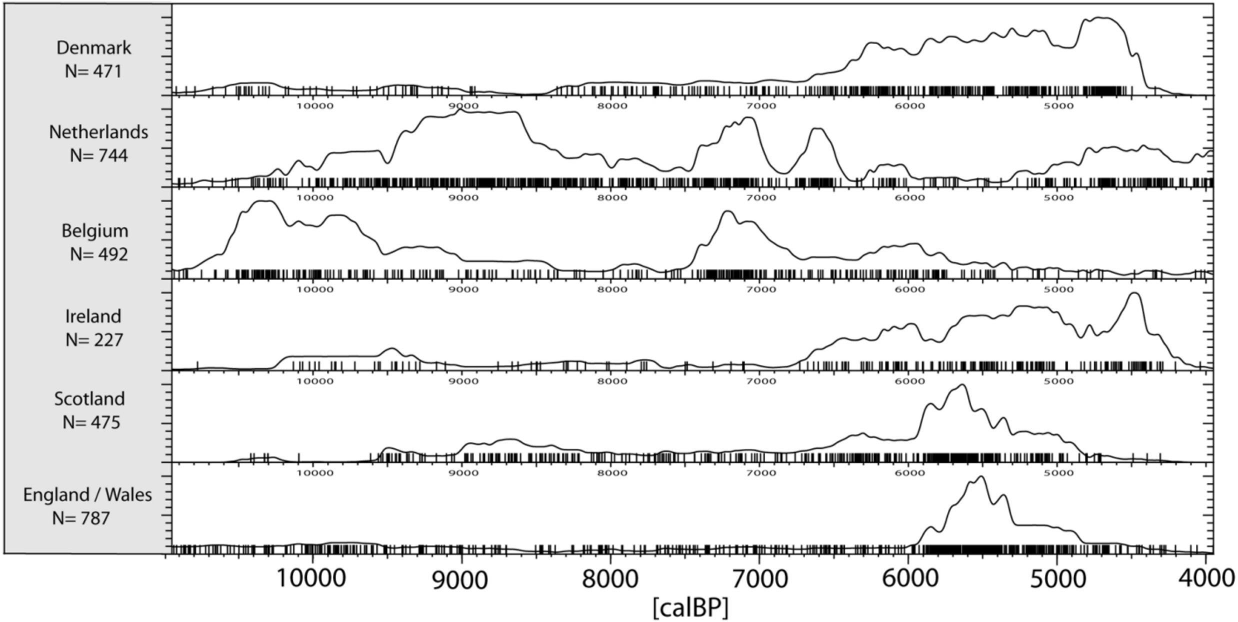

Fig. 9-2: Cumulative calibrated radiocarbon age distributions for selected countries from the NW-European Mesolithic-Neolithic database, in the age-range 11-4 ka calBP.

