METHODS

The present study aims to examine change in a human society within the context of climatic and environmental variation. Using an archaeological case study requires a detailed and independent chronology that can incorporate different sites in order to distinguish the different stages in this process of change.
Therefore, the material presented previously must be evaluated to facilitate the comparison of different archives in the same referential framework. For example, radiocarbon dating is the prevailing method for constructing chronological frameworks in Lateglacial archaeology. However, ^{14}C dates have to be calibrated because the radiocarbon timescale does not relate in a linear fashion to the calendar timescale. Consequently, a calibration of comparable radiocarbon ages does not necessarily result in comparable calender ages. The comparison of uncalibrated radiocarbon ages can lead to erroneous interpretations about the temporal relation of the dated materials (Blockley/Donahue/Pollard 2000b). Calibration of radiocarbon ages requires a calibration curve, which provides the calendar ages to a high degree of accuracy for the studied period. To construct a reliable calibration curve, high-resolution climate archives are vital. In addition, calibration results can, occasionally, be further distinguished through the use of the environmental data from the site. However, this environmental data is only useful if environmental development, at either site or broader scale, can be related to a calender timescale. This relation is usually established through events on a global scale such as volcanic eruptions or climate change. However, the response of the local environment to these global climate events depends on various factors relating, particularly, to the geographic and topographic site position. Thus, the site's spatial context is also important to create a reliable frame of reference.
In order to study changes in human behaviour within the context of climatic and environmental change requires a secure framework to produce reliable results. The current project uses intensive climate and environmental archives to provide background information necessary to create a spatio-temporal frame of reference. The methods used to create the referential framework and to evaluate changes in human behaviour are presented below.

CLIMATE AND CALIBRATION

Three main types of archives are used in the current study. The first type is the Lateglacial climate record (see Material-Climate, p. 7-30). These records formed the basis for the Lateglacial chronostratigraphy, helping to construct radiocarbon calibration curves (e. g. Jöris/Weninger 1998; Weninger/Jöris 2008; Reimer et al. 2009). Therefore, the climate and the calibration data are considered concurrently.

Defining the limits of Greenland oxygen isotope events

The Greenland eventstratigraphy (see p. 9-12) was selected as the base chronostratigraphy for this study because it combines global climate indicators with a high-resolution stratigraphy. Significant shifts in the oxygen isotope record were assumed to reflect both the onset and end of climate events. This type of shifts were defined as the main stratigraphic markers in the Greenland eventstratigraphy. This relation to climate events allowed other oxygen isotope records to be correlated to the Greenland chronology using these stratigraphic markers (Björck et al. 1998; Jones et al. 2002; Magny et al. 2006; Weninger/Jöris 2008).

However, in the first publications of this eventstratigraphy it was stressed that the onset and end of the various climate events could register asynchronously (Björck et al. 1998; Walker et al. 1999). This asynchrony resulted from a variation in the exact response to these climate changes. The response to climate changes, which are equivalent to the onset of a climate event, depend on how sensitive the chosen proxies are to climate changes along with the geographic and topographic location of the sampling site. Thus, delimiting the same event in archives from different geographic locations and/or based on different proxy data could result in some chronological offset on an absolute timescale. In the construction of the eventstratigraphy this offset of exact age was considered less important than the general correlation of the archives. In fact, on a geological timescale the offsets were negligible. Consequently, other stratigraphic sequences were tuned to the limits given in the Greenland eventstratigraphy to produce a chronological sequence that could be related to the absolute timescale of the Greenland ice-cores. Therefore, comparisons of these sequences in regard to the question of leads and lags in relation to climate change became more difficult due to the tuned limits (Blaauw et al. 2010). Moreover, with the increasing number of high-precision records using the same proxies and constructing a detailed Lateglacial climate history, precise age estimates are important. For instance, the precise age for the limits of several events was compared in various ice-core records to construct the GICC05 (cf. Southon 2002; Vinther et al. 2006; Rasmussen et al. 2006). Furthermore, the precise age of the event limits also made the correlation with records possible that had no oxygen isotope curves but a comparably precise chronology, such as the varve records (Litt et al. 2001). The combination of these terrestrial records placed the climate history in a temporal framework related to environmental development. Thus, the exact definition of the Greenland isotopic events and, in particular, the shifts between these events is of interest for this project because these limits provide useful correlation points.

In the Greenland eventstratigraphy, the limits of the proposed events (GS-2a, GI-1e, GI-1d, GI-1c, GI-1b, GI-1a, GS-1, Björck et al. 1998; for further Pleistocene and Holocene events: Walker et al. 1999; Lowe et al. 2008) were set at the mid-point of the slope in the oxygen isotope curve (Lowe et al. 2008, 10 tab. 1, Note). However, for some shifts the development of the deuterium excess was used instead. A high-resolution analysis of the NGRIP ice-core provided the ages for the oxygen isotope changes (Steffensen et al. 2008), and these limits are used throughout the present study.

In contrast, for some episodes in the Lateglacial Interstadial (GI-1c_3, GI-1c_2, GI-1c_1) no limits were previously given in the literature, although these episodes seemed to be reflected in the environmental development in north-western Europe (Litt/Stebich 1999; Litt et al. 2001; cf. Hoek/Bohncke 2001; Magny et al. 2006). Therefore, these limit were defined for the current project based on the δ^{18}O record[19] of the NGRIP ice-core (see p. 9-12). Again the mid-point of the slope between the episodes was chosen as limit. However, the problem of high-resolution data is to identify the main slope (Lowe et al. 2008, 10 tab. 1, Note; Steffensen et al. 2008). In this study, a simple difference of one data point to the next was calculated to reveal steep changes between the points. However, in the fluctuating record of the Lateglacial Interstadial, several steep shifts, i.e. large differences occurred. Moreover, the fluctuations swung in two directions: positive and negative. Often a steep positive change was followed by a comparable steep negative change. Thus, these changes reflected the amplitude of the fluctuations within the event or episode. However, these amplitudes

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[19] This record was released September, 10th 2007 from the Centre for Ice and Climate, University of Copenhagen and is obtainable from www.iceandclimate.nbi.ku.dk/data/. It contained information on various parameters in the NGRIP ice-core given in 20 year means. These parameters were the δ^{18}O value, the age and the counting error according to the GICC05, and the depth in the ice-core.

of fluctuations were of no instant interest, instead, the general, long-term shifts were investigated. To recognise these long-term shifts, the amplitudes had to be neutralised and the resolution had to be lowered to reveal the more systematic shifts. This neutralization and lowering of the resolution was achieved by an addition of the previously calculated differences between the successive data points. In general, 21 years lay between two successive data points of the oxygen isotope record. By adding three to five of these differences to lower the resolution a time period of 63, 84, or 105 years was generally covered. If in this addition changes in the same direction (positive or negative) accumulated the value increased, whereas if the values were fluctuating the value became smoothed. Thus, in this lowered resolution the systematic changes became identifiable. Nevertheless, the limit was set at the mid-point between the two points yielding the largest difference in the recognised series of changes.

To test the usefulness of this approach, the data points in the NGRIP record from 18,000 to 10,000 years cal. b2k[20] were studied. The three comparable dates of the oxygen isotope record given by Jørgen Peder Steffensen and his colleagues (Steffensen et al. 2008) in the high precision analysis were equivalent within less than ten years to the results of the calculations used in this project.

An interesting by-product of this larger scale comparison of the fluctuations in the ice-core record was that the amplitudes were most marked during the Late Pleniglacial and diminished significantly with the beginning of the Holocene. These smaller amplitudes reflected a more stable climate regime that, probably, had an impact on the natural environment. For instance, a stabilised climate could lower the migration pressure and permit biotic communities to establish in a favourable place and adapt *in situ* to smaller fluctuations. Such a stabilization or destabilization was presumably recognisable by hunter-gatherer groups and would influence their adaptive strategies.

Correlation of tephrochonology with GICC05

Even though various high-precision dating methods have been developed, absolute simultaneity can rarely be demonstrated. For example, a tephra layer of a volcanic eruption is not deposited simultaneously but, depending on atmospheric movements and distance to the volcano, within hours, days, or months after the eruption (Rasmussen et al. 2008, 19). The exchange of atmospheric isotopic ratios to comparable values can, similar to the tephra deposit, take months or even a century across distant areas (Kromer et al. 2001, 2529; Hua et al. 2009, 2985; Rasmussen et al. 2008; 19; Magny et al. 2006, 426 f.). The temporal resolution achieved by various dating methods for the Lateglacial included decadal to centennial deviations. Thus, in comparison to those deviations, volcanic tephras represent extremely high-precision, quasi-synchronous time markers.

Moreover, some tephra layers were deposited over large areas and in various archives such as ice-cores or varved lake sediments. Thus, the records from these various, tephra containing archives could be aligned along these markers. Therefore, a Lateglacial tephrochronology related directly to the Greenland ice-core chronology represents an important tool in combining various records within a common temporal frame.

A detailed Lateglacial tephrochronology of the NGRIP ice-core was published by Anette Mortensen and colleagues (Mortensen et al. 2005). However, this tephrochronology was presented without an age model. Instead the depth of the volcanic ash layers and single volcanic sherds in the NGRIP ice-core was provided. Some identified layers were correlated to ^{14}C-dated marine and continental records (Mortensen et al. 2005, 215 fig. 7; 217).

[20] b2k refers to »before 2000 A.D.« (see p. 8 and p. 591).

However, for the present approach this succession of volcanic layers was correlated to the GICC05. This correlation was made using the depths given for the volcanic ash layers with the depths given in the 20 year mean record of the oxygen isotope curve set in GICC05 (see above). If no exact matches were found the distance between the two nearest depths given in the oxygen isotope record was scaled evenly by the number of years counted between these depths. The exact depth of the tephrochronology was rounded to the next of these even steps. Clearly, the record was not deposited evenly but the error is far beyond the counting error and, thus, negligible. The age of the Vedde Ash was given in the publication of the GICC05 as important marker (Rasmussen et al. 2006), and was adopted for this study.

In addition to the volcanic ash layers with exact depths, the calcium corrected sulphate content ($SO^{2-}{}_4$ – Ca^{2+}) for the Lateglacial and early Holocene was also provided by Mortensen and colleagues (Mortensen et al. 2005, fig. 2). Peaks in the calcium corrected sulphate content were assumed to reflect volcanic eruptions (Mortensen et al. 2005, 210). However, the increase of this content as well as peaks within this content during cold periods was apparent and attributed to lowered precipitation and, perhaps, increased wind activities leading to peaks from various sulphate sources (Mortensen et al. 2005, 216). Thus, a sulphate background signal that was not related to volcanic activity seemed to vary between the warmer and colder periods. However, the changes of this signal due to altered volcanic activity patterns could not be excluded entirely. The calcium corrected sulphate content was also given in relation to its ice-core depth and the development of the oxygen isotope record by Mortensen and colleagues (Mortensen et al. 2005, fig. 2). For the present project, this record was correlated to the GICC05 by depth and, in addition, the records were checked graphically for the relations of significant peaks in the corrected sulphate content to fluctuations in the oxygen isotope record. This record was considered important due to volcanic events that were not identified by tephra layers or single volcanic sherds in the ice-core record such as the LSE. The chronostratigraphic position of some eruptions that were related to a significant sulphate output such as the LSE can be discussed based on this record.

Correlation of oxygen isotope records with GICC05

The atmospheric oxygen isotope composition in the ice-core records depended mainly on the temperature at the coring site during formation (Dansgaard et al. 1993; Steffensen et al. 2008) and, as a consequence, on the climate regime. Therefore, this isotope composition behaved comparably in regard to its relative patterns across the globe and the isotopic records can be correlated to each other by matching of significant positive or negative excursions (i.e. wiggles). In the current study, peak values were used as correlation points for minor excursions, whereas the major shifts such as the onset of the GI-1e were correlated at the mid-point of the shift.

However, in comparison to the Greenland oxygen isotope records, terrestrial $\delta^{18}O$ values were influenced by further factors such as water temperature, isotopic composition of the water and the catchment runoff, precipitation, altitude, sedimentation rate, and the amount of allochtonous material in the sample (Siegenthaler/Oeschger 1980; Grafenstein et al. 1992; Hoek et al. 1999; Wang et al. 2001). These additional influences could cause some delay in the registration of changes and/or an admixture of different signals leading to arbitrary results. The possible sources of error such as admixture can be revealed from the records. The discussion of precise leads and lags of isotopic records (Blaauw et al. 2010) exceeds the subject of this study. A quasi-simultaneity of the isotopic signals has to be assumed to allow for the correlation according to the idea of an eventstratigraphy. However, the climate system of north-western Europe is generally governed by the North Atlantic circulation which also influences the Greenland record (e.g. Lotter et al. 1992; Moros et al. 2004; Sirocko et al. 2005). This climate regime also influenced several additional signalling factors in terrestrial sequences such as precipitation and water temperature. Therefore, the signal of major shifts in this climate regime were intensified in the terrestrial records. Thus, isotopic compositions of authigenic deposits were strongly governed by the same major climatic signals as the Greenland isotope record and the major shifts should have occurred parallel in time. These time-parallel shifts are correlated.

To obliterate a major climate signal in the terrestrial records, several of the factors mentioned above as influencing the isotope signal need to co-occur. These obliterating situations occurred for instance in Gulickshof (Limburg, Netherlands) where an episode of ground water influx, presumably caused by the final melting of relict ground-ice, led to a disturbed oxygen isotope signal during the first part of GI-1c (Hoek/Bohncke 2001). In the southern German Ammersee a significant sub-decadal isotope excursion was registered during GS-1 and was also attributed to a high accumulation of detrital material caused by a warmer episode which destabilised the previously frozen soils (Grafenstein et al. 1999, 1657 fig. 4). In both cases, the introduction of larger proportions of allochtonous material caused the arbitrary values. This allochtonous component is usually considered within these sequences and can be identified. These periods of increased allochtonous impact have to be considered as problematic. However, if these disturbed episodes are relatively short they can be treated as gaps which can be spanned between two reliable correlation points. Nevertheless, the numerous additional factors related to the isotopic composition of terrestrial records influence the minor signals and as a consequence the correlation of single peaks was, and is, often not possible.

In summary, the correlation of the Greenland eventstratigraphy with terrestrial oxygen isotope records required archives formed mainly by authigenic deposition and for which the isotopic compositions of the contributing elements was, relatively, well known. The correlation was established by setting major shifts in the isotopic record as time parallel. Possible peaks of positive or negative excursions are only correlated in parts where this procedure seemed possible. Therefore, a correlation of the terrestrial oxygen isotope records to the Greenland eventstratigraphy should be regarded as an approximation, which should be confirmed by further indicators such as volcanic markers, counting of laminated sediments, and/or radiometric ages.

Correlation of laminated chronologies with GICC05

Since archives with no oxygen isotope signature cannot be correlated to the GICC05 using the eventstratigraphic wiggle-matching outlined above, other procedures are necessary.

In the case of varve records, a correlation to the ice-core records can be based on a numerical comparison of the couplets counted between marker horizons such as volcanic ash layers or between significant regime changes in the isotope record; changes in the sediment composition or other proxies such as pollen frequencies can also be used. If the counted ages for the identified events are statistically similar, a common factor ruling the shifts in the proxies can be assumed and, in consequence, a quasi-synchronous reaction is implied. Thus, the correlation of shifts in the different proxy records is again based on the assumption of time-parallel reactions to significant climatic events.

However, in both chronologies (ice-core and varve record) the counting errors are cumulative and increase to considerable numbers during the Pleistocene. Statistical comparison of the ages determined for various shifts during the Pleistocene record could result in similarity, even though a hundred years or more separated the detected shifts in the compared proxy records. In addition, if hiatuses occurred in the records and remain undetected, the numerical approach might be completely misleading. However, the identification of hiatuses remains difficult based on the numerical comparison alone. The development of further proxies in each record and between various records has to be compared to reveal the existence of a hiatus and to number the missing couplets (cf. Leroy et al. 2000). In the sediment records hiatuses and/or disturbances of the sequence were usually identified in the lithological inspection.

Many of the terrestrial proxies are not as sensitive as the isotope record and are influenced by local factors. The assumption of recorded changes in different proxy values being time-parallel remains therefore an approximation and, in general, problematic. In particular, if vegetation changes such as the decrease or increase of arboreal pollen are correlated the influential factors of the local conditions are high. Moreover, by the setting of the identified changes as quasi-synchronous could potentially mean that leads and lags between the records can no longer be identified. Therefore, this type of correlation is not used solely to establish contemporaneous events but is supplemented by volcanic markers and/or radiometric ages if possible. Some caution is necessary in the choice of the radiometric ages because the varve chronologies usually originate from aquatic environments where a hard-water effect can potentially alter dates taken on samples of water plants (see p. 259-263). Thus, these samples need to be generally rejected.

Comparison of the Greenland oxygen isotope record with dendrochronological data can also follow a numerical approach. In some dendrochronological sequences, deuterium isotopes were also measured (Friedrich et al. 1999), which can reflect climatic stresses affecting the plant. However, climatic changes in the Lateglacial occasionally altered the isotopic composition of the dendrochronological material resulting in delayed or no reactions in this record (Friedrich et al. 1999). Therefore, the isotopic records from the two different archives were not compared further.

Instead, the Greenland ice-core record and the dendrochronologies are correlated by the growth patterns of tree-rings (Friedrich et al. 2001b). The growth of tree-rings is also governed strongly by locational factors, particularly during the growth period (Friedrich et al. 2001b; cf. Stokes/Smiley 1968, 9-11). Besides the nutritional composition of the soil, local climate conditions such as temperature or precipitation are an important factor influencing tree-ring growth. Even though these patterns could be affected by local topographic settings or micro-climatic conditions, they are in general also influenced by the more global climatic regime. Thus, major climatic shifts are also detectable in the tree-ring patterns (cf. Kaiser et al. 2012), particularly, if they originate from a similar region. Since climatic conditions are strong factors in the tree-ring growth, the lags to the oxygen isotope record should in general be smaller than in sedimentary records. Nevertheless, without additional marker horizons the correlation will remain vague. Volcanic deposits are usually not directly detectable in the dendrochronological record in contrast to the sedimentary record but can be assumed by their impact on growth patterns (Kaiser 1993). However, these short-term effects in the growth patterns can also be caused by other events such as floods (Kaiser et al. 2012). Therefore, the testing of correlations on marker horizons is problematic in these records except for the trees were directly related to the volcanic event (Baales/Bittmann/Kromer 1998; Kromer et al. 2004).

In summary, the numerical correlation of the Greenland oxygen isotope record with other terrestrial archives requires several points of cross-checking but they make relatively precise estimates of duration times for the single events possible.

Modifying the CalPal-2007$_{\text{HULU}}$ radiocarbon calibration curve

The necessity of calibrating ^{14}C dates to the solar or calendar timescale is meanwhile a well known issue in chronological considerations (e.g. Münnich 1957; Weninger 1986; Blockley/Donahue/Pollard 2000b; Jöris/Weninger 2000; Blaauw et al. 2007; Bronk Ramsey 2008; Grimm/Weber 2008; Weninger et al. 2009; Jöris et al. 2011). Archives combining a reliable calendric timescale with numerous ^{14}C dates are necessary to construct a reliable radiocarbon calibration curve. In general, these combined data sets are provided by climate archives. For the Holocene, the dendrochronological data is used, whereas for the Pleistocene portion of the radiocarbon calibration curve various, mainly marine climate data sets are used. This use of climate data is due to the relative solidity of these archives. Therefore, the construction of a reliable radiocarbon calibration curve for the Pleistocene is only possible in the context of climate archives. However, the construction of a uniform radiocarbon calibration curve for the Pleistocene is still under discussion (Weninger/Jöris 2008; Reimer et al. 2009; Bronk Ramsey et al. 2012). In particular, the part from the Lateglacial to the limits of the radiocarbon method remain a matter of controversy (van der Plicht et al. 2004; Bronk Ramsey 2008; Weninger/Jöris 2008; Reimer et al. 2009). Nevertheless, the Lateglacial calibration curves also vary in detail due to contrasting algorithms creating the curves (Bronk Ramsey/van der Plicht/Weninger 2001) and due to the incorporation of different data. So far, the generally accepted dendrochronological data end in the early Lateglacial Stadial at 12,644 years cal. b2k (cf. Schaub et al. 2008b; Hua et al. 2009; Reimer et al. 2009; Kaiser et al. 2012). Thus, the construction of a radiocarbon calibration curve relies on other, mainly marine data sets for the ages prior to this date (Schaub et al. 2008b). In general, the data sets used to construct the calibration curves are similar during the Lateglacial (Fairbanks et al. 2005; Weninger/Jöris 2008; Reimer et al. 2009). However, the evaluation of the data sets produced variable results because each were created for different reasons.

