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Taphonomy in Archaeology

with Special Emphasis on Man as a Biasing Factor

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INTRODUCTION

Close team-work between archaeologists and palaeobiologists is of relatively recent date. From the palaeobiologist's point of view the work is exciting and challenging. The work is encouraging because of the infectious optimism of the archaeologist as to the amount of information it is possible to extract from bone material excavated at an archaeological site. On the other hand, the long tradition for careful excavation and treatment of archaeological evidence is often lacking in the case of animal bone material. Consequently, the newly opened field of contact between natural science and archaeology may lead to repeated conflicts of scientific nature. The palaeobiologist is all too aware of the incompleteness of the subfossil and the fossil material whereas the archaeologist often seems unwilling to admit discrepancies between the amount of bones left by the stone age man and the amount of bones retrieved from the site.

The role of the archaeologist is that of the optimistic interrogator asking questions like: How large was the population of prey animals around the site? How many people could the prey population sustain? How many people were inhabiting the site? For how long time was the site inhabited? At which time of the year was the site inhabited?

The palaeobiologist, on the contrary, responds cautiously with endless reservations, leaving the archaeologist somewhat frustrated by the unhelpful or incomplete answers to his many questions. Continuous, extensive communication is therefore necessary, concerning the causes of the reservations made by the palaeobiologist, in order to improve the mutual understanding between the two disciplines.

The fossilization processes have to be reconstructed from the study of the available end-products and their relations to the surrounding sediment. To a palaeontologist it is obvious that organisms are preserved as fossils only under exceptional circumstances; the incompleteness of the fossil record is almost a dogma in palaeontology (Rolfe & Brett 1969). It is essential that this fact be fully appreciated by the archaeologist as well.

The aim of this paper is to illuminate some of the several important processes involved in the conversion of a former living organism into a fossil. The science dealing with these processes was called *taphonomy* (*Taphos* = funeral; *nomos* = history) by Efremov (1940) and the subject has later been trated by Behrensmeyer (1975, 1985), Clark *et al.* (1967), Efremov (1953), Lawrence (1968), Müller (1951, 1963), Noe-Nygaard (1975 a, 1977), Olson (1971), Olson & Beerbower (1953), Schäfer (1962), Voorhies (1969), Gifford (1983) and many others. Lately Schiffer (1983) and Kristiansen (1985) have made parallel studies on identification of formation processes of archaeological material.

Taphonomy is the study of the transition in all its details of animal remains from the biosphere into the lithosphere (Efremov 1940, p. 85). It thus deals with the post-mortem relations between organic remains and their external environment. Lawrence (1968) outlined the environmental aspects of palaeontology (fig. 1). Taphonomy comprises two subdisciplines: biostratinomy and diagenesis. Biostratinomy explores the ef-

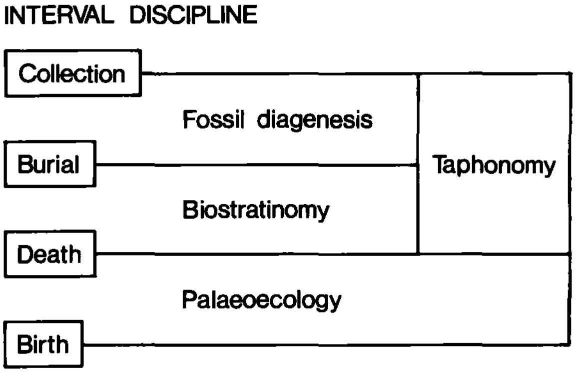


Fig. 1. The environmental aspects of palaeontology. Disciplines based upon time interval in the history of the organism or the organisms being studied (modified from Lawrence 1968).

fects of the surroundings upon organic remains in the interval between the death of the animal and its final burial. Diagenetic studies may unravel post-entombment effects upon organic remains (Lawrence 1971; Müller 1963).

Efremov (1940) expressed the relationship between taphonomy and palaeoecology very clearly. The ultimate goal of palaeoecology is the reconstruction of ancient communities, whereas taphonomy is concerned with post-mortal processes. Taphonomic considerations should be a prerequisite for palaeoecological studies, and the neglect of taphonomy leads to errors in palaeoecological results (Efremov in Dodson 1971). A major aim of analysing faunal remains from archaeological sites is the reconstruction of the palaeoecology of early man. Since taphonomic work thus by definition precedes palaeoecological work, archaeological studies would certainly benefit from more firmly based taphonomic studies of the deposits and their fossil content.

In archaeological deposits the post-mortem events comprise two types of taphonomic factors. The first is connected with a 'normal' death assemblage, such as losses through non-preservation and losses through current transport. The second type includes selective transport of special prey animals from the site and complete destruction of individuals belonging to certain species.