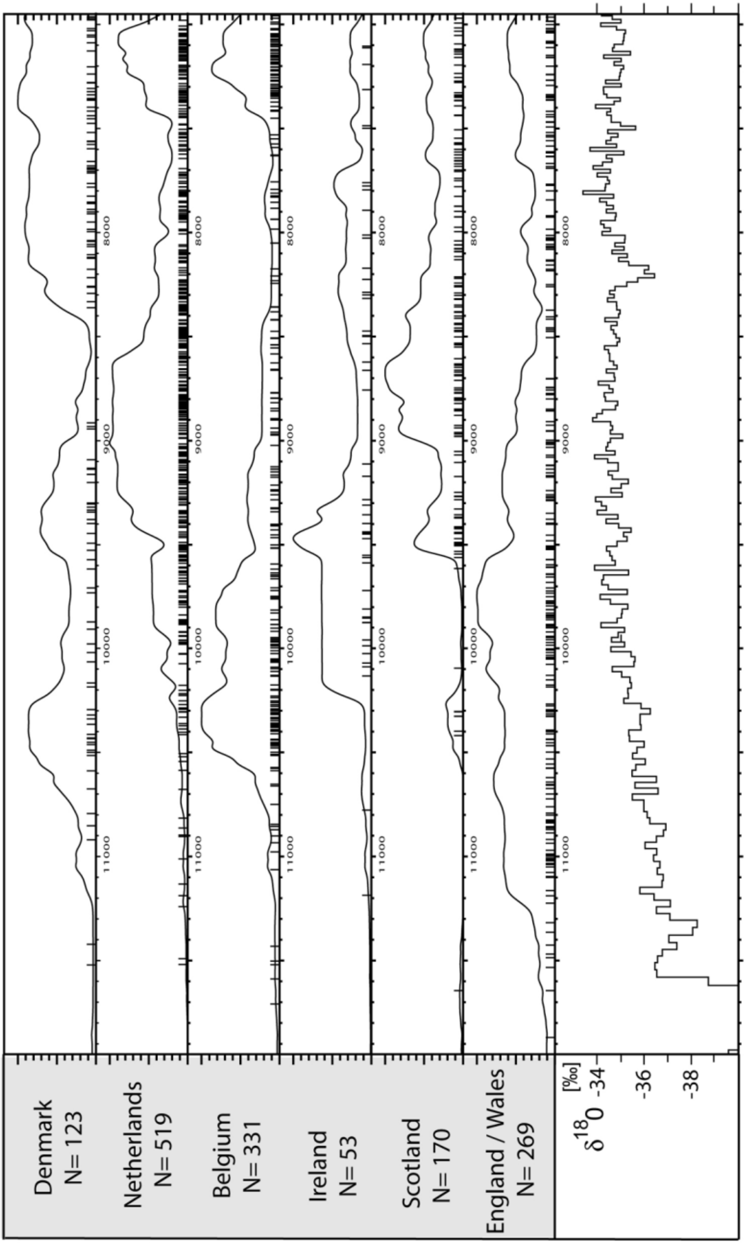

Fig. 9-3: Cumulative calibrated radiocarbon age distributions for selected countries from the NW-European Mesolithic-Neolithic Database, in the age-range 12-7 ka calBP (database filter set for 11-5 ka ^{14}C-BP).

5.3 Scotland

The Scottish database comprises 475 determinations. As for England/Wales and Ireland, one of the more notable trends is a marked increase in dates with the appearance of the Neolithic at c. 6000 calBP (Fig. 9-2). The immediately preceding Late Mesolithic is also well represented, primarily by dates from the shell middens of Oronsay on the west coast (Mellars 1987), and Morton on the east coast (Coles 1971). Though not linked directly to Doggerland, but perhaps following similar responses, sea-level rises throughout the Holocene may have had a substantial influence on the distribution of Mesolithic populations on the west coast, through the loss of land and the concomitant appearance of island groups. Stable isotope data from Cnoc Coig on Oronsay shows that by the Late Mesolithic settlement and subsistence were basically focussed on the coast year-round (Richards and Mellars 1998), with the suggestion of a strong sense of territoriality. The main impact of the inundation of Doggerland, and any resulting population re-distribution, will have been felt further south, particularly along the eastern shores of England.

5.4 Denmark

The picture for Denmark (Fig. 9-2) is that of a more-or-less steadily rising ^{14}C-population, all the way through the time-window under study (10-4 ka calBP). The general lack of radiocarbon dated Maglemose sites (ages older than 8500 calBP), in comparison to Ertebølle sites (ages younger than 8000 calBP) may be explained by rising sea-levels and corresponding flooding of sites, or loss in site visibility. The data set appears too small to support further conclusions, in terms of ^{14}C-based demography.

5.5 Belgium

The database for Belgium consists of 492 dates, with temporal distribution as shown in figures 9-2 and 9-3. The data from Belgium show two conspicuous peaks: a first between 10,500 and 9500 calBP and a second between 7500 and 6700 calBP. The sharp onset of both peaks is indicative for the availability of a series of unusually well-measured sets of radiocarbon samples. This is confirmed by a quick look into the database, following which the first data peak is clearly seen as caused by a strong focus towards dating of Early Mesolithic sites, especially in the north-western part of Belgium (Van Strydonck, Crombé and Maes 2001; Van Strydonck & Crombé 2005; see also Crombé, Van Strydonck and Boudin, this volume). The second peak coincides with the Early Neolithic LBK culture and related *groupe de Blicquy* from the loess area of Middle Belgium, which - compared to younger Neolithic cultures - have been dated (and excavated) much more intensively (Jadin 2003). Hence, the sum probability curve from the Belgian dates is strongly biased and certainly cannot be used for palaeodemographic purposes.

Concerning the Mesolithic, a recent analysis of the data available for NW Belgium (Crombé, Perdaen and Sergant 2008) has clearly shown a marked decrease in the number of sites from the mid Boreal till the Final Mesolithic, which coincides with a shift in site distribution from random to clustered (mainly along river valleys and wetlands). Rather than interpreting this as an indication of a reduced human population, however, this more likely reflects major changes in mobility induced by environmental changes (transition from open coniferous forest to dense deciduous forest) and/or social changes (decreasing territoriality and social competition).

