Wild West Frisia : the role of domestic and wild resource exploitation in Bronze Age subsistence

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Appendix

Chapter 1

A1.1. Example of a Middle Bronze Age West Frisian house plan

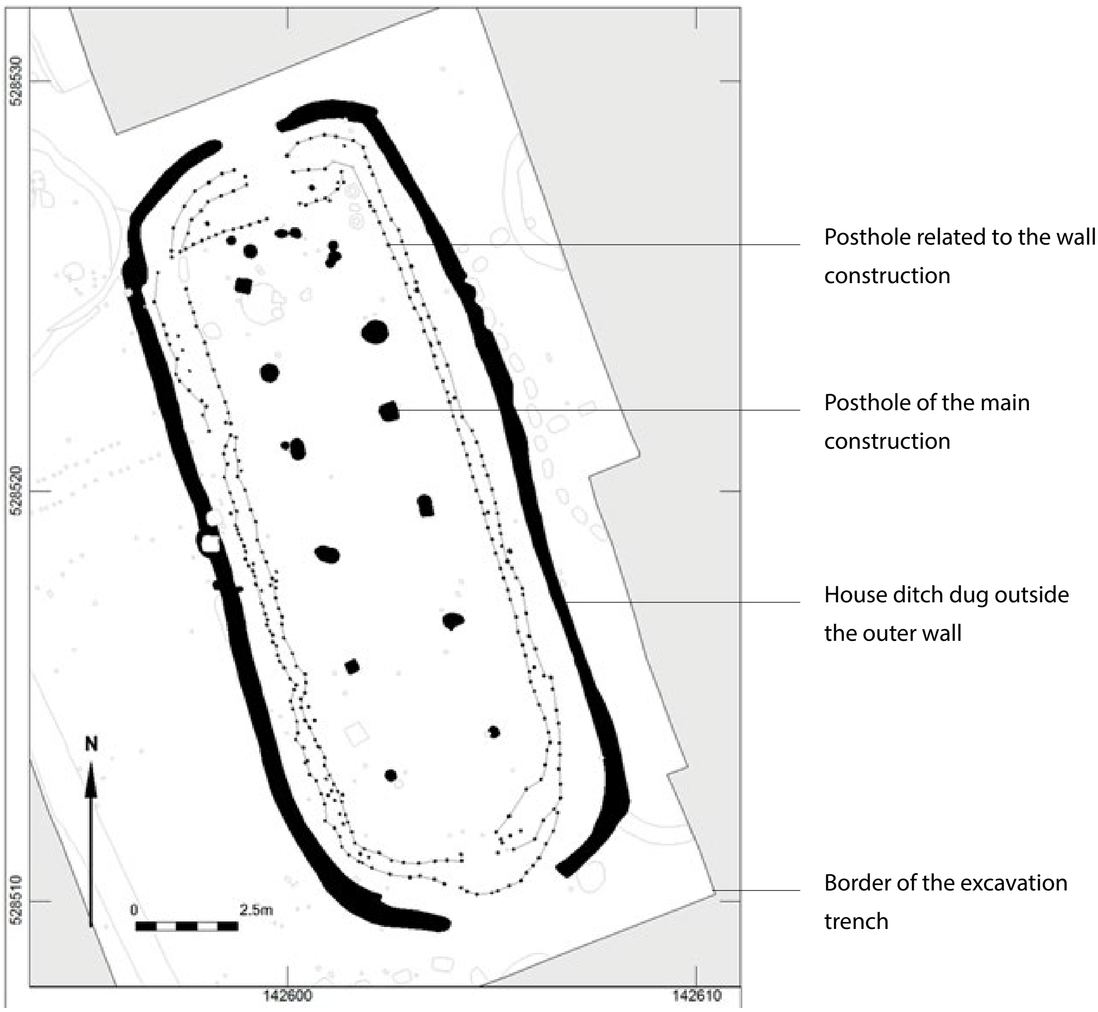


Figure A.0. West Frisian Middle Bronze Age house plan from Andijk-Noord (from: Roessingh in prep.).

Chapter 2

A1.2. Expectations of past fauna in the terrestrial habitat types in West Frisia

Figure A.1. The grassland and shrub land habitats with some of their representative mammal species (Images adapted from: BN de Stem 2008 and Ecosystema 2016).

Based on what is known about the subsoil, the hydrology of that soil, and the prevailing climate during the time researched, it is possible to make predictions of the past habitat types that might have existed in West Frisia (van Zijverden in prep.). West Frisia spans 40 km from the sea coast towards inland areas, creating very broad landscape possibilities. Among the habitat types are: grassland, shrub land, forest, wetlands, and marine intertidal/coast.

These habitat types will be discussed shortly below, broadly focusing on the characteristic flora and fauna that are expected for each landscape. Water types and expectation in fresh water, brackish water and saltwater will be mentioned in a separate section further below. Some animals were not present in the Bronze Age as they were introduced at a later period, so these are mentioned in the expectation, but excluded from further research.

Possible habitats and expectations:
(info from: Burton & Assen 1976 (mammals), Birdlife International 2012 (birds), and Vissengids 2016 (fish); photos and pictures adapted from: Mixed Forest 2007; BN de Stem 2008; Wetlands 2010; Oernatuur 2011; Heumensoord 2014; Ecosystema 2016).

Grassland:
Pure grassland is treeless and most mammals that thrive here are herbivorous or insectivorous.

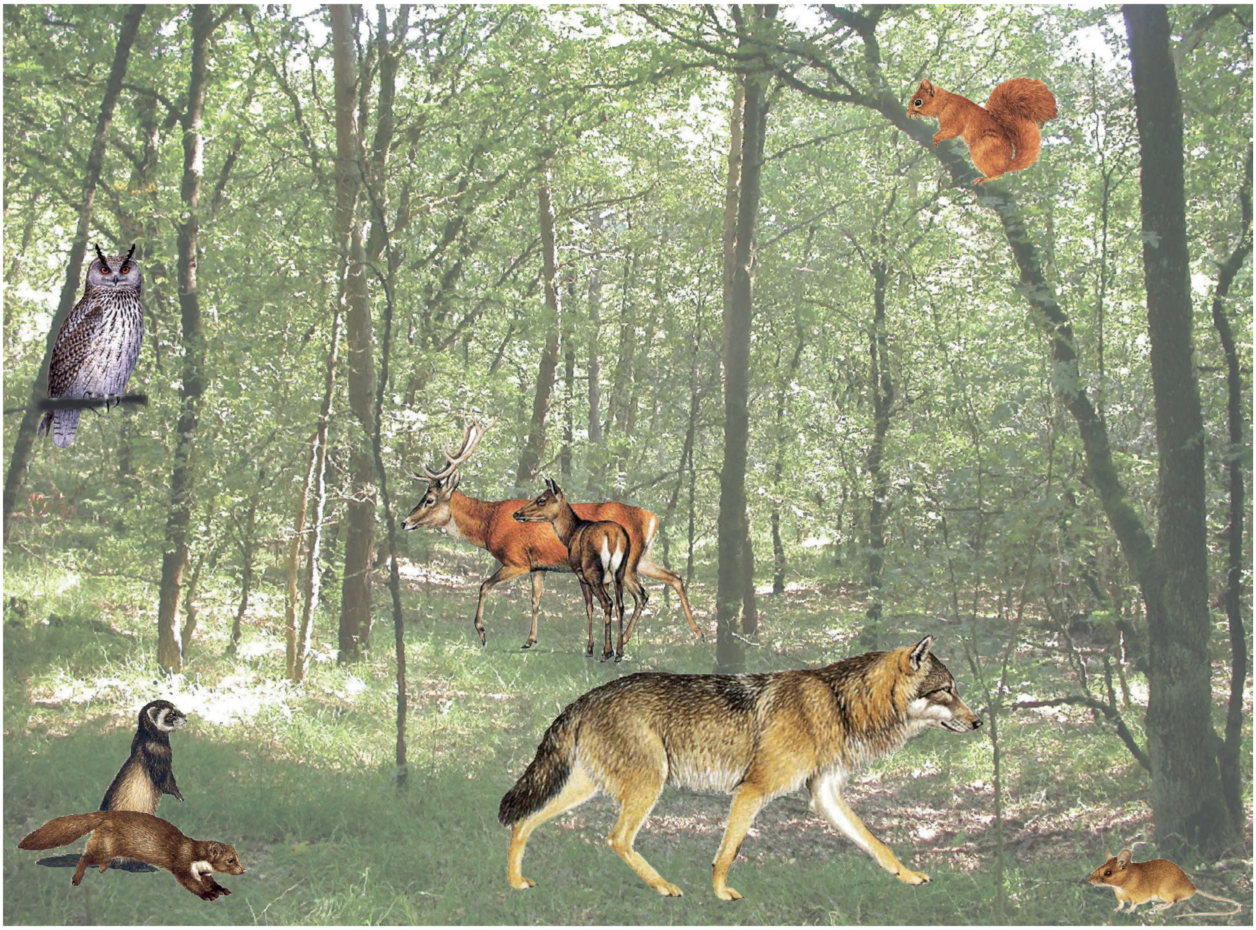


Figure A.2. The deciduous forest habitat with some of its representative bird and mammal species (Images adapted from: Heumensoord 2014 and Ecosystema 2016).

Mammals that characteristically prefer a pure grassland habitat include: common shrew (*Sorex araneus*), common vole (*Microtus arvalis*), field vole (*Microtus agrestis*), harvest mouse (*Micromys minutus*), wood mouse (*Apodemus sylvaticus*), European mole (*Talpa europaea*), and hare (*Lepus europaeus*). Based on the habitat preference, rabbit (*Oryctolagus coniculus*) belongs in this habitat and in shrub land. However, it was only introduced in the Netherlands during the Middle Ages (Gibb 1990, 115) and therefore it did not occur here in the Bronze Age. Many species of birds are expected in grasslands, so some groups have been made here. Among them are: birds of prey (*e.g.* buzzards, kites, falcons, harriers, kestrels), aquatic birds (*e.g.* ducks, geese), corvids, pipits, larks, wagtails, magpie, starling, ruff, blackbird, quail, white stork, Eurasian curlew, and northern lapwing.

The habitat grassland and its representative species can be summarized as presented in Figure A.1.

Shrub land:

Shrub land functions as the transitional area between grassland and forest. Here, grass fields are interchanged with patches of forest, consisting mostly of oak and ash, as well as patches with shrubs, such as hazel. The leaf litter produced by these patches provides ample hiding opportunities and can also provide a source of nutrients for a wider range of animals than pure grassland can. Compared to pure grassland, shrub land will harbour more carnivores.

Mammals that are expected here include: common shrew (*Sorex araneus*), pygmy shrew (*Sorex minutus*), common vole (*Microtus arvalis*), field vole (*Microtus agrestis*), harvest mouse (*Micromys minutus*), wood mouse (*Apodemus sylvaticus*), yellow-necked

Figure A.3. The mixed forest habitat with some of its representative bird and mammal species (Images adapted from: Mixed Forest 2007 and Ecosystema 2016).

mouse (*Apodemus flavicollis*), hedgehog (*Erinaceus europaeus*), hare (*Lepus europaeus*), long-eared bat (*Plecotus auritus*), weasel (*Mustela nivalis*), beech marten (*Martes foina*), wild cat (*Felis sylvestris*), badger (*Meles meles*), fox (*Vulpes vulpes*), and roe deer (*Capreolus capreolus*).

Birds that inhabit shrub land include: birds of prey, owls, warblers, finches, magpie, starling, nightingales, wrens, thrushes, doves, pigeon, tits, sparrow, cuckoo, Eurasian curlew, chiffchaff, woodpecker, woodcock.

The habitat shrub land and its representative species can be summarized as presented in Figure A.1.

Forest:
Forests can be deciduous or coniferous. Mixed forests can include either two or more dominant tree species in a deciduous forest, or a mix of deciduous and coniferous forest. For West Frisia, deciduous and deciduous mixed forest are the only two expected habitats.

Deciduous forest:
Deciduous forest are the habitat preference of amongst others the following mammals: bank vole (*Myodes glareolus*), yellow-necked mouse (*Apodemus flavicollis*), red squirrel (*Sciurus vulgaris*), horseshoe bats (*Rhinolophidae*), stoat (*Mustela erminae*), polecat (*Mustela putorius*), beech marten (*Martes foina*), badger (*Meles meles*), wild cat (*Felis sylvestris*), fox (*Vulpes vulpes*), wild boar (*Sus scrofa*), wolf (*Canis lupus*), roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*), and elk (*Alces alces*). Fallow deer (*Dama dama*) belongs in both types of forest habitats mentioned here, and occurred in the Netherlands until the last Ice Age. However, it

Figure A.4. The wetland habitat with some of its representative bird and mammal species (Images adapted from: Wetlands 2010 and Ecosystema 2016).

did not survive this period and became extinct in these regions. It was reintroduced later during the Middle Ages (Ueckermann & Hansen 1994) and therefore did not exist in the Netherlands until that time.

Mixed forest:
Mixed forests are the transitional forest between deciduous and coniferous forests. Mammals that occur in this type of forest, but not in pure deciduous forest include: pine marten (*Martes martes*), brown bear (*Ursus arctos*), several kinds of bat, and possibly lynx (*Lynx lynx*). All the other mammals that can be found here are the same as in a deciduous forest.

In both these forest habitats, the following birds can be expected are: birds of prey, owls, warblers, herons, egrets, finches, tree creepers, pigeon, dove, corvids, cuckoo, tits, woodpeckers, flycatchers, Eurasian jay, wood lark, nightingales, sparrow, Eurasian woodcock, starling, winter wren, and thrushes.

The deciduous forest and mixed forest habitats, and their representative species can be summarized as presented in Figures A.2 and A.3. Most of the species shown in these figures can exist in both types of forest mentioned above, and are not restricted to a particular forest type.

Wetlands:
Wetlands can be found in a wide range of habitat types, but four major types exist: swamp (forested wetland), marsh (herbaceous wetland), bog (acidic, peaty wetland fed by rainwater), and fen (neutral to alkaline, peaty wetland fed by groundwater). Swamps and marshes can occur in both fresh, brackish, and salt water. Bogs and fens, being fed by rain

Figure A.5. The intertidal/sea coastal habitat with some of its representative bird and mammal species (Images adapted from: Oernatuur 2011 and Ecosystema 2016).

and groundwater, respectively, can only occur in freshwater environments.

Mammals that are expected in wetland environments are: water shrew (*Neomys fodiens*), field vole (*Microtus agrestis*), water vole (*Arvicola amphibius*), nordic vole (*Microtus oeconomus*), Daubenton's bat (*Myotis daubentonii*), pond bat (*Myotis dasycneme*), mink (*Mustela lutreola*), otter (*Lutra lutra*), beaver (*Castor fiber*), and, in the summer, also elk (*Alces alces*).

As is to be expected from a rich environment such as a wetland, many birds are found here as well, including: birds of prey, warblers, sandpipers, kingfisher, aquatic birds (ducks, geese, swans), swifts, herons, owls, bitterns, egrets, plovers, terns, common coot, common moorhen, loons, common crane, gulls, wagtails, Eurasian curlew, tits, sparrow, ruff, grebes, and water rail.

The habitat wetlands and its representative species can be summarized as presented in Figure A.4.

Marine intertidal/coast:
Intertidal and coastal regions are characterised by the presence of saltwater in the near environment.

Not many mammals are expected in the intertidal and coastal regions, except for: harbour seal (*Phoca vitulina*), grey seal (*Halichoerus grypus*), dolphins, and whales.

Birds in these environments include: birds of prey, sandpipers, auk, aquatic birds (ducks, geese), stints, plovers, terns, gulls, godwits, Eurasian curlew, shag.

The habitat marine intertidal/coast and its representative species can be summarized as presented in Figure A.5.

A1.3. Expectations of fauna in the past aquatic habitat types in West Frisia

The expectations based on the geographical work by Van Zijverden (in prep.) show that the whole range of possibilities for the different water types and salinities can be expected for West Frisia, except for large rivers and mountain streams. An overview of the different aspects that can be important to a fish for its habitat is shown in Figure A.6, including the fish species that appear in each aquatic zone from the sea to the hinterland. For each fish water type mentioned in Figure A.6 a short general discussion will be provided below.