A flow chart showing the formation of the fossil assemblage from the death assemblage is shown on fig. 2. The influence of man is of major importance at several levels of the scheme.

He acts firstly as a biotic factor, influencing the size and composition of the animal populations by selective killing and eventually some cases even causing local or complete extinction of certain species (*e.g.* Aaris-Sørensen 1980 a). Secondly, he has interfered as a thanatic factor by the various ways of killing especially the locus of killing; and, thirdly, as a predator, responsible for the initial death assemblage.

Later the human factor plays a very important role in preventing or delaying the members of the death assemblage from entering the fossil assemblage by using the material in tool and food processing. Finally modern man is an important factor, contributing with collection and identification biases.

In the attempt to estimate human beings as a taphonomic factor in archaeological deposits it is of importance first to understand the taphonmic factors working on a natural death assemblage. The processes of preservation and transport must be understood before definitive reconstructions can be made at a higher level of complexity. It is of equal importance to have a firm knowledge of the mode of life and habitat requirements of the animals. In the following each of the factors listed in fig. 2 will be highlighted with emphasis on the role of man.

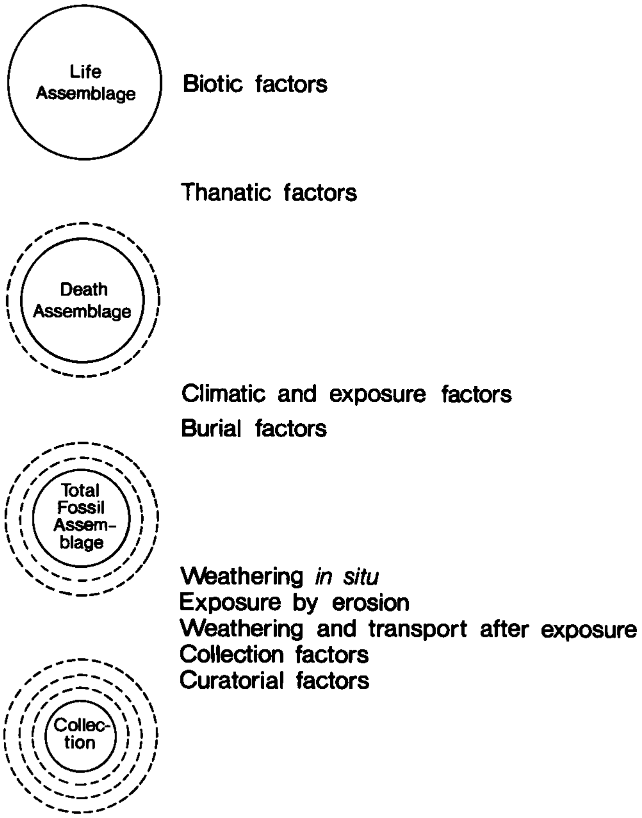


Fig. 2. The possible pathway from a living population to a sample of fossils. The different factors act differently on each species in each sample. The diameter of the circles is thus not representative for the assemblages (modified from Clark *et al.* 1967).

BIOTIC FACTORS

Biotic factors are defined by Clark *et al.* (1967, p. 155) as those factors which determine whether or not a population of any particular species will inhabit an area.

The age structure of the life assemblage is determined by the relations between birth rate, death rate, growth rate and the start of sexual maturity (Craig &

Oertel 1966). Reliable data on population dynamics are only available for a small fraction of modern mammal species and for an even smaller percentage of fossil species. An example is the detailed study of population dynamics of subfossil cave bear by Kurtén (1953).

In palaeoecological studies of Quaternary vertebrate faunas, the advantage of dealing with living species is obvious as opposed to the problems dealing with faunas of extinct vertebrate species from earlier geological periods.

The palaeoenvironment of the Quaternary species should be reconstructed, however, on the basis of a broad spectrum of geological disciplines, such as geomorphology, sedimentology, geochemistry, and palynology in addition to deductions based on the subfossil bone material alone. It is therefore advisable to combine modern population studies on the species concerned, with the knowledge of the palaeoenvironment deduced from the geological information.

Many factors must be taken into consideration in order to evaluate the preservation potential of a given species, and to interpret the reasons for its presence at a site correctly. When dealing with vagile animals, immigration and emigration may have an important influence together with the fundamental population characteristics. A detailed population study on red deer from the island of Rhum, Great Britain, was made by Clutton-Brock *et al.* (1985), and Koike (1987 a, 1987 b) made a comprehensive study of estimating Prehistoric hunting rates based on age composition of Sika Deer. Strandgaard (1972) undertook a population study on modern roe deer from Kalø in Jutland, Denmark. This last mentioned investigation might serve as an example of the kind of population study that is a necessary premise for the palaeoecological reconstruction based on the extremely biased samples collected in postglacial deposits, and it will therefore be reviewed in some detail.