5.6 The Netherlands

Following a careful screening of over 550 radiometric data, a set of 426 georeferenced and reliable ^{14}C-ages for the Mesolithic in the northern part of the Netherlands, i.e. above the river Rhine, was recently published (Niekus 2005/2006). This dataset, for which most of the dates are from the Groningen radiocarbon laboratory (Lab Codes: GrN, GrA), represents the backbone to the present Mesolithic database for the Netherlands, and which has been extended to cover the Early Swifterbant culture. However, since the present palaeodemographic studies relieve tension on the archaeological quality of the data to be accumulated, we have added a second large set of previously published Groningen data for this period (Lanting and van der Plicht 1995/1996; 1997/1998; 1999/2000), including dates from the southern part of the Netherlands. Put together, the present database for the Netherlands consists of N=744 dates, of which the majority (84%) are georeferenced (Table 9-2).

Of special interest for Mesolithic palaeodemography in Northwestern Europe is the existence of a major demise in the number of ^{14}C-dates available from the Netherlands round 8600 calBP. This demise was described by Niekus (2005/2006), using a ^{14}C-database containing carefully selected archaeologically samples. For the purposes of the new ^{14}C-database, as described in the present paper, we have loosened the quality selection criteria. As shown in figure 9-2, and equally well recognisable in figure 9-3, the demise appears again in the new database, the largest yet available. According to the elaborate studies undertaken by Niekus (2005/2006) to understand the availability of ^{14}C-data from the different regions of the Netherlands, and further studies by Raemaekers and Niekus described in this volume, it is conspicuous that the higher Pleistocene areas of the Northern Netherlands appear to be most strongly affected. This patterning was already observed by Waterbolk (1985), who undertook considerable effort in studying possible environmental reasons, and notably whether rising sea levels could have caused a shift in population from the higher Pleistocene grounds in the northern and eastern part of the country to the more low-lying landscapes in the western part. Following the abrupt drop in ^{14}C-data at 8600 calBP (Fig. 9-3), and which is also observed in the number of dated sites (Table 9-6 right column), the demise continues until 7500 calBP. It is followed by a clearly visible data peak centred on 7200 calBP during the final part of the Late Mesolithic, just prior to the beginning of the Swifterbant culture. If we focus on the period 8500-7500 calBP, the scarcity of dates in the western part of the Netherlands (provinces *Noord- and Zuid-Holland*) and in the coastal areas of Friesland and Groningen can be explained by the gradual drowning of these areas as a result of rising sea level (Niekus 2005/2006). As concluded by Raemaekers and Niekus (this volume), however, it is not only that the rapidly rising sea level restricts the visibility of sites in the low-lying coastal regions during this period. In the interior regions of the Netherlands, the sea level rise is associated with a correspondingly higher ground water level, which leads to enhanced peat growth. Both these effects - flooding of low-lying settlement areas and peat-coverage of higher areas - appear responsible for the strongly diminishing number of dates during the time-window. The problem is, as such, that we cannot clearly differentiate between a diminished number of settlements, and their diminished visibility.

Niekus (2005/2006) concludes, quite critically towards using the "dates-as-data" method for palaeodemographic studies, at least in the Netherlands, that neither traditional site-counts nor numbers of ^{14}C-dates alone seem suitable for estimating relative population densities. Indeed, in many cases the availability of ^{14}C-dates is more likely to reflect the population of Stone Age archaeologists working in a particular area (ibid. 80). Nevertheless, the problem remains that - by the same token - we cannot simply reject the hypothesis of population fluctuations due to rapid sea level rise. We can equally imagine a population decrease, caused by loss of settlement areas, as well as a population increase, due to an influx of people from the drowning North Sea basin. These questions call out for more detailed archaeological, environmental and geoarchaeological research.

5.7 Germany

It is important to note that, although seemingly large (N=521 dates), the Mesolithic ^{14}C-database for Germany is largely incomplete, due to our focus on the circum-North Sea regions. Only in certain cases does the database cover South

German sites (e.g. the five ^{14}C-dated Mesolithic burials in the Ofnet Cave (OxA-1571-1575, all dating close to 8200 calBP). As for North Germany, there is a further strong bias towards selected sites (e.g. Friesack, Siggeneben, Bebensee) and this bias is especially notable for the site of Rosenhof in Schleswig Holstein (Kalis and Meurers-Balke 2005), for which the Köln Radiocarbon Laboratory (Lab Code KN) has supplied N=221 dates (i.e. 42 % of the total data for Germany).