Stagnant to slow-flowing water:
Stagnant to slow-flowing water, sometimes also called the "bream zone" is characterized by relatively low amounts of oxygen and moderate to rich water, ground, and bank vegetation. It is usually found in brooks, small streams, ditches, etc.

Since this habitat type is expected for large parts of West Frisia, many fish species that thrive here can be expected, such as: sunbleak (*Leucaspius delineatus*), weather loach (*Misgurnus fossilis*), bream (*Abramis brama*), silver bream (*Abramis bjoerkna*), pike (*Esox lucius*), three-spined stickleback (*Gasterosteus aculeatus*), ten-spined stickleback (*Pungitius pungitius*), rudd (*Scardinius erythrophthalmus*), tench (*Tinca tinca*), bitterling (*Rhodeus amarus*), spined loach (*Cobitis taenia* taenia), gudgeon (*Gobio gobio*), crucian carp (*Carassius carassius*), and roach (*Rutilus rutilus*). Three-spined stickleback and roach are both non-specific in their preferences, but are most often found in this habitat. Two fish that also have a preference for this habitat are carp (*Cyprinus carpio*) and pike-perch (*Sander lucioperca*). However, these were introduced by the Romans and were not present in the Bronze Age.

(Fresh) open water:
Open water is characterized by relatively deep water with moderate to rich water and bank vegetation, but low amounts of vegetation on the ground of the water body. It contains a medium amount of oxygen on the surface, but this decreases with depth. Larger ponds and lakes are considered open water. Fish that prefer open water include: ruff (*Gymnocephalus cernuus*), ide (*Leuciscus idus*), bleak (*Alburnus alburnus*), perch (*Perca fluviatilis*), burbot (*Lota lota*), and catfish (*Silurus glanis*).

Fast-flowing water (*e.g.* rivers):
Fast-flowing water bodies are characterized by high levels of oxygen, but low amounts of vegetation. Small rivers and other fast flowing streams and brooks are considered for this habitat type. Fish expected to occur here include: ide (*Leuciscus idus*), chub (*Leuciscus cephalus*), dace (*Leuciscus leuciscus*), and stone loach (*Barbatula barbatula*).

Connection to the sea:
A connection to the sea is a broad description of habitat for fish that need to travel back and forth between fresh and saltwater for their reproduction (*i.e.* migratory fish), regardless of what other water type is used to achieve this. Therefore, a connection to the sea is an extra habitat type preference for fish that do not spend their whole life in one water type. Fish that are expected here include: eel (*Anguilla anguilla*), sturgeon (*Acipenser sturio*), mullets (*Liza spec.*), salmon (*Salmo salar*), sea trout (*Salmo trutta*), flounder (*Platichthys flesus*), shads (*Alosa spec.*), whitefishes (*Coregonus spec.*), three-spined stickleback (*Gasterosteus aculeatus*), and smelt (*Osmerus eperlanus*).

Open sea:
The open sea is characterized by highly saline water conditions with little to no plant life. In this category, only fish that live or come near the coast are discussed, or the species list would become endless. Fish that are (seasonally) expected near the coast include: grey gurnard (*Eutrigla gurnardus*), Atlantic cod (*Gadus morhua*), Atlantic herring (*Clupea harengus*), sprat (*Sprattus sprattus*), sole (*Solea solea*), stingray (*Dasyatis pastinaca*), thornback ray (*Raja clavata*), sea bass (*Dicentrarchus labrax*), and plaice (*Pleuronecta platessa*).

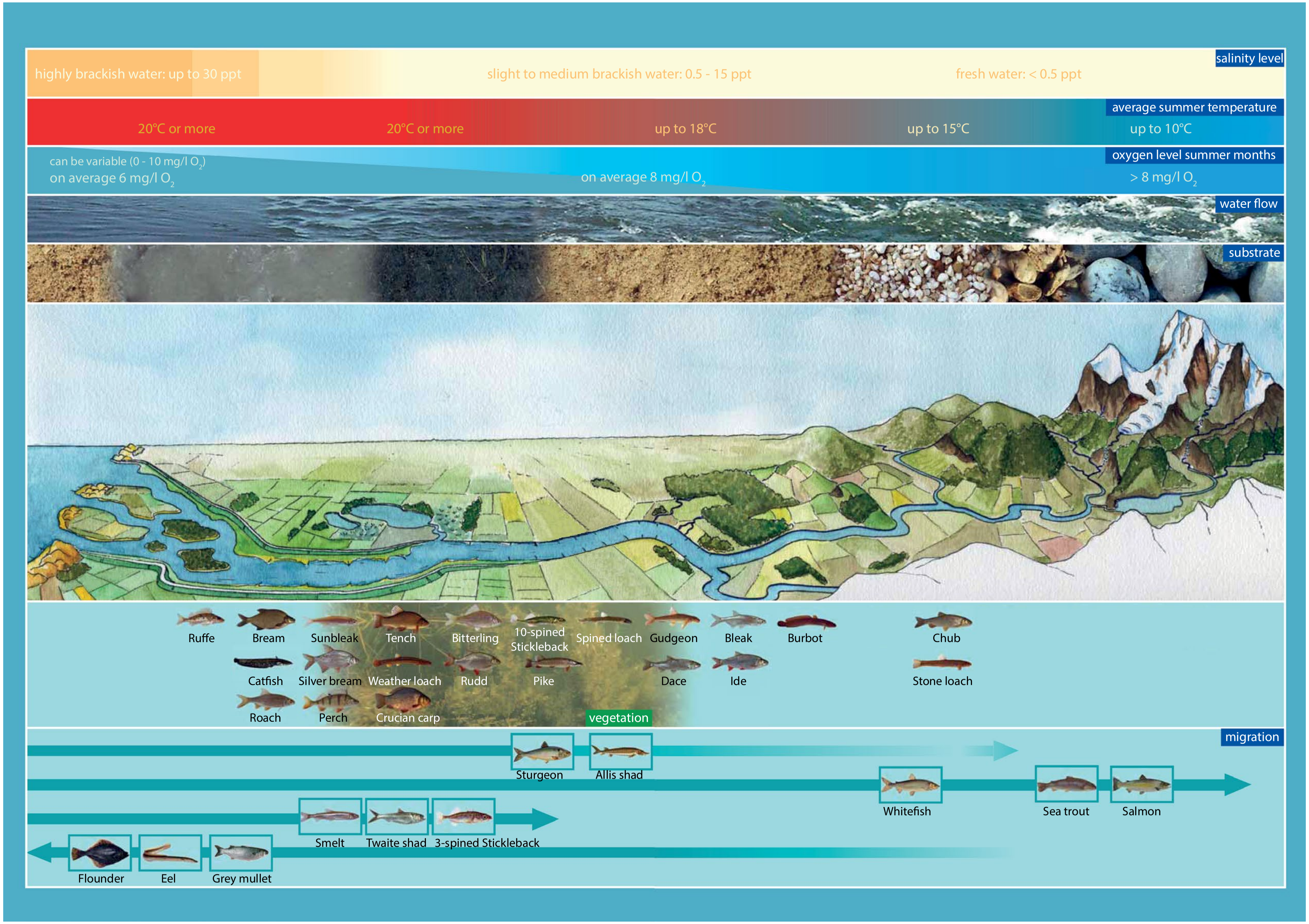


Figure A.6. Fish preferences for salinity level, temperature, oxygen level, water flow, substrate, vegetation and migration (adapted from Vissengids 2016).

Table A.1. Selected cultures that comply to the criteria set to resemble the West Frisian Bronze Age situation.

		Relative dependency on subsistence strategy (total = 10)				
Neighbourhoods						
Cultural code	Cultural group	gathering	hunting	fishing	animal husbandry	crop husbandry
A08c	Sukuma	0	0	0	3	7
A08e	Hehe	0	1	0	3	6
A10b	Ruanda	0	1	0	3	6
A10e	Nyoro	0	1	1	2	6
A19c	Tallensi	1	0	0	2	7
A24e	Luo	0	1	1	2	6
A25b	Nandi	0	0	0	5	5
C01d	Kafa	1	1	0	2	6
C15a	Basques	0	0	2	3	5
C23a	Albanians	0	0	0	4	6
C24c	Hutsul	0	1	1	4	4
E12a	Lepcha	0	1	0	3	6
E13b	Bhil	1	1	1	2	5
N24b	Tarahumara	1	1	0	3	5
average		0,29	0,64	0,43	2,93	5,71

		Relative dependency on subsistence strategy (total = 10)				
Hamlets						
Cultural code	Cultural group	gathering	hunting	fishing	animal husbandry	crop husbandry
A03e	Sotho	1	1	0	3	5
A23b	Otoro	0	2	0	2	6
C02a	Amhara	0	0	1	3	6
C03c	Dilling	1	1	0	3	5
C20b	Cheremis	0	0	2	3	5
C25b	Cherkess	0	1	0	4	5
E10b	Monguor	0	0	1	3	6
E15d	Coorg	0	1	1	2	6
average		0,25	0,75	0,63	2,88	5,50

Table A.1.(Continued) Selected cultures that comply to the criteria set to resemble the West Frisian Bronze Age situation.

		Relative dependency on subsistence strategy (total = 10)				
Villages						
Cultural code	Cultural group	gathering	hunting	fishing	animal husbandry	crop husbandry
A03d	Venda	1	1	0	2	6
A09b	Kikuyu	0	0	0	3	7
A13b	Katab	2	1	1	1	5
A18a	Bambara	2	0	1	2	5
A19a	Songhai	0	0	2	3	5
A19b	Dogon	2	0	0	2	6
A23a	Fur	0	0	1	3	6
C01b	Konso	0	0	0	2	8
C02b	Tigrinya	0	0	0	3	7
C04c	Kanembu	0	0	1	3	6
C07a	Riffians	0	1	1	3	5
Co7b	Kabyle	0	0	0	3	7
C07d	Tunisians	0	0	1	2	7
C11b	Druze	0	0	0	1	9
C12a	Turks	0	0	1	4	5
C12b	Kumyk	0	0	0	3	7
C13a	Greeks	0	0	1	3	6
C14a	Imp. Romans	0	0	2	2	6
C15b	Spaniards	0	0	0	3	7
C15c	Brazilians	0	1	1	2	6
C16a	Fr. Canadians	0	0	1	2	7
C18a	Dutch	0	0	1	3	6
C21a	Czechs	0	0	0	3	7
C21b	Lithuanians	0	0	1	4	5
C22b	Bulgarians	0	0	0	2	8
C23b	Hungarians	0	0	1	2	7
C24a	Russians	0	0	0	3	7
C24b	Ukrainians	0	0	1	3	6
C25a	Armenians	0	0	0	3	7
C25c	Khevsur	0	1	1	3	5
E09b	Manchu	0	0	1	2	7
E12d	Lolo	0	1	0	3	6
E13d	Pahari	0	0	0	4	6
E13e	Gujarati	0	0	1	2	7
E16c	Kol	1	0	0	2	7
average		0,23	0,17	0,60	2,60	6,40

Chapter 4

A1.4. Selected cultures as a parallel for the West Frisian Bronze Age based on the ethnographical work by Murdock (1981).

Selection criteria (Table A.1 and Figure A.7)

1. The subsistence economy should consist for at least 56-65% of both crop and animal husbandry (combined value of 6 or higher).
2. The type and intensity of agriculture should consist of intensive agriculture on permanent fields, using fertilization, crop rotation, or other techniques to ensure a short to no fallow period. In addition, cereal grains should form the main crops (Ic).
3. The settlement patterns should be either neighbourhoods of dispersed family homesteads (N), separated hamlets with permanent single communities (H), or compact and relatively permanent settlements (V).
4. The type of animal husbandry should be mainly bovine animals (B), or sheep/goat (S). In addition, milking (m) could be an option, but is not necessarily a prerequisite (o).

Cultures that meet the set criteria and their dependency on the different subsistence strategies, sorted by the size of the settlement

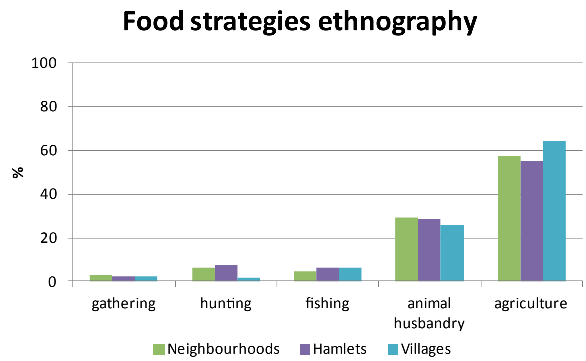


Figure A.7. Summary of the average values for the contribution of the different subsistence strategies for the selected cultural groups from Table A.1, for the different sizes of settlements.

Chapter 5

A1.5. Characterization of the Bronze Age domestic animal species cattle, sheep, pig, dog, and horse.

Cattle

Cattle (*Bos taurus*) in the Bronze Age were very different from present-day cattle. In fact, there is no real modern equivalent. In his dissertation, Gerard IJzereef has reconstructed the size and weight of Bronze Age cattle (IJzereef 1981). Bronze Age cattle were small, with an average withers height of 109 cm (IJzereef 1981, 55), and an average weight of 175 kg (IJzereef 1981, 60). Both male and female animals were horned, with the exception of one find from Enkhuizen Haling, where a hornless skull (*i.e.* born without horns, not dehorned) was uncovered (van der Jagt 2014, 59).

A recent cattle breed that slightly resembles Bronze Age cattle is for example Dexter cattle (see Figure A.8). Although this cattle breed has a similar withers height to Bronze Age cattle, the weight and overall proportions are different. Bronze Age cattle were more slender in relation to their size (Figure A.9).

The small size of Bronze Age cattle is the result of continuous diminution in size since the Neolithic, which continued well into the Iron Age (Filean 2006 and references therein). This phenomenon can have various reasons. Small cattle might be the result of inbreeding (*e.g.* Sutherland 1956), or a conscious selection of smaller individuals by the farmer. Farmers might prefer small cattle for several reasons. For example, small cattle are more manageable and more efficient producers, especially on small-scale farms. For their size, small cattle produce more meat and milk than their larger

Figure A.8. Dexter cattle (Photo by author at the farm of A. Slagter, Wolvega).

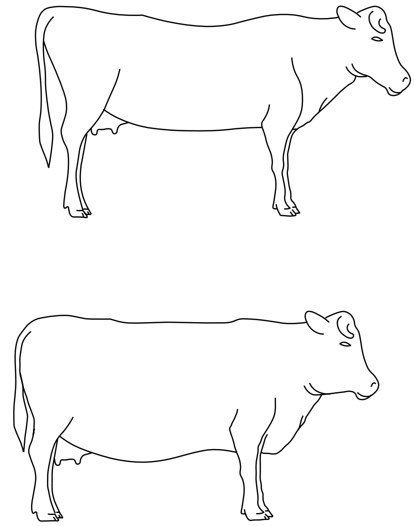


Figure A.9. Differences in build between Bronze Age cattle (left, from: IJzereef 1981, 66, Fig. 26), and modern Dexter cattle (right); average withers height of both breeds lies around 110 cm.

counterparts for the amount of nutrition they need, especially when grazed on pasture (Long *et al.* 1975). However, having smaller cattle does not lead to a reduction in labour time.

No matter the size of an animal, the number of animals kept is the deciding factor for the amount of work to be done.

Sheep

West Frisian Bronze Age sheep (*Ovis aries*) were also small, with a withers height of on average 62.3 cm and an average weight of 27.4 kg, although the weight is an approximation (IJzereef 1981, 98). Both males and females were horned; no hornless individuals were encountered anywhere in West Frisia. It is unknown whether sheep in the Bronze Age shed their wool which would have allowed plucking, or whether they needed to be periodically sheared. IJzereef has concluded from his measurements that sheep from Bovenkarspel Het Valkje resembled either Merino-type sheep, the terpschaap, the Drents Heideschaap or Shetland sheep based on several characteristics (IJzereef 1981, 95, 101). However, these comparisons are merely morphological, and no hard conclusions should be drawn solely based on this data, as the centuries of human breeding selections may have changed the phenotypical characteristics of the sheep. IJzereef however, does not mention the possibility that Soay-type were kept in West Frisia.