The aim of Strandgaard's investigation was to determine the factors regulating the size of the roe deer population in an area of 400 hectares of suitable biotope. No shooting took place within the investigation period of 3 years. The area of investigation comprised 165 hektares of forest land and 235 hectares of farmland. During the whole period from 1966–68 there was a total of 156 individuals of an age of 6 months or more in the area. The size of the population per year varied between 96 and 112. The roe dear is a stationary territorial animal; thus gains to the population almost exclusively comprised fawns born and reared in the area. Population losses could be ascribed to different reasons, the most important of which were emigration and death caused by accident or illness. The reasons were both age and sex specific. For 1–2 year males and 1 year females emigration was the only important factor, while the majority of losses was due to death resulting from illness or accidents for the 3–11 years old males, and for the 2–13 years old females. The sex ratio of fawns was close to 1:1 until nine months of age. Among the adult animals the populaton had stabilized at a ratio of one male to two females.

On the basis of this information it is possible to draw a curve of the theoretical age distribution in a population where emigration is unhindered and where no shooting takes place (fig. 3). It can be seen from the figure that the annual emigration rate is higher for males than for females in the ½–1½ year class. It is almost 50% for males as opposed to 30% for females in the same age class. From the two curves in fig. 3 it is possible to calculate the number of animals in each age class that are lost from the population.

The emigration factor which regulates the size of the population is of a different nature in the two sexes. In the case of males the same territory can be held for the adult life span of an individual. If none of the older males dies, there will thus be no chance for young bucks to establish themselves within a certain territory, and they will have to migrate to find a new territory in a suitable biotope, sometimes far away. These emigrating young males often have to pass through areas with only little cover and they are therefore more exposed to attacks by enemies such as man and other predators.

In the case of females the relationship between mother and daughter ceases to be friendly when the mother is going to give birth to the new fawn, and the young female has to leave the mother and find her own foraging range.

The population regulating factors are thus partly of social character, but the available food is also a major regulating factor. In areas where feeding conditions are favourable the population density may be high. In the Kalø population grass and clover are the most important food plants. During spring and early summer the cover of grass and herbs in the still open forest is of great importance. The white wood anemone is particularly important as a source of vitamin-C, as the roe deer is unable to produce this vitamin itself (Lydiksen 1972). During winter time, buds and shoots serve as the main food source, not to mention the beet heaps.

Within the area examined at Kalø a stable population of 100 animals, was able to exist where three quarters of the territory was covered with grass when there was the supplementary possibility of feeding on beet heaps. A further premise was that there was no shooting and that migration was free.

In the Mesolithic period in Denmark the grass-covered areas were probably not as extensive as they are in the open farm land of today, but rather the dense mixed forest covered large areas leaving limited space for grazing areas (Troels-Smith 1942; Iversen 1967). Migration was as free as the forest allowed but the growth of the human population led to increased hunting pressure. This combined with the increasing density of the forest might have resulted in reduction in the population size of game animals. Certain species such as aurochs and to some extent elk, as well as some birds, were totally eradicated by the combined effects of man and environmental changes.

For comparison it should be mentioned that today 35,000 roe deer are shot every year in Denmark, and the population has never been so large as it is now owing to the large areas covered by farm land (Strandgaard, pers. comm. 1975). In the Mesolithic period where the feeding possibilities were less favorable than today, the territories had to be larger, to sustain the same number of animals. The available biotopes were fewer in number, and they could not house so many animals. The total population of roe deer in Denmark probably was thus considerable smaller in the Mesolithic period than it is today.

Lack of food might lead either to expansion of territories or, where this is not possible, to reduced fertility. In order to avoid overpopulation the females may give birth to only one fawn instead of the normal two (Strandgaard 1972, p. 167). The climatic factors are of importance in winter time when food becomes scarce, and it is not uncommon to find animals starved to death in early spring after a period of severe frost. Most of the modern roe deer population survive on the beet heaps in the farm land areas and on the heather *Calluna* in the moor areas during winter time. In the Mesolithic period winter foraging might have been difficult in the dense forest. Red deer and roe deer might have been forced to gather in great numbers around lakes, water courses and at the edge of woods. They would thus have been an easy targets for the Mesolithic hunter who in this way might have contributed to the postulated decrease in game animals during the Atlantic period.

Predators on roe deer in modern Denmark are fox, stray dogs and man. The effect of man has been mentioned and no available data exists about the influence on the roe deer population of fox and dog, although a considerable number of premature dead roe deer was recorded as killed by dog in the records at the Game Biological Station at Kalø. Probably they play only a negligible role in a healthy population. If predation occurs, it will probably affect the juveniles and thus increase the already considerable mortality in this part of the population, as previously stated.