However, even allowing for such selective data collection, there remains a major blank area on the site maps, for all periods (Fig. 9-6 and 9-7), between the northern Netherlands and Denmark. The obvious reason for this blank area is the almost totally lacking Mesolithic research in the coastal regions of Lower Saxony (Joachim Eckhart, pers. comm. 2007). But there may exist a more subtle reason for the lack of sites. This region contains the largest number of bogs in Germany, the location and formation of which have been studied systematically during the German priority programme "Changes of the Geo-Biosphere" (e.g. Gerdes, Petzelberger and Scholz-Böttcher 2003; Behre 2005). According to results presented by Gerdes, Petzelberger and Scholz-Böttcher (2003), about 50% of the bogs of Lower Saxony consist of raised bog peat, the formation of which is closely related to high levels of precipitation. Totally different conditions are characteristic for the 50% fen peat formation, which in closely related to groundwater levels. A remarkable detail, in terms of the relation between archaeological site visibility, peat growth and rising sea-levels, is obtained for fen bogs on the Oldenburg-Ostfriesland ridge (i.e. within 100 km of the present North German coastline). Here, an unexpectedly abrupt onset of peat growth is observed c. 8000 calBP (Gerdes et al. 2003, Fig. 9-11).This is the very moment the global sea-level first reaches modern levels, with subsequently much less drastic sea-level oscillations. Since similar conditions can be expected for the adjacent coastal regions in the Northern Netherlands, these observations provide strong support for the observations made above (cf. Raemaekers and Niekus, this volume), concerning the visibility of Mesolithic sites in the Northern Netherlands.

The observation that archaeological sites can be quite effectively hidden from view, when overgrown by peat, is also clearly apparent for sites situated much further inland. A good example is Duvensee, situated today c. 36 km from the coast in Schleswig-Holstein, where extensive excavations have uncovered a series of Mesolithic 'Wohnplätze' (Schwantes, Gripp and Beyle 1925; Bokelmann 1991, 1995; Bokelmann, Averdieck and Willkomm 1981), a number of which specialised in hazelnut roasting (Holst 2007). The sites were arranged along the northwestern edge of a small lake, and were apparently in use at different times during the Early Holocene, as shown by the ^{14}C-ages (Tab. 9-6). It is interesting to observe that - quite similar to the Netherlands - the North edge of the Duvensee shows a clear de-

Lab-Code	Site	Material	$\delta^{13}C$ (‰	^{14}C-age
KI-1883.01	WP 1	charcoal	-23,80	9200 ± 160
KI-1883.02	WP1	hazelnut shell	-23,90	9170 ± 120
H-431/379	WP 1	hazelnut shell	n.d.	9095 ± 170
KI-1884.01	WP 2	charcoal	-24,40	9420 ± 130
KI-1884.02	WP 2	hazelnut shell	-25,50	9280 ± 100
KI-1111	WP 6	hazelnut shell	-22,30	9100 ± 130
KI-1112	WP 6	hazelnut shell	-23,20	8840 ± 110
KI-1113	WP 6	hazelnut shell	-23,50	9090 ± 130
KI-1818	WP 8	birchbark mat	-25,40	9640 ± 100
KI-1819	WP 8	birchbark mat	-26,70	9410 ± 110
KI-1885.01	WP 8	hazelnut shell	-24,80	9420 ± 130
KI-1885.03	WP 8	charcoal	-23,90	9440 ± 130
KI-3041	WP 9	charcoal	n.d	9590 ± 90
KI-3042	WP 9	charcoal	n.d.	9380 ± 80
KI-3043	WP 9	charcoal	n.d.	9600 ± 90
KI-3044	WP 9	charcoal	n.d.	9440 ± 80
KI-2125	WP 13	charcoal	-25,85	8630 ± 160
KI-2126	WP 13	charcoal	-25,97	8700 ± 80
KI-2378	WP 13	charcoal	-25,40	8740 ± 85
KI-2128	WP 13(b)	burnt bark from fireplace	-27,48	7950 ± 75
KI-2731	WP 19	charcoal	n.d.	8040 ± 80
KI-2734	WP 19	charcoal	n.d	7970 ± 90
KI-2737	WP 19	wood from fireplace	n.d.	7840 ± 70
KI-2738	WP 19	wood from fireplace	n.d.	7840 ± 120
KI-2739	WP 19	charcoal	n.d.	7970 ± 100
KI-2743	WP 19	charcoal	n.d.	7950 ± 120
KI-2744	WP 19	charcoal	n.d.	7900 ± 100
KI-2747	WP 19(b)	bark mat	n.d.	7680 ± 100
KI-2736	WP 19(b)	charcoal	n.d.	7600 ± 140

Table 9-6: ^{14}C-dated Mesolithic hazelnut roasting sites, Duvensee.