This is remarkable, since Soay sheep, from the island of Soay in the St. Kilda archipelago (UK), are usually seen as the living descendants of prehistoric domestic sheep and would therefore most closely reflect the type of sheep kept by people from north-western Europe during the Bronze Age.

However, based on the type of sheep and wool uncovered in the Northern Netherlands, Soay sheep might not have been the sheep breed kept in the Bronze Age in West Frisia, or indeed north-western Europe.

A wild population of Soay sheep consists of dark-coloured (sometimes with a pale belly)

Figure A.10. Examples of yarn balls found in the Emmererfscheidenbog in Drenthe in the north-eastern Netherlands (Photos by author at the Drents Museum in Assen, Drenthe).

individuals that shed their wool once a year (Clutton-Brock & Pemberton 2004), which can be hand-plucked during moult. Conversely, many Bronze Age archaeological wool finds from the Netherlands (Vons-Comis 1990, 183; Butler 1979, 122-4; Schlabow 1974: 193, 207-8; van der Sanden 1998, 131-41; van der Sanden 2002, 141) as well as throughout Europe (*i.e.* Scandinavia, Hallstatt in Austria, and the Balkans), actually lack pigmentation and have very different fibre characteristics from Soay wool (Ryder 1983, Rast-Eicher & Jorgensen 2012). Finds related to wool include yarn balls (such as in the Emmererfscheiden bog in Drenthe, the Netherlands; Figure A.10), sheepskins, and produced textiles, and based on these objects, many processing stages could be researched.

Wool lacking pigmentation only occurs on the underside of wild Soay sheep, and, as an interview with a wool sheep breeder has brought to light, wool from the belly of a sheep is of the lowest quality, surpassed only by leg wool (pers. comm. B. Stikkers). First of all, belly wool is often present in such small amounts, that a large amount of sheep would have been needed to create a piece of clothing. In addition, this wool is of low quality because sheep lie on their belly, which can result in dirtying and felting of the wool. Therefore, this wool would not be preferable to use for garments in general, let alone undergarments, such as was discovered in the Emmererfscheiden bog in Drenthe, the Netherlands (Vons-Comis 1990). Further research has even indicated that the Soay sheep type with the pale underside might be a recent result of cross-breeding (Gratten *et al.* 2010, 213).

The fibre characteristics of the wool finds are also different from Soay wool, which has been shown by Rast-Eicher & Jorgensen (2012) for Scandinavia and Central Europe, and by Mrs. Stikkers for the Dutch finds. Based on fibre characteristics, the possibility of Soay sheep being in the Netherlands during the Bronze Age is rejected as well (pers. comm. B. Stikkers). She thinks a more likely candidate would be short-tailed northern breeds that naturally shed their wool annually. Rast-Eicher and Jorgensen also propose that wool in the Bronze Age was acquired by plucking, which they base on the presence of hair follicles, since these are absent after shearing (Rast-Eicher & Jorgensen 2012, 1231).

If the sheep kept in the Bronze Age in Europe were indeed not Soay, it remains unclear which sheep breeds were likely candidates. Based on a comparison between Bronze Age sheepskins and textiles, Rast-Eicher and Jorgensen indicate that several sheep breeds must already have existed in the Bronze Age throughout Europe (Rast-Eicher & Jorgensen 2012, 1233-4, 1240). Still, it remains uncertain where we should place Bronze Age sheep from the Netherlands in this image.

Interestingly, DNA research in which several sheep breeds were analysed for their ancestry, has shown that sheep have a varied ancestry. This research furthermore seems to imply that Dutch sheep resemble Northern European sheep breeds more than those of Central Europe (Kijas *et al.* 2012, 3-4).

Dr. Lenstra from the University of Utrecht, who cooperated in this DNA project with Kijas, suggests that a panmictic population (*i.e.* a large population in which all individuals are potential partners) of prehistoric sheep, consisting of geographical local varieties may have existed (pers. comm. H. Lenstra), which might be seen as breeds.

Another result from this DNA project was that a sheep with the primitive characteristics of the Drents Heideschaap (*i.e.* horns, composition of hair/wool) has existed in the northern Netherlands for at least 4000 years (Kijas *et al.* 2012; pers. comm. H. Lenstra).

When all the above results based on the wool from Drenthe, the sheep bone characteristics of West Frisian sheep, and the general DNA research are combined, the most likely candidate for sheep kept in the Northern Netherlands is the Drents Heideschaap-type (Figure A.11). This sheep has similar physical characteristics to the West Frisian sheep types proposed by IJzereef (*i.e.* build, male and female have horns, etc.), has existed in the Netherlands for a very long time, and has fleece characteristics that are compatible with the archaeological wool finds (*i.e.* yarn balls and textiles).

Figure A.11. The proposed modern sheep breed equivalent of Bronze Age West Frisian sheep: the Drents Heideschaap (adapted from: Fryslansite 2015).

Since no finds of woollen textiles from West Frisia have (yet) emerged, there cannot be conclusive evidence that the Drents Heideschaap-type sheep also existed there in the Bronze Age. However, since there is evidence for a connection between West Frisia and the eastern part of the Netherlands (cf. Chapter 5), it can be assumed that a Drents Heideschaap-type sheep could have been present in West Frisia as well.

Pig

Pigs (*Sus domesticus*) in West Frisia did not resemble present-day pigs. They were large and still showed similarities to wild boars based on several bone measurements (IJzereef 1981, 81). This also means they would most likely have had more hair than present-day pigs, and probably had similar colour patterns to wild boar.

A possible explanation for this “wild” aspect of the pigs was given by IJzereef. He postulates that: “(…) tame females mated, deliberately or spontaneously, with wild males” (IJzereef 1981, 81). This constant supply of new genes would greatly diminish the risk of inbreeding, which would normally be very high when low numbers

Figure A.12. Domestic pigs and piglets roaming freely around Romanian settlements on the banks of the Danube delta. Since these pigs interbreed with wild boar, piglets show a combination of pink domestic pig skin with the characteristic boar piglet stripe pattern (photo courtesy of: P. Valentijn).

of pig are kept. Baeté & Vandekerkhoven similarly indicated such practices in the Middle Ages, whereby female domesticated pigs in heat were tied to a tree, in the hope of being impregnated by male wild boars. Male domestic pigs were kept in the settlement, preventing the interbreeding with wild female boars (Baeté & Vandekerkhoven 2001, 9).

An example of such an extensive pig keeping practice was witnessed by the author in the Danube delta in Romania (Figure A.12), where "domestic piglets", which roamed freely outside settlements with domestic females, possessed the characteristic stripe pattern of wild boar piglets.

Dog

Dogs (*Canis familiaris*) in the Bronze Age were of varying size and build, ranging from medium-sized relatively frail statured dogs to large dogs with a strong build (*i.e.* withers height: 48-65 cm; IJzereef 1981, 107). Modern dog breeds comparable to these measurements include the pointer, the sheepdog (IJzereef 1981, 104), and the German shepherd dog (Figure A.13).

Horse

Similar to Bronze Age cattle, the horse (*Equus caballus*) during this time is also of small stature. Although exact calculations on size were not possible based on the West Frisian data, finds from Denmark suggest a withers height of around 133 cm (Nyegaard 1996, 48), which is comparable to present-day ponies. This withers height can be found in the small Steppe horse/pony and several pony breeds such as the New Forest pony (Figure A.14).

A1.6. Liver fluke in West Frisia

For sheep in a wet environment many diseases can pose a threat, but liver fluke infection is often considered one of the worst. A figure of the life cycle of liver fluke is shown in Figure A.15.

Although both cattle, humans, and pigs can be infected (Lenton & Behm 2000, 201; Boray & Murray 1999, fig.1), liver fluke infections are known to eliminate up to 40% of sheep flocks at a time (Njau *et al.* 1988).

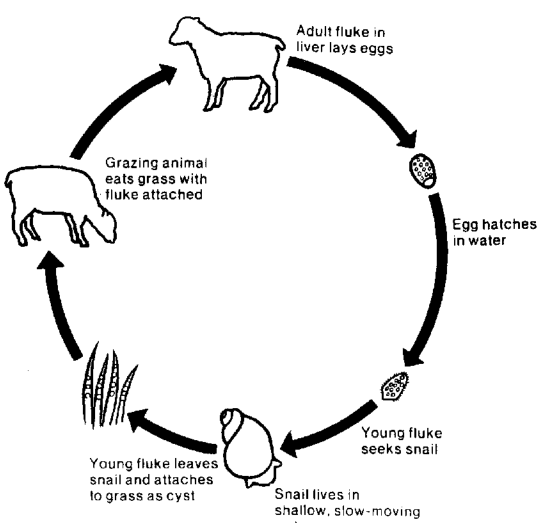
The question is whether liver fluke infection could be one of the reasons for the overstocking practice observed in West Frisia (cf. Chapter 5). In order to answer this question, it first needs to be ascertained that the liver fluke existed in the Bronze Age. Indeed, eggs of liver fluke (*Fasciola hepatica*) have been found in human and cattle remains at a Late Neolithic site at Karsdorf in Southern Saxony Anhalt, Germany (Dittmar & Teegen 2003), so it surely must have existed in the Bronze Age.

Besides mammal hosts, a liver fluke needs another – intermediate – host, a snail. The most well-known host snail for liver fluke is Galba truncatula (= Lymnea truncatula) (Lenton & Behm 2000, 202). In addition, recent research in Belgium has indicated that the snail *Radix balthica* (= *R. peregra* = *R. ovata*) can also fulfil this role (Caron *et al.* 2014). Both these molluscs are found, in very high numbers, at sites such as Bovenkarspel and Westwoud (IJzereef 1981, 129; Buurman 1996, 150).

Finally, the liver fluke needs an appropriate habitat in which to lay its eggs after parasitizing the snail and before being ingested by a mammal. This habitat is characterized by the presence of

Figure A.13. Examples of modern dog breeds which match the Bronze Age dog sizes found at Bovenkarspel; left: pointer; middle: sheepdog; right: German shepherd dog (from: Webbrittannica n.d.; Knowledgebase n.d.; German Shepherd Information n.d.).

Figure A.14. Modern horse and pony breeds with a comparable withers height to the Bronze Age horse; left: Steppe horse; right: New Forest pony (from: Mongolian Derby 2013 and Keyassets 2013).



To the left: Figure A.15. Liver fluke life cycle (from: ACGA n.d.).

slow moving water and specific aquatic vegetation. The fish remains have given indications for ample appropriate liver fluke habitats in and around the settlement (cf. Chapter 2, section 2.4.1), and plant remains indicate that aquatic plants and plants bordering small streams were also present (Chapter 2, section 2.3.4). Summarizing, all the factors needed for liver fluke to thrive were available at the sites of West Frisia. The high number of potential casualties to this and other diseases may have caused people to overstock sheep in West Frisia.

A1.7. Faustitas: a new method to construct a mortality profile from archaeological bone material and interpret past herd use and dynamics

1. Introduction

Zooarchaeology aims at understanding past human-animal interactions, including the use of animals by humans. This understanding is achieved by careful examination of bone material from excavated archaeological sites and subsequent analyses. The main analyses performed to elucidate past use of animals are sex and age determination based on individual bones. From the sex and age ratios within the bone assemblage the composition of the culled (*i.e.* killed) herd is reconstructed. The age composition in particular can be used to deduce the culling selections and the exploitation of the herd by past humans.

The age of animals can be determined based on both teeth and post-cranial bones. Teeth can provide information on the age of a slaughtered animal by analysing eruption and wear of dental elements. However, although teeth provide more precise information on age-at-death, post-cranial bone material is often well represented in the archaeological record, therefore providing a large(r) dataset for analysis and interpretation.

Post-cranial bones provide information on age based on the epiphyseal part of the bone, which becomes fused when the bone has completed its growth. This fusion occurs at a different age for each epiphysis, and for each animal species. When epiphyseal fusion, or lack thereof, is recorded in archaeological bone material, this can therefore signify a minimum or maximum age at death. Ideally, all the dental and post-cranial bone elements from all individual animals are retrieved during excavation, so that the combination of identified ages from teeth and bones can provide exact ages at slaughter. However, such finds are very rare. Instead, usually the entire bone assemblage of an excavated site, which consists of an unknown combination of elements from different individuals, is used for the age determination analysis. From this collection of bones, a slaughter pattern, or general mortality profile is constructed.

The mortality profile based on epiphyseal fusion data of post-cranial bones is often constructed with the method described by Chaplin (1971). Thereafter, the method of Payne (1973) is employed to interpret the possible past uses of a herd based on the mortality profile. Both methods have been practiced for over 40 years in the zooarchaeological research field. However, after a critical re-evaluation of their methodology, the present study has shown that these basic methods, and the subsequent interpretation of bone material, should be rethought and revised (section 2.1).

In addition, a new method is presented for the interpretation of post-cranial bone material to ensure that this large dataset is used correctly, and to its full potential. This new method is called Faustitas, named after the Roman goddess protecting livestock and herds.

Faustitas is a user-friendly Open Source online programme for cattle and sheep age data which allows the user to construct an improved mortality profile and interpret past herd characteristics based on raw post-cranial bone data. The new mortality profile is constructed by a method which removes internal data biases, and has the option to evaluate the potential effects of taphonomy on the original dataset (section 3.1). Furthermore, Faustitas enables the user to enter this new mortality profile data in a simulation to reconstruct past herd dynamics. Reconstructed past herd dynamics include: the potential of the herd for different types of production (*i.e.* use), long-term viability of the herd, as well as the age ratios which existed in the original live herd.

Although Faustitas is by no means restricted to any particular time period, the benefits of this new programme will be demonstrated here based on Bronze Age bone data from the area of West Frisia, the Netherlands.

2. Theory and calculation

2.1 The method of Chaplin

In his method, Chaplin (1971) calculates percentages of fused and unfused bones for each age group in order to establish the age ratios of animals within a bone assemblage (Chaplin 1971, 129-33). In order to test the validity of Chaplin's method, a fictive dataset of twelve complete cattle skeletons was used, of which the ages of the animals were known *a priori*. Age groups obtained by applying Chaplin's method to this dataset could thus be compared with the known age classes to identify similarities or differences in outcome.

The known age dataset consisted of twelve cattle skeletons, divided into four equal age groups ranging from 0-4 years. Each age group in turn consisted of three individuals of varying ages within that group. The expected outcome of calculations based on this dataset should therefore ideally match the four equal age groups of 25% each.

The twelve cattle skeletons were subsequently assumed to be complete archaeological finds, from which all post-cranial bones, which could provide information on age, were retrieved and analysed by the method of Chaplin. The results of this analysis can be observed in Figure A.16. It is clear that the results obtained do not resemble the expected equal ratios of age groups, even under the applied ideal archaeological circumstances. Most likely, an even more pronounced under- and over-representation occurs of the different age groups in actual archaeological bone assemblages. Although the method of Chaplin has formed the basis for research towards reconstructing mortality profiles based on archaeozoological data, several inherent aspects of this method have hindered the interpretation of what is observed in the resulting graph. It is in fact very difficult to evaluate whether the observed age

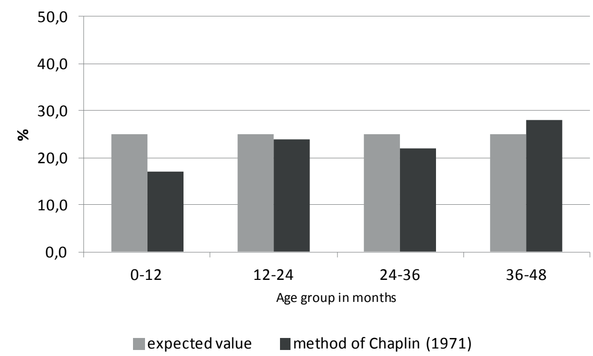


Figure A.16. Expected age group ratios (grey) versus calculated age group ratios based on the method of Chaplin (dark grey).

differences in the resulting mortality profile derive from aspects of the raw data, from calculations, or from actual past human practices, since they could also be the result of internal data biases, underlying mathematical procedures, and implicit assumptions. This will be researched next.