For instance, the IntCal radiocarbon calibration curve aimed to estimate the calendar age of a ^{14}C date or a series of ^{14}C dates in the statistically most reliable way (cf. Buck/Litton/Scott 1994; Heaton/Blackwell/Buck 2009). The mathematical reliability was consequently a major ambition of this curve. However, the increase of the statistical accuracy resulted in a decrease of the precision of the calibrated ages. This decrease was due to the rejection of possible uncertainties and the incorporation of partially large deviations combined with the application of a random walk prior model, this approach resulted in relatively accurate but not very precise calendar ages. By contrast, the CalPal radiocarbon calibration curve is aimed to produce a most precise calendar age to be able to relate the result exactly to the climatic and environmental development (Jöris/Weninger 1998; Jöris/Weninger 2000; Weninger/Jöris/Danzeglocke 2003). Therefore, further proxy data combined with the ^{14}C data sets such as the Cariaco greyscale were used for their comparability and consistency in the CalPal approach (Weninger/Jöris 2008). Thus, a second line of evidence was created. In accordance with the aim at precision, the decision on reliable data sets was made differently to the IntCal approach. The CalPal approach increased the precision by a careful selection of data sets and the single dates forming these data sets. The selection tried to eliminate potential dating errors and to synchronise the data sets with palaeoclimate signatures and, more generally, with calendric age models (Weninger/Jöris 2008). Thereby, large deviations and many uncertainties were often resolved. For instance, proposed modifications such as a change in the reservoir ages in the Cariaco data (see p. 13-15) were applied to this data set in the CalPal radiocarbon calibration (Weninger/Jöris 2008, 778f.). In contrast, the IntCal group also mentioned this proposal but banned the data due to the remaining uncertainty of the reservoir ages (Reimer et al. 2009, 1116). This ban resulted in a scarcity of precise data across an important cliff in the Lateglacial calibration record (cf. Reimer et al. 2009, 1120 fig. 2) and wider statistical error margins in this period. Nevertheless, the CalPal approach also required a statistically provable probability concept (Bronk Ramsey/van der Plicht/Weninger 2001). In an article, Bernhard Weninger and his colleagues demonstrated the non-commutative character of the radiocarbon calibration and identified their approach as a quantum probability concept (Weninger et al. 2011), which fits with their aim at precision.

The evaluation of archaeologically visible changes in human behaviour in the context of climatic and environmental developments requires precise dates. Furthermore, the relation of these dates to the high-precision chronostratigraphy of Lateglacial north-western Europe is an equally important requirement for this study. The current project aims to evaluate human behaviour within a tightly defined spatio-temporal framework. Thus, the approach used in the construction of the CalPal-2007$_{HULU}$ radiocarbon calibration curve and the CalPal program is preferred for the present study.

Thus far, the CalPal-2007$_{HULU}$ radiocarbon calibration curve is only stored and made readily applicable in the CalPal calibration program (Weninger/Jöris 2004). This program is furthermore preferred because it offers a non-dogmatic use of calibration data sets (cf. Reimer et al. 2009, 1112). Although the CalPal-2007$_{HULU}$ radiocarbon calibration curve is recommended and set as default, other calibration curves such as the IntCal04 calibration curve (Reimer et al. 2004) or single data sets such as the German Lateglacial pine chronology (see p. 25-30; Kromer et al. 2004) or the Cariaco dates (see p. 13-15; Hughen et al. 2006) can also be chosen as calibration data. Furthermore, the downloaded version of the CalPal program enables the user to review, change, and shift the single data sets. Thus, this calibration progam permits the construction of a new calibration curve by changing existing data and/or the inclusion of a new data sets.

Clearly, the »health warning«[21] (Pearson 1987, 103) of Gordon Pearson is still valid but the concern of people without detailed knowledge building their own calibration curves (Reimer et al. 2009, 1112) seems exaggerated. In fact, a short survey of archaeological papers of the past decade using calibrated data show that most archaeologists are aware of the complexity of calibration. Therefore, they took the advice of someone from a radiocarbon facility (e.g. Jacobi/Higham 2009; Weninger et al. 2009) and/or applied and quoted ready made calibration curves and instantly usable calibration programs (e.g. Barton et al. 2003; Gamble et al. 2005; Shennan/Edinborough 2007; Grimm/Weber 2008; Langlais et al. 2012). Furthermore, the wish for a consensual use of calibration data which »makes direct comparison between different studies easier« (Reimer et al. 2009, 1112) is also fulfilled by the use of the CalPal-2007$_{HULU}$ radiocarbon calibration curve and the CalPal program since the majority of archaeological studies of the last half-decade relating to the Pleistocene record used this set.

However, some alterations of the chosen CalPal-2007$_{HULU}$ radiocarbon calibration curve have to be performed for the present approach. Some data such as the early Younger Dryas tree-ring data from Switzerland (Schaub et al. 2008a) and Tasmania (Hua et al. 2009) became available only after the publication of the last update of this radiocarbon calibration curve (Weninger/Jöris 2008). These newly available data fall into the controversial period of the changing reservoir ages in the Cariaco record and help to identify the change of the reservoir ages in the Cariaco record more precisely. Since no new update is available thus far, the additional data series is correlated to the radiocarbon calibration curve in the present study.

Therefore, newly available data are graphically correlated to the existing calibration data sets based on the wiggles of the ^{14}C data series. Furthermore, the ^{14}C dates of the Gänziloo series were connected to the growth patterns of the tree-ring rings (see **fig. 13**). Thus, the position of these tree-rings widths based on the result of the previous wiggle-matching is tested against the relevant tree-ring data sets (Kaiser et al. 2012). In addition, a correlation with the tree-growth patterns allows for assumptions about the onset of the Lateglacial Stadial and, consequently, on its duration. Based on these assumptions, the data set can be compared numerically to the GICC05.

The resulting numerical calendar ages as well as the relating ^{14}C dates are used to construct a database using the Windows editor and the DAT-file of the Lateglacial pine chronology (Kromer et al. 2004) which was downloaded with the CalPal program as a blueprint. This resulting database is introduced into the CalPal composer

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[21] »Health warning! Proper calibration is not easy for the non-mathematician, but doing it incorrectly, wrongly interpreting the result, or even not understanding the potential of calibration may seriously damage your archaeology. Take advice from the experts – know what calendrical band-width is necessary for correct interpretation and discuss this with the dating laboratory, preferably before taking and certainly before submitting samples. Think first, not after you get the radiocarbon date.« (Pearson 1987, 103).

using the method suggested in the select_info file of the CalPal downloaded version. By the use of this database a modified version of the CalPal-2007$_{\mathrm{HULU}}$ radiocarbon calibration curve is created in the CalPal composer. This modified version is used to calibrate the ^{14}C dates in this project. Thus, the underlying algorithms and probability concept of CalPal are used as well as the approach of constructing a solid calibration curve based on climate archive, only the data are supplemented in detail.

ENVIRONMENT

The second set of archives considered in this project are the environmental archives (see Material-Environment, p. 30-48) which are supplemented by directly ^{14}C-dated, vegetal and faunal samples (see p. 49-51). The natural environment formed the fundamental resource for the survival of hunter-gatherers. During the Lateglacial the natural environment underwent profound changes. In the present study, several approaches were used to illustrate these changes and relate them to the previously presented chronostratigraphy. In general, two aspects of the natural environment were considered: the physical geography and the living environment. Within the latter, the focus was set on the terrestrial vegetation and the mammal fauna.

Modelling of the physical geography

During Pleistocene climate changes the physical geography was fundamentally altered through rising and falling sea levels and advancing and retreating ice sheets alongside isostatic and eustatic changes in land relative to the sea level. To establish environmental change in relation to climate change and the environmental development, the physical geography must be known. Since current maps of the physical geography of Lateglacial north-western Europe were inadequate, the creation of adequate maps was the first step in modelling the Lateglacial environments.

Most changes in physical geography occur very gradually and, thus, changes only become detectable over long periods of time. Consequently, data on physical geography are usually displayed in maps with relatively low temporal resolution and the maps created for this study also encompass relatively long time intervals. In contrast, in maps with high temporal resolution changes to the physical geography become too gradual to be recognisable. Furthermore, some developments of the physical geography can only be identified by terminal points and not the gradual stages between these points. For example, the ice sheet development is mainly reconstructed by the position of end moraines. The development of glaciers is relatively complex (IUGG (CCS) – UNEP – UNESCO 2005) and was more complex in the past than originally assumed (Ivy-Ochs et al. 2009). Even with modern methods of dating exposure ages (Ivy-Ochs et al. 2008; Heyman et al. 2013), a high-precision decadal or centennial chronology for the developments of the European ice sheets during the Lateglacial is not possible. Thus, combining a specific ice sheet stage with for instance a sea level stage in a temporal high resolution map could easily lead to incorrect impressions because the changes in the physical geography progressed at varying paces. The resulting potential for combining asynchronous stages due to various, uncorrelated age models increases with the choice of increasingly high temporal resolution. Therefore, the accuracy of maps with a very high temporal resolution can be questioned for the Pleistocene.

However, the creation of maps with relatively long time slices requires that various mean values need to be applied, for example, for the ice sheet regression or the sea level. Some developments are coupled

map no.	events	limits of calendar ages (in years cal. b2k)	duration (in calendar years)	limits of the ^{14}C ages (in years ^{14}C-BP)
0	2000 A.D.	*c.* 5-0	5	×
1	GS-1	*c.* 12,750-11,700	1,050	10,750-10,000
2	GI-1c-a	*c.* 13,950-12,750	1,200	12,000-10,750
3	GI-1e-d	*c.* 14,700-13,950	750	12,350-12,000
4	GS-2a	*c.* 16,000-14,700	1,300	13,100-12,350
5	LGM (GS-3-GS-2c)	*c.* 26,550-19,050	7,500	22,000-16,000

Tab. 47 Approximate periods covered by the maps of Lateglacial north-western Europe. The ^{14}C ages were read from the CalPal2007$_{\mathrm{HULU}}$ calibration curve and further compared to the ^{14}C dates and the eventstratigraphic attribution of their samples in the databases created for the present study. For the ^{14}C ages of the LGM cf. Street/Terberger 1999, 262 fig. 4.

altitude	RGB	shade	chroma	intensity
-250 m	148	160	0	139
-5 m	248	160	0	233
50 m	228	160	0	215
300 m	148	160	0	139
6000 m	28	160	0	26

Tab. 48 Settings of the greyscale shader used in Global Mapper.

such as the ice sheet regression and the sea-level. Furthermore, many of these developments were the result of the global climate system. Thus, to avoid incorrect correlations due to divergent age models, the long time slices were chosen according to the Greenland eventstratigraphy (Björck et al. 1998; Blockley et al. 2012).

For the present study, the Lateglacial was sub-divided into four time slices (**tab. 47**). These time slices were chosen as meaningful periods for this project due to their relation to the Greenland eventstratigraphy as well as the general climatic and environmental development of north-western Europe (cf. Litt et al. 2001; Lowe et al. 2008). Furthermore, with the same layouts as used for these four maps a modern map (A.D. 2000) and a map of the LGM (Clark et al. 2009; cf. Starnberger/Rodnight/Spötl 2011) were created.

In this project, north-western Europe was delimited at 45-60° northern latitude and 10° western to 25° eastern longitude.

A first set of these maps which extended 5° less in eastward direction was made available online for public use (Grimm 2007). The updated set is used in this study for the visualization of the setting of the various sites within Lateglacial Europe and to highlight the changing Lateglacial landscape. Meanwhile these maps are also available online in the project archive under »Change (Karten)«: http://monrepos-rgzm.de/forschung/projekte/projektarchiv.html.

Creating the base map

A single base map of north-western Europe and the surrounding sea beds was created as a basis for the four Lateglacial and the two additional maps. This base map was built from the SRTM30_plus record which included bathymetric data. This data set was read into the program Global Mapper v8.01 and displayed in a geographic projection (latitude/longitude). According to the SRTM documentation (cf. documentation file at http://dds.cr.usgs.gov/srtm/version2_1/SRTM30/), the 1984 revision of the World Geodetic System (WGS84) was chosen as reference datum.

Furthermore, a simple greyscale shader was specifically created in Global Mapper to display the data set. This shader had five fixed altitudes and relating grey values (**tab. 48**). The values between the fixed points were interpolated by the program. In addition, in the vertical options of the program the hill shading was enabled and the vertical exaggeration was turned to 8.1 times. Moreover, the light direction was set to 0 for the altitude and 45 for the azimuth, and the ambient lighting was turned to 0.75. These settings resulted in a good visibility of the geomorphological relief of north-western Europe.

The resulting map was exported as 1200 dpi GeoTiff in the geographical limits named above.

Graphic revision of the base map

The resulting map was graphically modified by removing some perturbation especially in the bathymetric data. This perturbation were probably due to Holocene undulation movements of sea sediments and sediment fans from Lateglacial to Holocene river mouths (e.g. Bourillet et al. 2003; Busschers et al. 2007). Furthermore, in the cases where the physical geography was significantly altered such as in the case of open pit mining the relief was smoothed. In addition, gaps occurred occasionally in the maps and they were also filled according to their surrounding.

Compilation of the Lateglacial maps

To create maps of Lateglacial Europe from the base map various margins, for example, of the ice sheets, the sea, or of the Baltic Ice Lake had to be compiled. These margins were set as an additional layer on top of the base map. Mean values of the ice sheet regression, the sea level, or the development of the Baltic Ice Lake were created for the specified periods (**tab. 47**).

Mean values for the sea level changes were chosen according to the relative sea level development based on Barbados and Sunda Shelf data (Weaver et al. 2003, fig. 5B) and calibrated from this combined record at the mid-point of the time periods specified above. The sea level for the maps are 60 m b.s.l. for GS-1, 70 m b.s.l. for GI-1c-a, 90 m b.s.l. for GI-1d-e, and 105 m b.s.l. for GS-2a. In the LGM map the sea level was set to 120 m b.s.l. (Peltier/Fairbanks 2006), although meanwhile a minimum sea level of 123 m b.s.l. was identified for the LGM (Hanebuth/Stattegger/Bojanowski 2009). Maps with the different sea levels were created in Global Mapper by setting the water colour to opaque and the sea level to the specified values. These maps were exported as GeoTiffs in the geographical limits named above. From these GeoTiffs the area covered by the sea was chosen as extra sea-level layer. These five different layers were set on the base map creating the first stage of the LGM and the four Lateglacial maps.

Based on the studies compiled by Svante Björck (Björck 1995a), layers with the development of the Baltic Ice Lake were created for the maps 1-3 (map 1: Björck 1995a, fig. 5; map 2: Björck 1995a, fig. 4; map 3: Björck 1995a, fig. 2). In the periods of the maps 0 and 5 this lake was irrelevant. However, for the period of map 4 no conclusive data exist, although for the second half of this period indications were found that melt-water and icebergs passed through the Öresund to the Kattegatt which was gradually silted up (Björck 1995a, 21). Furthermore, sub-aquatic sediments from this period were only found at considerable modern water depths (Björck 1995a, 22). Nevertheless, some type of ice lake probably existed in this period and to take this in account the same extension as during GS-1 (Björck 1995a, fig. 5) is given for GS-2a. This stage is equivalent with the maximum southward extension of the Baltic Ice Lake.

The maximum extent of the British ice lakes was not ascertained to relate to the LGM and the dating for the various lake shore lines also remained uncertain (Clark et al. 2004, 368-370). Moreover, for the period encompassed by the Lateglacial maps no ice lake margins seemed relevant in Britain.

However, many smaller lakes and kettle-holes (Kaiser 2004; Clausen 2010) and, possibly, large wetland landscapes (Cziesla 2001, 392) as well as the major European rivers (Antoine et al. 2003a; Wallinga et al.

2004; Streif 2004; Ménot et al. 2006) changed the appearance of the landscape in detail (see **fig. 6**). For this type of information, no comprehensive compilation for the Lateglacial has been found thus far. In addition, the various stages of rivers or lakes were often not precisely dated or, in fact, datable. Therefore, this hydrological data was not included in the general Lateglacial maps.

The modern glacier margins are plotted onto map 0 (A.D. 2000) at a mean altitude of 2,490 m a.s.l. according to the Simming Ferner glacier tongue in 1989 (Ivy-Ochs et al. 2006, 121 fig. 4) and a mean of the lowest elevation point of glaciers in the surrounding of Trins/Austria (IUGG (CCS) – UNEP – UNESCO 2005, 118-120 tab. A). Even though the various glacier margins occur at various altitudes a specific (mean) altitude was chosen because putting the contemporary altitude of each glacier onto the map would have meant an unnecessarily large data processing for the purpose of these maps. Certainly, in the near future such precise data of modern and, possibly, past moraines will be available as shape-files for GIS-programs. Thus far, the margin lines used in the present study represent rather schematic indication of the actual glaciers and were graphically smoothed in order to receive a graphic impression of the ice sheet. This graphic impression should indicate the imprecise reconstruction. This partial smoothing process was applied to the glaciers of the other maps as well, since they also rely on significant interpolations. As previously stated, correlations of moraines to the same glacier advance was occasionally difficult (Ivy-Ochs et al. 2009) and the ice sheets only retreated in some sub-units of the studied period. The position of the ice sheets in these periods can only be evaluated by the use of exposure dates and interpolated data. The various interpolations and choices are described in the following by ice sheet.

The Scandinavian ice sheet regression is well documented in Sweden (Lundqvist/Wohlfarth 2001, fig. 6) and the rest of Fennoscandia as well as in northern Germany and northern Poland (Boulton et al. 2001, fig. 12). The Swedish record was given priority due to the relevance of the area for the Lateglacial archaeology and, furthermore, the comparably fine-grained chronology which was mainly based on radiocarbon dating of the moraines. Therefore, the interpolated ^{14}C age ranges of the present maps were compared to the ^{14}C dates of the moraines (Lundqvist/Wohlfarth 2001, 1142-1145) and not the calibrated dates (Lundqvist/Wohlfarth 2001, fig. 6). The age ranges given for the moraines overlapping the period of the maps were selected. In the case of more than one moraine falling into the age range of the maps, the one dated closer to the mid-point of the period was chosen. Thus, the GS-1 ice margin limit was set at the Younger Dryas moraine (Lundqvist/Wohlfarth 2001, 1145), the GI-1c-a margin at the Levene moraine (Lundqvist/Wohlfarth 2001, 1144 f.), the GI-1e-d margin at the Berghem moraine (Lundqvist/Wohlfarth 2001, 1144), and the GS-2a margin at the Göteborg moraine (Lundqvist/Wohlfarth 2001, 1143 f.). The limits were followed through northern Scania and southern Kronoberg according to the interpolation in Boulton et al. 2001, fig. 12 and the margin lines given in Lundqvist/Wohlfarth 2001, fig. 6 south of Karlshamm. These margins could be connected through the Baltic Sea region to their margins in the Baltic States (Boulton et al. 2001, fig. 12). For the LGM the Brandenburg-Lezno margin was used as a maximum value (Boulton et al. 2001, fig. 12).