mise in settlement intensity around 8600 calBP (7600 BP), again for reasons awaiting clarification. One possibility is that rising groundwater levels may have forced the population to move to higher regions, but this is difficult to decide, due to the worse conservation of archaeological sites on corresponding mineral soils. It is also possible that diminishing hazelnut growth during the second half of the 9th millennium calBP, widely observed around the Baltic region (Ralska-Jasiewiczowa et al. 1998; Tinner and Lotter 2001; Seppä et al. 2007), may have been responsible for these changing Mesolithic settlement patterns in Northern Germany (Holst 2007). Whatever the solution, there are presently no reasons (just as in the

Netherlands) to assume that these patterns are (causally) related to the 8200 calBP climate event *sensu strictu* (i.e Hudson Bay outflow). Satisfactory explanations for the clearly strongly biased ^{14}C-datasets at the end of the 9th millennium calBP all point towards the major environmental changes that occurred in the second half of the 9th millennium calBP, notably the rapidly rising sea-level and closely associated final flooding of Doggerland (Shennon et al. 2000; Behre 2003), rapidly rising groundwater levels and peat growth (Geyh 1980; Gerdes, Petzelberger and Scholz-Böttcher 2003), as well as fast influx of saltwater from the North Sea into the Baltic (Emeis et al. 2003).

6. Quantisation effects (Lock-In) due to atmospheric ^{14}C-variations in database cartography

As described above, the availability of software-facilities for rapid cartographic processing is crucial for demographic and cultural studies with large radiocarbon databases. In the following, we address the question of whether or not to apply corrections to estimates of site-numbers, when based on radiocarbon data, to allow for the existence of secular atmospheric ^{14}C-variations. This is a non-trivial problem, and any solution requires significant number-crunching. To illustrate the problem, let us assume that the research goal is to produce a set of maps showing the overall distribution of radiocarbon-dated sites, for different countries and selected time-windows. The following applies when these maps are to be used in demographic studies, in which case caution is advisable to ensure that site-counts per map/period/region are not artificially biased. Now, as is well-known for cumulative ^{14}C-probability distributions, to avoid artificial clustering of the data in certain ^{14}C-age scale windows, care must be taken to allow for the non-linear shape of the tree-ring calibration curve. The same problem turns up with site-mapping based on ^{14}C-ages. As illustrated in figure 9-4, in the early Holocene (here: 11-7 ka calBP) the tree-ring ^{14}C-age calibration curve has a complex shape, both in terms of medium-term (centennial) variations in average slope, as well as due to the existence of short-term (decadel) shape oscillations. In the case of accumulative ^{14}C-probability distributions, the variable shape of the tree-ring calibration curve is associated with variations in data availability such that, for flat regions of the calibration curve, more dates are to be expected than from the steep parts. According to Weninger (1997), there is no solution to the correction problem, both on theoretical grounds (related to the fact that the probabilistic algebra underlying the calibration problem is non-commutative), and also for practical reasons (because the application of corrections leads to frequency changes in the data that are mostly beyond control). However, other authors have proposed that corrections should be applied to the shape of the calibrated accumulative frequency distribution, to counteract the enhancement of dating probability by Stolk et al. (1994). The same problem now reappears when we address the development of methods for automated ^{14}C-database cartography. Clearly, when aiming at cartographic analysis of ^{14}C-dated sites, both the maps and corresponding data selection must be referenced to the calendric time scale, not to the conventional