The mathematical procedures employed by Chaplin include the calculation of percentages of fused and unfused bones per age group, and the subtraction of these values from each other to obtain the age data for each specific age group (Chaplin 1971, 179-80). This methodology is based on the implicit assumption that the total number of fused and unfused bones on average would represent the age composition of the herd at a certain time. The reasoning continues in a further implicit assumption that each subsequent age group should contain less individuals than the previous, since in every age group individuals are lost to slaughter. This assumption is made clear by the fact that percentages of age groups are subtracted from each other. In cases where subsequent age groups contain more instead of less individuals than the last age group, Chaplin's method results in producing negative values for certain age groups. This type of irrational outcome underlines the inability of this method to deal with different types of culled herd composition. In a dead/culled herd composition, age group ratios may in fact vary widely in size depending on the use of the herd and the selections of humans made on it (Cribb 1985, 87-8). So, although in essence Chaplin's assumption of subsequent age groups becoming smaller due to

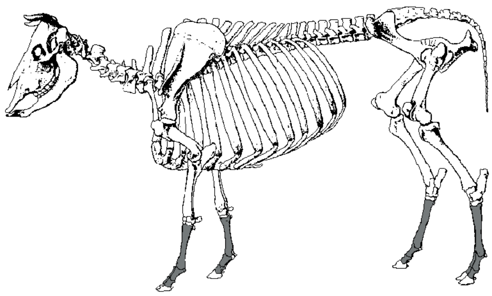


Figure A.17. Overview of a cattle skeleton indicating post-cranial bones which occur more than twice in dark grey (i.e. metapodia, which includes both metacarpal and metatarsal bones; and the [1]st and [2]nd phalanx).

slaughter practices is not wrong, it is only applicable when examining a live herd at a certain moment in time, not the dead reflection of it.

A final important aspect of the method of Chaplin negatively affecting the construction of the mortality profile and its interpretation is the lack of correction for internal biases which are always present in raw post-cranial bone data. First of all, calculations on epiphyseal fusion data obtained from post-cranial bones do not consider the number of times a bone was originally present in the body. For example, cattle phalanges have a higher chance of being uncovered relative to tibias, since phalanges occur at a ratio of 4:1 in the cattle skeleton. This means that the age group to which they belong (*i.e.* 1-2 years; Table A.4) will become relatively over-represented (Figure A.17).

A second bias which exists in the bone data is related to the unequal number of bones which can provide information on age. For instance, only two cattle bones can inform about the age of 0-1 year, whereas seven bones represent ages three and up (Table A.4). For a fair interpretation of the data, both of the above internal biases should be removed.

The third bias is the result of taphonomy: taphonomical processes greatly affect a bone assemblage prior to excavation, either by pre- or post-depositional processes. These processes cause some bones to be absent more often than others from the eventual uncovered assemblage. Although not all taphonomical effects can be identified or corrected for in a bone assemblage, at least one property of bone does allow for such a correction: density.

Bones from young and sub-adult individuals are not yet (all) fused and these unfused bones possess a lower density in comparison to fused bones from older animals. This aspect of young bone results in a gross under-representation of young(er) animals in a bone assemblage (Munson 2000), and is further exacerbated by the presence of ravaging dogs or pigs on a settlement (section 3.1). In order to most closely approach the original age ratios of animals in a bone assemblage, therefore, a correction for these taphonomical processes is required before further calculations are performed.

Faustitas corrects for all three biases presented above, producing a more mathematically accurate mortality profile based on post-cranial bones. This accuracy allows for the possibility to research past human practices without the unwanted influence of noise deriving from data biases.

2.2 The method of Payne

In his article, Payne (1973) discusses several optimal age-at-death mortality distribution graphs for meat, milk, and wool production, which are compared to mortality profiles to deduce the past use of a herd or flock. In practice however, these optimal graphs have proven far from optimal for several reasons. Firstly, the assemblage of bones recovered from a site seldom falls within just one of the use categories described by Payne, hindering the interpretation of multiple uses of a herd. Furthermore, these mixed uses of herds are very hard to interpret based on static data such as a mortality profile, and, finally, for many time periods it is not assumed that production of a herd was optimal at all.

Since the publication of the method of Payne, several researchers have discussed the (applicability of) ageing methods (*e.g.* Steele 2005; Twiss 2008), but these have mainly been focused on dental data. In addition to these discussions, other authors have shown that the optimal graphs presented by Payne are not realistic for comparative purposes (*e.g.* Cribb 1985; 1987; Munson 2000). Both Munson and Cribb remark that, based on ethnographical parallels, most animals are slaughtered well before they reach 15 months of age (Cribb 1985; 1987; Munson 2000, 395-6). This observation is in stark contrast to the optimal slaughter age assumed by Payne of 18-30 months. Cribb furthermore identifies an important problem fundamental to all zooarchaeological interpretations: it is very hard to reconstruct dynamic processes (*e.g.* herd use) from their static reflections (*i.e.* mortality profile) in the archaeological record (Cribb 1985, 81 and references therein). In order to accommodate this inherent problem and improve the interpretation of past herds, Cribb has developed a simulation. This simulation attempts to identify the underlying dynamic properties of a herd which ultimately result in the mortality profile (Cribb 1984; 1985; 1987). The mortality profile therefore becomes an input of a simulation rather than a direct means of comparison to elucidate the past use of the herd or flock. As mentioned, Cribb has been able to show the invalidity of Payne's optimal graphs by comparing its assumptions with observed ethnographical and historical data (Cribb 1985, 88-90). Sadly, Cribb's simulations of actual zooarchaeological data never quite matched with his expectation based on these ethnographical and historical parallels. However, this mismatch was most likely not due to inadequacy of the simulation programme, but rather because Cribb had employed mortality profile data based on the method of Chaplin, with its inherent disregard of the effect of internal biases and taphonomy on the data.

Since Faustitas does incorporate corrections for the aspects related to the construction of the mortality profile discussed above (section 2.1), the method of Cribb is now applicable to zooarchaeological data as well. By incorporating Cribb's method, Faustitas therefore allows for the simulation of past dynamics. In this manner, information on long-term viability, use potential, and composition of the original live herd based on post-cranial bone material can be obtained.

3. Material and methods

3.1 Faustitas: mortality profile

The mortality profile in Faustitas was constructed based on epiphyseal fusion data of post-cranial bones, which was recorded based on the method of Habermehl (1975). The threshold for the number of bones (*i.e.* fused, unfused, and fusing) in a zooarchaeological complex before application of the new method is 100 (cf. Hambleton 1999, 39). The removal of internal data biases was achieved by correcting for the frequency of specific bones present in the skeleton, as well as for the number of bones which could inform about a certain age group (section 2.1). After these corrections, the resulting values were used further to calculate the number of bones per age group (*e.g.* 1-2 years), and fusing category (*i.e.* category 1: unfused bones and fusing bones, category 2: fused bones) (Table A.2).

First, for the calculation of bones in a certain age group based on fused bones, the oldest age identifiable by bones (excluding vertebrae) was regarded as the upper limit of the data. Therefore, the following method was applied: when a younger age contained more bones than the consecutive older age(s), the total number of bones of the older age(s) was subtracted from this value. Hypothetically, an age of older than 42 months consists of 16 bones. When the age of older than 36 months consists of 20 bones, 16 of these bones could possibly be explained by the age of older than 42 months as well, but four do indeed reflect individuals of an age older than 36 months to 42 months. In the instance that the age of older than 36 months contains less than 16 bones (cf. Table A.2), all these bones could possibly also belong to the age of older than 42 months, and in this case the age of older than 36 months after subtraction is assigned a value of zero. The age of older than 24 months is calculated similarly, by subtracting the values of the categories after subtraction of older than 42 months (16 bones) and from older than 36 months (zero bones) from the 48 bones present in the older than 24 months category, resulting in 32 bones left for this age after subtraction.

By calculating in this manner for all ages, minimum values for each age are obtained.

Where the category of unfused and fusing bones is concerned, the opposite calculation was applied, since here, the youngest age forms the lower limit of the data. Apart from unborn individuals, which

Table A.2. Example of the corrections made on number of bones for each relative age (older and younger than a certain number of months), based on unfused and fusing, and fused post-cranial bones.

age (months)	unfused and fusing bones	unfused and fusing bones after subtraction	age (months)	fused bones	fused bones after subtraction
< 10	0	0	> 7	6	0
< 15	1	1	> 12	59	0
< 18	1	0	> 15	65	17
< 20	8	7	> 20	1	0
< 24	0	0	> 24	48	32
< 30	10	2	> 36	2	0
< 36	2	0	> 42	16	16
< 42	3	0			
< 48	4	0			
TOTAL	**10**	**10**		**65**	**65**

are not included in this method, animals cannot be younger than zero years of age. So, when an older age of unfused and fusing bones consists of more bones than the previous age(s), values are subtracted and the resulting value again reflects the minimum number of individuals which can be explained by the bones for this age. Note that Faustitas thus produces the most cautious representation of the mortality profile, in that no use is made of percentages, and that calculations cannot result in negative values.

The final mortality profile is obtained by dividing the resulting values of the two bone categories per age after subtraction, containing the data of fused and unfused/fusing bones. This division also incorporates a final correction for the varying age breadths present in each of the fusion age groups. These groups differ in the number of months they represent: 0-1 year is represented by bones of 7-10 months (3 months), whereas 2-3 years is represented by bones of 24-36 months (12 months) (Table A.4). By applying this last correction, the mortality profile is, as much as possible, corrected for internal biases present in the data. The final and different type of bias which can be present in the data, which results from external factors, is taphonomy. A correction for this phenomenon is, however, only partially possible due to the multitude of contributing factors. Several authors have, however, provided guidelines for when and how a correction can be achieved (Binford & Bertram 1977; Munson 2000; Munson & Garniewicz 2003). The zooarchaeological record can be severely affected by the presence of dogs and/or pigs at a site due to a high chance of the occurrence of ravaging (*i.e.* the destruction of bones by gnawing). Ravaging has an especially large effect on small bones and bones of low density (Munson 2000), meaning that young animals (*i.e.* younger than two years, but especially younger than one year of age) are most susceptible to such and other degradational processes. This high susceptibility inherently results in a large under-representation of young animals in ravaged assemblages and thus the eventual mortality profile. The effects of ravaging can be recognized in an assemblage by the ratios of certain bones. When the ratio of total number of distal ends (high density) versus proximal ends (low density) of humeri is

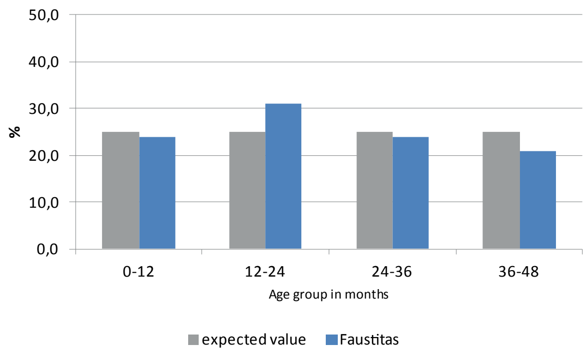


Figure A.18. Expected age group ratios (grey) versus calculated age group ratios based on Faustitas (dark blue).

higher than 4.7:1, taphonomical processes have definitely affected an assemblage (Munson 2000). Therefore, a ravaging correction, as proposed by Munson (Munson 2000, 400 and references therein), can be applied to the calculated mortality profile in Faustitas (Figure A.20) when the presence of pigs and/or dogs on a site can be presumed, and the ratio of the distal and proximal ends of humeri are within the ravaging range.

3.2 Faustitas: simulation

The simulation used in Faustitas (Figure A.21) is derived from the work of Cribb (Cribb 1984; 1985; 1987). Although based on the same assumptions, the simulation presented in Faustitas has undergone slight technical adjustments in comparison with the original simulation. Cribb allowed the user to enter several variables related to livestock mortality and birth rates, but neglected to mention how these variables resulted in the single simulation solution he presented. Indeed, a re-iteration of Cribb's simulation has shown that based on this type of data, there is always more than one solution for the entered variables. In the simulation in Faustitas, this aspect is made transparent and instead, the user can make deliberate decisions based on all simulation results, and choose which data should be incorporated in the final conclusion. Additionally, because some of the variables are dependent on each other, only two variables need to be entered in Faustitas (*i.e.* expected mortality of adults (mA) and birth rate (B) based on ethnographic parallels), which are subsequently used for the simulation of the other variables. The various different outcomes of the simulation are portrayed both in table and graph form, in which all the variables are shown. In order to ensure graphical clarity, the possible uses for herds are only shown in table form. The results of the simulation can be compared to the expected birth rate and mortality values of each age group (0-1 years, 1-2 years, and > 2 years) to arrive at indications for past herd use. Finally, the simulation can be applied to any animal husbandry situation and time period, as long as underlying assumptions are adjusted accordingly.

3.3 West Frisian data

The data used to exemplify the use of Faustitas derives from the excavated Bronze Age site Bovenkarspel Het Valkje, the Netherlands, which yielded large amounts of zooarchaeological material (IJzereef 1981). This site was occupied from ca. 1600-750 BC, but only the Dutch Middle Bronze Age B (1500-1000 BC) will be considered here. People in this time period can be characterised as small-scale mixed subsistence farmers with small, self-sustaining herds (Chapter 5). Ethnographical parallels used for the simulation input were obtained from several sources from around the world (birth rate: Mukasa-Mugerwa 1989; Negassa & Jabbar 2008; mortality rates: Dahl & Hjort 1976; Fall 1982; Muma *et al.* 2009; Fiore *et al.* 2010; Inamdar 2012).

The data presented here has been analysed as part of the research project "Farmers of the Coast", funded by the Netherlands Organisation for Scientific Research (NWO).

4. Results and discussion

The validity of Faustitas was tested in a similar manner as the method of Chaplin, with the aid of the fictive cattle dataset (section 2.1). Furthermore, the archaeological Bronze Age dataset from Bovenkarspel was tested with Faustitas, and the results compared with the outcomes based on the methods of Chaplin and Payne.

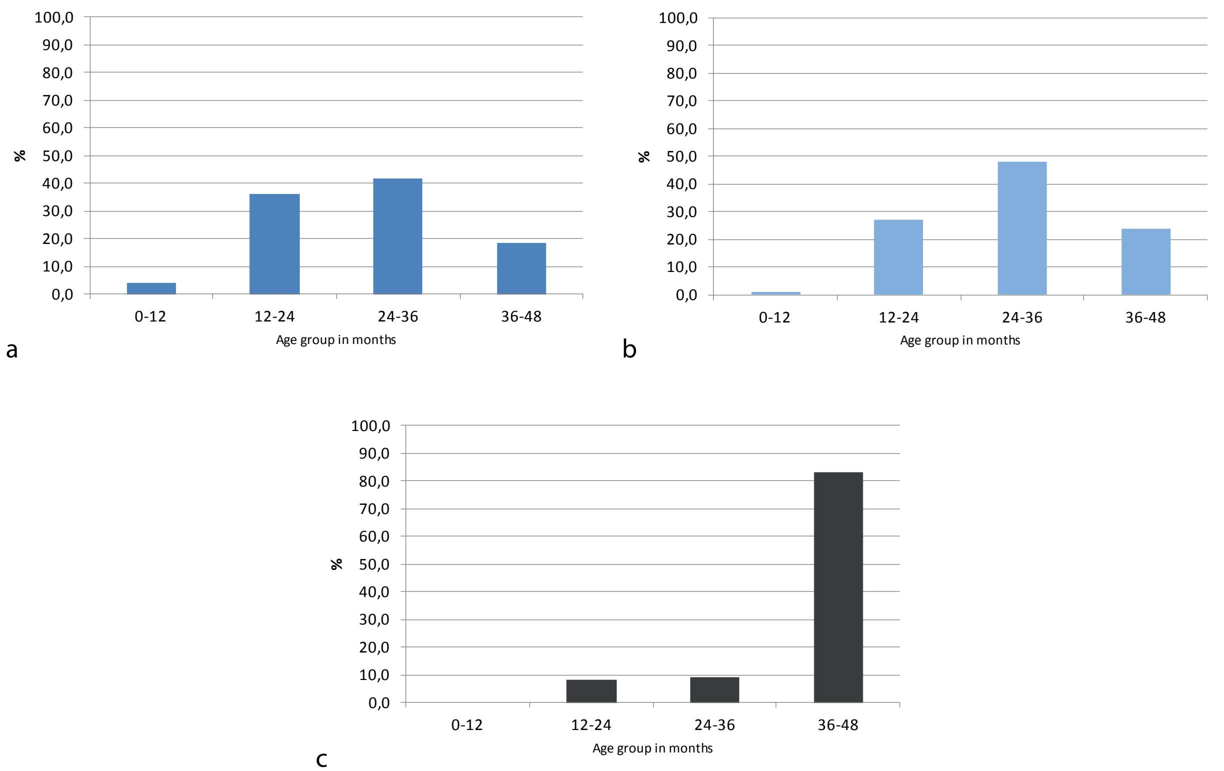


Figure A.19 Mortality profile for cattle from Bovenkarspel Het Valkje for the Dutch Middle Bronze Age B situation (1500-1000 BC) based on: a. Faustitas with ravaging correction; b. Faustitas without ravaging correction; c. Chaplin (1971).