For the British ice sheet only the moraines of the Younger Dryas (Loch Lomond readvance ice limit) and the LGM (maximum extend of moraines) were given in a record of glacial landforms (Clark et al. 2004; cf. Sejrup et al. 2009). Thus, for maps 1 and 5 these available maximum values were chosen. For the present maps 2-4 the British ice margin lines were interpolated between the two known margin lines (Younger Dryas and LGM) according to the percentage of maximal regression between the corresponding marginal lines in the Scandinavian ice sheet (Younger Dryas to Brandeburg-Lezno margin; **tab. 49**). For instance, between the Brandenburg Lezno and the Younger Dryas margin, the Scandinavian ice sheet had shrunk by approximately 720 km, whereas the British glaciers had changed between the maximum extend to the Loch Lomond readvance over some 285 km. Between the Brandenburg-Leszno and the Göteborg moraine lay some 600 km and, thus, the glacier had already shrunk some 85 %. The same percentage for the British ice sheet would

map no.	distance (in km) from LGM margin (Scandinavian ice sheet)	% of regression between LGM and GS-1 margin	distance (in km) from LGM margin (British ice sheet)
5	0	0	0
4	*c.* 600	83.33	*237.49*
3	*c.* 650	90.28	*258.30*
2	*c.* 700	97.22	*277.08*
1	*c.* 720	100	*c.* 285

Tab. 49 Approximate regression distances of the Scandinavian ice sheet and calculated regression distances of the British ice sheet based on a percental relation to the Scandinavian ice sheet. Calculated values are set italics.

result in a regression of some 240 km. At these calculated distances the relief was followed to create a potential ice sheet. Clearly, this linear interpolation of the British ice sheet according to the Scandinavian development for the specified periods neglects the closer position of the British ice sheet to the warming gulf stream and many other important issues contributing to the complex history of this ice sheet (cf. Hubbard et al. 2009). However, these approximations suffice to introduce the potential limitation which an ice sheet represents for the expansions of the living environment including human groups.

Moreover, at the time when the first set of maps were made, no reliable data from the central North Sea Basin was available and, thus, whether the British and the Scandinavian ice sheets have coalesced during the LGM was unclear (e. g. Sejrup et al. 2000; Sejrup et al. 2009; cf. Svendsen et al. 2004). A coalescence has meanwhile become probable for the maximum extend of the ice sheets (Carr et al. 2006). Presumably, this coalescence of the two ice sheets had considerable impact on the drainage systems of north-western Europe and, possibly, also on the whole climatic regime of the North Atlantic climate region (cf. Toucanne et al. 2009). However, by the beginning of the time period studied here the two ice sheets were already two separate formations (see **fig. 19**; Carr et al. 2006).

Although data on the development of the Alpine glaciers has been published before (e. g. Hantke 1980; Hantke 1983), these were not used in the present approach because these data sets were too detailed to be successfully and beneficially processed.

Further comprehensive data about the Alpine ice sheet has been published since the first set of maps was produced (Reitner 2007; Federici et al. 2008; Kerschner / Ivy-Ochs 2008; Ivy-Ochs et al. 2008; Ivy-Ochs et al. 2009). However, this data did not sufficiently change the general picture of the Lateglacial geography. Thus, to draw an Alpine ice sheet on the Lateglacial maps, specific altitudes were chosen for the margins of each stage comparable to the procedure with the modern glaciers. These altitudes were interpolated by adding or subtracting equilibrium line altitude (ELA) values from the values of the Gschnitz moraine at Trins / Austria. The upper end of this moraine was located at 1,410 m a. s. l. with an ELA of -700 m (Ivy-Ochs et al. 2006, 116-118, especially tab. 1). This moraine developed presumably during the Late Pleniglacial (cf. Kerschner / Ivy-Ochs 2008) and was chosen as mean altitude for map 4 (**tab. 50**). In the Younger Dryas the Egesen moraine developed which in the Gschnitz valley was found at 1,930 m a. s. l. (Ivy-Ochs et al. 2006, 121 fig. 4) and the ELA was accordingly at -180 m (cf. Ivy-Ochs et al. 2006, 117 tab. 1). Moraines reflect the transgression of glaciers and, thus, develop only in the periods of glacier advance. Due to the complex growth patterns of glaciers, moraines from different locations are difficult to combine to a single glacier front (cf. Egense moraine in Ivy-Ochs et al. 2009). Thus, the relatively stable and reliably determinable ELA was preferred as a calculation factor in contrast to the use of moraines. Even though the ELA and the altitude of the glacier front are not linearly related, the values from GS-1 and GS-2a in the Gschnitz valley give a linear frame in which altitudes can be estimated based on the ELA, also for regression stages (**tab. 50**). For instance, no moraines were associated with the Lateglacial Interstadial because the ice sheet was regressing during this event. In general, the ELA was considered to be above the Younger Dryas one, i. e. ELA

map no.	relative ELA (in m) in Gschnitz valley	altitude (in m a.s.l.)
0	×	2,490
1	-180	1,930
2	*-110*	*2,000*
3	*-325*	*1,735*
4	-700	1,410
5	-1,100	*1,010*

Tab. 50 Mean altitudes chosen for the Alpine ice sheet regression. Modern altitude based on the 1989 Simming Ferner glacier tongue (Gschnitz valley/Austria; Ivy-Ochs et al. 2006, 121 fig. 4). Lateglacial values are calculated based on relation of the relative equilibrium line altitude (ELA) and the altitude of the moraines in the Gschnitz valley/Austria (Ivy-Ochs et al. 2006). Calculated values are set in italics.

< -700 m (Ivy-Ochs et al. 2006, 118 tab. 1). However, the Daun stage seems to date only shortly before the onset of the Lateglacial warming (cf. Ivy-Ochs et al. 2008, 567) or may even represent the first cold readvance during the Lateglacial (Ivy-Ochs et al. 2006, 120). Therefore, an ELA for the first part of the Lateglacial Interstadial can be set according to the values of the Daun stage. For this stage an ELA of -400 to -250 is given and a mean of -325 m was chosen. Thus, the margins for limiting the early Lateglacial ice sheet were set to 1,735 m a.s.l. based on the ELA and glacier front relation in the Gschnitz valley. For the LGM, the ice sheet limits were also interpolated at an ELA of -1,100 m (Ivy-Ochs et al. 2006, 118 tab. 1). The second part of the Lateglacial Interstadial was given an ELA of -110 m assuming this ELA to be above the Egesen ELA of a minimum of -180 m (Ivy-Ochs et al. 2006, 118 tab. 1). Furthermore, this ELA of the second part of the Lateglacial Interstadial was assumed to possibly be above the ELA of the early Holocene Kromer/Kartell readvance which was at a minimum of -120 m. Finally, in the graphic implementation of the glaciers during the Lateglacial Interstadial, the major river valleys were considered to have been cleared from ice due to melt-water activity.

Alongside these changes, isostatic uplift influenced the physical geography especially in northern Europe (Kiden/Denys/Johnston 2002; Reicherter/Kaiser/Stackebrandt 2005; Shennan et al. 2006). However, the geomorphological relief in many regions that were strongly affected by isostatic uplift is, in general, very strong, particularly, in the transition areas of land and sea. Thus, the margins given in the maps for the sea-level were usually not affected by changes due to isostasy. Furthermore, isostatic uplift decreased significantly with the distance to the main glaciated areas and would only result in very slight differences in the shading of the maps. Nevertheless, if more accurate maps were planned these movements should be taken into account. However, the introduction of isostatic data would require a revision of the SRTM data before making the base map.

The recolonization of north-western Europe by a living environment was further restricted by the development of the grounds. For instance, the occurrence of permafrost and the pedogenic development of sediments alter the carrying capacity of these areas for vegetation species. However, pedogenesis is influenced by several local factors (see **fig. 18**) and the soil development in the Lateglacial was thus far only recorded in single profiles but not on a larger surface. The various zones of frozen grounds (seasonally frozen ground, sporadic permafrost, discontinuous permafrost, continuous permafrost) were probably very narrow in the Late Pleniglacial (Huijzer/Isarin 1997, 409) and permafrost was absent during the Lateglacial Interstadial (Vandenberghe 2001, 193). Only during the Lateglacial Stadial were significant parts of north-western Europe again under permafrost conditions (Isarin 1997).

In conclusion, the maps of Lateglacial north-western Europe give a static picture of gradually advancing processes and presumably do not reflect the landscape at any specific point in time. Perhaps, in the future more detailed and precise maps can be compiled by the use of data published in shapefiles or comparable formats. Nevertheless, the present maps represent good estimations of the landscape development at the various stages and provide an impression of the major constraints (water and ice cover) for the expansion of the human habitats.

Since neither orthomorphic nor equal-area nor equidistant projections are necessarily needed in the present study, the maps displayed in the present work were vertically stretched in a 2:3 proportion. The resulting maps appear a good mixture of equal-area and equidistant projections. However, if distances are given in the present work they were measured using the »ruler > line« tool on the free online program Google^{TM} Earth.

Qualitative and quantitative assessment of data from the living environment

Besides the physical environment, the living environment also shaped the human habitat. Data from the Lateglacial living environment can be found in profiles (see p. 40-48; cf. Lotter et al. 1997; Lowe et al. 1999) and also in the form of directly dated samples (see p. 49-51). The pollen profiles are corrected for the chronostratigraphic constraints in their record but they are not further modified in the present study. In contrast, the directly dated samples require some evaluation and are then used to create frequency distributions to allow for assumptions on the presence of some species in the studied regions.

Evaluation of the radiocarbon database

^{14}C dating is one of the standard methods of dating in modern archaeology (Geyh 2005, 1. 69). In this project, ^{14}C dates form an integral part in contextualizing Lateglacial human activity and environmental developments. To accomplish and corroborate this contextualization, meaningful ^{14}C dates are necessary. To select these meaningful results, the existing record of ^{14}C dates has to be reviewed regarding the reliability of each sample. The reliability has to be questioned because »Errors in radiocarbon dating start at the moment of excavation and build through the process of dating« (Jacobi / Higham 2009, 1896). Generally, unreliable dates originate from inaccuracies in the apparatus and measuring procedure, contamination of the dated sample, and / or a mistaken association of the dated sample with the supposed significance of the result.

To account for the technical inaccuracies, the radiometric dating facilities give their results with a standard deviation. Therefore, this source of error is not further considered in the present study.

The necessity to evaluate ^{14}C dates for their significance has been emphasised since the early days of the technique (Johnson 1952; Dean 1978; Pettitt et al. 2003). The significance is dependent on the question that the ^{14}C date is intended to answer. In principle, the result of ^{14}C dating gives the age at which the incorporation of carbon into the sampled tissue stopped and the radiometric decay began. This age is equivalent with the death of the tissue. Thus, if a result is meant to date the death of the tissue the dated event is identical with the event that was supposed to be dated (target event, Dean 1978). In this case, concerns regarding potential contaminations form the main base for the test of reliability. However, the age of a sample is often considered as significant for other target events. For example, the age of a bone, which originated from an animal which was killed in a human hunting episode is assumed to date also the human activity. Often this association is not established as easily as in the given example and incorrect associations resulted in a divergence of the ^{14}C result and the target event. For instance, the heartwood is the dead tissue in the core of trees. If a sample from this part of the wood is dated the result can significantly predate the possible target event of the felling of the tree (Schiffer 1986). Therefore, the association of the two types of events (dated and target) has to be clarified and the period bridging the possible offset between the events has to be estimated (see p. 265-269).

The ^{14}C dates of environmental samples date the presence of selected environmental material relevant to Lateglacial hunter-gatherers in a particular region at a specific time. Thus, dated events mark the end of the target events, which are the life of the samples. In this case, old wood samples are well suited because they reflect the living years of the sample. In contrast, the results from faunal samples are more difficult to interpret because the place of death and the area of living are not necessarily identical. In particular, archaeological material such as bone and antler tools require a more cautious interpretation. These tools could potentially have been introduced to the region from elsewhere by Lateglacial hunter-gatherers and the sampled species were not in fact present in a region during the dated period (cf. Bratlund 1996a). Therefore, individual finds are evaluated critically in this study, particularly, if the sampled material originated from a human tool (cf. Riede et al. 2010, 307). The frequent occurrence of a species in a particular region during a specific time is considered a more reliable indicator for the presence of the species in the region.

The evaluation of contamination represent the major factor when considering which samples to use for modelling the Lateglacial environment. Contaminations can affect the dated samples during the lifespan of the dated material (Deevey et al. 1954; Olsen et al. 2010), during the deposition (Turney et al. 2000), during storage (Wohlfarth et al. 1998), and also during the dating procedure (Burky et al. 1998). In general, to evaluate the potential offsets various details of the ^{14}C-dated sample have to be accessible (Kra 1986, 766; Jacobi/Higham/Lord 2009, 7-9; cf. Lowe/Walker 2000; Pettitt et al. 2003).

Contaminations which occur prior to the dating procedure require a precise pretreatment chemistry (Hajdas 2008). However, samples that have incorporated »old« carbon isotopes (reservoir) during their lifespan must be rejected for dating past events. These samples are mainly water plants, shells, ostracods, fish, and other biota with strong dependence on hard water aquatic environments (Fischer/Heinemeier 2003; Rick/Vellanoweth/Erlandson Jon M. 2005; Olsen et al. 2010). In these environments, organisms absorb radiocarbon dissolved from the surrounding mineral throughout their lifespan. The contemporary atmospheric carbon signal is overprinted by these considerably older isotopes. Consequently, the concentration of carbon isotopes in the sampled tissue does not relate to the concentration of carbon isotopes in the atmosphere at the time of the death of the organism. Therefore, samples from these materials are in general rejected as unreliable in this project.

Furthermore, there are multiple ways of contamination during the deposition of the sample. Besides contextual contamination (see above, cf. p. 265-269), bio-geochemical processes in the soil (Hiller et al. 2003; Brock et al. 2011), particularly connected to (ground) water activity are a major source for contamination at this stage (e.g. Hedges/Millard 1995; Turney et al. 2000; Geyh et al. 1983; cf. Zazzo/Saliège 2011). In addition, contamination by micro-organisms can occur during storage. This type of contamination can be prevented by keeping the samples as sterile as possible, storing them in a dried state, and reducing storage times between recovery, analysis, and dating (Wohlfarth et al. 1998).

Radiocarbon dating facilities have tried to remove any type of contamination that occurred prior to the preparation of the sample for the dating (e.g. Münnich 1957; Gillespie/Hedges 1983; Lanting/Niekus/Stapert 2002; Higham/Jacobi/Bronk Ramsey 2006; Hajdas 2008; Olsen et al. 2008). Pretreatment protocols were developed, which are undergoing constant refinement and are regularly adapted to newly identified sources of error (Bronk Ramsey/Higham/Leach 2004, 18). These protocols increased the dating precision. Thus, contamination originating from deposition or storage are assumed to be sufficiently resolved by dating facilities for dates obtained since the late 1990s. For some of the earliest radiocarbon dates the incorporation of modern carbon during deposition or storage might represent a source of error. Therefore, these results should be checked for the δ^{13}C value to see if significant contamination is possible and/or for the contextual reliability of the resulting age. However, erroneous results were also due to the choice of sample material. In the »classic« method of radiocarbon dating (β-counting or conventional dating, Libby 1952) a significant amount of Pleistocene material was required to produce statistically reliable results. Due to the limited preservation of datable material in Northwest-European Lateglacial archaeology, bulked samples were often dated. This procedure is sufficient if the material is comparable and originated from the same event such as animals killed during a single hunting episode. In this case, this bulked sample also yielded a reliable date for the target event. More often, however, this relation of archaeological material remained unclear and was even proven false in some cases (e. g. Holocene admixtures in Stellmoor, Bratlund 1999). Consequently, bulked samples need to be more cautiously and rigorously assessed and compared to the overall site context. Nevertheless, results are not excluded due to the use of different methods for obtaining the ^{14}C date (β-counting or AMS, cf. Banks et al. 2008) because it is not the technique but the choice of sample that causes the contamination.

Further contamination is possible during the pretreatment and/or dating procedure. Generally, contamination during this phase can best be recognised and minimised by repetitive and transparent evaluation of the laboratories dating procedures (Bronk Ramsey/Higham/Leach 2004, 23) and inter-comparison of the results from various laboratories (Boaretto et al. 2002; Scott et al. 2004). For instance, over a decade ago problems with the ion-exchanged gelatin pretreatment (lab code: AI) were recognised in the Oxford Radiocarbon Accelerator Unit (Burky et al. 1998). This finding led to the abandonment of this method (Higham/Jacobi/Bronk Ramsey 2006, 182). Furthermore, in the initial phase of ultrafiltration pretreatment procedure at the same laboratory the collagen was insufficiently cleared from humectant (glycerine, Higham et al. 2007). This possible source of contamination needs to be mentioned because several Lateglacial dates are affected by these insecurities. Some of these measurements were redated suggesting that the impact on very small samples was more significant than on larger samples (Jacobi/Higham/Lord 2009, 9; Higham et al. 2007, S2). In general, the effect of small contaminations increases when the sampled material decreases in size (Wohlfarth et al. 1998, 144; Bronk Ramsey 2008, 259). Therefore, minimum amounts of datable carbon are required, in particular for AMS dating. Currently, this minimum is around 1 mg C for AMS facitilites (Higham/Jacobi/Bronk Ramsey 2006; Bronk Ramsey 2008). Samples with smaller amounts of carbon are considered unreliable in the present study. In general, the small sample sizes resulted from the wish to receive measurements with only minimal destruction of the dated sample. Perhaps in the future, for some materials, non-destructive sampling may become possible (cf. Steelman/Rowe 2004) and, presumably, will permit further important objects such as the Poggenwisch rod (Bosinski 1978) to be directly dated.

In addition, the dating procedure for various tissues and fractions requires specific consideration. For example, the collagen or amino acid fraction which represents approximately 30 % of the living tissue is normally dated in tooth, bone, and antler material (Burky et al. 1998). This fraction does not survive burning. However, a considerable portion of the Lateglacial archaeological fauna material has been only preserved in a charred state. In these samples the carbonate fraction can be dated (Lanting/Aerts-Bijma/van der Plicht 2001). A comparative dating program for cremated bone from Lateglacial and early Holocene sites produced concordant results for the Holocene but revealed some inconsistent results for the Lateglacial (Lanting/Niekus/Stapert 2002). Possibly, this inconsistency relates to an insufficient degree of bio-apatite recrystallization during the burning process leading to the still existing possibility of exchange processes with dissolved soil bicarbonate (cf. Olsen et al. 2008). Exchange processes with dissolved elements in the soil water occur in clay-containing sediments rather than sandy sediments. Moreover, these exchange processes are less of a concern in arid environments (Zazzo/Saliège 2011). Therefore, dates made on cremated bones, but without further structural analysis, have to be compared carefully to their context. The sediment structure and the drainage of the sediment as well as other independent dating results should be taken into account for this comparison. Often this type of additional information is only partially available and, thus, the majority of dates on or containing burnt bone material have to be rejected. In the future, additional analyses concerning the fire use and burning temperatures on archaeological sites (cf. Moseler 2014; Werts/Jahren 2007) can perhaps help to evaluate the preservation of reliably datable burnt bone material.

^{14}C-dated mammoth ivory occasionally produces dubious results such as the sample from a carved piece of ivory from the concentration II in Gönnersdorf (see **tab. 20**) yielding a mid-Lateglacial Stadial age (OxA-2069). Even though tusks grow continuously, the tusks are well vascularised throughout the animals life in contrast to wood and, thus, the tusks are living tissue. Consequently, ^{14}C dates on ivory should produce a date for the death of the animal not for the growth date of the tusk. In contrast to other dental material ivory is rather soft because it is largely formed of dentine (Heckel 2009, 76). Perhaps, contamination by infiltration occurs more easily in ivory than other dental material due to this soft consistency. However, the dense structure (Heckel 2009, 76) does not provide space for undetected infiltration of other substances on a molecular level. Therefore, ivory appears, in general, not to be a target of contamination and should not be rejected a *priori*.