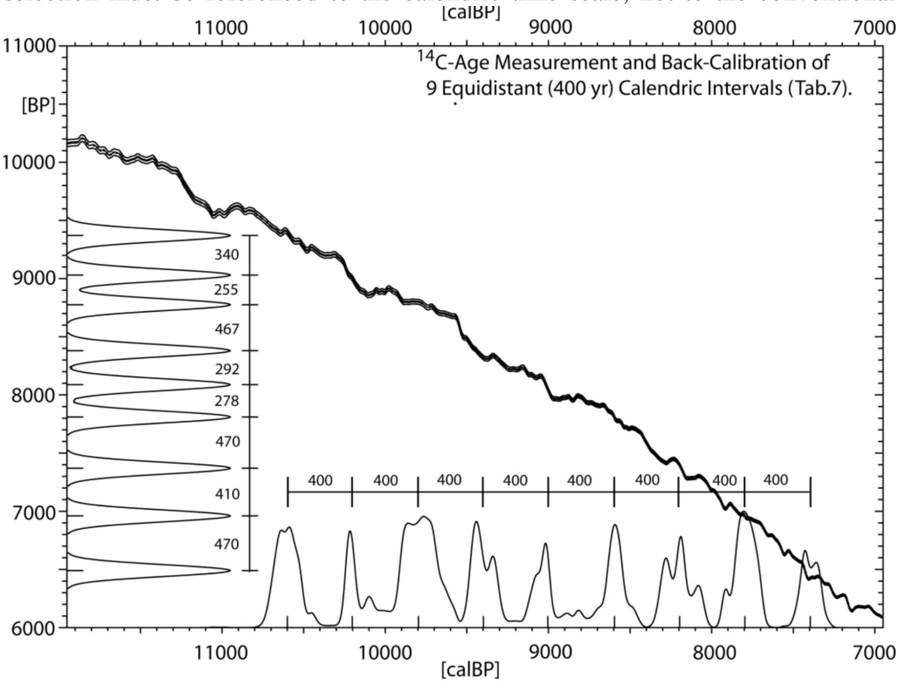

Fig. 9-4: Tree-ring radiocarbon calibration curve (Reimer et al. 2004) showing: 1) a set of nine selected (input) equidistant 400 yr intervals on the calendric time scale, 2) the calculated (output) ^{14}C-values on the ^{14}C-scale, and 3) back-calibration of these ^{14}C-ages to the calendric time-scale. This graph illustrates why it is impossible to define sharply defined time-window filter-values for the purposes of palaeodemographic ^{14}C-database cartography, on both scales (^{14}C and calendric). First, due to the atmospheric ^{14}C-variations, the selected 400 yr intervals on the calendric time-scale are not sharply defined, but have fuzzy end-values leading to fluctuations in time-window length. Second, these calculations are performed to simulate a database-filter for archaeological ^{14}C-ages with constant standard error of ±50 BP. Note that realistic archaeological ^{14}C-data have highly varying standard deviations, leading to corresponding fluctuations in window-length (again on both time-scales) as function of ^{14}C-data errors.

Calendric Age-Interval			**^{14}C-Scale-Interval**	**^{14}C-Span**		
[calBP]			**[^{14}C-BP]**	**[^{14}C-BP]**	**Total Nr of sites**	**Nr of sites in NL**
10600 -	10200		9370 - 9030	340	78	16
10400 -	10000		9230 - 8875	355	82	13
10200 -	9800		9030 - 8775	255	70	11
10000 -	9600		8875 - 8620	255	71	18
9800 -	9400		8775 - 8380	467	97	20
9600 -	9200		8620 - 8225	395	84	20
9400 -	9000		8380 - 8088	292	98	24
9200 -	8800		8225 - 7930	295	108	32
9000 -	8600		8088 - 7810	278	110	31
8800 -	8400		7930 - 7590	340	109	34
8600 -	8200	'8.2 ka Interval'	7810 - 7370	470	130	39
8400 -	8000	'8.2 ka Interval'	7590 - 7175	415	106	25
8200 -	7800		7370 - 6960	410	109	19
8000 -	7600		7175 - 6730	445	112	15
7800 -	7400		6960 - 6490	470	105	17
7600 -	7200		6730 - 6275	455	111	16
7400 -	7000		6490 - 6095	395	146	16

Table 9-7: Calendric and ^{14}C-Scale Intervals used in Mapping.

^{14}C-age values. This initial decision is illustrated in table 9-7, which shows the ^{14}C-ages for a number of time windows on the calendric scale, all of which have 400 year length. These are the age-intervals, for which a set of site-distribution maps is to be constructed. Corresponding ^{14}C-age values are given in the second column. The third column shows the length of the ^{14}C-interval, calculated from the values given in column two. The fourth column shows the number of archaeological sites in the database, with ^{14}C-ages within this ^{14}C-age interval. Our approach is to apply the necessary filter on the raw input ^{14}C-ages, not on the calibrated ages (which are not contained in the database anyway). For example, the 400 year interval 9400-9000 calBP on the calendric age-scale does not correspond to 400 years on the ^{14}C-scale, but instead only to 292 ^{14}C-years (8380-8088 ^{14}C-BP). This is in part due to the rather steep average slope of the tree-ring calibration curve, in this period, and partly because the given interval ends at 9000 calBP with a jump in the calibration curve (Fig. 9-4). In comparison, the 400 year calendric interval 9800-9400 calBP corresponds to 467 ^{14}C-years. In consequence, if not corrected, for these two time-intervals the varying shape of the ^{14}C-age calibration curve would introduce an artificial bias of up to 44 % [(467-292)/400] on the site-counts. We allow for this in the CalPal-software, by (user-friendly) time-window selection on the calendric time scale, and (optional) data processing automatically performed on the ^{14}C-scale. The necessity of such complicated filter procedures, further complicated by the regular update of high-precision calibration curves every few years (most recently: Reimer et al. 2004), explains why CalPal-databases generally do not contain tree-ring calibrated ages. When needed, these are quickly produced during run-time. To allow processing of realistic archaeological data, which have finite measurement errors, the numeric time-window algorithms are based on finite ^{14}C-age errors. For the purposes of the present studies, with mapping performed in the early Holocene, the ^{14}C-errors used in time-window calculation have been set to ± 50 ^{14}C-BP.