4.1 From Chaplin to Faustitas

The fictive cattle data used to test the validity of the method of Chaplin (section 2.1) was also entered into Faustitas (Figure A.18). The results in Figure A.18 can be regarded as mathematically correct because all possible internal biases of the data were removed, and will no longer have affected the ratios observed (cf. section 3.1). Therefore, the results can now more accurately be related to past human practices than was possible based on the method of Chaplin. Thus, Faustitas presents an improved methodological step for zoological research and subsequent archaeological interpretation. What is clear from Figure A.18 is that the resulting age groups approach the expected equal age ratios of 25% in a different manner than the method of Chaplin, and that especially the youngest age group is better matched by Faustitas. Some differences can still be observed between age groups in Figure A.18 (*i.e.* an over-representation of 1-2 year old individuals), but since this will be a constant aspect of the Faustitas method (unaffected by biases as much as possible) these can be taken into consideration during interpretation.

Because of the few remaining internal properties of the underlying relative bone data (*i.e.* older than and younger than), it is not possible to arrive at a perfect match. More research might be employed in the future to test the internal dynamics of the new method and improve its matching qualities further (section 5 Conclusion and future prospects).

4.2 Ages of Bronze Age cattle

Cattle bone data from Bovenkarspel (Table A.4). was analysed using Faustitas. An additional correction for ravaging was applied, since the humerus distal:proximal ratio was very high (*i.e.* 8.7:1; threshold: 4.7:1). This ratio indicates that taphonomical processes will have severely affected the bone material, removing all but a few young

Table A.3. Faustitas simulation model input and output for Bronze Age cattle from Bovenkarspel Het Valkje, the Netherlands.

Ethnographical model input	**Value**	**Meaning**
Birth rate	0.2-0.7	0.2-0.7 young born annually per female
Expected mortality young (0-1 year)	0.1-0.6	10-60% young die annually
Expected mortality immature (1-2 year)	0.1-0.2	10-20% immature die annually
Expected mortality adult (> 2 year)	0.1-0.3	10-30% adults die annually
Mortality profile model input		
No. of bones	619	total number of bones with age determination
Target mortality young	0.04	mortality young based on mortality profile Faustitas
Target mortality immature	0.36	mortality immature based on mortality profile Faustitas
Target mortality adult	0.60	mortality adults based on mortality profile Faustitas
Simulation output		
Growth rate	1.08	8% annual growth of the herd
Birth rate	0.48	0.48 young born annually per female
Simulated mortality young	0.03	3% young died annually
Simulated mortality immature	0.27	27% immature died annually
Simulated mortality adult	0.16	16% adults died annually
Potential for meat production	0.17	potential of the simulated herd for meat production
Potential for milk production	0.13	potential of the simulated herd for milk production

animal bones from the original assemblage (cf. Munson 2000; section 3.1). The mortality profile of the West Frisian data is shown in Figure 19a, with Figure 19b added to show the effect of the ravaging correction. As a contrast, the mortality profile based on the method of Chaplin is shown in Figure 19c. The mortality profile produced by Faustitas shows the slaughter of animals of mainly 1-3 years old, whereas Chaplin's method resulted in the almost exclusive slaughter of animals older than 36 months. This comparison between the figures clearly signifies the importance of the removal of internal biases in the data as well as external taphonomical effects.

Animals younger than one year are nearly absent from both assemblages. This is surprising, since high numbers of dead young animals are always expected for this particular animal husbandry situation; unwanted youngstock is slaughtered and high natural mortality of young animals occurs within these types of farming communities (*i.e.* small-scale farmers with self-sustaining herds; section 3.3). Therefore, in

Faustitas

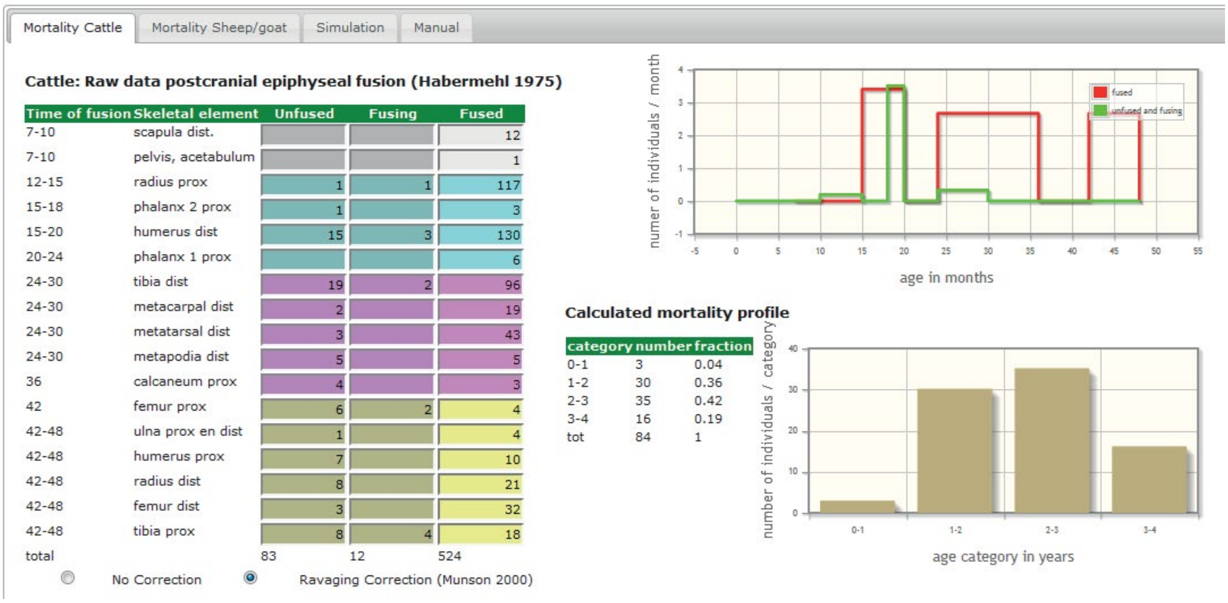


Figure A.20. Screenshot of the raw data input page for the construction of the mortality profile.

this case, the absence of dead young animals might be related to the very high impact of taphonomy on the original assemblage rather than other factors (section 4.4 Further discussion). When very few remains are present, even the application of the ravaging correction can no longer aid their visibility. Clearly, this example emphasizes the importance of a continuous comparison between expected and observed data as a vital aspect in the interpretation of past animal husbandry practices.

4.3 Use of Bronze Age cattle herds

The mortality profile produced by Faustitas, as well as additional ethnographical data on birth rate and mortality rates were used as input for the simulation of past herd dynamics. A summary of the ethnographical input to the simulation (cf. section 3.3), the mortality data from the reconstructed mortality profile (Figure 19a), and the resulting simulation output information is shown in Table A.3.

For the Bronze Age, it is assumed that flocks were self-reproducing units (Chapter 5). Therefore, the growth rate of the herd is expected to be higher than one, or else the herd would be declining in size on an annual basis. Based on this assumption (*i.e.* only growth rates higher than one were included), the values of the output of the simulation (Figure A.21) were averaged.

Table A.3 shows that the simulation based on the Middle Bronze Age cattle data has resulted in different kinds of information about the past herd. Based on the assumptions made, the herd's growth rate was 1.08 (*i.e.* 8%) and the birth rate 0.48, both of which are characteristics of healthy herds (cf. Cribb 1987, 403). The simulated mortality values of the different age groups have resulted in values which are mostly in the range of the expected values based on ethnographic parallels (Table A.3: compare simulation output with ethnographical input). The mortality of young animals however, lies slightly below the observed values in small-scale farming communities, and the mortality of immature animals is slightly higher than was expected based on ethnographic examples. These differences may be related to taphonomical processes affecting the original bone assemblage or to the application of a different animal husbandry practice than was expected for this time period and location (section 4.2; section 4.4 Further discussion). Still, the potential for meat and milk production of the herd is comparable to the expectation and does

Faustitas

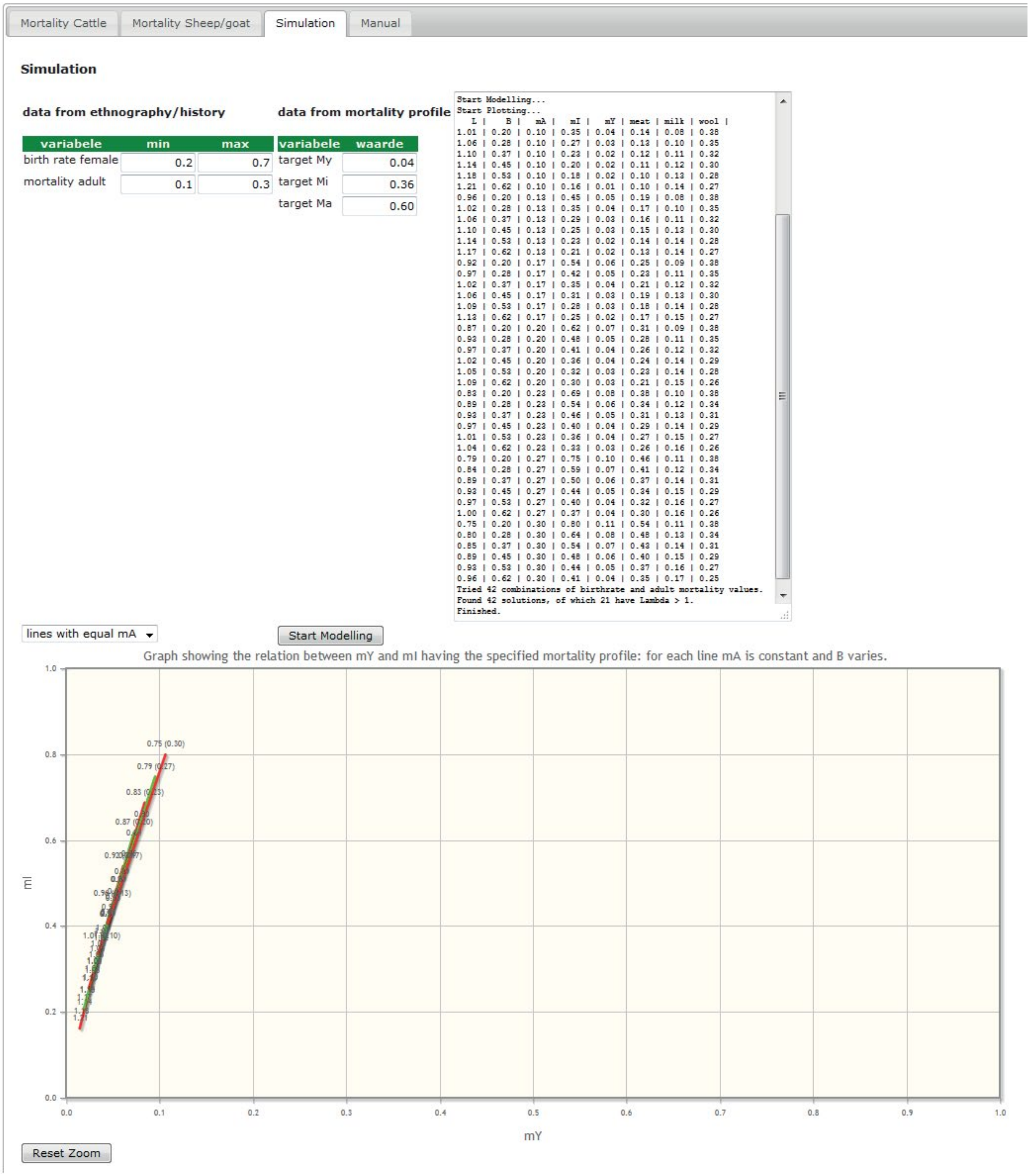


Figure A.21. Screenshot of the input page for the simulation of past herd dynamics.

concur with what is observed in parallel small-scale farming communities: the exploitation of animals for multiple purposes is preferred over specialisation towards a single use (Schiere & Kater, 2001). This result is in contrast with conclusions drawn based on Payne's method, which would have resulted in a herd used for traction (Payne 1973, 284, figure 3; Hambleton 1999).

Finally, the composition of the original live Bronze Age herd based on the simulated data also agrees with live herd compositions observed in small-scale farming communities (*e.g.* Lehloenya *et al.* 2007, 220-1), consisting of around 58% adults (> 2 years), 17% immature (1-2 years), and 25% young (< 1 year) animals (data not shown). Therefore, the cattle herds in Bronze Age West Frisia can be considered to have been healthy growing herds with the potential for the exploitation of multiple uses, concurring with the expected small-scale animal husbandry practices for this area (Chapter 5).

4.4 Further discussion on the use of Faustitas

Faustitas has shown its potential for the interpretation of past use of herds by people. Although the example used in this research was based on Bronze Age data, it must be emphasized that Faustitas can be applied to any archaeological bone dataset, as long as the basic prerequisites regarding number of bones and applied fusion identification method are met (section 3.1). Indeed, different assumptions and ethnographic or historical parallels will be required for different studies, but the simulation remains applicable regardless.

Alternatively, only the mortality profile may be of interest to the researcher, without using the simulation. For example, if no (self-sustaining) herds are expected in a certain situation, because animals are being bought individually or imported, expectations for growth rate and mortality rates of the total herd will be different or even not applicable. Past uses of these animals may however still be made clear through the application of only the mortality profile part of Faustitas (Figure A.20). In some cases, subsequent interpretation based on simulation is not therefore required for answering certain research topics. When it is applied however, the simulation of past herd characteristics should always occur on a tentative basis because the model and its output are built upon many assumptions. The Bronze Age example shown in this research interprets past herd properties based on 619 bones which could reflect 500 years of animal husbandry practices. Animal husbandry itself is a dynamic process, which can change annually depending on both internal and external factors, thus affecting the composition and use of the herd. Rather than providing definitive answers, the simulation results and their interpretation should therefore be regarded more as providing indications for possible use and practice, as well as forming a source for generating new ideas about past herds. New ideas and hypotheses resulting from the simulation could be re-tested by adjusting the target mortality profile data and by running a consecutive simulation accordingly.

Faustitas uses post-cranial bone data to identify slaughter ages, but a final remark must also be made regarding the interpretation of ages based on dental information. Although often regarded as a more reliable aging method due to its more specific age categories in comparison to bone material, the same, if not more taphonomical effects occur on jaws of young individuals (Munson 2000; Munson & Garniewicz 2003). Young animals can therefore be similarly highly under-represented in the dental record. A ravaging correction should thus actually also be applied to this type of age data, where appropriate (cf. section 3.1), in order to remove possible biases present before interpretation (cf. Munson 2000). After such corrections, post-cranial bone and dental data should be more comparable, and perhaps may even become complementary when interpreting mortality profiles.