THANATIC FACTORS

Thanatic factors are defined by Clark *et al.* (1967, p. 155) as the factors surrounding an animal's death determining whether or not its body will arrive upon the surface as a member of the death assemlage (fig. 2). As thanatic factors mortality relative to age, causes of death and locus of death should be mentioned. The normal causes of death are disease, physical accident, poison, starvation, predation and when man is involved killing by weapon and traps.

Causes of death

From a relatively stable living population, such as the one described from Kalø by Strandgaard (1972) with known emigration and immigration rates, it is possible to calculate the age composition of the bodies derived from it by constant death. Like many other species, the roe deer had a high juvenile mortality (fig. 3). In the population of 42 males the loss from the ½–1½ year group was 19 = 42%, most of them were shot or otherwise killed.

Different types of mortality may result in death assemblages with different age composition in relation to the life assemblages. Three types can be distinguished:

1. Mass mortality caused by instant killing of the whole population resulting in a death assemblage identical to the life assemblage. As examples can be mentioned poisoning, flooding or massacre such as total slaughtering of a herd of e.g. bison. The latter herds

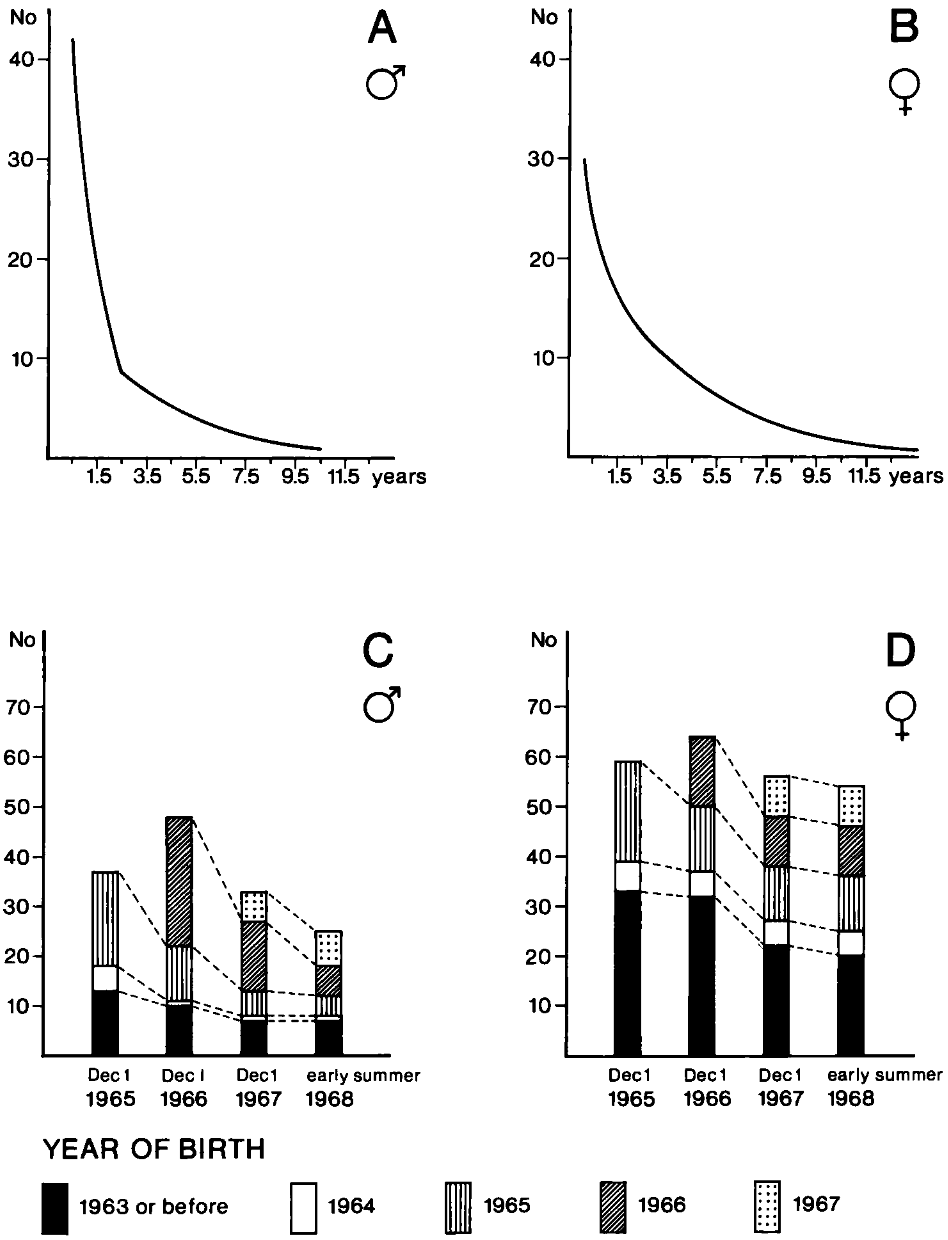


Fig. 3. A, B: Theoretical curves of age class distribution in a roe deer population free from shooting and with unhindered emigration. C, D: The turnover in the male and female roe deer population of the Ringlemose Forest, Kalø (modified from Strandgaard 1972).

commonly included thousands of animals of all age groups.