Speaking more generally, in processing archaeological ^{14}C-data, the non-linear shape of the ^{14}C-age calibration curve produces a wide variety of complications, and these are also conspicuous on the level of database mapping. In analogy to the arguments put forward for single ^{14}C-ages, it could be argued that for flat regions of the calibration curve more ^{14}C-dated single sites are to be expected than for steep regions. This argument is correct, but, as previously concluded (Weninger 1997), the best solution is nevertheless not to perform mathematical corrections, which would only lead to further complications. This becomes most clear, perhaps, under the auspices of the following two *Gedankenexperiments*. First, having constructed a map showing some ^{14}C-dated site distribution, it would cause confusion if we were immediately obliged to delete certain sites (depending on their age), to allow for variations in atmospheric ^{14}C-level. Second, let us consider, as alternative method, the variable weighting not of sites, but of site-counts. This would correspond to the weighting method applied by Ottaway (1973) for single dates, as well as to the correction procedures for ^{14}C histograms as proposed by Stolk et al. (1994). By analogy, we would have to introduce partial site-corrections of the type "this dot on the map represents a ^{14}C-scale-corrected 84% site" and "here we have a partial 44% site-dot". To conclude, the atmospheric ^{14}C-variations produce significant distortions in ^{14}C-chronology, both on the level of single ^{14}C-ages (multiple readings), on group level (frequency distortion), as well as in ^{14}C-database cartography (diffuse length of time-window, affecting site-counts). Awaiting further analytical methods, for purposes of site-mapping we apply the simple method of data-filtering on the calendric time-scale, with the length of filter-windows allowing for the atmospheric ^{14}C-variations, but without further secondary corrections.

7. The database: site distributions

We now have a complete set of analytical methods at our disposal, and necessary software methods, by which it is possible to study the geographic distribution of ^{14}C-dated sites contained in the new Northwest European ^{14}C-database. As already mentioned, the database is completely (95%) georeferenced, meaning that geographic coordinates are available for 95% of all ^{14}C-ages. For the purposes of mapping it is first necessary to differentiate between individual ^{14}C-ages and the typically multiple-dated archaeological sites. Figures 5/6/7 show all sites covered by the database (N=1033 site-points; N=3808 dates), projected onto a digital 3D-map of North-West Europe. In designing these maps, for convenience, the coast-line has been set at -40m modern sea level, to simulate a late phase of Doggerland. The sites are mapped according to (constant) 400 calendar yr time-intervals, with windows overlapping. The maps have been constructed for constant time-windows of 400 yrs, with 200-yr overlap to allow for the quantisation of time-window length (on both time-scales), in the present studies based on archaeological ^{14}C-data with simulated standard errors of ± 50 ^{14}C-BP.

8. Conclusions

This paper describes an extensive regional radiocarbon database for the Mesolithic and Early Neolithic of Northwest Europe. The database contains over 4100 dates from c. 1000 sites, of which 95% are georeferenced. The database was initially constructed to support models of regional population history and cultural evolution in the early Holocene. However, careful analysis of the temporal and geographic patterns underlying the database shows that frequencies, both of ^{14}C-ages as well as sites, are for all countries under study strongly biased by external factors. We have recorded significant bias in data frequencies due to the following, partially related, factors:

Fig. 9-5: Digital 3-D SRTM-Map showing the distribution of ^{14}C-dated sites for time-windows 10600- 9200 calBP. Each time-window has a constant length of 400 calendric years. For the majority of sites more than one date is available.

Fig. 9-6: Digital 3-D SRTM-Map showing the distribution of ^{14}C-dated sites for time-windows 9400 - 8000 calBP. Each time-window has a constant length of 400 calendric years. For the majority of sites more than one date is available.