5. Conclusion and future prospects

Faustitas is a considerable step forward for zooarchaeological research because it allows for the interpretation of past animal use by people on a much more mathematically correct basis than ever before. Internal biases in the data are removed and taphonomical processes can be taken into consideration before a mortality profile is constructed. Furthermore, more insight is gained in past herd characteristics

time of fusion in months (Habermehl 1975)	skeletal element and side of fusion	unfused	fusing	fused
		n	n	n
7-10	scapula distal	-	-	12
7-10	pelvis, acetabulum	-	-	1
12-15	radius proximal	1	1	117
15-18	phalanx 2 proximal	1	-	3
15-20	humerus distal	15	3	130
20-24	phalanx 1 proximal	-	-	6
24-30	tibia distal	19	2	96
24-30	metacarpus distal	2	-	19
24-30	metatarsus distal	3	-	43
24-30	metapodia distal	5	-	5
36	calcaneum proximal	4	-	3
42	femur proximal	6	2	4
42-48	ulna proximal and distal	1	-	4
42-48	humerus proximal	7	-	10
42-48	radius distal	8	-	21
42-48	femur distal	3	-	32
42-48	tibia proximal	8	4	18
	Total	83	12	524

Table A.4 Cattle bone data from Bovenkarspel Het Valkje, Middle Bronze Age B (1500-1000 BC).
Ravaging ratio: (humerus distal:humerus proximal) 148/17=8.7

by being able to examine underlying dynamic processes of the live herd, which will ultimately have resulted in the dead reflection uncovered in the zooarchaeological record. Herd characteristics which can be researched include birth rate, growth rate (*i.e.* long-term viability), and potential uses of the herd for meat, milk, and/or wool production. Still, many more steps can and should be taken to ensure that zooarchaeology continues to advance as a research field in the future. The internal dynamics of the Faustitas method could be tested to a higher degree in order to ensure model and simulation robustness. Furthermore, the matching qualities of the method need to be tested in more detail to further

Table A.5. Grazing requirements on grassland pasture only of the different West Frisian domestic animal species based on 6DSE/ha (after: van Gool et al. 2000).

Dry Sheep Equivalent	Number of animals/ha	Animal/ grassland pasture required
Cattle (Dexter): 4 DSE	1.5 cattle/ha	1 cattle/0.7 ha
Sheep: 1 DSE	6 sheep/ha	1 sheep/0.2 ha
Goat (average): 1.55 DSE	3.9 goats/ha	1 goat/0.3 ha
Horse (pony): 5 DSE	1.2 horses/ha	1 horse/0.8 ha

decrease the likelihood of results occurring due to coincidence, for example by generating 100 random populations rather than one (cf. section 4.1).

Faustitas can also be further improved by extending its use: several additional features can be added in the future to accommodate a wider range of research possibilities. First of all, the model could be extended by adding an option to include post-cranial bone data based on the method of Silver (1969). Furthermore, options such as the potential of a cattle herd for traction purposes may be included.

Additional simulation options developed by Cribb include the possibility to investigate the effect of long-term changes of variables (*e.g.* birth rate) on herd composition and use, allowing the user to investigate the effects of changing animal husbandry practices over time. Another additional simulation option includes the incorporation of the effect of periodical negative events (*e.g.* disease) on a herd to test its ability to withstand said events and remain viable in the long-term (Cribb 1987, 389).

A final addition to Faustitas might include the incorporation of more animal species to accommodate the research towards more types of animal groups, which may be either wild or domestic animal species. In this manner, both animal husbandry and hunting practices may be researched (cf. Steele 2003).

Ultimately, whether additions are made or not, Faustitas, just as in Roman times, will continue to ensure the protection of livestock and herds, although now within the realm of zooarchaeological interpretation. The programme Faustitas will eventually become available as an open-access website at the Leiden University website. Until that time, anyone interested can contact the author for access to the program at: faustitasmethod@gmail.com.

Table A.6. Grazing requirements on 2/3 grassland and 1/3 woodland pasture of the different West Frisian domestic animal species based on 1 GVE/4 ha (after: by Baeté & Vandenkerkhoven 2001).

Groot Vee Eenheid/ Large Livestock Unit	Animal/grassland and woodland pasture (2.3; 1/3) required
Cattle (Dexter): 0.8 GVE	1 cattle/3.2 ha
Sheep: 0.2 GVE	1 sheep/0.8 ha
Goat (average): 0.3 GVE	1 goat/1.2 ha
Horse (pony): 1.0 GVE	1 horse/4.0 ha

A1.8. Calculation of grazing requirements

Calculating required pasture per animal species on grassland pasture only

In order to calculate the required pasture per animal, the stocking rate for these grazing grounds need to be calculated first. Stocking rates can be expressed as DSE (Dry Sheep Equivalent) values, which means the amount of food consumed by a sheep that is not pregnant. Other species will have proportionally higher or lower values when consuming more or less food than a dry sheep.

Under grassland pasture conditions on clayey soils (which is assumed for the West Frisian situation), 6 Dry Sheep Equivalents can graze on 1 ha (van Gool *et al.* 2000). This means that the values from Table A.5 should be kept in mind for grazing on grassland pasture only for the sizes of the domestic animal species kept in West Frisia (see A1.4).

Calculating required pasture per animal species on grassland and woodland pasture combined

Since woodland pasture can form a part of the grazing grounds of some animals as well, calculations were also made to include this pasture type.

In the article by Baeté & Vandenkerkhoven (2001), GVE (Groot Vee Eenheden; Large Livestock Units) values are used instead of DSE values. The GVE value of sheep in this article is set at 0.2 (Baeté & Vandekerkhoven 2001, 22). This value was proportionally translated into the values of the other animal species, based on the DSE values of van Gool *et al.* (2000).

Based on the article by Baeté & Vandenkerkhoven (2001, 21), grazing for most animals occurs at 2/3 grassland pasture, 1/3 forest pasture when vegetation is to remain the same. West Frisian soils are considered rich in nutrients, meaning that:

Stocking rate forest on rich soils: 1 GVE/ 10ha
Stocking rate grassland on rich soils: 1 GVE/ 1 ha

Under the stocking rate of 2/3 grassland pasture and 1/3 forest pasture, grassland will, in terms of nutrition (see stocking rate above), therefore be able to support 1 GVE/0.7 ha, and woodland 1 GVE/3.3 ha, resulting in a total of 1 GVE/4.0 ha for the combination of grassland and woodland.

Therefore, the stocking rate for 2/3 grassland pasture and 1/3 forest pasture: 1 GVE/ 4ha.

In addition, 17.5% (0.7/4.0) of the total calculated acreage of grassland and woodland will thus consist of nutrient-rich grassland pasture, because a smaller area is required to obtain sufficient nutrients. The other 82.5% (3.3/4.0) will consist of the relatively nutrient-poor woodland pasture.

The resulting GVE values for the different West Frisian domestic animal species can be seen in Table A.6.

Calculating required total pasture per household for different grazing scenarios

The total acreage of required per household is calculated based only on the article by Baeté & Vandenkerkhoven, because their values for required grassland pasture only are very comparable to those obtained from van Gool *et al.* (compare Table A.5, column 3 and Table A.6, column 1).

Herd size per household:
5-8 cattle
5-15 sheep/goat (75% sheep, 25% goat)
1 horse

Scenario 1: Grassland pasture only (Baeté & Vandekerkhoven 2001):
Cattle: 4.0-6.4 ha
Sheep: 0.8-2.3 ha
Goat: 0.4-1.1 ha
Horse: 1.0 ha +
Minimum: 6.1 ha
Maximum: 10.8 ha

Scenario 2: Grassland and Woodland for goat only, other species on grassland (Baeté & Vandekerkhoven 2001):
Cattle: 4.0-6.4 ha
Sheep: 0.8-2.3 ha
Goat: 1.5-4.5 ha
Horse: 1.0 ha +
Minimum: 7.3 ha (6.0 ha grassland, 1.3 ha forest)
Maximum: 14.2 ha (10.5 ha grassland, 3.7 ha forest)

Scenario 2: Grassland and Woodland for all species (Baeté & Vandekerkhoven 2001):
Cattle: 16.0-25.6 ha
Sheep: 3.0-9.0 ha
Goat: 1.5-4.5 ha
Horse: 4.0 ha +
Minimum: 24.5 ha (4.3 ha grassland, 20.2 ha forest)
Maximum: 43.2 ha (7.6 ha grassland, 35.6 ha forest)

Figure A.22. Emmer wheat (Figure from: Educational Technology Clearinghouse 2011).

Figure A.23. Hulled barley (photo courtesy of C.C. Bakels).

Chapter 6

A1.9. Characterisation of the West Frisian cultivated crop species and the ard

Emmer wheat

Emmer wheat (*Triticum dicoccum*) is one of the principal food crops in prehistoric Europe, being adaptable to diverse climates and altitudes. It is a hulled wheat crop, which means that its grain kernels are enclosed by glumes that remain attached to the kernel when ripe. In emmer wheat, two kernels ripen within each spikelet (Figure A1.22; Zohary & Hopf 2012, 39-40). Processing emmer wheat kernels requires extra steps to remove the glumes and prepare them for human consumption.

Barley

Hulled barley (*Hordeum vulgare* var. *vulgare*) and naked barley (*Hordeum vulgare* var. *nudum*) are other main food crops of prehistoric Europe, which can withstand poorer soil conditions than emmer, including moderate aridity, lower amounts of soil nutrients, and low levels of salinity (Zohary & Hopf 2012, 51-2). Kernels of six-rowed barley, the species present in Bronze Age West Frisia, appear in triplets on either wide of the awn (Figure A.23). Similar to hulled wheat species, the processing of kernels of hulled barley requires extra steps to remove the glumes when their ultimate use is for human consumption, whereas this is not required for naked barley to the same extent.

Figure A.24. Broomcorn millet (from: Forestry Images n.d.).

Figure A.25. Linseed/flax (from: Southeast Farmpress 2013).

Broomcorn millet
Broomcorn millet (*Panicum miliaceum*) is a food crop that can withstand the harshest environmental conditions, including high temperatures, poor soils, and severe aridity (Zohary & Hopf 2012, 69). It is a crop that has a short growing season and which grows best during the warm summer months. Broomcorn millet is cultivated as a food crop, and its small seeds are situated in panicles (Figure A.24). When ripe, the husked seeds are prone to shattering (*i.e.* falling from the panicle to the ground), which can lead to considerable harvest losses. In addition, crops tend to lodge (*i.e.* lie flat on the ground) when rains occur to often towards the end of the growing season. For human consumption, broomcorn millet seeds first need to be de-husked.

Linseed/flax
Linseed/flax (*Linum usitatissimum*) is a crop that can provide both oil-containing seeds and fibres for the production of linen textiles (Zohary & Hopf 2012, 101). Usually, specialisation towards one use occurs, because fibres are of lower quality when seeds are ripe and vice versa, but crops grown for both purposes also exist (Figure A.25). The seeds can be pressed to obtain a high-quality edible and/ or lighting oil. For obtaining the fibres, stems are harvested before the seed is mature and they are further processed by drying the stems, letting them rot in water to allow the decomposition of the stem tissue, and subsequently separating the wanted fibres through pounding and combing.

The ard
Prehistoric ploughs are plough that cut the soil, rather than turn the soil. They are collectively called ards, and exist in several different types and sizes (for overviews, see Tegtmeier 1993; Fries 1995). For West Frisia, it is assumed that the Donnerup ard type, an Early Bronze Age ard uncovered in the Donneruplund bog near Velje, Denmark (Figure A.26), is the ard type used for cultivation.

A1.10. Calculation of the turn radius of a cattle pair with ard

The turning radius of a cattle pair and ard can be calculated to gain insight into the approximate distance between subsequent furrows and radius of turning points at the edge of an arable field. When calculating this turning radius, the cattle pair and ard can be compared to a modern vehicle (Figure A.27)

The plough mark that is preserved in the soil, is represented by the turning radius of the plough, which in this case is the circle formed by the inner cattle plus half the length of the yoke (Figure A.28).

When the length of the ard is considered the same as the distance between the axles of a vehicle (since the middle of the yoke and the ard point in the soil are the turning points), w = 2 m (Aborg & Bowen 1960: 145). The turning angle of the cattle pair is unknown and is therefore varied between 10 and 30 degrees, so α = 10, 20 or 30. From these values r can be calculated according to the following formula:

r=w/sqrt(2-2*cos(2* α)) (Davdata 2016)

$r_{a=10}$=1.83m, $r_{a=20}$=1.54m, $r_{a=30}$=1.01m

Adding to these values half the width of the yoke (*i.e.* 0.75m) means that the turning radii lie around 2.59m, 2.29m, and 1.76m. This means that the turning diameter of an ard lies somewhere between 3.5 and 5 metres, depending on the angle at which the cattle can turn whilst attached to the yoke and ard.

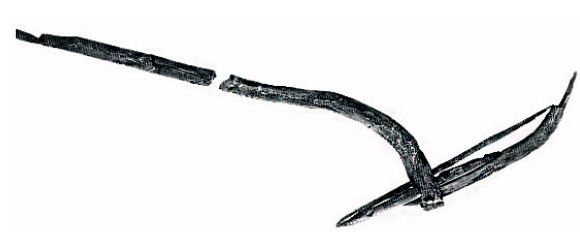


Figure A.26. Prehistoric plough, or ard, which cuts the soil, but does not turn it. The West Frisian ards were most likely similar to this example, uncovered in a bog in Donneruplund, Velje, Denmark (from: Denmark's history 2014).

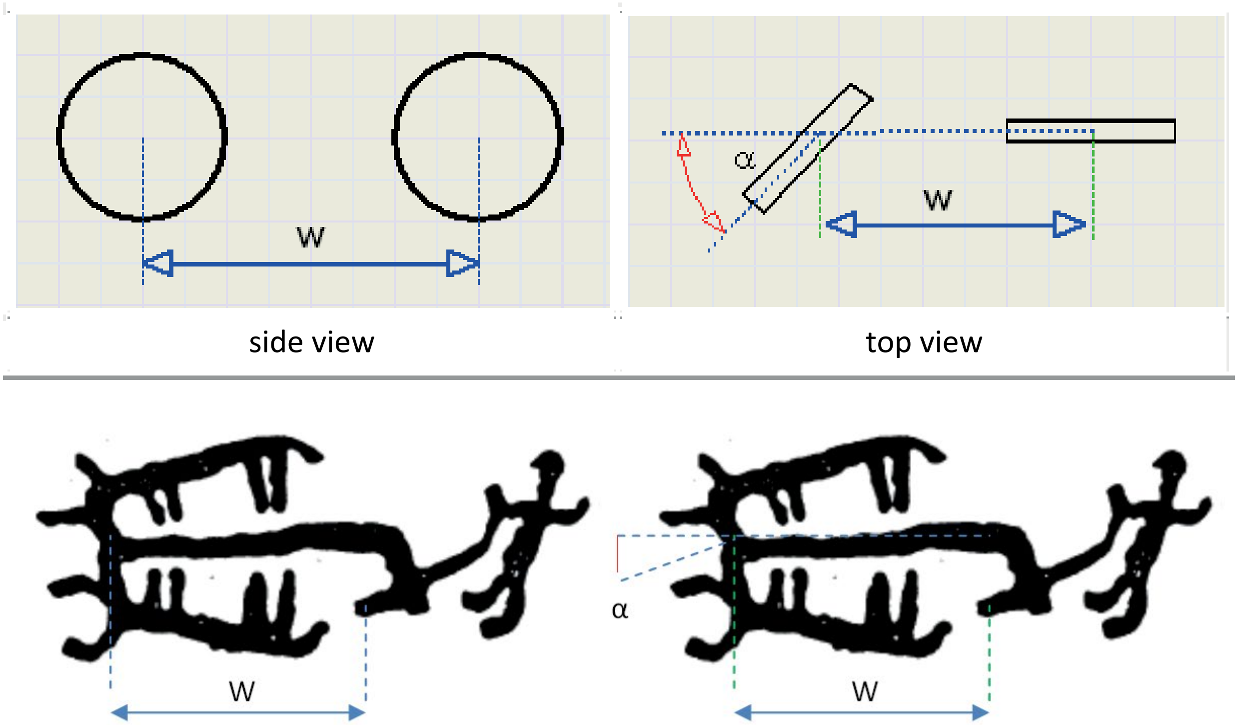


Figure A.27. Comparison of a modern vehicle and a Bronze Age cattle pair and ard for the calculation of the turning radius. Above: W represents the distance between the two axles (*i.e.* wheels or the distance between yoke and ard share), α the turning angle of the front turning point (*i.e.* front inner wheel or inner cattle in yoke) (from: Davdata 2016). Below: Scandinavian rock art depicting a cattle pair with plough and human (from: Fredsjö 1956, Figure 35); indicated are the distance W and the possible turning angle α.