2. The attritional mortality owing to steady death within the population throughout the year. The resulting death assemblage of this natural mortality thus results from the combined effect of birth rate, growth rate and death rate.

3. Seasonal mortality is a variety of the natural mortality. It is caused by pronounced fluctuations in the mortality rate throughout the year. Factors causing seasonal mortality may be drought, freezing over of the feeding grounds, or seasonal hunting by man.

Thus a death assemblage composed of individuals that have died in a mass mortality directly reflects the age composition of the living population. A death assemblage composed of individuals that died naturally reflects the age composition of the turnover in a population. A death assemblage composed of animals that died seasonally reflects neither the age composition of the natural population nor the age composition of the long-term turnover. It is thus important in the analysis of the population dynamics of fossil material to be able to distinguish a seasonally accumulated death assemblage from the others. This is in many cases possible by careful examination of the seasonal indicators in the fossil fauna. Seasonal mortality may often be the prevailing type in accumulations influenced or made by man. The various seasonal indicators are described below.

Time of death

It is of importance to be able to distinguish between the different types of death assemblages. Only assemblages caused by mass mortality or by natural, attritional mortality can be used directly in population studies. Assemblages influenced by seasonal mortality may give useful information on the ecology of the involved species but it is too variable to give useful information about population dynamics. Analysis of seasonal indicators can be used as a method to distinguish the different types of death assemblage.

Several taphonomic factors are acting on a death assemblage comprising seasonal accumulations of bones. Firstly, different animals are available at the various seasons throughout the year. Secondly, the human interest in the various animals commonly change with the different seasons. During the winter deer antlers may be the aim of the hunters as well as fur animals, whereas the main target during the summer is the soft skin of the calves, fish and birds, and in both cases the food of course. Thirdly, the effect of the weathering and exposure on the bones varies with the ontogenetic age of the bones, and the duration of exposure, the juvenile bones being more easily weathered than the hard bones of adult animals. Fourthly, the rate at which the bone material is buried may change with the season. During winter time it is likely to take longer to cover the bones with sediment. The bones may be accumulated on the ice of a lake or if deposited in water the slow rate of sedimentation will delay the burial of the bones.

The seasonal migration of some animals such as birds, reindeer, salmon and trout, influences the composition of the population on a certain locality at a given time and thereby on the selection available to the stone age hunter. The palaeobiologist's sample will show a bias with over-representation of some species and under-representation of others when compared with a sample representing the annual average. On the other hand it is of paramount importance to be able to determine from the bone deposits at which time of the year a certain site has been populated in order to establish the interrelationship between the hunter and his surroundings. It is important to realize that some seasonal indicators are more easily recognized than others (Noe-Nygaard 1969, 1977, 1983; Payne 1972).