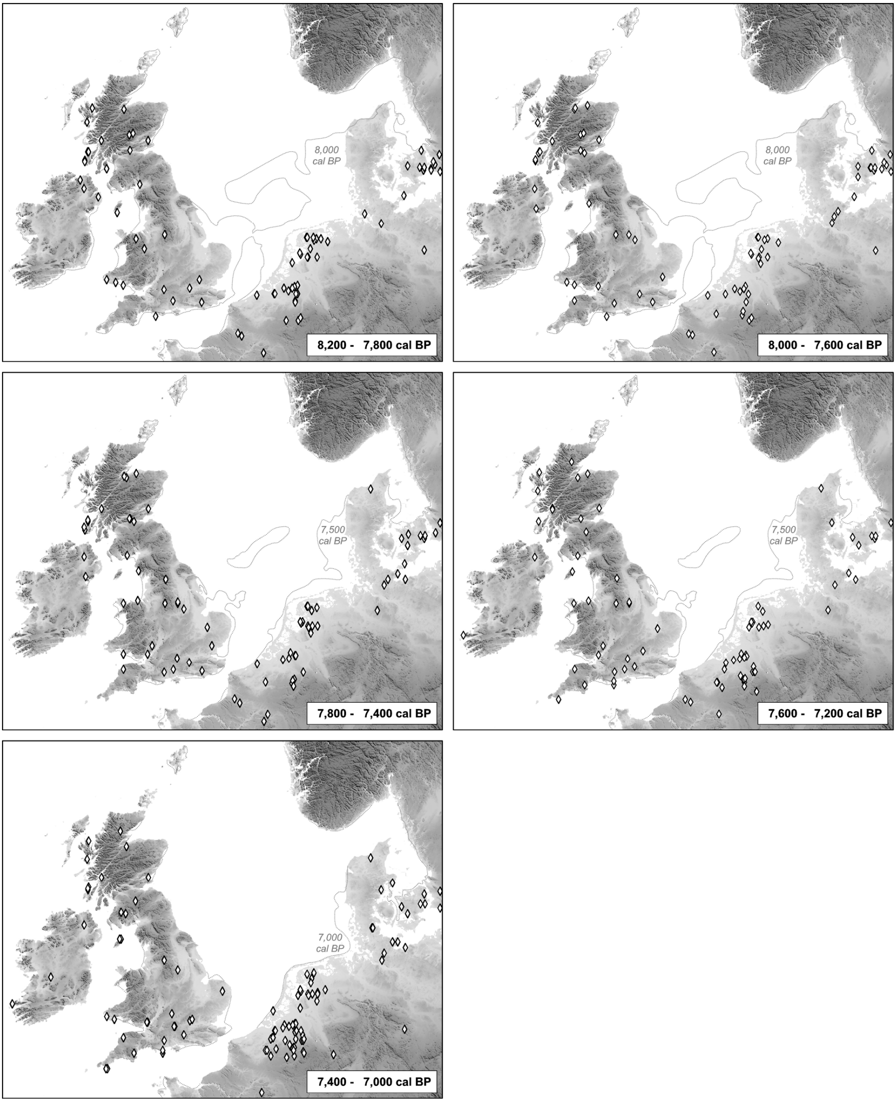

Fig. 9-7: Digital 3-D SRTM-Map showing the distribution of ^{14}C-dated sites for time-windows 8200 - 7000 calBP. Each time-window has a constant length of 400 calendric years. For the majority of sites more than one date is available.

Generally non-meaningful relationship between site-extent, number of ^{14}C-ages, and material on the one side, and human population on the other. We abbreviate this in stating that the 'transfer function' necessary to connect (radiometric) 'dates' and (population) 'data' remains undefined.

Dedicated research (e.g. research focus on certain periods, specific sites or on administrative regions such as municipalities, provinces, *Landkreise* etc.)

Uncontrolled environmental conditions (e.g. rising sea levels, peat growth)

Unexplored regions (e.g. regional ‘black holes’) due to lack of research or inaccessibility.

Local and regional differences in ^{14}C-funding and facilities.

Variations in archaeological site visibility and site formation processes.

In counteraction, detailed regional level analyses are required to allow for these biasing factors, on a case-by-case basis. The database can nevertheless be used casually, for many purposes. Special caution is advisable in palaeodemographic applications, due to the strong quantisation effects caused by secular atmospheric ^{14}C-variations. These effects appear on the level of individual ^{14}C-ages (multiple readings), on group level (frequency distortion), as well as in mapping studies. In mapping studies, the atmospheric ^{14}C-variations cause age-dependent fluctuations in site-counts that are difficult to account for, due to the diffuse length of time-windows.

We conclude that, to be successful, the envisaged ^{14}C-demographic research certainly requires complementary archaeological and environmental studies. Future work could profit from new methods to extend the present single-sample based definition of 'archaeological site'. Further studies could also address the question of how to define meaningful transfer functions (by which to correlate radiometric data and human population) as well as the equally open topic of error analysis.

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