To test technically reliable results against their context, the ^{14}C date has to be calibrated and the calibrated age can be compared to the chronostratigraphic indications of the context from which the sample originated.

The normal distribution of a ^{14}C measurement becomes more complex when plotted against a wiggling calibration curve and, in consequence, the result represents a function of the shape of the calibration curve (Blockley / Donahue / Pollard 2000a, 114; Weninger et al. 2011). The resulting probability is no longer evenly distributed on the calendar timescale and the calibrated age should therefore be given in time ranges (Pearson 1987, 100; Blockley / Donahue / Pollard 2000a, 114; cf. Geyh 2005, 70 f.). The mathematical probability for these calibration results is given by the various calibration programs, generally with 68 % or 95 % confidence ranges. Due to the unsteady calibration curve in the Lateglacial the 68 % must not be the best match (cf. Blockley / Donahue / Pollard 2000a) and, therefore, the 95 % version is chosen here. However, the higher confidence range which covers most possible readings from the calibration curve also blurs the result. This increase of imprecision is the case, especially, in strongly fluctuating parts or plateaus of the calibration curve. High-precision measurements may result in several, disconnected readings or a very long period on the calendar timescale. In general, the large period should be given as a calibration result. However, further considerations based on additional chronological information from a site can help to formulate the most probable interpretation. To tackle the interpretative problem of varied chronostratigraphic indicators such as pollen- or lithostratigraphy connected to the ^{14}C dates, statistical methods were developed (e. g. Buck / Litton / Scott 1994; Bronk Ramsey / van der Plicht / Weninger 2001; Blackwell / Buck 2003; Hamilton / Buchanan 2007; Jacobi / Higham 2009; Steele 2010). In particular, Bayesian approaches were used for this purpose (e. g. Rhodes et al. 2003; Wohlfarth et al. 2006; Blockley et al. 2008; Gearey / Marshall / Hamilton 2009; Blockley / Pinhasi 2011). However, many of these approaches neglected the quantum-theoretical aspects of radiocarbon calibration resulting in over-correction of the data by a frequency normalisation disregarding Heisenberg's uncertainty principle (Weninger et al. 2011). Moreover, for these approaches a considerable corpus of information and numerous radiometric dates in combination with the qualitative evaluation of the reliability of each date is necessary to produce reliable results. The majority of Lateglacial sites from north-western Europe does not, in fact, fulfil these requirements. Instead the tight connection with the eventstratigraphy based on the argumentative interpretation of the chronological information is attempted. Therefore, the relation of the context to the sample has to also be considered. Disturbances such as cryo- or bioturbation can cause displacements in the stratigraphic position of the sample to a higher or lower position. Furthermore, heavy samples such as bones can sink into softer ground or lighter sediment can be washed out and replaced by successive sediment, whereas heavier samples remain *in situ*. Therefore, the contextual confirmation of a ^{14}C date requires a good knowledge about the stratigraphic development at the site. If no reason for the rejection of a ^{14}C date is found it is regarded as reliable in this project.

In summary, a qualitative evaluation of ^{14}C dates requires a comprehensive understanding of the history of the sample in relation to the site formation process and its effects on the sample. The outcome of this evaluation is usually a significantly shrunken database (see **tab. 5**) which, nevertheless, produces preciser and more reliable results (cf. Grimm/Weber 2008).

Probability and frequency distributions of radiocarbon dates

To use reliable ^{14}C dates in an approach to model the Lateglacial environment required distinguishing the samples by species and from where the sample originated. Some species were selected (see below) and the reliable ^{14}C dates of these species were sub-divided according to the sub-areas of this study (see p. 31-40). These sub-sets were calibrated with the CalPal program and the reviewed Lateglacial calibration curve. Probability distributions of calibrated data sets have been considered as proxies reflecting frequencies of material remains created by human societies (dates-as-data; Rick 1987; Gamble et al. 2005). In this approach, the increase of ^{14}C dates during a specific period was assumed to be caused by increased human activity in this period (Gamble et al. 2004; Shennan/Edinborough 2007). Thus, a type of eventstratigraphy of human activity was created by the probability distributions. The recognition of divergent dates for the onset of a probability event in different areas was assumed as reflecting dispersal patterns (Housley et al. 1997; Hamilton/Buchanan 2007; Steele 2010).

In this study, the probability distributions of ^{14}C dates for the sub-sets are considered as reflecting the probable presence of the species in the sub-area. However, absence of a specific species cannot be proven by this proxy[22], only the presence can be shown as statistically probable. These data sets are partially biased by sampling strategies. Therefore, these probability curves are not taken as equivalent to demographic developments. Some further cautions are necessary in the interpretation of these distributions. In particular, calibration relics, the impact of the mathematical approaches creating the probability distributions (Blockley/Donahue/Pollard 2000a; Blackwell/Buck 2003; Shennan/Edinborough 2007), and preservation biases (cf. Surovell/Brantingham 2007) need to be excluded as factors influencing the distribution.

A comparable, event-like approach was used in palaeontology with a first and a last appearance date (FAD/LAD; e. g. Walsh 1998; Aaris-Sørensen 2009) setting the limits for the presence of a species in a specified area. For the period between these dates a continuous presence of the species is assumed. However, sometimes the evidence is sparse and then the continuity of the species presence is as questionable as the probability distributions. Additional information such as stratigraphic evidence, comparison to neighbouring areas, and modern analogies have to be integrated to sustain the conclusions (Aaris-Sørensen 2009, 7). Yet, if the database is sufficiently large, the combination of FAD, LAD and the probability distribution can provide a useful set in environmental studies to describe the statistically reliable presence of a specific species. This combined record contributes to the modelling of the regional environmental development.

However, ^{14}C dates on vegetal samples that were identified to species are rare in the Lateglacial record of north-western Europe. The typical species used as fuel for hearths on Lateglacial sites in north-western Europe were birch (*Betula* sp.), juniper (*Juniperus* sp.), pine (*Pinus* sp.), and willow (*Salix* sp.). However, only a few samples of birch and pine have been dated from the study area (see **tab. 5**). Their probability distribution produced no significant patterns. However, the presence of these samples can prove the presence of these resources at least in small numbers at specific periods.

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[22] Although the observation that »Absence of evidence is not evidence of absence...« (Sagan 1995) is a general scientific theorem and, therefore, appears trivial, it was neglected previously in the interpretation of ^{14}C date frequencies (Housley et al. 1997; Riede 2008; cf. Terberger/Street 2002).

Among the faunal samples the focus is set on the mammal species that were mainly hunted by Lateglacial humans such as reindeer (*Rangifer tarandus*), horse (*Equus* sp.), elk (*Alces alces*), red deer (*Cervus elaphus*), and large bovids such as bison (*Bison priscus*) and aurochs (*Bos primigenius*). Although the presence of specific faunal species could also provide insights into the Lateglacial climatic (Hernández Fernández / Peláez-Campomanes 2005) and the vegetation development (Fahlke 2009; Musil 2010), these species are only used as a general cross-checking parameter. Usually, the climate and the vegetation records are used to check the reliability of the faunal results.

To provide a more detailed picture of the possible presence or absence of selected species which in addition is more reliable than the probability distribution of only directly ^{14}C-dated specimens, tables of potential presence in the sub-areas were made containing columns for the different short-term isotope events and the selected fauna species in rows. The potential presence was indicated by simple colour coding (white: no indication; grey: possible indication; black: reliable indication). A comparison of this type of table with a pollen diagram is not possible in the same detail as a comparison of the probability distribution with the plant development. Nevertheless, in these tables the reliability of the data for a specific time is evaluated and therefore, these tables are an important supplement to the probability distributions.

Mapping the data from the environment

The finished maps of Lateglacial north-western Europe were read into a GIS program (previously ESRI ArcView® 9.3; since June 2012: Quantum GIS, version 1.8.0 »Lisboa«) by geo-referencing the four corner points of the maps. Within these programs the environmental data were plotted onto the relevant map by the use of the coordinates from the geo-databases (see p. 52 f.). For the mapping, the previously created sub-sets (see above) are used. The calibrated age range of each dated sample is compared to the limits of the Greenland eventstratigraphy and thereby the sample is attributed to the Lateglacial event to which it dated. With this attribution all samples of a selected species dating to a specified event could be plotted on the relevant maps.

Frequency distributions to interpolate areas of probable occurrences of a particular species during a selected time are technically possible based on the created point pattern. However, the numbers of samples per time slice are very small and, consequently, the extent of purely interpolated areas would be very large. As a result, the significance of frequency distributions based on these samples are doubted and, therefore, this technique is not used. Instead the single samples are plotted in a point pattern on the maps.

The maps of Lateglacial north-western Europe are also applied in a very conservative manner in the present study. Even though mathematical approaches to process large numbers of data as well as complex networks of spatial data sets are known in geography as well as in archaeology (Nakoinz 2009), the number of reliable pieces of evidence are too few in the present study to permit these statistical analyses to produce reliable results. In fact, sufficiently complex and detailed material databases to permit geostatistical analyses to produce reliable results for the Lateglacial on a large scale do not yet exist. Thus far, the first usable models of the Lateglacial landscape are only created on smaller scales (De Smedt et al. 2013). Although recommending the use and the consequent refinement of the geostatistical approaches for future research, the necessity of a qualitative evaluation of the existing record and a compilation of numerous data sets is regarded as a basic precondition to produce reliable results with the various types of geostatistical approaches. Therefore, this project tries to contribute to this future research aim by evaluating the present archaeological data and creating reviewed databases. Thus, the conservative use of the maps is, fundamentally, due to the material based orientation of the present study.

ARCHAEOLOGY

The third of the three main types of archives used in this study is the archaeological record. The archaeological material presented previously (see Material-Archaeology, p. 53-244) forms the basis for the analysis of past human behaviour. Systematic changes in this behaviour during the studied time frame are particularly relevant as they are considered to reflect the process of transition within a social system. The main aim of this project is to examine such a process on the example of the transition from the Late Magdalenian to the FMG way of life in the context of Lateglacial climatic and environmental developments. The character of the process can either be described as gradual or as rapid. In this study, the former is assumed to reflect an evolutionary process, whereas the latter is considered as a revolutionary process. The two types of processes (revolution and evolution) are assumed to be distinguished by the tempo in which they affect most parts of the human life (see Introduction, p. 1-5). Consequently, to distinguish between the two types of process, reliably dated assemblages are necessary. The formation of a reliable, chronological basis is therefore a key requirement to understand the transition process. This evaluation has to be supplemented by an analysis of the integrity of the archaeological assemblages. Furthermore, various lines of evidence have to be incorporated to identify various changing parameters such as lithic resource exploitation, changes in prey preference, or settlement systems and to prevent the overestimation of single rapid adaptation of one parameter. Therefore, the following methods were used to evaluate the chronological integrity of the assemblages as well as various approaches to systematically assess evidence for changing parameters within these assemblages.

Chronological evaluation of the integrity of the archaeological sites

A secure chronological attribution of the selected assemblages forms the base of the present study. The reliability of the chronological attribution of an archaeological assemblage depends on the integrity of the assemblage as well as on its position in the chronological development (cf. Weniger 1989; Crema/Bevan/Lake 2010; Fougère 2011). The position in the general chronological development is usually estimated by environmental chronostratigraphies and especially by ^{14}C dates. However, the latter require some evaluation regarding their reliability and significance (see p. 259-263 and below). Furthermore, the integrity of the assemblage can also be sustained by multiple ^{14}C dates. However, assemblage integrity is mainly constituted by a spatial analysis that is often combined with considerations about the *chaîne opératoire* of relevant parts of the lithic assemblage. Spatial analyses of Lateglacial sites have frequently been undertaken in the last decades (cf. Gaudzinski-Windheuser et al. 2011a). However, detailed analyses of each site exceed the possibilities of the present study but for many cases detailed analyses were already published (see Material-Archaeology, p. 53-244) and are used in the considerations about the internal chronology of the sites.

Evaluation of the radiocarbon database

Radiocarbon dating has become an integral part in contextualizing Lateglacial sites within the development of the surrounding environment as well as with other, often distant archaeological sites. Therefore, the verification of this type of date is an indispensable step in the chronological attribution of Lateglacial sites. Roger Jacobi and Tom Higham state that »Errors in radiocarbon dating start at the moment of excavation and build through the process of dating« (Jacobi/Higham 2009, 1896). Consequently, ^{14}C dates have to be evaluated in regard to all potential sources of error. However, the inaccuracies resulting from the apparatus and measuring procedure are accounted for in the standard deviation given by the radiometric dating facilities. In general, contaminations occurring prior to the dating procedure are removed by the dating facilities during sample pretreatment. However, some still important technical reasons for contamination and rejection of ^{14}C dates were presented previously (see p. 259-263) and apply also to the archaeological material.

Besides technical reasons for the rejection of radiocarbon results, many contextual reasons exist. These contextual reasons relate particularly to the significance of a ^{14}C date. The necessity to evaluate ^{14}C dates for their significance was already emphasised in the first substantial publication on radiocarbon dating (Johnson 1952). The evaluation of the significance of the dating result (dated event) for the questioned activity (target event) is a relevant part in the review process of the archaeological radiocarbon record (Dean 1978). Especially, questions concerning the site formation process and the position of the sampled material therein have to be challenged (cf. Pettitt et al. 2003).

Bulked samples that combine material of various ages are a common source of erroneous results and, occasionally, this combination can also occur unintentionally if the sampling was not performed carefully (cf. Bodu et al. 2009b).

Even though the combination of various events can be prevented by dating samples that consist of a single piece such as a bone, the contextual integrity and the archaeological significance of these samples can also be questioned (cf. Housley et al. 1997, 34). For example, the death of the dated tissue which started the radiometric clock can instantly relate to the human activity of interest if the dated tissue is a bone of an animal killed by humans. However, the association of the two types of events (dated and target) is not always so clear in archaeological assemblages.

In archaeological contexts, the dated event generally predates the target event, for example if the target event is an occupation episode in which »old« material was used for construction (animal skulls as trophies; mammoth femur from Gönnersdorf, Street/Terberger 2004, 296), as jewellery (fossil molluscs), for the carving of figurines and tools (fossil ivory, shed antler), or as fuel for hearths (jet and deadwood). In this case, the bridging period between the different events has to be established (cf. Dean 1978). To establish reliable estimates, other material that was more closely related to the human occupation should be dated. A good sample would be a bone with a probable deadly impact mark or a bone with cutmarks which suggested filleting of the meat. If the bone was of no use prehistoric humans would presumably not have made the effort to strip a bone of rotten meat which they could not consume. Consequently, the meat was probably relatively fresh[23] when processed by humans. The dated event (death of the animal) and the target event (filleting by humans) can be assumed as relatively close events in time.

The offset relating to the life history of the dated material such as the »old wood« effect were regularly considered to fall into the period covered by the standard deviations. However, based on the current accuracy and precision in ^{14}C dating, this reduction of all uncertainties to the period of standard deviation appears problematic. For example, in the case of charcoal which was burnt in a prehistoric hearth, a period shorter than the standard deviation is generally assumed for the bridging event between the

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[23] In fact, for this scenario some offset could also be made plausible in the presence of permafrost and cold water environments which could have served as natural refrigerator to store faunal material (Bokelmann 1979, cf. Grønnow 1987). However, the decay of soft tissues such as meat would began very quickly after the melting of permafrost. Therefore, this natural ice storage could not form a significant offset of ages in the Lateglacial (see p. 258). In cold water the meat is known to ferment (Grønnow 1987, 158) and, presumably, various organisms inhabiting this environment would began to decompose the meat. Thus, the storage of meat bearing parts in cold water environment is also temporally limited.

burning (target event) and the separation of the pieces of wood from the tree (dated event). In Lateglacial north-western Europe, the charcoal from archaeological sites was usually determined as pine (*Pinus* sp.), birch (*Betula* sp.), juniper (*Juniperus* sp.), willow (*Salix* sp.), or poplar (*Populus* sp.). Some of these shrubs and trees can live for several hundred years and, consequently, the heartwood would already produce a considerably older date than the sapwood which is contemporary with the separation. In this case, the dated event and the target event of wood diverge (Dean 1978, 228; Schiffer 1986, 16-19). Nevertheless, regularly occurring storms and forest fires keep the age structure, in general, comparatively young in areas comparable to the Lateglacial environment, such as Sweden. An analysis of age structure in pine (*Pinus sylvestris*) populations from eight localities in Sweden revealed that these trees rarely became older than 300 years (Agren/Zackrisson 1990, 1052). Some high-precision AMS-dates from periods with a relatively even part of the calibration curve such as the dates from Doetinchem in the Netherlands (Johansen et al. 2000) produce calibrated results for the Lateglacial which range between 200 and 300 calender years. Thus, an offset of more than 300 years, for example, due to the age of the tree would already fall outside the standard deviations. In addition, wood used for burning should preferably be dry because the moisture in fresh wood produces considerable amounts of smoke. Drier heartwood can be used but in forest environments also deadwood can be collected. Significant drying can occur in several months to a few years. However, the decay of the wood sets a natural limit to this offset. The natural decay resistance of the heartwood is, in general, considered relatively strong and, thus, the use of deadwood could result in an additional offset. Based on the reconstructed, generally moist, environments during the Lateglacial Interstadial and the modern environments in which pines grow, decreased decay times are possible for the specimens from the Lateglacial Interstadial (cf. Schiffer 1986, 17 f.). Nevertheless, the survival of wood into later prehistoric periods, perhaps, in specific environments cannot be neglected as possible source of erroneous results (cf. Grieben, Grünberg 2006). Consequently, the use of heartwood from deadwood could result in some significant offset between the dated event (death of tree) and the target event (burning of wood). In total, this offset could surpass the standard deviations. In general, the history of the sample prior to becoming a resource for humans should always be kept in mind when relating dated and target event. Clearly, wood is an extreme example but this precaution also applies to faunal material. Although the majority of mammals does not become very old, the decay resistance of some hard tissues such as antler, bone, or dentine can be relatively high. For instance, modern experiences prove that in permafrost regions and, particularly, in melting permafrost regions significant offsets can occur between the death of the animal (mammoth) and the use of it as a resource (ivory trade, Haynes 1991, 47 f.; Stuart et al. 2002;Kramer 2005). This use of fossil material was considered also probable during prehistoric times (Street et al. 2006, 761). Thus, the depositional history of the material prior to becoming a resource also requires consideration in the review process. However, to distinguish between the use of »old« material and an actual »old« occupation of a site is sometimes not possible (cf. Napierala 2008a).

Another offset could occur from the time of use of the organic material. In addition to the offset between the dated event and the target event, the question arises which is the target event of interest? The use of the implement could be of interest relating to the development of tool types, whereas the discard age could be interesting if dating the use of a particular location. For instance, hunters killed a reindeer and used the antler to carve an antler point. Modern experiments with organic implements revealed an astonishing durability of these pieces (cf. Pétillon 2006, 88-95). So, perhaps, the resistant tool was used for several years resharpened and, possibly, inherited to the next generation which finally lost or discarded the implement. Comparable considerations apply to special objects such as molluscs, figurines, or drilled animal teeth. However, this type of offset is also largely assumed to be covered by the calibrated age range for Lateglacial dates.