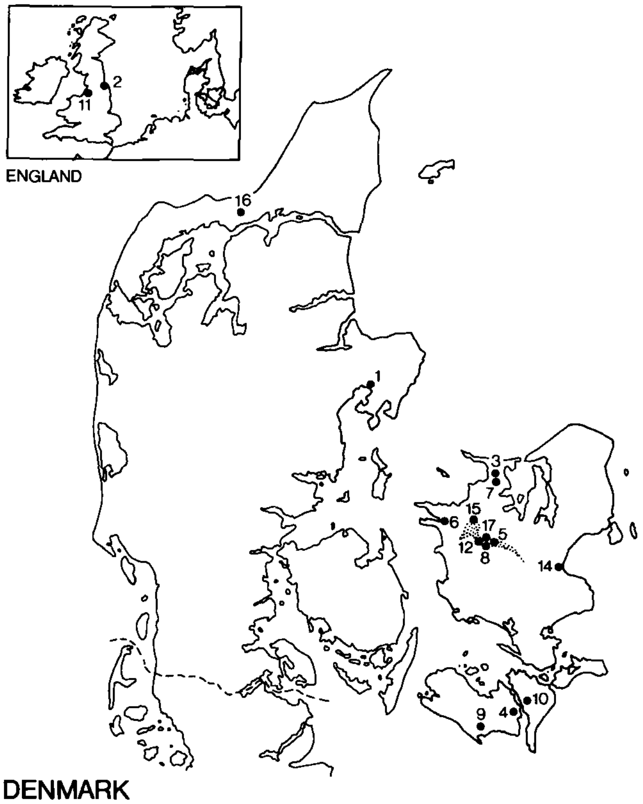


Fig. 4. Map showing the geographic position and dating of the sites mentioned in the text. 1, Kalø. 2, Star Carr. 3, Vig. 4, Grænge Mose. 5, Muldbjerg. 6, Aldersro. 7, Prejlerup. 8, Storelyng VI. 9, Skottemarke. 10, Taaderup. 11, High Furlong. 12, Præstelyngen. 13, Aamosen (shaded area). 14, Ølby Lyng. 15, Kongemosen. 16, Brovst. 17, Ulkestrup Lyng.

Summer time indicators are several, such as the occurrence of seasonally migrating animals and juveniles of both birds and deer. Winter time seasonal indicators are fewer and less easily recognized. Of the few positive indicators, certain migrating species, and skulls with unshed antlers of red deer, elk and reindeer should be mentioned. It is even more difficult to determine whether a particular site has been inhabited only at one season, or repeatedly, at the same season, over several years. Furthermore, the same site may show signs of both winter and summer habitation without necessarily having been permanently inhabited, e.g. the preboreal Star Carr site (Noe-Nygaard 1975a, b). The site may have been visited on several occasions throughout the year for different purposes.

Migrating species as seasonal indicators. In many countries, such as Denmark, bird migration is of considerable importance to the seasonal standing population. A great number of summer visitors arrive to breed in spring, but fly south for the winter; other species arrive as guests from the north to winter in Denmark. Some species visit the country only briefly in transit during the spring and autumn migrations, while still other species are basically resident the whole year, although their numbers may increase dramatically by the addition of migrating individuals at various seasons. Furthermore, the climate of Denmark in the Mesolithic period was altogether warmer than now, leaving the possibility for more species to winter in the country (Løppenthin 1967). It is thus obvious that extreme care has to be taken in deductions based on only one or a few fragments, and in the light of possible differences between seasonal behaviour of birds today and in Mesolithic Denmark. It happens that a species changes its way of living during time; a resident bird may become a migrator and vice versa; other birds may have changed biotope, particularly in response to environmental changes caused by man. A comparable illustration example among the insects is the beetle *Bembidion glacialis* which is nocturnal in Denmark, whereas the population introduced into Greenland has changed its life habit to day activity on south facing escarpments (Henriksen 1933).

Among fish the extensive migration of the salmon and the eel are well known and involves both fresh water and the sea; but the former spawns in fresh water and the latter in the sea. Many other fish change biotopes during the year and may only be used with caution as seasonal indicators. Several mammals also migrate; an obvious example is the reindeer, but various sea mammals are also migratory.

The breeding period. In most animals the breeding period is short and clearly defined. This is true for most of the birds, and finds of juvenile bones and even egg-shells are good seasonal indicators. The leather-like egg-shells of the water tortoise *Emys orbicularis* have been found in several Mesolithic deposits, e.g. in the Aamose Bog (fig. 4) (Degerbøl & Krogh 1951).

Daily growth lines and spawning rings observed between the year rings on bivalve shells may be used to establish the time of the year at which they died, assuming that the time at which a year ring is formed is known for the species (Coutts 1970; Deith 1983; Koike 1980; Meehan 1982; Noe-Nygaard *et al.* 1987).

The most common prey animals in the Mesolithic period in Denmark are red deer, roe-deer, wild boar, elk and aurochs. They all have a short birth period of about one month except for aurochs. The occurrence of juvenile bones or teeth in eruption in skulls of these animals are important seasonal indicators (Noe-Nygaard 1969; Richter in Andersen *et al.* 1982). With knowledge of the biology of the different species it is often possible to estimate the time of year at which such young animals were killed within a couple of months.

Epiphyseal fusion. It is of great importance to be able to distinguish juvenile and adult bones and to precisely estimate the ontogenetic age of the juvenile bones. Characteristic features of juvenile bones are the loose epiphyses, the porous structure of the bone wall, and the rough mat surface of the bone. There are no marked muscle attachments and the marrow cavities are filled with marrow with red corpuscules and spongy bone tissue at the ends. The longitudial fusion of the metapodial bones in the Cervidae is not completed in very young animals. In contrast, bones from adults have a shining hard surface with well developed muscle attachments. The epiphyses and the diaphyses are furthermore completely fused, sometimes with obliteration of the articulation seam. The marrow cavity is wide, free of spongy tissue, filled up with marrow and the bone walls are thick. The adult bone is heavy whereas in the gerontic bone resorption of the bone wall gradually reduces the weight of the bone and produces a very wide marrow cavity (fig. 6).