A1.11. Identifying manuring practices in West Frisia based on 15N isotope analysis

The West Frisian Bronze Age fields, manured or not manured: a preliminary report on the $\delta^{15}N$ values of charred grain

Corrie Bakels

1. Introduction

Several proxies may provide information regarding the question whether fields were manured in the past, but there is one direct approach available, through the measuring of the $\delta^{15}N$ values of charred grain. The spreading of solid animal dung on fields enhances the $\delta^{15}N$ in the crop (Kanstrup 2011). Slurry or artificial fertilizer do not produce this effect, but as those kinds of fertilizer are not considered to have been used in prehistory the method may prove valuable in the case of the Bronze Age.

2. Material and methods

2.1 Archaeological material

For the first trials reported on in this contribution charred grain from eight West Frisian features was chosen *i.e.* Bovenkarspel-Het Valkje find numbers 7, 10 and 105, Enkhuizen-Haling find number 23, Twisk find numbers 1-1-19 and 1-1-20 and Westwoud find number 4 and 39/4. The first six are dated Middle Bronze Age, the last two Late Bronze Age. Except for Enkhuizen-Haling all finds came from the research conducted by Buurman (1996). The Enkhuizen-Haling site was excavated by ARCHOL BV and its botanical material retrieved by E. van Hees from the Faculty of Archaeology, Leiden University (van der Linde *et al.* 2014).

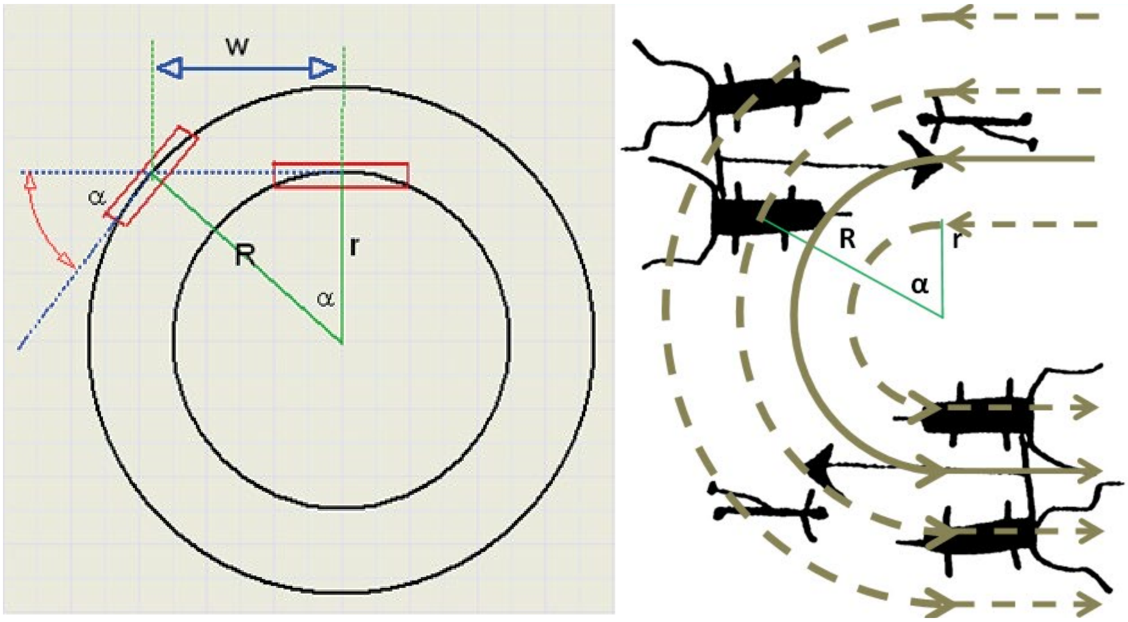


Figure A.28. Variables required to arrive at the turning radius. W represents the distance between the two axles, α the turning angle of the front turning point, R the radius of the front turning point, and r the radius of the back turning point (from: Davdata 2016. Left: calculation variables; right: example of a turning radius with a cattle pair and plough (rock art) (after: Payne 1948, plate V.2).

As the main cereals grown in West Frisia were emmer wheat (*Triticum dicoccum* Schübl.) and hulled barley (*Hordeum vulgare* L.), both species were selected for the analysis. The Bovenkarspel-Het Valkje features provided both, the others one kind of grain. All in all 11 samples were available for analysis (Table A.7).

From each sample subsamples were taken to be sent to the Centre for Isotope Research at Groningen, the Netherlands. Subsamples comprised 10-20 grains, but in the case of Enkhuizen-Haling only seven specimens were available (see table).

All grains were free from remnants of rachises and glumes, as chaff is reported to give a different $\delta^{15}N$ signal (Bogaard *et al.* 2007; Bol *et al.* 2005).

In Groningen the subsamples were treated by the acid-base-acid (ABA) method, ground and their $\delta^{15}N$ values established.

2.2 Providing baselines

$\delta^{15}N$ values of prehistoric crops are meaningless if they cannot be compared with $\delta^{15}N$ values of crops grown without any manure. The baseline value is not a single, fixed value but is influenced by the substrate and the kind of crop (see for instance Bateman *et al.* 2005; Högberg 1997).

To provide the best possible baselines, both emmer wheat and hulled barley were grown in tubs filled with West Frisian sandy clay, dug from an off-site prehistoric horizon, 120cm below the present surface. This clay was not polluted by modern fertilizers.

The plastic tubs were placed on concrete tiles to avoid contact with modern soil and protected by a large cage from the activities of cats and birds (Figure A.29). The whole experiment was set up in a part of the Hortus Botanicus at Leiden closed to the general public.

Table A.7. The samples and the results.

Locality	Date	crop	N specimens	$\delta^{15}N$
Bovenkarspel-Het Valkje 7	Middle Bronze Age	emmer wheat	10	9.65
Bovenkarspel-Het Valkje 7	Middle Bronze Age	hulled barley	10	13.50
Bovenkarspel-Het Valkje 10	Middle Bronze Age	emmer wheat	20	9.57
Bovenkarspel-Het Valkje 10	Middle Bronze Age	hulled barley	20	12.72
Bovenkarspel-Het Valkje 105	Middle Bronze Age	emmer wheat	12	10.00
Bovenkarspel-Het Valkje 105	Middle Bronze Age	hulled barley	12	9.63
Enkhuizen-Haling 23	Middle Bronze Age	emmer wheat	7	11.63
Twisk 1-1-19	Middle Bronze Age	emmer wheat	12	6.61
Twisk 1-1-20	Middle Bronze Age	naked barley	12	8.16
Westwoud 39/4	Late Bronze Age	emmer wheat	12	10.30
Westwoud 4	Late Bronze Age	hulled barley	12	9.13
Recent experiment	recent	emmer wheat in nitrogen	15	3.31
	recent	emmer wheat in air	15	3.30
	recent	hulled barley in nitrogen	15	3.26
	recent	hulled barley in air	15	2.40

Figure A.29. Growing grain for baselines in tubs.

The experiment will last two years as it is the intention to sow summer and winter varieties of emmer wheat and hulled barley, and to do this twice to avoid the influence of a possible bad summer or winter. The first sowings took place in the spring of 2014 and this crop provides the results discussed below. The emmer wheat was provided by ARCHEON at Alphen aan den Rijn, the Netherlands but came originally from Italy. The summer barley was obtained from the firm Vreeken.

The grain was harvested in the beginning of August and charred for two hours at a temperature of 2500 °C. This temperature was chosen because Fourier Transform Infrared Spectrography (FTIR) conducted by A. van Hoesel showed that the prehistoric grain had become charred at temperatures between 2300 °C and 2700 °C. Experimental work by Kanstrup *et al.* (2012) have shown that a heating time of two hours is sufficient. Charring was conducted in two kinds of atmosphere, in a flow of nitrogen and in an environment with a limited access to air.

The charred grain was sent to Groningen and treated in the same way as the Bronze Age grain.

3. Results and discussion

The results are presented in Table A.7 and Figure A.30.
It is obvious that the $\delta^{15}N$ values of the grain grown for the baselines are much lower than those obtained for the Bronze Age grain. Whether the grain was charred in a nitrogen or air environment does not seem to matter. The value for barley charred in air is lower than that for barley charred in nitrogen, but in another experiment where baselines were obtained for sandy soil, this effect is the other way round thus it may be assumed that the difference falls within the normal range. The samples Bovenkarspel-Het Valkje 7 and 10 were obtained from features close to each other and it is quite possible that they originate from the same crop. If so, the size of a batch, 10 or 20 grains, does not seem to lead to a difference in the obtained values.

Values for Middle Bronze Age emmer wheat vary between 6.6 and 11.6. The Late Bronze Age Westwoud does not stand out but falls within this range. The baseline is 3.3. Values for Middle Bronze Age barley vary between 8.2 and 13.5. Again Late Bronze Age Westwoud does not differ. The baseline is 2.4-3.3. The question is whether the enhancement in $\delta^{15}N$ is due to manuring with animal dung. Although the climate during the Bronze Age was slightly different from the present one, the varieties of the emmer wheat and barley were probably not the same as the, unknown, Bronze Age ones, and the baselines provided by one season only, the δ^{15N} values of the prehistoric grain is still considered to be the result of some external agent. This might be animal dung, but this explanation brings another problem *i.e.* the presence of a sufficient large number of cattle and/or sheep to produce dung in larger quantities. In her chapter 6 Y. van Amerongen states that animal manure was most likely not produced in the required amount on the small-scale farms of West Frisia. If so, some other agent has to be looked for.

A1.12. Calculation of available storage space in the attic of West Frisian houses

Here, it is calculated what the approximate storage area on attics in West Frisian houses may have been (Figure A.31). When it is assumed that storage could only occur on a platform on the cross frames (which can support the weight), the measurements for an average West Frisian attic are as follows: b = 1.5m, h = 3.0m, l = 20.0m (Roessingh in prep.), so V equals 45m^3.

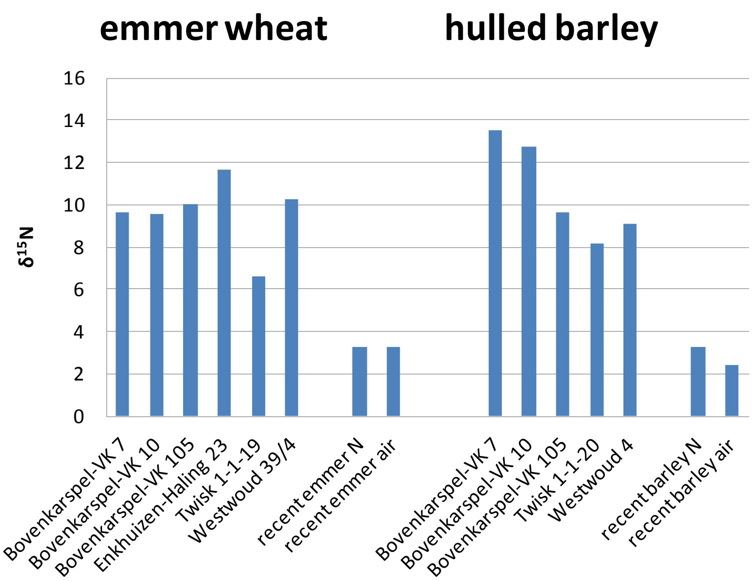


Figure A.30. $\delta^{15}N$ values (Y-axis) of the grain.

Chapter 8

A1.13. Calculation of the required area per household for habitation, and crop and animal husbandry (i.e. total human impact on the environment).

Settlement area

Only grassland pasture:

Per household (and partially derived from Gregg's calculations):

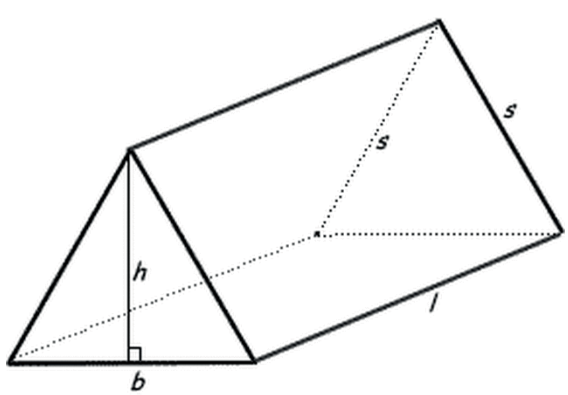


Figure A.31. Volume calculation of a triangle: Volume: V = ½ * (bh) * l

Grassland pasture = 6.1-10.8 ha (see A1. 1.7 above)
Meadow = 3.4 ha (Gregg's value/6)
Woodlot = 7.8 ha (Gregg's value/6)
Village, including houses, outbuildings, and gardens = 0.75 (Gregg's value/6)
Arable fields + fallow fields = 3.6-5.4 ha (1.8 ha per household, 1-2 year fallow)
+

Minimum = 21.65 ha = 0.22 km^2
Maximum = 28.15 ha = 0.28 km^2

Grassland and woodland pasture (2/3 grassland, only goat woodland):
Per household (and partially derived from Gregg's calculations):
Grassland pasture = 6.0-10.5 ha (see see A1. 1.7 above)
Woodland pasture = 1.3-3.7 ha (see see A1. 1.7 above)
Meadow = 3.4 ha (Gregg's value/6)
Woodlot = 7.8 ha (Gregg's value/6)
Village, including houses, outbuildings, and gardens = 0.75 (Gregg's value/6)
Arable fields + fallow fields = 3.6-5.4 ha (1.8 ha per household, 1-2 year fallow)
+

Minimum = 22.85 ha = 0.23 km^2
Maximum = 31.55 ha = 0.32 km^2

A1.14 Science-based artist impression of the reconstructed Middle Bronze Age West Frisian landscape