Even though the dated event generally predates the target event in archaeological contexts, sometimes the dating result post-dates the target event. In Lateglacial contexts, this type of offset can frequently be attributed to depositional displacements. For instance, a projectile can be shot into an otherwise unassociated context such as soft, limnic or fluvial sediments. If material from this sediment is dated, the target event (use or loss of implement) predates the dated event (deposition of the material). For example, the various single finds of Lateglacial organic points in north-western Europe (e. g. Stampfuss / Schütrumpf 1970; Cziesla 2007b) can sometimes be younger than the context in which they were found. However, if the organic projectile is dated directly the target event post-dates the dated event again.

Finally, an incorrect attribution is also possible. For example, charcoal resulting from other events such as natural fires can be interchanged with charcoal from a hearth if the surrounding sediment is rich in charcoal and animal burrows. Furthermore, animal remains can enter a site through a multitude of natural causes and these remains are not always possible to distinguish from fauna introduced to the site by human activity. Besides humans, various kinds of predators such as wolves, foxes, or birds of prey can introduce bone material to a site. In cases of poor surface preservation of the bones, the cause for the damage on a bone cannot be detected with certainty and the distinction between human or others predators as the causal agent is unclear. Nevertheless, for some materials such as antler the introduction by other predators is less frequently attested. Furthermore, animals could have died naturally on the site (»background fauna«). However, if these »natural« remains are dated they produce an age unassociated with human activities.

The previous points illustrate that ^{14}C dates are only as reliable as the context of the sampled material and emphasise the importance of analysing the site formation process as well as the history of the sample for evaluating the reliability of radiocarbon dates. Each date of the radiocarbon database (see p. 49-51) was evaluated according to the technical reasons (see p. 259-263) and to the above described contextual reasons for rejection.

After this technical and basic contextual analysis, the reliable dates have to be calibrated to permit these dates to be compared with their climatic and environmental surrounding. Thus, calibration is a necessary step to result either in the confirmation of the ^{14}C date by its context or in a reconsideration of the previous assumptions regarding the reliability of the date or regarding the development of the context. Furthermore, this comparison with the context can also help to narrow the most probable reading from the date range or multiple readings resulting from the unsteady calibration curve.

Even though the strength of radiometric dating is the production of independent dates, the precision of the dating of a single archaeological assemblage (target event) can be increased by testing all dates from the same context against one another. For example, the sample history of reliable dates is clarified and the various dated events should relate closely to the same target event. Thus, by the overlapping age ranges the target event becomes more clearly defined. Therefore, several dates from a single assemblage are appreciable and, in addition, increase the precision of the radiometric age of the assemblage. To test whether the measured spread of several dates from a single site can be explained as a random process, a χ^2-test using the program Statave (Robinson 1988) is applied to the uncalibrated dates. The uncalibrated dates represent the raw measurements and their probability distributions can be described as Gaussian normal distributions. If the combined dates are consistent with the resulting weighted mean in the 2σ-range, they relate statistically to the same event. In contrast, the probability distributions of calibrated ages are altered further by the calibration curve and are no longer normal distributions which would complicate the test significantly. However, this constraint emphasises the importance of the previous technical and contextual evaluation to select already the reliable uncalibrated ^{14}C dates.

If by this time no reason for the rejection of a ^{14}C date is found, it is regarded as reliable in the present study.

Thus, ^{14}C dates help to clarify the chronological position of a single site and, moreover, compendia of regional ^{14}C dates can also be compared to show possible movements of dated characteristics (e.g. Rick 1987; Housley et al. 1997; Blockley/Donahue/Pollard 2000a; Blackwell/Buck 2003; Gamble et al. 2005; Shennan/Edinborough 2007; Hamilton/Buchanan 2007; Steele 2010). In fact, combined probability distributions of calibrated radiocarbon dates were themselves applied as a proxy for human activity in a specific region allowing for a conclusion on past population histories (dates-as-data; Rick 1987; Gamble et al. 2004; Gamble et al. 2005; Shennan/Edinborough 2007). However, several restrictions to this method have to be considered before interpreting population histories based on radiocarbon probabilities. In particular, preservation biases need to be excluded before discussing population dynamics. Only this revision allows for an interpretation of the results regarding the evidence of absence. Furthermore, over-representation of single, but numerously dated assemblages have to be levelled, which could be possible by using weighted means. Mathematical methods underlying the creation of probabilities from a calibration curve can cause some offsets (cf. Shennan/Edinborough 2007) and the strongly wiggling atmospheric carbon level can lead to the almost invisibility of some parts and over-representation of others in large series of ^{14}C dates (cf. Weninger et al. 2011). Since this is a systematic problem, it cannot be entirely solved mathematically but requires deductive argumentation. In this case, the positioning of the single archaeological units could help to evaluate the consistency of the observed probability distribution of ^{14}C dates. Furthermore, if the development of target events such as the use or discard of bone and antler points was aimed to be dated by these probabilities distributions, a bridging relation between the dated material and the target developments has to be established.

Therefore, these combined probability distributions are not used for the archaeological material in the present study. Since the age of the dated assemblages is established other graphs such as battleship diagrams or simple column graphs provide a clearer impression of the changes and continuities in the archaeological material.

Quantitative assessment of raw material sources

The decisions by hunter-gatherers concerning raw material procurement and exploitation provide insights into their economic behaviour within the landscape. Furthermore, the use of specific resources help to understand land use and, thus, mobility patterns (Floss 1994; Pettitt/Rockman/Chenery 2012). A diachronic perspective of these patterns could even reveal derived habits of landscape knowledge (cf. Rockman 2003b). In addition, if a tendency towards an increasingly careless and wasteful use of the raw material is detected, then a good knowledge and a reliable availability of the resources can be assumed (cf. Conneller 2007). However, due to the relation with the mobility pattern and the function of a site, the use of the raw material has to be considered within the character of the site and the function of the site within the settlement system. A first step towards classifying the sites according to this general handling of raw materials is attempted by a quantitative assessment of the raw material resources.

The exact origin of the resources other than mineral and fossil material is difficult to establish. Thus, in the present study only the fossil and the mineral, in particular, lithic raw material resources are considered further.

A general quantitative assessment of the lithic raw material resources is difficult to establish because often different values are given for the different raw materials. For example, often the numbers of artefacts made from a specific raw material are given but these numbers can relate to specific types or sizes of artefacts. However, the different raw materials are also given per weight or by proportion of the total artefacts. The weight would be of particular interest because it allows for considerations about the transport efforts of the hunter-gatherer group. However, the weight is rarely given and, therefore, it is not useful in a comparative approach. Occasionally, only general tendencies of the raw material composition are given such as »the majority« and »a few«. This imprecision hampers a quantitative comparison of various assemblages.

To account for this variety a simplified differentiation of raw materials is used in which the various types of data are classified into three classes: major types, regular types, and minor types. The major types are the dominant raw materials which comprise 30 % of the lithic material or more. Regular types make up 5-29 % of the assemblage and minor types produced less than 5 % of the lithic artefacts. Thus, the classified raw materials are further differentiated according to the approximate minimum distance from which the material occurred (see **tabs 12. 25. 36**).

Furthermore, assuming an economically adapted use of the resources, the accessibility as well as the richness of a source influences the use of the raw material within an assemblage and, consequently, the position of the site within the settlement system. Thus, with the profile of the exploitation strategy used for a raw material, the availability of a source can be assumed (**tab. 51**) and tested against distances known from modern surveys. The influence of raw material availability on the settlement system can consequently be further considered.

Qualitative and quantitative assessment of the lithic assemblages

Lithic assemblages are the most common records on Pleistocene sites. To analyse these records a multitude of methods have been established. In the present study, the focus lies particularly on the composition and the size of the different assemblages to reveal changes in these general values.

The size and the composition of lithic assemblages were considered as dependent on the duration of a prehistoric occupation (Richter 1990) but also related to the function of the site (cf. Löhr 1979). The function is assumed from the activities accomplished at a site, which were partially based on the diversity of the material found at the site (butchering debris, hunting equipment, jewellery) and partially on the composition of the lithic tool inventories and the functions attributed to the tool classes. In fact, different activities influence the size of the assemblage in various ways and were accomplished over various periods of time. For instance, the blank production process produces more debris than the application of retouched tools. A skilled flintknapper requires several minutes to a few hours to complete a blank production process (Fischer 1990; cf. Olausson 2010, 45 f.), whereas a few retouched tools such as end-scrapers which were assumed to be used for hide work (Rots 2005; Sano 2012b) could reflect a considerably longer lasting activity. However, the size and composition of the assemblage is also influenced by what part of the site was excavated (complete, an activity zone etc.). To quantify the influence of the excavated area on the size of the assemblage a simple index of artefacts per excavated square-metre (density index = no. of artefacts / no. of excavated square-metres) was calculated. This index is named density index because it identifies the density of artefacts per square-metre. The density index is given as artefacts ≥ 10 mm per excavated square-metres and in parentheses the value for total artefacts per excavated square-metres is given.

Exploitation analysis

The exploitation analysis of archaeological assemblages should provide information on the handling of the resources. The handling of a resource, in particular, lithic raw material, has been identified as an important

source	rich	poor
distant	attentive use: some wastes, few heavily exploited cores, few discarded retouched artefacts	sparse, specialised use: single retouched artefacts
near	wasteful use: plenty wastes, hardly exploited cores, blanks, some retouched artefacts	specialised use: few wastes, few heavily exploited cores, few retouched artefacts

Tab. 51 Idealised model of raw material economy based on source availability.

difference between the Late Magdalenian and the FMG in Central Rhineland, whilst the origin of the resources remained almost unaltered (cf. Floss 2002). The Late Magdalenian exploitation was described as efficient relating to the transport of the raw materials. For instance, ready prepared cores or blanks were brought to the sites. Furthermore, the choice of usually high-quality raw material suggested that poorer qualities were discarded at the source of origin. In contrast, the FMG seemed to transport raw material nodules over considerable distances and only tested the material at the site where the raw material was used.

Consequently, the distance from where a raw material was brought to a site (see p. 269 f.) and the way in which the material arrived at the site (raw nodule, ready made core, blank, ready made tool, or used tool) also shape the understanding of how past territorial ranges were used. This information allows for a consideration of mobility and the means of transporting material. Harald Floss had standardised a combined analysis of the *chaîne opératoire* with the raw material resources to distinguish the status of the material at the site (Floss 1994; Floss 2002). However, this analysis has been accomplished by him for the Central Rhineland and is only partially possible for the published material from the other parts of the study region.

In contrast, a more general exploitation analysis of the lithic material is used in the present study. Although more detailed studies such as the one described above are generally appreciated, for the more general character of the present study a more abstract and universal distinction of the handling of the raw material suffice. Therefore, the general index of the relation of cores to the complete lithic material including particularly debris (exploitation index = no. of artefacts [total] / no of. cores) is selected. Since the total number of artefacts is not always given, the same index is created with the no. of artefacts ≥ 10 mm. This exploitation index is assumed to reflect the fragmentation of the assemblage and, thus, the handling of the raw material at the site. In an idealised model, in which the raw material was brought to the site only as raw nodules, and then the material was transformed, used, and discarded on the spot, this index would reflect the average number of artefacts which originate from a single core. In archaeological lithic assemblages, this idealised model is modified by the introduction of ready prepared cores, blanks, and/or tools to the site, the discard of material, which was made elsewhere, at the site, and the export of cores, blanks, and/or tools made at the site as well as taphonomic processes such as trampling (for the general problem of quantifying lithic assemblages cf. Hiscock 2002). Furthermore, this exploitation index is influenced by the function of the assemblage as well as the exploitation strategies of the raw material. Nonetheless, this exploitation index can provide an insight into how the various raw materials were differently reduced and whether differences can be found within assemblages with the same dominant raw materials. Due to the constraints, the results of the exploitation index are only considered in relation with further results from this study.

A further refined index of the ratio of blanks to cores would produce a value for the approximate number of blanks which were produced by a single core. This value could give an insight in the quality of the raw material, the technical abilities of the knappers, and/or the aim of the exploitation. Thereby, some assumptions about the choice of raw material can be made which further contribute to the understanding of the exploitation strategy and the resource economy. This refined index is not calculated in the present study because of inconsistently given data in the literature relating to the blanks and a general methodological question of which blanks should be selected for this index. Besides the blanks which the knapper aimed for, blanks were produced during the complete preparation process but many of these specimens were probably considered as waste products. For instance, cortical flakes were discarded by the Late Magdalenian, whereas in FMG assemblages these blanks were often transformed into end-scrapers. So the aimed blanks seemed very different ones. In this project questioning the procedure of change this different validation had to be considered for the creation of a blank-to-core-index but the archaeological distinction between this different validation of the blanks is difficult to establish, in particular during the transitional phase. Consequently, should all blanks including broken ones be taken into account for the exploitation potential of a core or only the complete blades and bladelets? In the future, a comprehensive study which has direct access to different assemblages and, thus, makes the comparison of various blank type indices possible is desirable. In particular, a study focused on this aspect could provide an interesting component to connect analyses relating to the technical thinking with those on the resource exploitation strategies of Lateglacial hunter-gatherers.

For the Paris Basin, Boris Valentin demonstrated that the changes in the exploitation strategy of cores were accompanied by the tendency of using two or more platforms on the cores (Valentin 1995, 567 f.). Therefore, the cores were classified according to the numbers of platforms previously (see **tabs 13. 26. 37**). For those assemblages in which the numbers were not given, the figures of the cores were evaluated regarding the visible platforms and the directions of the blank negatives.

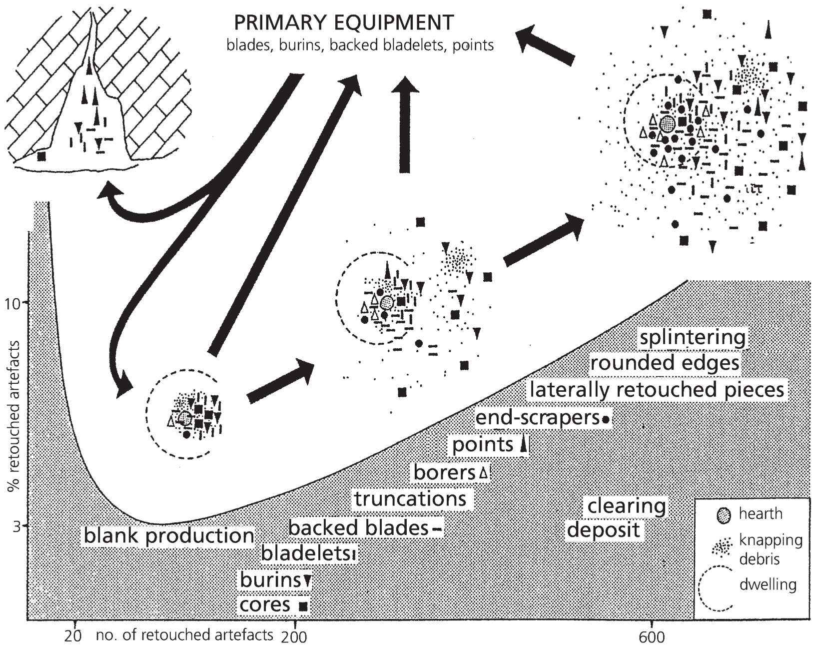
Furthermore, a second index which relates the retouched artefacts to the cores (function index = no. of retouched artefacts / no. of cores) is used to weight the influence of the two major functions of a lithic assemblage (blank production, tool use) at the site.

Functional analysis

The function of a site is of particular interest in the considerations about the position of the site in a hunter-gatherer settlement system (cf. Binford 1980). This settlement and mobility system were considered to change between the Late Magdalenian and the FMG. The Late Magdalenian record displayed characteristics of a forager system with a variety of settlement types, whereas the assemblages of the FMG seemed to indicate a collector system with a high mobility of mainly residential camps. However, the decrease of camps with special functions can only be revealed if the activities performed at the known sites were shown.

Indices such as the relation of retouched lithic material to the complete number of lithic artefacts (Löhr 1979; cf. Hiscock 1981) or cumulative diagrams of retouched tools (cf. Bohmers 1961) were regularly used to describe the function of a site and/or the intensity of its use. In this project, the percentage of retouched artefacts ≥ 10 mm is given (% retouched artefacts = no. of retouched artefacts / [artefacts ≥ 10 mm / 100]) and added in parentheses by the same index calculated with total artefacts instead of artefacts ≥ 10 mm. Retouched artefacts reflected the importance of standardised tools for the activities at the site, whereas micro-wear analyses have proven the supplementary use of unretouched materials (e. g. Plisson 2002; Plisson 2007; Sano 2012b). Furthermore, the relation of retouched artefacts to the complete material depends on the type of raw materials used at the site and their splintering properties. Recalcitrant material produces more splinters and thereby increases the total amount of material. According to Hartwig Löhr (Löhr 1979), the size of an assemblage further depends on the duration and the intensity in which the activities were performed at a site. Therefore, Löhr set the percentage of the retouched artefacts in relation to the total number of the artefacts and compared the result to the diversity of the inventories (**fig. 27**). A very general

Fig. 27 Idealised scheme of the spatial development and the increasing diversity of lithic artefact assemblages on Upper Palaeolithic to Mesolithic sites depending on the duration of the occupation (Löhr 1979, 307 Abb. 33, translations by the present author).



classification was primarily used in the present study to distinguish assemblages of various sizes (**tab. 52**). However, these classes have to relate to the two different sets of data (total artefacts / artefacts ≥ 1 cm) given for the assemblages. The sub-division of the two sets of classes was made in a similar exponential way. Thus, if the two given classes vary significantly (more than one class), the material from the assemblage is fragmented into particularly small or particularly large pieces. Thus, a comparison of similarly sized assemblages compensates for the influence of raw material properties or duration on the proportion of retouched artefacts.

Based on the same suggestions of Hartwig Löhr and further observations of Claus-Joachim Kind (Kind 1985), Gerd-Christian Weninger developed a classification of assemblages to distinguish various types within the Magdalenian of north-western Europe (Weniger 1989). He based his classes on the number of cores (class A-E) and the number of retouched artefacts (class a-e). In the present study, the relation of cores to retouched materials (function index = no. of retouched artefacts / no. of cores) is also used as a functional indicator. In this functional index, the cores represent the blank production process, whereas tools reflect the activities performed with the material[24].

The composition of the retouched tool inventory was used to describe the function of sites and to distinguish between various types of assemblages. Therefore, the two most numerous formally retouched artefact groups were set in bold in the presentation (see **tabs 14. 27. 38**). Moreover, Laurent Lang distinguished three groups of Magdalenian inventories in the Paris Basin based on the amount of points among the LMP and the relation of end-scrapers to burins (Lang 1998, 96). His group 3 was correlative with the Late Magdalenian yielding no points and generally more burins than end-scrapers. Furthermore, Lang considered the burins being principally used for working antler material, in particular, to produce antler spalls for various types of points (Lang 1998, 99). Thus, changes in the relation of end-scrapers to burins were assumed as representing a functional change. However, he noted that *becs* (or *Zinken*) as well as other lithic

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[24] Even though the LMP were not used at the site, they are included in this index because they were produced at the site and the equipment which they represent was made or repaired at the site and, thus, their presence shows an activity of resource use other than preparation of the raw material.

class	numbers of lithic artefacts ≥ 1 cm	numbers of total lithic artefacts
0	1-500	1-1,500
1	501-1,000	1,501-3,000
2	1,001-2,000	3,001-6,000
3	2,001-4,000	6,001-12,000
4	4,001-8,000	12,001-24,000
5	8,000>	24,000>

Tab. 52 Numerical classes of lithic artefact assemblages chosen in the present study.

artefacts were possibly also used for working antler. An inference from these assumptions of Laurent Lang is that decreasing numbers of burins and (heavily retouched) borers could indicate a decrease of work with antler material and, perhaps, a diminishing importance of antler as a resource. Nevertheless, burins and borers could have also been replaced by other tools such as splintered pieces or unretouched blades (cf. Sano 2012b). Thus, along with the absence of worked antler, micro-wear analysis of several lithic artefacts including unretouched pieces should supplement the observations of the retouched inventory to conclude how important antler was as a material resource. Moreover, Lang also found a relation of the increasing number of lithic points with a decreasing importance of burins in his studied assemblages (Lang 1998, 96). He suggested that this relation reflected the presence of alternative projectile heads (bone/antler vs. lithic) but he could not decide whether the lithic points were used because antler was not available as material for projectile heads or if antler points were abandoned because lithic points were invented (Lang 1998, 99). This question cannot be answered by this study either. However, the relation of end-scrapers to burins (end-scraper-burin index = no. of end-scrapers / no. of burins) as well as the percental presence of borers (% borers = no. of borers / [no. of retouched artefacts / 100]) as alternative tools for working antler can be studied. Furthermore, the numerical presence of projectile points can also be compared to the numbers of burins (see **tabs 14. 27. 38**). The results of this comparison (point-burin index = no. of points / no. of burins) have to be seen critically in the present study because the points were only determined from the displayed LMP specimens. If the complete LMP inventories were analysed the numbers of points within the assemblages could alter and would, consequently, alter the results of the point-burin index. Nonetheless, the surveyed numbers used in the present study should be sufficient for a first assessment whether lithic points outnumbered the lithic artefacts supposed to be used in the work of bone and antler material. In this sense, the result of this assessment can be regarded as an indication for the function of an assemblage. In a comparison of the Lateglacial assemblages, this tendency can also be considered as an important parameter reflecting the chronological development of the hunting equipment.