With the different species the adhesion and later fusion of the epiphyses to the diaphyses takes place at different times for the various bone elements. It is necessary to know the species in order to determine the ontogenetic age of a juvenile bone. In species with marked

Table 1
Sex: Female

Epiphyseal fusion
Capreolus capreolus

Age in months	*0.25*	*0.5*	*6*	*10*	*10*	*12*	*18.5*	*20*
Maxilare tooth row	*dp2* *dp4*	*dp2* *!* *dp4* *(m1)*	*dp2* *dp4* *m1*	*dp2* *dp4* *m1* *(m2)*	*(d)p2* *(d)p4* *m1* *m2*		*p2* */* *m3*	*p2* *m3*
Dentale tooth row	*dp2* *dp4*	*dp2* *dp4* *(m1)*	*dp2* *dp4* *m1*	*dp2* *dp4* *m1* *(m2)*		*(d)p2* *(d)p4* *m1* *m2*	*p2* */* *m3*	*p2* *m3*
Cervical vertebrae, prox.	/	-	-	-	+	-	-	+
Cervical vertebrae, dist.	-	-	-	-	+	-	-	/
Thoracic vertebrae, prox.	/	-	-	-	+	-	-	/
Thoracic vertebrae, dist.	/	-	-	-	/	-	-	/
Lumbar vertebrae, prox.	-	-	-	-	/	-	-	-
Lumbar vertebrae, dist.	-	-	-	-	+	-	-	-
Scapula	-	-	+	+	+	+	+	+
Pelvis	-	-	+	+	+	+	+	+
Humerus, prox.	- d	- d	-	- /	- +	/	?	
Humerus, dist.	- d	- d	+	+	+	+	+	
Radius, prox.	-	-	+	+	+	+	+	
Radius, dist.	-	-	-	-	-	-	/	
Ulna, prox.	-	-	-	-	-	/	/	
Femur, prox.	- d	- d	/ d	-	-	/	/	
Femur, dist.	- d	-	-	-	-	-	/	
Tibia, prox.	- d	-	/	-	-	-	-	
Tibia, dist.	-	-	-	-	-	-	+	
Metacarpus fused	+	+	+	+	+	+	+	
Metatarsus fused	+	+	+	+	+	+	+	
Metacarpus, prox.	+	+	+	+	+	+	+	
Metacarpus, dist.	-	-	-	-	-	-	/	
Metatarsus, prox.	+	+	+	+	+	+	+	
Metatarsus, dist.	-	-	-	-	-	-	-	
Calcaneus	-	-	/	-	-	+	+	+
Phalanges	-	+	+	+	+	+	+	+