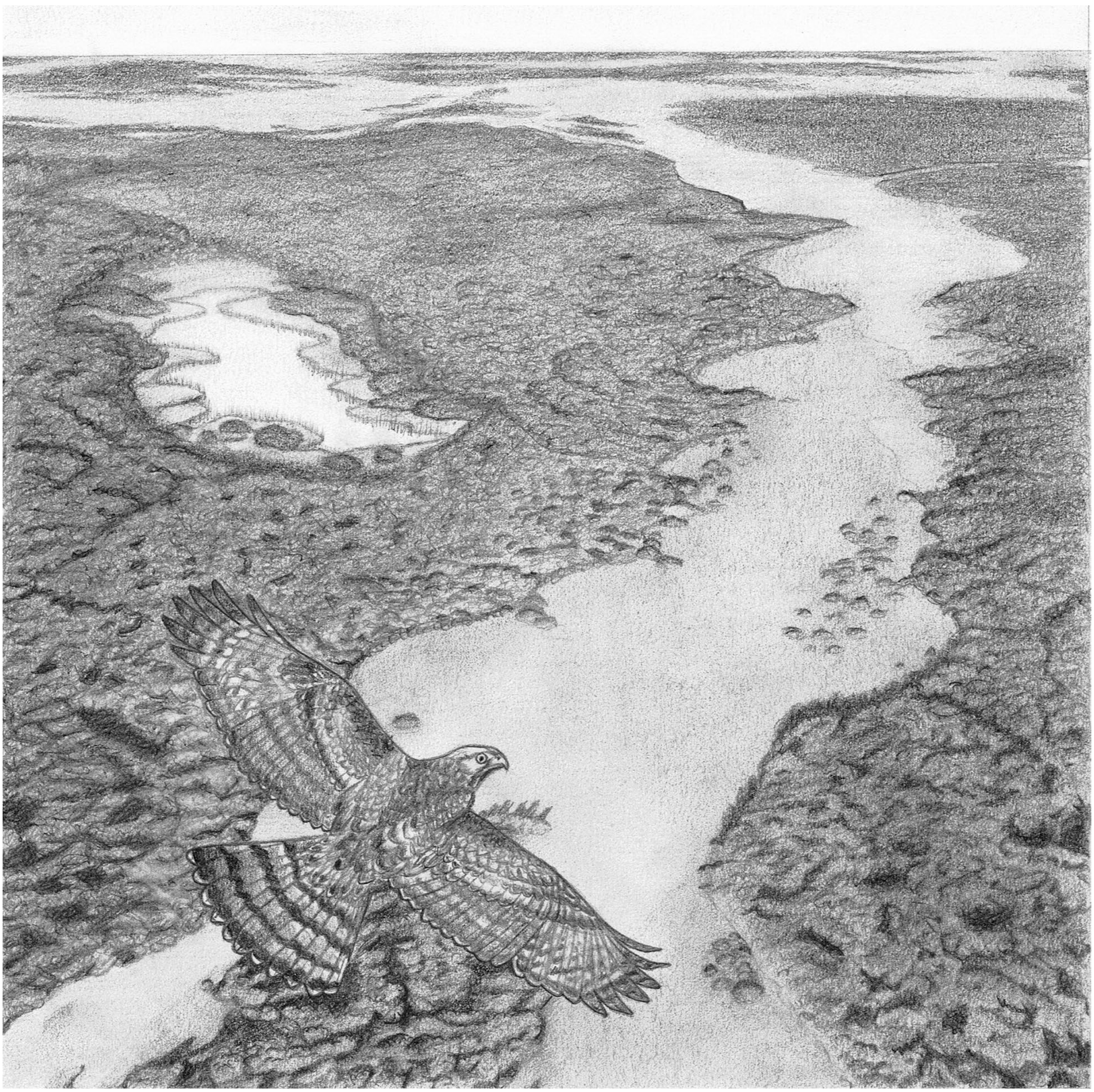


Figure A.32. Reconstructed Middle Bronze Age landscape based on zoological and botanical remains from sites, as well as soil characteristics of West Frisia

A1.15. Calculation of dietary requirements according to adaptations made to the work of Gregg (1988)

Table A.8. Table 60 from Gregg 1988: Farmer resource proportions (% of annual diet) under low red deer densities

resource	red deer	roe deer	boar	fish	beaver	small game	plants	livestock	milk	crops
	3.4	0.5	3.3	2.0	0.2	1.9	2.8	15.3	7.7	62.9

Table A.9. Table 61 from Gregg 1988: Farmer monthly resource fractions, all livestock (% of annual total)

Resource	sept	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
red deer	8.5	8.0	6.5	7.5	15.0	14.0	15.0	6.5	4.0	3.5	5.5	6.0
roe deer	7.5	7.5	7.5	9.5	12.5	11.5	12.0	8.5	6.0	5.5	5.5	6.5
boar	7.5	7.5	13.5	13.5	12.0	10.0	10.0	4.0	4.0	5.5	6.0	6.5
fish+small game	14.0	3.0	2.0	2.0	1.5	2.0	3.5	7.0	25.0	14.0	13.0	13.0
beaver	0	0	0	20.0	20.0	20.0	20.0	20.0	0	0	0	0
plants	12.0	10.0	7.0	5.0	5.0	5.0	5.0	7.0	10.0	10.0	12.0	12.0
livestock	5.7	7.2	7.2	7.2	7.2	12.4	14.5	14.0	7.3	5.9	5.7	5.7
milk	9.0	0	0	0	0	0	16.0	16.0	16.0	16.0	14.0	13.0
crops	8.2	8.2	8.2	8.2	8.2	8.2	8.6	8.6	8.2	8.2	8.6	8.6

Table A.10. Appendix F from Gregg (1988): Farmer monthly resource fractions, all livestock (% of annual total), low red deer densities (% of monthly diet)

Resource	sept	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
red deer	3.6	3.4	2.7	3.2	6.3	5.9	0	0	0.9	1.5	2.2	2.4
roe deer	0.4	0.4	0.4	0.5	0.7	0.6	0	0	0.3	0.3	0.3	0.3
boar	3.0	3.0	5.4	5.4	4.8	4.0	0	0	0	2.2	2.3	2.5
fish	3.5	0.7	0.5	0.5	0.4	0.5	0	0	6.2	3.5	3.1	3.1
beaver	0	0	0	0.4	0.4	0.4	0	0	0	0	0	0
small game	3.4	12.8	12.3	12.0	9.4	0.9	0	0	0.2	0.2	2.7	3.2
birds	0	0	0	0	0	0	0	0	0	0	0	0
plants	4.1	3.4	2.4	1.7	1.7	1.7	0	0	0.9	3.4	3.9	3.9
livestock	10.6	13.4	13.4	13.4	13.4	23.1	25.8	24.9	13.6	11.0	10.1	10.1
milk	8.5	0	0	0	0	0	14.3	14.3	15.0	15.0	12.5	11.6
cereal	62.9	62.9	62.9	62.9	62.9	62.9	62.9	62.9	62.9	62.9	62.9	62.9

Table A.11. Adapted farmer resource proportions (% of annual diet) based on the West Frisian situation (pulses and legumes are grouped under wild plants, since these crops are not cultivated in West Frisia).

resource	red deer	roe deer	boar	fish	beaver	small game	plants	livestock	milk	crops
	3.4	0.5	3.3	2.0	0.2	1.9	5.7	15.3	7.7	60.0

Table A.12. Raw monthly resource percentages for the West Frisian situation (including shortages and surpluses).

Resource	sept	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
red deer	0.2890	0.2720	0.2210	0.2550	0.5100	0.4760	0.5100	0.2210	0.1360	0.1190	0.1870	0.2040
roe deer	0.0375	0.0375	0.0375	0.0475	0.0625	0.0575	0.0600	0.0425	0.0300	0.0275	0.0275	0.0325
boar	0.2475	0.2475	0.4455	0.4455	0.3960	0.3300	0.3300	0.1320	0.1320	0.1815	0.1980	0.2145
fish	0.2800	0.0600	0.0400	0.0400	0.0300	0.0400	0.0700	0.1400	0.500	0.2800	0.2600	0.2600
beaver	0	0	0	0.0400	0.0400	0.0400	0.0400	0.0400	0	0	0	0
plants	0.6840	0.5700	0.3990	0.2850	0.2850	0.2850	0.2850	0.3990	0.5700	0.5700	0.6840	0.6840
livestock	0.8721	1.1016	1.1016	1.1016	1.1016	1.8972	2.2185	2.1420	1.1169	0.9027	0.8721	0.8721
milk	0.6930	0	0	0	0	0	1.2320	1.2320	1.2320	1.2320	1.078	1.0010
crops	4.9200	4.9200	4.9200	4.9200	4.9200	4.9200	5.1600	5.1600	4.9200	4.9200	5.1600	5.1600
SUM	8.0231	7.2086	7.1646	7.1346	7.3451	8.0457	9.9055	9.5085	8.6369	8.2327	8.4666	8.4281
surplus/ shortage	0.1769	0.9914	1.0354	1.0654	0.8549	0.1543	-1.3055	-0.9085	-0.4369	-0.0327	0.1334	0.1719
half of value above	0.0885	0.4957	0.5177	0.5327	0.4275	0.0772	-0.6528	-0.4543	-0.2185	-0.0164	0.0667	0.08595

Table A.13. Final monthly resource percentages for the West Frisian situation.

Resource	sept	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
red deer	0.2890	0.2720	0.2210	0.2550	0.5100	0.4760	0	0	0.1360	0.1190	0.1870	0.2040
roe deer	0.0375	0.0375	0.0375	0.0475	0.0625	0.0575	0	0.0425	0.0300	0.0275	0.0275	0.0325
boar	0.2475	0.2475	0.4455	0.4455	0.3960	0.3300	0	0	0	0.1652	0.1980	0.2145
fish	0.2800	0.0600	0.040	0.0400	0.0300	0.0400	0	0	0.5000	0.2800	0.2600	0.2600
beaver	0	0	0	0.0400	0.0400	0.0400	0	0.0400	0	0	0	0
small game	0.1769	0.9914	1.0354	1.0654	0.8549	0.1543	0	0	0	0	0.1334	0.1719
plants	0.6840	0.5700	0.3990	0.2850	0.2850	0.2850	0	0	0.3516	0.5537	0.6840	0.6840
livestock	0.8721	1.1016	1.1016	1.1016	1.1016	1.8972	2.2185	2.1420	1.1169	0.9027	0.8721	0.8721
milk	0.6930	0	0	0	0	0	1.2320	1.2320	1.2320	1.2320	1.0780	1.0010
crops	4.9200	4.9200	4.9200	4.9200	4.9200	4.9200	5.1600	5.1600	4.9200	4.9200	5.1600	5.1600

Table A.14. Farmer monthly resource fractions for the West Frisian situation.

Resource	sept	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
red deer	3.5	3.3	2.7	3.1	6.2	5.8	0.0	0.0	1.7	1.5	2.2	2.4
roe deer	0.5	0.5	0.5	0.6	0.8	0.7	0.0	0.5	0.4	0.3	0.3	0.4
boar	3.0	3.0	5.4	5.4	4.8	4.0	0.0	0.0	0.0	2.0	2.3	2.5
fish	3.4	0.7	0.5	0.5	0.4	0.5	0.0	0.0	6.1	3.4	3.0	3.0
beaver	0.0	0.0	0.0	0.5	0.5	0.5	0.0	0.5	0.0	0.0	0.0	0.0
small game	2.2	12.1	12.6	13.0	10.4	1.9	0.0	0.0	0.0	0.0	1.6	2.0
plants	8.3	7.0	4.9	3.5	3.5	3.5	0.0	0.0	4.3	6.8	8.0	8.0
crops	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
livestock	10.6	13.4	13.4	13.4	13.4	23.1	25.8	24.9	13.6	11.0	10.1	10.1
milk	8.5	0.0	0.0	0.0	0.0	0.0	14.3	14.3	15.0	15.0	12.5	11.6
Monthly contribution of subsistence strategies												
animal husbandry	19.1	13.4	13.4	13.4	13.4	23.1	40.1	39.2	28.6	26.0	22.7	21.8
hunting	9.2	18.9	21.2	22.6	22.7	12.9	0.0	1.0	2.0	3.8	6.3	7.2
fishing	3.4	0.7	0.5	0.5	0.4	0.5	0.0	0.0	6.1	3.4	3.0	3.0
crop husbandry	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
wild plant gathering	8.3	7.0	4.9	3.5	3.5	3.5	0.0	0.0	4.3	6.8	8.0	8.0

Table A.15. Micro-nutrient composition of different Bronze Age food sources and diets based on well-being. Also the amount of required food per food category is noted.

	emmer/ barley mix (50/50)	raw milk	beef	farmer's diet (emmer/ barley, beef, and milk)	farmer's diet, no milk	wild plants (greens)	full diet (farmer's diet + wild plants)	fish (eel)
Amount of required food:	**750g**	**200 ml**	**110g**			**100g**		**50 g**
Micro-nutrient:								
Vitamin A (ug)	3	9	0	12	3	94	106	522
Vitamin C (mg)	0	0	0	0	0	122	122	1
Folate (ug)	94	3	2	99	96	unknown	99	8
Iron (mg)	121	0	22	143	143	12	155	0
Zinc (mg)	136	1	59	196	195	6	201	1

Dietary requirements based on calories
By using the Table A.11 and the same farmer monthly resource fractions as Gregg (Table A.9), the following monthly resource percentages were obtained for the West Frisian situation (Table A.12):

In addition, the sum of all the resource percentages per month was calculated (Table A.12), which was used in accordance to the work of Gregg (1988, chapter 7) to assess whether there were surpluses or shortages during each month. These surpluses and shortages were then used to calculate the possibly required additional food from wild resources, such as wild plants, boar, red deer, fish, and roe deer during certain months (Gregg 1988, 186).

The results of these calculations can be observed in Table A.13.

The values from Table A.13 were finally re-calculated to arrive at the farmer monthly resource fractions (Table A.14). These values were used to evaluate the availability of resources in West Frisia throughout the year, as well as to calculate the contributions of each subsistence strategy based on calories (Table A.14 bottom rows).

Dietary requirements based on well-being
Several sources were consulted to arrive at the dietary requirements based on well-being (see references in Chapter 8, section 8.3.1). First of all, the recommended critical micronutrient intake values for people consuming a staple diet based on cereals were researched. Then, calculations were made of the nutrient composition of a farmer's diet (consisting of emmer/barley mix, beef, and milk). Finally, nutrient composition calculations were made of the food groups lacking in the farmer's diet, but which are essential for well-being. Using all this information, the following values for the different food sources for a healthy diet were obtained (Table A.15) Ultimately, the required food amounts from Table A.15 were combined with the monthly availability to arrive at the monthly dietary composition throughout the year, based on well-being (Table A.16).

Table A.16. The required amounts of food (in g) per food group, in proportion to the availability throughout the year (cf. Table A.14).

	sept	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
wild plants	100	100	200	200	200	200	100	100	100	100	100	100
game	55	110	110	110	110	55	55	55	55	55	55	55
fish	25	25	50	50	50	50	25	25	25	25	25	25
milk	200	200	0	0	0	0	200	200	200	200	200	200
domestic meat	110	55	55	55	55	110	110	110	110	110	110	110
crops	750	750	750	750	750	750	750	750	750	750	750	750

Table A.17. Calculations made to arrive at an estimation of the importance of the different subsistence strategies in the Bronze Age.

	Murdock 1981 selections			**average**	**+ 56% Ertuğ**		
subsistence strategy	**Neighbour hoods**	**Hamlets**	**Villages**	**food**	**subsistence**		
wild plant gathering	2.86	2.50	2.29	3	7	14	14
hunting	6.43	7.50	1.71	5	5	10	10
fishing	4.29	6.25	6.00	6	6	11	11
animal husbandry	29.29	28.75	26.00	28	28	14	25
crop husbandry	57.14	55.00	64	59	59	29	40
TOTAL	100	100	100	100	104	78	100

A1.16. Estimating the importance of the different subsistence strategies in the Bronze Age

The relative importance of each of the subsistence strategies in the Bronze Age was estimated by several assumptions based on the results in this thesis, as well as ethnographical parallels. First of all, it is assumed that plants and animals, especially wild varieties, do not necessarily only contribute to subsistence in terms of consumption. Raw material obtained from these (wild) sources is also very important for the creation of tools, clothing, and shelter (cf. Chapter 4, 7, and 8). Their overall contribution to subsistence should therefore be increased with respect to farming strategies, which contribute less in the form of raw materials.

Second, in terms of consumption, the various food categories contribute more than just calories. In fact, food groups such as wild plants are essential to remain healthy, but are not consumed in comparable large quantities to for example cereals, which form the staple food. Therefore, when health is considered, which is essential for subsistence, the wild plant food group must increase in importance with respect to instances where only calories are considered (cf. Chapter 7 and 8).

Third, in every researched selected culture based on the work by Murdock (1981), crop husbandry always contributes most to subsistence, followed by animal husbandry. It is assumed that this was also the case in the Bronze Age.

The following calculations were made to arrive at the estimation:

The average values of Figure A.7 were employed as a starting point (Table A.17, column 5). Subsequently, the work of Ertuğ was used as an indication of the importance of wild plant gathering when not solely performed for consumption. She indicates that 56% of the wild plants is not collected for consumption (Ertuğ 2004, 165), so 56% importance was added to wild plant gathering (Table A.17, column 6). The resulting total percentage was logically higher than 100%, so the other strategies needed to be adjusted accordingly.

Since it is assumed that wild plants and animals in the new model for Bronze Age farming in general should increase in importance with respect to crops and domestic animals (see above), values for wild plant gathering, hunting, and fishing were multiplied by two, whereas farming strategies were divided by two (Table A.17, column 7). Finally, since the total was now less than 100, the values for farming were again raised according to their relative importance and ratios, under the assumption that crop husbandry is always more important than animal husbandry in small-scale mixed farming communities (Table A.17, column 8).