The general diversity of the retouched artefact inventory is documented by counting the major tool classes which are common in the Lateglacial: LMP, burins, end-scrapers, truncations, borers, composite tools, and others[25]. If a class is not present, this class is recorded to see if a particular class of standardised tools becomes abandoned in the process of change (cf. Lang 1998). The abandonment of a typical retouched artefact class such as borers or burins can in general be regarded as a departure from a conforming behaviour which was common for the Late Magdalenian. Moreover, according to a model of Hartwig Löhr, the

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[25] Splintered pieces are not formally retouched tools but suitable lithics used as punches. Therefore, they are not included among the group of others. Retouched pieces such as end-scrapers were often secondarily used. In this case, the artefacts were counted among their primary use. According to the settlement model of Hartwig Löhr (Löhr 1979), splintered pieces appeared very late during the occupation of a site when the assemblages had become more diverse (cf. Richter 1990). Although pieces with splintering are occasionally described from FMG sites, »true« splintered pieces were hardly mentioned and usually not numbered in the lithic assemblage descriptions. The possible disappearance of these specimens is certainly an interesting fact for considerations about changes in the settlement system but due to this uncertainty in the literature the present project cannot evaluate when or whether these types disappeared.

	high number of cores	low number of cores
low diversity of retouched artefacts	special task camp: workshop	special task camp: hunting camp
high diversity of retouched artefacts	base camp	short-term habitation and/or far from source

Tab. 53 Idealised distinction of site types based on the diversity of retouched artefacts and the number of cores.

diversity of a lithic inventory, in particular, of the retouched artefacts increased with the number of activities performed at a site (few: special task/many: residential) and that the number of activities was related to the duration of the occupation of this site (Löhr 1979). Following this idea, Jürgen Richter introduced the diversity index of Simpson ($D = \sum(P_i2)$)[26] to evaluate the degree of specialisation or diversity of lithic assemblages (Richter 1990). Furthermore, according to Löhr's and Richter's model, the presence of all the major tool classes indicates a relatively long duration and the accomplishment of several activities during the occupation. However, Löhr also emphasised that the production of further blanks and retouched artefacts is of some importance as a marker for longer durations. Consequently, the number of cores is an important value to put the diversity of retouched tools in relation to the duration and general function of the site (cf. Weniger 1989; Richter 1990). In the present study, the different numbers can be taken from previously presented tables (see **tabs 14. 27. 38**).

Based on these different values a simple model of the site function can be established (**tab. 53**). Sites with a high diversity of retouched tools suggest different activities at the site, whereas a low diversity indicates a special purpose for which the site was used. In assemblages with a high number of cores, several assumption are possible: either the exploitation of the raw material was a special task, many flintknappers were present, and/or the spot was used over a longer period. In contrast, low numbers of cores make a special task other than flintknapping, a small group of flintknappers, and/or a short duration of the camp more probable. Based on this simple model, changes in the settlement system due to changes in the function of sites should be identifiable.

Projectile analysis

Modern and historic hunter-gatherers of cold to temperate climate environments often obtain their nutritional needs from animal resources (Cordain et al. 2000). Therefore, hunting and fishing equipment such as projectile implements were considered as important tools in their subsistence strategies. Consequently, changes in this equipment could be a result of significant changes in the subsistence strategies as well as a trigger for alterations of these strategies. Moreover, these implements were altered more readily than tool classes such as burins, end-scrapers, or borers. This frequent change in the shape of the projectile implements make them better chronological markers than other tool types. Therefore, projectile implements were preferably used in the primary description and differentiation of lithic assemblages in an early classification process (see p. 55-74; Breuil 1913; Schwabedissen 1954; Taute 1968). The important relation of projectile implements to the subsistence strategies as well as the on-going discussions of differences in these implements relating to social information (Wiessner 1983; Mesoudi/O'Brien 2008a; Hamilton/Buchanan

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[26] In this formula, D is the diversity index, P is the minimal number of pieces of a given tool type divided by the total number of retouched artefacts, and i relates to the considered tool types. The latter precision is relevant because of the compilation of laterally and other artefacts without standardised retouches in the tool type »others« and the exclusion of splintered pieces as tool category in this project.

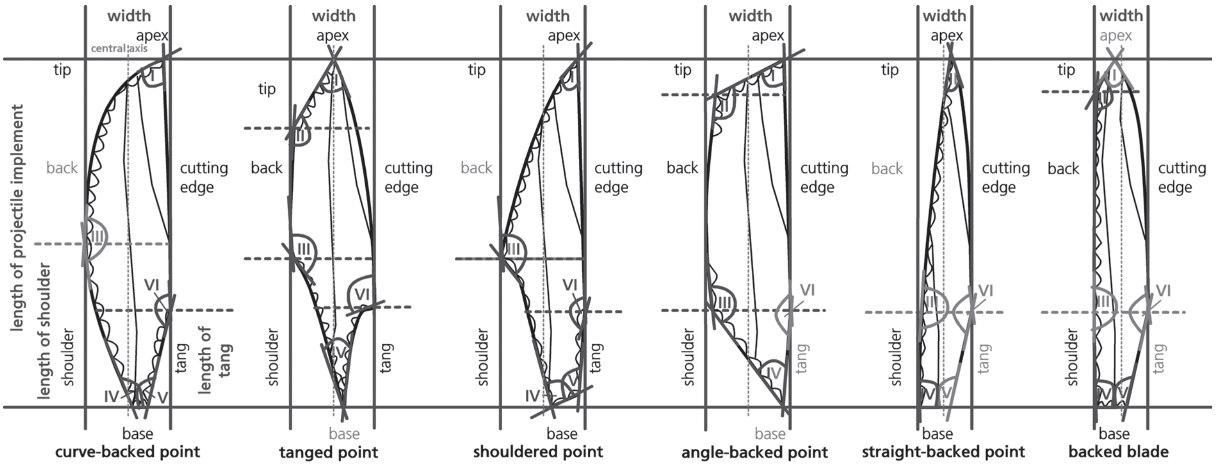

Fig. 28 Schematic outlines of various Lateglacial LMP. Terms and measured characters on various projectile implement types as applied in the present work (cf. Ikinger 1998, 41; Burdukiewicz/Schmider 2000, 98; Riede 2011). Characters, which are difficult to be distinguished and/or measured are given in light grey and were not measured. Angles are numbered: **I** tip-cutting edge angle; **II** tip-back angle; **III** back-shoulder angle; **IV** shoulder-base angle; **V** base-tang angle; **VI** tang-cutting edge angle. – For further details see text.

2009; cf. Barton 1997) and to their use (Cattelain 1997; Hughes 1998; Lyman/van Pool/O'Brien 2009; Riede 2010; Lombard/Haidle 2012) caused the continued importance of these implements in typological studies (Ikinger 1998).

In the Lateglacial, hunting equipment was generally associated with organic points and the lithic LMP. The former group was only rarely preserved in the Lateglacial Interstadial. However, the latter group frequently represented one of the most numerous classes of formally retouched pieces on archaeological sites (see **tabs 14. 27. 38**). In the literature, the different relation of pointed pieces to backed bladelets were considered as relevant (Lang 1998). This difference was related to different technical systems and is also of interest in the current project. The LMP were often very fragmented and the taxonomic classification of single fragments was often based on the surrounding context. Furthermore, within the FMG, the morphological distinction of the projectiles were considered as chronologically, functionally, and traditionally distinctive factors. However, the precise distinction in the morphology of the single point types often remained unclear. Therefore, in the present study a morphometric approach to classify the complete or almost complete implements was selected. Only with this type of quantification, can an evaluation of the impact of function or inventions and innovations on the LMP inventories be achieved.

Accordingly, the shape diversity of lithic projectile implements was established per selected assemblage. Therefore, all LMP which were identified in assemblages from the selected sites and illustrated in a readable figure were collected in a database, currently comprised of 1,201 entries. The figures were reviewed and classified according to a general concept of the Lateglacial projectile morphology and some major rules of attribution. Thus, a common denomination of the projectile parts is initially proposed (**fig. 28**).

Usually, two edges of the Lateglacial projectile blank were distinguished by a retouched and an unretouched edge. The latter remained sharp and is therefore termed the cutting edge. The apex is generally formed from the cutting and the retouched edge. However, in the case of backed blades this »apex« can be formed by two unretouched edges. The upper part of the LMP is either where the apex was located or for the backed blades/bladelets the distal part. The complete upper part of the LMP is named the tip. The intermediate part of the retouched edge was named the back. The lower part of the retouched edge was called the shoulder regardless of a retouched angle. In pieces without an obvious angle, the shoulder is regarded as the part between the maximum width and the base. In simple backed blades/bladelets, the proximal

class	primary criteria (general shape)	secondary criteria (forming of the retouched edge)
couteau à dos	size (length ≥80 mm and/or width ≥25 mm)	×
backed blade/bladelets	no point	×
simple point	point, no tang	angle or curvation, partial retouch (truncation)
straight-backed point	point, no tang	no angle, no curvation, apex beyond middle axis
curve-backed point	point, no tang	no angle but curvation
angle-backed point	point, no tang	angle/s, no curvation
tanged point	point, tang	×

Tab. 54 General classes of LMP used in the present study and the main criteria for their distinction. These general classes are used to distinguish the LMP diversity. – For further detail see text.

end is generally regarded as the base, except for pieces with a single truncation. These pieces are assumed to have been used as hafted as a part of a larger projectile (cf. Leroi-Gourhan 1983). In this case, the single truncation is assumed to have served as stabilizing retouch for the base of the piece against a recoil caused by the impact on the target. Therefore, the truncation is considered as the base. If the cutting edge was also retouched at the lower part, this retouch was classified as the tang. This denomination was comparable to the shoulder independent of the forming of this tang retouch. However, if the shoulder and the tang exhibited this retouch both had to form a concave for the distinction of a tanged point (see below). The limits of the three parts of the retouched edge were occasionally difficult to distinguish for some projectile implements. For example, the tip and the back merged in backed blades/bladelets and curve-backed points and the back part to the shoulder also merged in straight-backed points as well as backed blades/bladelets. Thus, some Lateglacial types cannot be distinguished by the morphology of the three parts of the retouched edge but require some further rules of classification as well as angles (including their presence and absence) as additional differing values.

Firstly, incomplete specimens were attributed in this secondary classification to an undifferentiated LMP class. Incomplete meant that the upper and/or lower part of the piece were significantly damaged by other modifications than human retouch. These other modifications were, for example, impact fractures or fractures due to sediment pressure. If pieces were refitted and the lower and the upper part of the LMP were preserved the refitted LMP pieces were regarded as one complete specimen. In the Late Magdalenian, backed bladelets were sometimes intentionally broken (**pl. 1, 28-30**). This behaviour produced a particular problem because a remaining piece was clearly preserved incompletely and had to be attributed to the undifferentiated LMP class. If the blank was completely refitted the numerous backed bladelets had to be counted as one piece. In this case, problems arise with the numerical and, thus, proportional differences for the comparison of the projectile implements. However, since the diversity of the projectile implements was the aim of the classification, the numerical problems could in general be neglected. Nevertheless, the most numerous class was identified to describe the inventory. Thus, to describe an inventory correctly according to the dominant projectile type some valid numbers had to be ascertained. Therefore, some almost complete pieces were also attributed to the backed blade/bladelet class in the Late Magdalenian assemblages following a contextual assumption.

Furthermore, if the size of a fragment already exceeded the metric limits of a *couteau à dos* (length ≥80 m and/or width ≥25 mm; cf. Le Tensorer 1981; Audouze/Beyries 2007) the piece was exceptionally attributed to the *couteau à dos* class. This class was not morphologically but metrically distinct (**tab. 54**) assuming that these exceptionally large specimens were used differently. According to use-wear analyses, these pieces were presumably used as knives or saws, perhaps, in the butchering process (Audouze/Beyries 2007, 190. 200; Sano/Maier/Heidenreich 2011, 1478). These large pieces could possibly have served as heads of thrusting spears[27] (cf. Riede 2009), but they were assumed as too large and heavy to represent projectile implements (Valentin 2008a, 213f.). Nevertheless, the use of such heavy implements in heavier projectiles and/or hunting equipment cannot be excluded completely (Letourneux/Pétillon 2008; Sano 2009).

Secondly, implements were attributed according to their general shape. By this general shape, two further classes were added to the metrical class of the *couteaux à dos*: backed blades/bladelets and points. Within this general shape criteria, the tanged points could already be differentiated from the other Lateglacial points because of the intentional forming of the cutting edge. Intentional forming of the tang part was observed in various types of Lateglacial points which consequently fall into the transition such as some Hamburgian shouldered points or the penknife points (cf. Grimm/Jensen/Weber 2012). However, a proper tang is characterised by concave retouches along shoulder and tang part. Probably, this type of tang composed of the basal part related to the hafting properties of the implements and helped to fix the piece on top of a shaft. This hafting on top of a shaft is characteristic for implements which are traditionally understood as an arrow- or dart-head. In contrast to the other Lateglacial points, the tip part of the tanged pieces was occasionally not formally retouched, perhaps, because better cutting properties were more important than the stability of the lithic implement. Moreover, microscopic analyses on breakage patterns and adhesives on other Lateglacial points suggested that these implements were possibly used as barbs rather than heads of a projectile (Baales 2002; Rots/Stapert/Johansen 2002). Since the differentiation of use for these implements is considered as an important change, the tanged points are distinguished as a special class in this early step. The backed blades and bladelets are also assumed to have been used differently to pointed pieces in a composite projectile system.

They are differentiated from the other two types by neither displaying a tang nor an intentional point.

Among the points, a third rule was used to distinguish further groups. This rule was to distinguish the points according to the general form of the mainly retouched lateral edge. The forming could take a straight, an angled, or a curved shape and resulted from the relation of the tip part to the back and the back to the shouldered part of the implement (**fig. 28**). A denticulated retouch could partially obscure this general forming of the retouched edge. In this case, the drawing of mean lines through the denticulated parts helped to distinguish the underlying morphological tendency. For the British Creswellian, Roger Jacobi and Allison Roberts pointed to the existence of angle- and curve-backed points (Jacobi/Roberts 1992). This variant was also observed occasionally in the present study (**pl. 10, 4-5. 17**). In general, these pieces were attributed to either the angle-backed or the curve-backed group depending on the transition from the tip to the back part and the similarity to the other specimens of the same context. Furthermore, on occasions the shoulder part and sometimes additionally the back were not retouched. Thus, the retouch was applied only to the tip part and in a strict classification these pieces had to be attributed to the truncation class. However, several of these specimens were already singled out in the primary publications (e.g. Baales 2002, 140, projectile type E), usually, because they were significantly different from the typical truncations in the inventories. For example, many of these pieces were made on flakes rather than on blades or bladelets. In contrast to the retouches of typical truncations, the position of the retouches on the blanks of these pieces was often steeply oblique forming an acute angle of the retouched and the unretouched edge at the apex. These singled out specimens are named simple points in the present study. Perhaps, they already herald the move toward Mesolithic microliths. Straight backed point types are difficult to distinguish from backed blades/bladelets. Following the previously mentioned assumption that backed points and backed

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[27] In the present study, the simple distinction of terminology by the use of the weapon delivery system as proposed by Felix Riede is used. Thus, thrusted hunting instruments are named spears, thrown instruments (also by the use of spear-thrower/atlatl technology) are darts, and instruments fired from a bow are arrows (Riede 2009, 28; cf. Hughes 1998). Only the latter two types of instruments are subsumed as projectiles.

type	blank preference	pointed ends	forming of the blunted edge	continuity of retouch	forming of the basal retouch	forming of the base in relation to the blunted edge	micro-burin technique	modifications of the cutting edge
simple point	flake	monopoint	straight/curve	no	none	none	no	none
straight-backed point	none	monopoint	straight	yes	none	none	no	none
Micro-Gravette	none	monopoint	straight	yes	straight	straight (acute to approximate right-angle)	unknown	none
Federmesser	none	monopoint	curve	yes	none	none	no	occasionally, a notch shortly underneath the apex
penknife point	blade/bladelet	mono- / bipoint	curve	yes	convex/concave/straight	oblique (acute angle – bipoint)	unknown	occasionally, the base remained natural and instead the lower part was retouched (monopoint)
Malaurie point	blade/bladelet	monopoint	curve	yes	convex/concave/straight	approximate right angle	unknown	none
bipoint	regular blade	bipoint	curve	no	pointed	oblique (obtuse angle)	unknown	none
Cheddar point	regular blade	bipoint	angle	yes	straight	oblique (obtuse angle)	unknown	none
Creswell point	blade	monopoint	angle	yes	none	none	unknown	none
Hamburgian shouldered point	blade	monopoint	angle	no	none	none	yes	occasionally, the lower part was also retouched
Havelte point	regular blade	monopoint	angle	no	pointed/straight	oblique (acute angle)	yes	tang: oblique or concave retouch of the lower part forming a tang with the retouch of the principally retouched edge
Lyngy-Bromme type tang point	large flake	monopoint	angle/cavity	no	none	straight (approximate right-angle)	no	tang

Tab. 55 General characterisation of some Lateglacial LMP types according to the selected morphological factors. The micro-burin technique was usually associated with Mesolithic microliths but recent studies have revealed the presence of the technique also on Lateglacial material (Weber 2012) and emphasised the role in the removal of the bulb (Grimm/Jensen/Weber 2012) which shaped particularly the thickness and evenness of the implement.

blades/bladelets were used differently in the projectile installation, the difference of the two types must relate to the way the retouch transformed the complete blank and, in particular, the tip part. Consequently, the position of the two lateral edges in the tip part in relation to the complete blank was chosen as differentiation between backed blades/bladelets and straight-backed points. In the case of straight-backed points, the retouched edge crossed the middle axis of the blank and the apex was set in the half of the blanks unretouched edge. Furthermore, the unretouched edge and the retouched edge met in an acute angle. In backed blades/bladelets, the angle of the apex was variable with acute, right-, and obtuse angles occurring. In contrast to straight-backed points, the apex of backed blades/baldelets was always set on the side of the retouched edge in relation to the middle axis of the blank.

Thus, this classification differentiated seven main groups of projectile implements (**tab. 54**). The more of these classes were identified in an assemblage, the more diverse the composition of the projectile implements discarded at the site. The diversity of an inventory could indicate either a differentiated use of projectile types or an on-going transition of preferred LMP types. If different projectiles and/or projectile heads were used for hunting of different species (differentiated use) a diverse assemblage would represent the discard of varied hunting activities. However, in sites with organic preservation this hypothesis could be tested against the number and the diversity of the discarded faunal remains (see p. 282-285). If a change of preferred hunting equipment was reflected by the diversity of the LMP inventory a phase of trial-and-error in the technical system could be reflected. Furthermore, this process of variation in the hunting equipment could have been caused by changes in the subsistence strategies. Therefore, the comparison of this value to the preserved faunal remains seems particularly relevant with regard to the influence of the preferred prey on the preference of lithic projectile implements.

The weight of the projectiles could be an interesting, additional value for comparing the preference of the LMP. The weight of an implement probably correlates to its size. Both characteristics were possibly correlative with the use of the projectile in the different delivery systems such as arrow or dart (Riede 2009; Riede 2010; cf. Letourneux/Pétillon 2008) as well as the choice of prey such as whether small or large game, land mammal, or fish were hunted (Ellis 1997). However, the weight of the various implements could not be compared in the present study because this information was not usually available in the literature per piece. Occasionally, ranges of weight were recorded for the projectile points from a single assemblage. Assuming the correlation of size and weight, the sizes of the LMP were instead measured.

Therefore, the most complete LMP were chosen for this metric comparison which should demonstrate the diversity of the LMP inventories within each assemblage as well as between the various assemblages. This comparison should help to formulate suggestions on the influence of the available raw material as well as technical skills and operational habits of standardisation on the type and the size of the LMP. Various descriptions for the measuring of single types of Lateglacial points such as tanged points (Riede 2011), shouldered points (Burdukiewicz/Schmider 2000; Thévenin 2003), or curve-backed points (Ikinger 1998) exist. However, these attempts were, in general, designed for a specific type of LMP, whereas a combination of all these measuring systems supplemented with one for backed blades is needed in the present analysis. Thus, some major types of Lateglacial points were compiled and the major morphological criteria for the differentiation defined and systematised (**tab. 55**; cf. Schwabedissen 1954; Sonneville-Bordes/Perrot 1956; Bohmers 1961; Célérier 1979; Ikinger 1998; Burdukiewicz/Schmider 2000; Riede 2011; Grimm/Jensen/Weber 2012). Based on this system, which is adjusted to the variety of types present in the Lateglacial of north-western Europe, the same values could be measured on various LMP (see **fig. 28**).

In addition, measurements of the maximum values for length, width, and thickness, the length of the shoulder and the length of the tang if it was present were taken. The length of the shoulder was only measured when an angle was observable.

This consideration reveals that measuring some angles is also important to describe the pieces morpho-metrically. Besides the angle between the back and the shouldered part, a further five angles were frequently observed on Lateglacial points: the apex angle between the cutting and the retouched edge, the angle between tip and back part, the angle between shoulder part and base, the angle between base and tang retouch, and the angle between the tang retouch and the cutting edge. Besides influencing the shape of the LMP significantly, the angles are assumed to be of technical importance which helped to position the LMP in the projectile shaft and to reinforce the edges against forces related to the impact. Furthermore, the angle between the ventral surface and the dorsal formed by the retouch of the tip could be related to the entering ability of the point. However, this part is often damaged and the profile of this region is not usually displayed. Therefore, this angle is not considered further.

Angles are only measured where retouched edges are involved because only these areas are obviously shaped by the decision of a human toolmaker. Some LMP types do not exhibit all six angles or fulfil the requirement of at least one retouched edge and, thus, these angles are considered as not present. For example, if the back and the shoulder part are not retouched the angle inbetween them is regarded as not present and, consequently, not measured. Moreover, the variety of LMP types poses further problems regarding the angle determination: In the case of curve-backed points the angle between the tip and the back and the one between the back and the shoulder are regarded as unmeasurable due to the curved outline. Principally, these angles are set to 180° in the case of straight-backed implements such as backed blades/bladelets. Another problem is the forming of the base which was sometimes reduced to a punctiform base, for example in some tanged points or in the bipoints (see **fig. 28**, tanged point). In this case the shoulder-base angle and the base-tang angle become identical. Furthermore, for some implements the tip-back and the back-shoulder angle are identical (see **fig. 28**, curve-backed point and shouldered point). In the database this factor is noted by using the Roman number of the identical angle.

In addition, further observations such as potential impact fractures were noted. Particular attention was paid to the occasionally observed notches on the unretouched edge, often in the apex region. These notches could represent intentional elements in the shaping of the pieces, for instance, to fasten a string or a special type of impact fracture (cf. Plisson 2009, 46). Clearly, these notches depend on the hafting and/or the use of the implements. If recorded more systematically this observation could help to further shape our understanding of past projectile technologies.

To receive the metrical values necessary for this comparison, drawings of complete or almost complete LMP were selected from each assemblage for measuring. These drawings were compiled in a graphic program (Adobe Photoshop) and scaled to a natural scale (M 1:1). The resulting 14 tables can be found in the supplementary figures in the appendix (**pls 1-14**). The measurements were taken with the measuring tool of the graphic program enabling to take the sizes as well as the angles. Thus, the potential error of the program applied to all specimens in a comparable manner and, therefore, can be neglected as a source of error in the comparison of the results. For the present project the measured data and morphological description of the various parts of the points had to rely on drawings of the implements. Clearly, the quality of these drawings could cause some imprecision of the measured data due to the different thickness of pens or the sometimes ambiguous character of drawn retouches. For the future, an analysis on the actual lithic implements would be more appropriate. For a first assessment of whether significant morpho-metric differences can be observed these drawings are sufficient.

In total, 335 implements were measured. Of these artefacts, the length and the width was preserved completely in 148 specimens which can be used in a metrical comparison of the material. This comparison is performed with the freely available data analysis package PAST (Palaeontological Statistics; Hammer/Harper/Ryan 2001). For the comparison of the data per assemblage, xy-graphs with convex hulls are

class	minimum number of individuals (MNI)
A	1-10
B	11-20
C	21-50
D	50>

Tab. 56 Classes of faunal assemblages based on minimum numbers of individuals (MNI) of larger herbivores (Weniger 1989, 346).

used. »The convex hull is the smallest convex polygon containing all data points« (Hammer/Harper/Ryan 2001, 24). The diagrams are interpreted with the assumption that the larger the areas of overlap emerge, the more similar are the data sets. Since standardisation and changing standardisations are of a particular interest in studies of transitions, the variance (Hammer/Harper/Ryan 2001, 37) of the different metrical values per assemblage is further compared in regard to the chronological development. Clearly, in future analyses more sophisticated statistical analyses are possible with sufficient morpho-metric data (cf. Ioviță 2009; Ioviță 2011). However, for the present study this simple comparison is sufficient for the presentation of diversity and similarities among the LMP from various sites.

Quantitative assessment of the faunal assemblages

Faunal assemblages from archaeological contexts represent the most instant reflection of Lateglacial subsistence strategies. Furthermore, these subsistence strategies allow for suggestions of site function and considerations about settlement behaviour. For example, if complete or almost complete carcasses of larger mammals were found at a site, a relatively close hunting ground was assumed (Müller et al. 2006). The transport of a horse which presumably weighted more than 250 kg (Groves 1994, 40) required considerable effort. Thus, the skinning and the first filleting of the animal was generally assumed to have taken place at the hunting ground from where the required material was transported to the residential camp. However, if the complete animals were valuable the residential camp must have been moved to the hunting ground (Müller et al. 2006) or the complete animals must have been brought to the residential site (cf. Street/Turner 2013). Both strategies represented considerable effort. In both cases, various factors such as the weight of the animal, the distance between the residential site and the hunting ground, and the size of the group contributed to the estimate of the effort. For instance, if the group size is small the moving of a residential camp is as difficult as with a big group but for the latter sufficient space is necessary at the new settling ground. In contrast, the transport of large mammals is easier with more people. Consequently, can the size of the group or the number of hunted animals decide whether to move the camp to the food or the food to the camp? Or are the classic distinctions of hunting grounds, special task camps, and residential sites (cf. Binford 1980) not applicable to the Lateglacial?

Thus, to quantify the assemblages a classification system based on a system developed by Gerd-Christian Weninger is used. He differentiated four classes of faunal assemblages based on the minimum numbers of individuals (MNI) of large herbivores found at Late Magdalenian sites to distinguish differences in the size of the sites (**tab. 56**; Weniger 1989, 346). Clearly, this classification is not correlative with economic gain of these resources such as leather/fur or meat (cf. Rozoy 1978). The different size within his large herbivore group such as ibex and horse and, consequently, the different output of, for instance, meat would make such a comparison very vague. In addition, even comparable resources were probably used differently, for example, horse hide clearly served a different purpose than the winter coat of an arctic fox. Therefore, a validation of the resources would be necessary but this validation system cannot be given for past societies. Hence, the MNI are considered to reflect a quantification of animals brought to the site or hunted at the site helping to characterise the function of the site. The additional information on the parts of the animals recovered at the site and the combination with the spatial analysis of the sites help to further evaluate the site function.

class	MNI of *Rangifer tarandus*	MNI of *Equus* sp.	MNI of *Bison priscus / Bos primigenius*	MNI of *Cervus elaphus*	MNI of *Alces alces*	MNI of *Capreolus capreolus*	MNI of *Sus scrofa*
1	1-15	1-10	1-10	1-5	1	1-3	1-5
2	16-30	11-20	11-20	6-12	2-3	4-6	6-12
3	31-75	21-50	21-50	13-30	4-6	7-16	13-30
4	75>	50>	50>	31>	7>	17>	31>

Tab. 57 Classes of faunal assemblages based on minimum numbers of individuals (MNI) for variously behaving larger herbivores. – For further details see text.

Besides the actual number of animals brought to the site, the conditions of preservation could change the classification significantly. In particular, preservation of bone material is probable to change with the changing climatic and environmental conditions, for instance, slower sedimentation due to the lack of aeolian deposition and the increasing attack by micro-organisms, humic acids, and roots within the sediment could result in a significantly higher destruction of the faunal material. Consequently, the changing environment of the Lateglacial could cause a classification into a lower class. For instance, the very low numbers of individuals (MNI = 5) found in the 25 *loci* of the upper horizon of Le Closeau were certainly due to the poor bone preservation in a temperate forest. In fact, faunal material was preserved only at eleven concentrations of the upper horizon and only four of those yielded determinable material (cf. Bodu 1998). Thus, a reliable MNI for the material brought to Le Closeau during the younger period could not be calculated, whereas the material from the lower horizon was well preserved and numerous (Bemilli 1998; Bignon / Bodu 2006) indicating the environmental changes as an important factor in the preservation of the faunal assemblages. Thus, a generalised classification of large herbivores according to the MNI is only useful as a comparison as long as the conditions of preservation are also considered as relevant agent in the formation of the assemblage.

Moreover, since the faunal composition in the landscape changed, the Lateglacial hunters had to adapt their behaviour to the new species if they remained in these landscapes. To compare the faunal assemblages similarly to Weniger (Weniger 1989) as an indicator for the formation of the assemblage, the considered species should reveal comparable ethologies in regard to their group sizes[28]. For example, a large number of reindeer (*Rangifer tarandus*) can be hunted in a single driving event when they congregate in herds of sometimes hundreds or thousands of animals (Baskin 1990; Reimers / Colman 2006). To receive a comparable number of elks (*Alces alces*) which are known to live a more solitary existence, many hunting events were necessary. Furthermore, in regard to the territorial ranges of elks (Ball / Nordengren / Wallin 2001), a large number of elks could only be accumulated over a considerable period of time or from a large territory. Thus, comparable numbers of these two species reflect very different human activities. The classes suggested by Weniger (Weniger 1989) are therefore adapted to the ethology of the species considered relevant in the present project (**tab. 57**). Horses (*Equus* sp.) were the most important prey species during the Late Magdalenian of the study area (Bridault / Bignon / Bemilli 2003; Street / Turner 2013). The data on group size in wild horses is rare because the main observation on horse groups come from animals raised in captivity (Houpt / Boyd 1994). However, a comparison with feral animals and wild living equids such as Zebras suggests that wild horses would have formed similar herds (Goodwin 1999). Also, the numerous depictions in Palaeolithic art (Pigeaud 2007), in particular, of horse groups such as the panel of horses in the Early Upper Palaeolithic Chauvet Cave (Clottes / Arnold 2001) suggest the presence of groups of horses. These groups could be of various compositions (stallion groups, harems, female and young groups). Nevertheless, with the changing environment of the Lateglacial Interstadial the behaviour of horses could also have adapted to

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[28] Special thanks is due to Sabine Gaudzinski-Windheuser, Monrepos, for suggesting this useful differentiation.

the more forested environment by decreasing group size (MacFadden 1992, 263-298). In total, the groups given by Weniger appear a good mixture of this species. Since steppe wisent (*Bison priscus*) and aurochs (*Bos primigenius*) are extinct, their group sizes are also unknown. For the aurochs some past observations exist and describe herds of a maximum of 30 animals in some parts of the year (Frisch 2010). For the European wisent (*Bison bonanus*) which were reintroduced into the wild in eastern Central Europe group sizes of 8-13 animals have been recorded (Pucek/Belousova 2004, 26). However, these animals inhabit mainly forest landscapes, whereas the American bison (*Bison bison*) were found in open grassland landscapes more comparable to the Late Pleniglacial landscape of Europe inhabited by the steppe bison. Large herds of American bison such as reported by early explorers visiting the Great Plains can no longer be attested (Knapp et al. 1999) but modern, free-ranging American bison are known to form groups of 3-26 animals but in general these groups were also around 16-17 animals (Fortin/Fortin 2009). Thus, the size classes given by Weniger are probably a good estimate for the large bovids. In contrast, reindeer groups appear on average larger with observed mean group sizes around 19 animals in the time of the largest diffusion of the animals and of more than 300 animals in the time of autumn migration (Baskin 1990). However, the groups of taiga reindeer are considerably smaller with occasionally only some 3-5 animals in a group (Baskin 1990). Due to the relatively large retreat areas during the Lateglacial, the occurrence of forest reindeer seems rather anecdotal in the Lateglacial record (cf. Riede et al. 2010). For this species a larger classification is chosen. As with most species used in the present study, red deer (*Cervus elaphus*) forms various group sizes depending on the seasons as well as on the habitat (Bonenfant et al. 2004). Even though large groups of up to 56 animals (Bonenfant et al. 2004, 885) were observed, this species usually forms smaller groups and solitary animals are also frequently observed (cf. Hebblewhite/Pletscher 2002). Hence, the classification for this species is selected smaller than for the previous species. Elk (*Alces alces*) is known to live mainly solitary in occasionally large territories (Ball/Nordengren/Wallin 2001). Therefore, this species is grouped in the smallest classes. In addition to the group of species compared by ^{14}C-dated material, the classification of faunal material found on archaeological sites is expanded by roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*). Roe deer groups also vary in size but in general these groups are very small with around 4-5 animals (Pays et al. 2012). Male wild boars (*Sus scrofa*) are often solitary (cf. Ebert et al. 2010), whereas females and young ones can form groups of up to 42 observed animals (Hartley 2010). However, in general the groups are smaller and, thus, wild boar is treated as comparable to red deer in the present study.

The population density is another important factor for the group sizes as well as the impact of predators. These factors are relatively difficult to estimate for Lateglacial Europe and are therefore not further taken into consideration. However, since displacement processes are probable for some species in the Lateglacial, the five classes are supplement by a class 0 which indicates the absence of a species in an assemblage. Consequently, the variable classes can be compared within the archaeological assemblages as well as with the probability distributions for this species in the region (see p. 263 f.).

The increasing diversity of species which in general lived in smaller groups could possibly result in a more generalised subsistence strategy. However, the few faunal assemblages from FMG sites were regularly described as dominated by either elk, red deer, or aurochs (Bokelmann/Heinrich/Menke 1983; Baales/Street 1996; Coudret/Fagnart 2006). Thus, a specialisation in an available resource could still be possible. To evaluate whether the specialisation patterns changed, the diversity index of Simpson ($D = \sum(P_i^2)$)[29] is calculated for the faunal assemblages analysed in this study.

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[29] In this formula, D is the diversity index, P is the minimal number of individuals of a given species divided by the total minimal number of individuals, and i relates to the calculated species. The latter precision is of some importance since in the present study amphibian and small mammals as well as other probable intrusions were excluded from the assemblages.

	small MNI	high MNI
low diversity	short episode	hunting camp
high diversity	provisioned/opportunistic episode	base or agglomeration camp

Tab. 58 Idealised distinction of site types based on the faunal diversity (Simpson index) and the total MNI (minimal number of individuals).

A previous study on the diversity of Magdalenian assemblages suggested that this index is useful in the distinction between specialised hunting camps and residential sites (Gaudzinski/Street 2003). Particularly in relation to the complete size of the assemblage (total MNI), differences of the site types should become evident (**tab. 58**). In this relation, very small MNI cannot produce high diversity indices due to the dependence of this index on the total MNI. However, the possible diversity values increase exponentially and with two animals an intermediate diversity can be reached and with three to five individuals values can be reached which are comparable to the anaylsed Late Magdalenian assemblages (Gaudzinski/Street 2003). Thus, relatively small MNI with high diversity are possible and would reflect a successful opportunistic hunting episode or a special task camp with provisioned food. However, more frequent are small assemblages with a low diversity which reflect a very short-term camp or a single hunting episode. High numbers of MNI combined with a high diversity reflect a generalised prey choice and speak in favour of a base or agglomeration camp, whereas sites with high MNI but with a low diversity indicate a hunting camp.

This simplified distinction works well for seasonally governed landscapes with large animal herds which were partially migratory and human hunters with a logistic settlement pattern (Binford 1980) such as assumed for the Late Magdalenian. However, several of these factors were changing in the transition to the FMG, for instance, the group size decreased and the animals were in general more faithful to their habitat. Thus, the number of animals which could be hunted during one episode decreased in comparison to driving events of large herds, whereas the increased diversity of species allowed for a higher diversity to be reached. Consequently, the differences between base/agglomeration camps and hunting camps could have been obliterated. However, these differences could have also shifted similarly towards smaller MNI and, thus, the difference between provisioned or opportunistic episodes and base/agglomeration camps could have been blurred. These possible obliterations have to be discussed before the question whether the settlement system changed from a logistic to a foraging one can be considered.

Hunting strategies as sensitive systems for the human survival, in particular in provisioning for otherwise meagre periods, are improbable to be changed easily but are more likely to be gradually adapted. Thus, if a sudden change was revealed by the comparison of the diversity index and the total MNI, this result would be a strong argument for a revolutionary change. However, a direct change from the one system to the next appears improbable and, thus, an intermediate stage could be possible. In fact, the relevance of the contribution of smaller mammals, particularly, in times of crisis was emphasised in the last decade (Bridault/Fontana 2003; Munro 2003; Napierala 2008b). Besides the migratory behaviour and the group size of the hunted species, the total MNI depends on further factors such as the size of the hunted animals. If the size of hunted animals decreases, the total numbers of animals have to increase to compensate for the size of the animals. Yet, smaller mammals such as hare are usually considered to be hunted or rather trapped more easily than larger mammals such as horse. Therefore, also the MNI of smaller mammals such as fox, hare, or beaver are recorded and given in a percentage relation to the MNI of the larger herbivores. If the transition from the Late Magdalenian to the FMG subsistence patterns caused a crisis, this value should increase temporarily before the FMG pattern was established.

	high diversity of retouched artefacts	low diversity of retouched artefacts
low diversity of fauna	short-term base camp/long-term hunting camp	short episode
high diversity of fauna	base or agglomeration camp	provisioned special task/opportunistic episode

Tab. 59 Idealised distinction of site types based on the faunal diversity (Simpson index) and the diversity of formally retouched artefacts (Simpson index).

Evaluation of the settlement behaviour

The general organisation (setting and hierarchy) of quasi-contemporary settlements within a defined area was described as settlement system (Binford 1980). Classically, Lewis Binford differentiated the forager and the collector settlement systems mainly based on the differences in their mobility (low residential mobility contrasted by high residential mobility) and the diversity of settlements with varied functions (few residential and many special task camps contrasted by many residential, few special task camps). Deriving from ethnography where the agents can still be observed and/or asked, the concept refers to a single social group and the area this group occupies. These groups and ranges can also be assumed in the Lateglacial but are considerably more problematic to be established from the archaeological record. In fact, such social structures in the past are aspired results and should not be prerequisite assumptions (cf. Thomas theorem, Merton 1949). However, these ethnographic examples helped to create models for the explanation of subsistence economies of the past and configuration of meso- and macro-scale predictions, for instance of the location of archaeological sites. However, both scales can also be based on a »bottom-up« approach of considering the already known archaeological sites without connecting them to a single group but a general habit (Bratlund 1996a; Gaudzinski/Street 2003; Banks et al. 2006; Banks et al. 2008). Furthermore, the geographical construct of a land-use system (Levy 1983; Amick 1996; Gaudzinski-Windheuser et al. 2011a) helps circuiting the territorial and social problem. This system refers to a limited study area in which quasi-contemporary settlements are set in relation to one another either based on their assumed function in human life cycles or their general distribution. In the latter, the sites can be distributed (cf. »compactness of settlement«, Murdock/Wilson 1972) either scattered, clustered, or concentrated allowing assumptions on environmental diversity, resource availability (Butzer 1982; Whallon 2006), and/or demographic stages (Bocquet-Appel et al. 2005). However, the study areas in these approaches need to be carefully chosen because they can reflect the exploitation area of more than one prehistoric group with perhaps complementary economies. Hence, for the analysis of a single group in a limited area the settlement system in the sense of referring to a single social unit and the area exploited by this group is still the best theoretical concept for a hierarchical ordering of human behavioural patterns.

Based on the idealised models from the previous two sub-chapters about the faunal and lithic composition of the assemblages (**tabs 53. 58**), the sites in the studied areas can be classified and their function evaluated. Furthermore, contrasting the two diversity indicators makes an additional confirmation of the use of the sites possible (**tab. 59**). However, some assumptions on what was to be found ideally on a site of a specific type must be formulated for a consistent classification and differentiation of the sites (**tab. 60**) but the validity of these characteristics must later be tested again using the archaeological record. By the diachronic composition of the assemblages, the development of the settlement systems within the sub-areas can be analysed by the possibly changing preference of site functions. These systems have to be balanced between several groups, for instance, to allow for communal hunting or the establishment of agglomeration camps of various types. This connection to foreign groups can also be reflected by exotic raw materials in the archaeological record.

type	used by	composition of archaeological evidence
agglomeration camp	several groups (contemporarily)	- larger structures - large assemblage with numerous and diverse material - high raw material diversity, often from distant sources - high number of cores - high number and diversity of retouched artefacts - numerous faunal remains with a high species diversity - single to several seasons - numerous exotic items and special goods - very diverse functions
base camp	one group	- larger structures - large assemblage with numerous and diverse material - diverse raw materials from local and distant sources (but during longer occupation, tendency towards one dominating, local raw material) - high number of cores - high number and diversity of retouched artefacts - numerous faunal remains with a high species diversity - several seasons possible - some exotic items and special goods - diverse functions
short-term residential camp	one group	- small structures - medium to small assemblage with diverse material - not very diverse raw material, mixture of local and distant sources - small number of cores - small number of diverse retouched artefacts - some faunal remains from some species - a single season - few if any exotic items and special goods - diverse functions
special task camp: hunting	team, one group, several teams or groups (contemporarily or at different times)	- small structures if any - small assemblage with a limited diversity - exclusive to very diverse raw materials from local to distant sources depending on the number of events and the origin of the participants - very small number of cores - medium to high number of specialised retouched artefacts - numerous faunal remains with very low diversity - usually a single season - no exotic items or special goods - specialised function
special task camp: workshop	team, one group, several teams or groups (contemporaneously or at different times)	- no structures - large assemblage with very limited diversity - almost exclusively the local raw material - very high number of cores - very small number of retouched artefacts - few if any faunal remains - various seasons - no exotic items or special goods - specialised function

Tab. 60 Idealised distinction of site types based on the archaeological evidence.

Consequently, the balance of these settlement systems forms the base for an inter-group communication and, thus, changes in the settlement system can be assumed to reflect major social transformations. Therefore, many of the values recorded in the present project contribute to the differentiation of how sites were used (**tab. 60**).

Mapping of archaeologically relevant variables

Finally, the maps of Lateglacial north-western Europe (see p. 254-259) were imported into a GIS-program (previously ESRI ArcView® 9.3; since June 2012: Quantum GIS, version 1.8.0 »Lisboa«) by geo-referencing the four corner points of the maps. The archaeological variables were also introduced into the GIS-program using the database of Lateglacial archaeological sites (see p. 52 f.). As with the environmental samples, the use of these maps is very conservative due to the relatively small numbers of reliable material and the large areas without data. However, since some variables have different frequencies of material found at a single site, this difference is displayed by the use of proportionally altered sizes of the symbols.

Systematisation of change and social systems in archaeology

The major focus of this project is the process of change within social systems. To achieve this aim, tempo and mode of change as well as social systems must be identified based on patterns identified in the archaeological material. A theoretical framework is required to create data that facilitates this identification. This framework should be based on quantitatively and/or qualitatively assessable observations in various parts and levels of the archaeological record.

Identifying tempo and mode of change based on archaeological material has a long tradition in archaeology (cf. O'Brien/Lyman 2002; Gamble et al. 2004; Valentin 2008a). In comparative analyses of archaeological assemblages, or parts of these assemblages, such as the retouched artefact inventory, similarities and differences in the analysed material were established. Quantification of the observed variations in a geographically and chronologically referenced dataset allowed the formation of quasi-contemporary groups and diachronic periods in the archaeological record. Thus, change between groups and between periods was identified. Moreover, analysing the chronological appearance and disappearance of these variations within a specific area and/or a specific group permitted estimations of the tempo of change in this area or within this group providing a basis to describe the mode of change between different periods (gradual, step-wise, or a mixture).

Besides identifying variation and establishing the tempo and mode of these changes, it is necessary to evaluate the observed patterns to recognise the agents. This valuation is relevant to establish social units and to understand the effectiveness of a change in past societies. For example, some observations of variation can relate to individual preferences and abilities reflected in the archaeological material such as alteration in retouch directions or the collection of peculiarities, whereas other variations relate to norms conformed to by several individuals such as those visible in the spatial organisation of a site or the use of a specific LMP type across wider areas; other changes reflect agreements of several groups as proposed for long distance transport of raw materials. The quantification of who performed a change makes a distinction possible between individual variation and changes of social norms. Thus, the relevance of this valuation becomes particularly apparent when comparing different definitions of archaeological units, such as those for the Late Magdalenian or the typical Azilian (see p. 55-74), which were often considered as normative reflections of past social units (Leroi-Gourhan 1993, 233; Barton 1997; Floss/Terberger 2002, 137 f.; Bradtmöller et al. 2012; Langlais et al. 2012).

Since endemic perspectives of prehistoric societies are not available, common patterns and characteristics in the archaeological record have to be taken as proxies for relatedness and communication between the creators of the record. Based on the assumed relatedness and communication, social units were established. However, a problem with using these proxies is the appearance of the convergence phenomena. Similarities

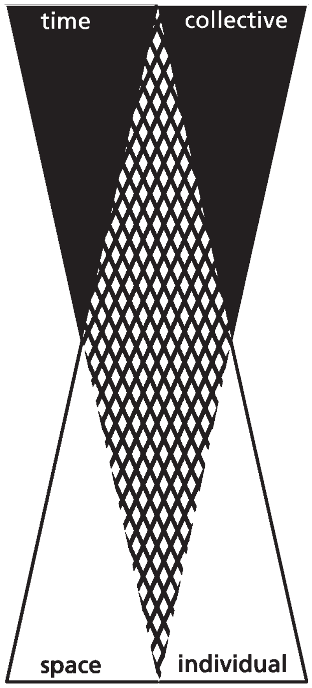
	equivalent	**examples from Europe and the Near East**
ATU 1	period	Palaeolithic, Mesolithic, Neolithic, LUP, Epipalaeolithic
	sub-period	Early Mesolithic, Late Epipalaeolithic, Pre-Pottery Neolithic
ATU 2	technocomplex and culture	Aurignacian, Arched backed Piece Complex, Magdalenian, Badegoulian, Natufian
	culture and industry	Upper Magdalenian, Late Natufian, PPNB, Final Creswellian
	industry and assemblage	Perigordian Vc, Magdalenian IV, Lower Epigravettian with shouldered points
ATU 3	artefacts and type fossils	*Zinken*, navettes, Mouilah points, lignite figurine, fox canine pendant
	attribute	scalar retouch, cut marks on animal bones, truncation, post-hole depth

Tab. 61 A provisional hierarchy of archaeological taxonomic units (ATU) for the study of population history (Gamble et al. 2005, 195 tab. 2; examples partially modified by present author).

probably occur in a comparison of universal principles which are limited in their variation. For instance, physical characteristics of lithic material limit the possibilities of successfully detaching elongated flakes (blades) from a core. Consequently, the appearance of similar conical blade cores such as in French Magdalenian and US-American Clovis contexts or similarities in essential hunting equipments such as bifacial points, known for instance from French Solutrean and US-American Clovis assemblages (cf. Bradley/Stanford 2004; Straus/Meltzer/Goebel 2005), are examples of convergence rather than the result of a transmission chain. Thus, to exclude convergence as reason for similarities in the archaeological record, a geographic and/or temporal relation between the analysed assemblages must, as a minimum, be established to argue for social transmission. Moreover, complex behavioural recipes such as the blank production or subsistence strategies were preferably taken as determinants for constructing social units. This preference was due to the assumption that complex behavioural recipes were formed by specific combinations of limited variables and these combinations could in detail only be acquired by social transmission (cf. Mesoudi/O'Brien 2008b).

If these complex behavioural recipes persisted over longer periods of time they could be assumed as traditional behaviour. Traditional behaviour is not necessarily an optimally adaptive behaviour but maladaptive behaviour becomes extinct or modified rather quickly. Karl W. Butzer already described human societies as an adaptive system which is formed by a web of parameters and which has to adjust within this interwoven web to internal and external changes (Butzer 1982, 286). He also suggested to borrow this adaptive system from biology to make an effective examination of the temporal dynamics of behavioural change possible in the form of scale analysis. In ecology, complex adaptive systems which were ordered hierarchically have been used since the 1950s (cf. Odum 1953). However, the connection with these systems, Butzer's adaptive systems, and the archaeological record still remains to be established. A hierarchical system was previously introduced in archaeology by David L. Clarke who provided a useful classification system of the archaeological record to form a theoretical basis for the analysis of this record (Clarke 1968).

Subsequently, an open and widely unbiased hierarchical system was borrowed in the form of biological taxonomy and combined with a classification similar to Clarke's system of the archaeological record to create archaeological taxonomic units (ATUs; Foley/Lahr 1997; Gamble et al. 2005). Clive Gamble and his colleagues structured this taxonomy of archaeological units for the study of population history (**tab. 61**) into a mega-scale (ATU 1), a meso-scale (ATU 2), and a micro-scale (ATU 3; Gamble et al. 2005, 195). They declared this hierarchy as a provisional one that can (and presumably has to) be further refined. This ongoing improvment process is in accordance with the concept of operational taxonomic units (Sokal/Rohlf 1962) that are clearly characterised as a temporary arrangement not a fixed set of attributes. Although the hierarchical concept was similar to the classification introduced by Clarke, it did not contain his attribute and artefact system which he had added as a sub-system to the material culture system (Clarke 1968, 134-145). In the present project, this sub-system is introduced as molecular scale (ATU 4) and relates to single

unit	level	equivalent	examples from NW-Europe	determinants
ATU 1 tradition / community	Level 1	epoch	Palaeolithic/Mesolithic	
	Level 2	period	Upper Palaeolithic/Early Mesolithic/spatial behaviour	
	Level 3	subperiod	Late Upper Palaeolithic/Final Palaeolithic/settlement behaviour	
ATU 2 alliance / population	Level 1	technocomplex	Magdalenian/Azilian/Tanged Point Complex/occupation behaviour	
	Level 2	industry	Late Magdalenian/*Federmesser-Gruppen*/settlement network	
	Level 3	faciès/group	*faciès Cepoy-Marsangy*/Nebra group/settlement system	
ATU 3 household / family group	Level 1	assemblage/settlement	animal processing/*chaîne opératoire*/residence camp/Gönnersdorf I-IV/Irlich	
	Level 2	artefact group/ concentration	mammals/retouched artefacts/workshop	
	Level 3	artefact/structure	reindeer/curve-backed point/burin/hearth/accumulation	
ATU 4 individual	Level 1	type	cutmarked metatarsus/bipointe/burin on truncation/hearth pit	
	Level 2	attribute	filleting cutmark on animal/butt *en éperon*/ oblique truncation/heat-coloured sediment	
	Level 3	trace	isotope analysis/micro-wear analysis/micromorphology	

Tab. 62 A refined provisional hierarchy of archaeological taxonomic units (ATU) for the study of human behavioural patterns (modified after Gamble et al. 2005, 195 tab. 2).

artefacts and their attributes which can be analysed and compared in the archaeological record (**tab. 62**). These attributes are assumed to reflect a range of normative behaviours, which depend, at least partially, on the characteristics and composition of the piece (Clarke 1968, 140f.).

Gamble and colleagues suggested that from the micro- to the mega-scale this provisional hierarchy was influenced increasingly by time, whereas the influence of space decreased (Gamble et al. 2005, 195). These two determinants are helpful when organising further data in this hierarchy: ATU 4 and 3 can be considered in a rather material and spatially oriented sense, whereas ATU 2 and 1 have a stronger systematic and temporal focus. Consequently, the approximate limits between the units in the present study are patterns based on single artefacts (ATU 4-ATU 3), on single sites (ATU 3-ATU 2), and on a relatively short period of time and/or a restricted geographical area (ATU 2-ATU 1). Thus, similar to single genes or individuals in biologic taxonomy, an application of this ATU system allows for a comparison of similarities and differences in archaeological assemblages based on single aspects of artefacts and single artefacts (cf. Riede 2011; Burdukiewicz/Schmider 2000). In addition, this system permits the ranking of research dependent on whether it was focused on single artefacts, assemblages, or groups of assemblages and the results can be arranged comparable to genera, families, clades, or trees (cf. Lewontin 1970). The flexible hierarchical order reflects the varying focus of research between reductionistic and increasingly holistic perspectives. Moreover, considering the previously highlighted valuation of similarities and differences, the number of people that conform to a norm also increases in this hierarchy. Hence, observations in ATU 4 usually reflects the creation of a single person; in ATU 3 a household or family group formed the observed structures and patterns; the similarities studied in ATU 2 can be assumed as collective agreements of a larger social unit or alliance, and in ATU 1 traditional behaviour of one or several groups can be proposed.

Various levels in the original provisional hierarchy were intentionally blurred by Clive Gamble and his colleagues »in order to emphasise that ATU 2s primarily assist the historical investigation of the spatial organization of human populations« (Gamble et al. 2005, 195). In this study, the units are further refined to facilitate the incorporation of further archaeological material analyses in the still provisional hierarchy of human behavioural patterns (**tab. 62**). Besides single archaeological objects, structural elements of settlement sites are introduced to allow considerations about mobility, settlement, and spatial behaviour within this system as a supplement to technological and subsistence focused analyses. Behavioural expressions as read from the archaeological material can through this approach be recorded on the molecular (ATU 4) or micro-scale (ATU 3) and become identifiable as patterns by the clustering on the meso-scale (ATU 2). In this way, a reliable fundament builds the meso-scale and based on this solid basis further classifications on a mega-scale (ATU 1) become possible, understandable, and/or interpretable. Archaeological records from various areas and periods can, in this way, be assembled in a common analytical set of behavioural patterns. The use of this system facilitates the distinction to a specific analytical level and, thus, assists the implementation levels of analysis as recommended in various evolutionary sciences (Lewontin 1970; Dean 1978; Thomson 1992). Furthermore, the concept of ATUs is deprived of most interpretative preconditions and incorrect preconditions made at an earlier stage of analysis can be modified more easily. Comparably, exact distinctions between the various levels and the units remain to be discussed and defined more precisely, if necessary. In combination, variations of single artefacts can be documented in ATU 4 as single phenomena and reflect individual reactions to an alteration of an internal or external force. In contrast, variations in ATU1 are diachronic developments and represent collective agreements, which can be applied in a variety of spaces. By using this system, contributions to various levels of this ATU system are possible and these contributions can supplement each other to enhance, systematically, the understanding of the development of human behaviour and its underlying mechanisms.

A connection of this hierarchy of archaeological material with observations of tempo and mode of changes in this material makes it possible to identify and distinguish large and slow changing variables from those that are small and fast in duration. The importance to differentiate between these variables was already described by ecologist Crawford S. Holling when formulating a theory of resilience and adaptive cycles of social-ecological systems (Holling 2001; Holling/Gunderson 2002; cf. Walker et al. 2006; Walker et al. 2012). Smaller variables are usually nested in larger variables and as a result stabilised by these slower changing variables, whereas innovation necessary to remain adaptive was provided by the faster changing, smaller variables. The balance of stability and variation between these variables can be disturbed by changes in external drivers. The application of this theory permits focusing on the impacts of climatic and environmental change as potential external drivers for human systems. The destabilisation of the analysed system by the external drivers can result in a process of reorganisation if the threshold of resilience of this system is passed. Consequently, considerations of system changes in this adaptive cycle model also reveal the effects of resilience on the development of a system.

The transformations within an adaptive cycle were also used as theoretical background to describe collapse and reorganisation in archaeology (Redman 2005; Bradtmöller et al. 2012). These studies were mainly focused on identifying adaptive cycles or different phases of these cycles but the process of change or the effects of resilience were usually not further considered in detail. Moreover, although different hierarchical levels were emphasised as important for the interpretation, this hierarchy was usually not applied to the archaeological record. Thus, the analogies to the archaeological record often remained at a general theoretical-interpretative level and were only occasionally filled with case studies (Redman/Kinzig 2003; Rosen/Rivera-Collazoa 2012).

In the present study, the provisional hierarchy of ATUs to study behavioural patterns is used to establish the different hierarchical levels within a social system and in combination with the tempo and mode of the observed changes help to reveal the resilience mechanisms of Lateglacial hunter-gatherer groups in

Northwest-Europe. Significant changes in human behaviour such as reactions to climate and environmental change, for instance by migration or variation of traditional behaviour, should be documented particularly on the indistinct meso-scale (ATU 2). Therefore, the present study is focused on the levels of ATU 3 and ATU 2. Characteristics of the archaeological material, observable attributes from archaeological sites, and patterns in both scales are documented and ordered into the hierarchical ATU system. Using this taxonomic system also helps in regard to questions of attribution of untypical assemblages such as the horizon III.1 of Pincevent, Bois Laiterie, and Gönnersdorf SW by hierarchically structuring the similarities and differences. Furthermore, this systematisation contributes to reveal how closely related groups are such as the Magdalenian faciès Cepoy-Marsangy (MfCM) and the Early Azilian or the Hangest-sur-Somme and Conty sites and the Early Azilian and/or the FMG.

In summary, using this hierarchisation of archaeological observations, impacts of changes found in the archaeological record can be studied on different levels of Lateglacial hunter-gatherer groups. Moreover, using such a hierarchical order for archaeological material allows for the human behavioural evolution to be integrated into the hierarchy of social-ecological systems.