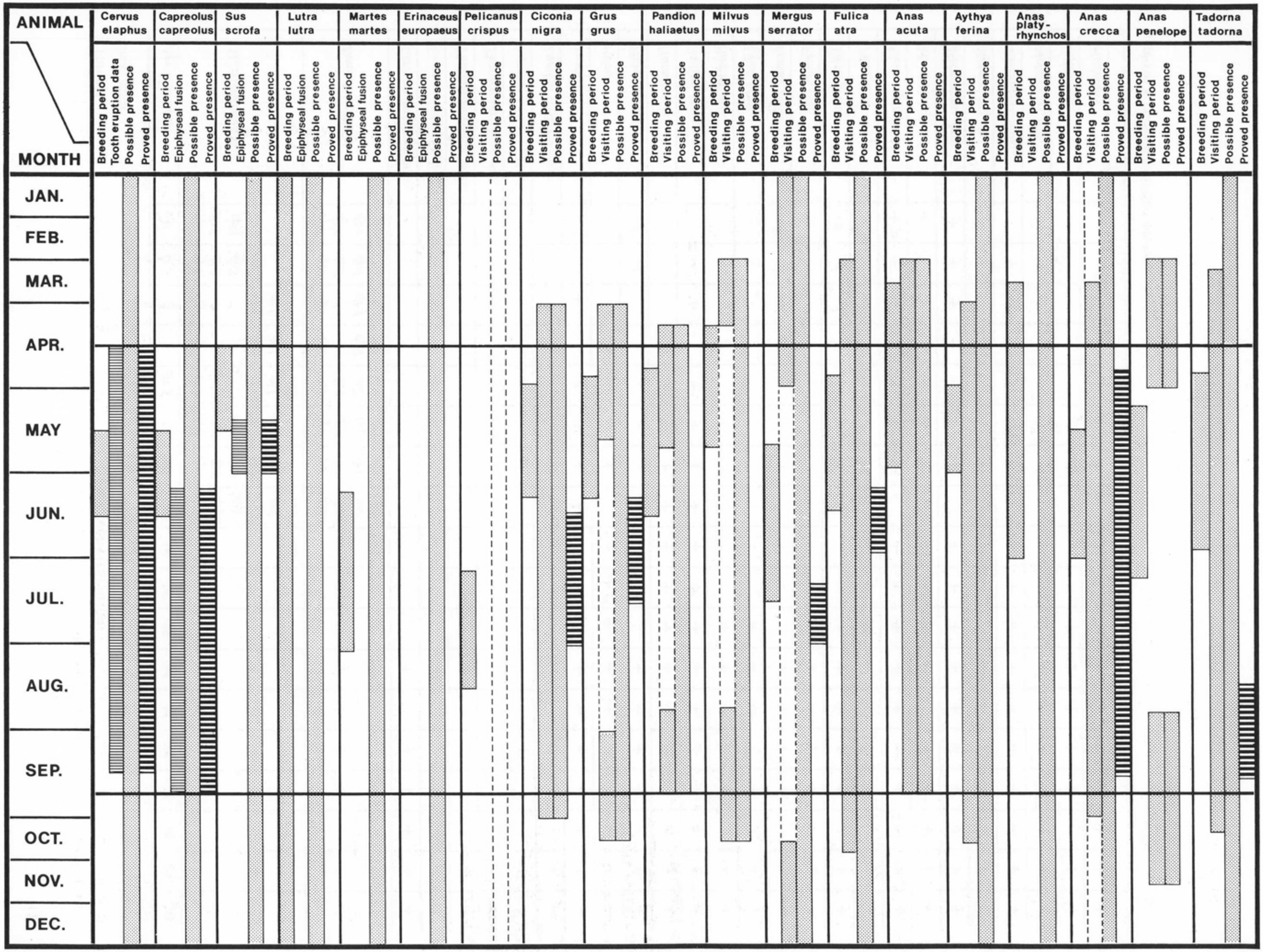
Table 1. The time in month of epiphyseal fusion for female *Capreolus capreolus*. - = not fused; + = fused; / = fused but with wide open suture; d = the epiphysis in question is divided into two.

Table 2
Sex: Male

Epiphyseal fusion
Capreolus capreolus

Age in months	*0*	*0.5*	*3*	*5*	*9.5*	*12*	*12*	*13*	*16*	*18*	*22*	*24*	*24*	*24*	*24*	*24*	*29*	*30*
Maxilare tooth row	*dp2* *dp3* *dp3* *dp4*	*dp2* *dp3* *dp3* *dp4*	*dp2* *!* *!* *dp1* *m1*	*dp2* *!* *!* *dp4* *m1*	*dp2* *!* *!* *dp4* *m1* *m2*	*dp2* *dp4* *dp4* *m1* *m3*	*dp2* *dp4* *dp4* *m1* *m3*	*(d)p2* *(d)p3* *(d)p3* *(d)p4* *m1* *m3*	*m3*	+	+	+	+	+	+	+	+	+
Dentale tooth row	*dp2* *dp3* *dp4*	*dp2* *dp3* *dp4*	*dp2* *!* *dp4* *m2*	*dp2* *!* *dp4* *m1*	*dp2* *dp4* *m2* *m1*	*dp2* *dp4* *m1* *m2*	*p2* *p4* *m1* *m3*	*(d)p2* *(d)p4* *m1* *m3*	*m3*	+	+	+	+	+	+	+	+	+
Cervical vertebrae, prox.	-	-	-		-	-	-		-	-		+	/	+	+	+	+	+
Cervical vertebrae, dist.	-	-	-		-	-	-		-	-		-	/	/	/	-	+	+
Thoracic vertebrae, prox.	-	-	-		-	-	-		-	-		-	/	/	/	/	+	+
Thoracic vertebrae, dist.	-	-	-		-	-	-		-	-		-	-	+	/	-	/	+
Lumbar vertebrae, prox.	-	-	-		-	-	-		-	-	/	-	/	+	/	/	+	+
Lumbar vertebrae, dist.	-	-	-		-	-	-		-	-	-	-	/	+	/	-	+	+
Scapula	-	-	+/		+	+	+	+	+	+		+	+	+	+	+	+	+
Pelvis	-	-	/		+/	+	+		+	+/	+/	+	+	+	+	+	+	+
Humerus, prox.	-d	-d	-		-	-	-	-	-	-	-	+	+	+	+	/	+	+
Humerus, dist.	-	-	/		+	+	+	+	+	+	+	+	+	+	+	+	+	+
Radius, prox.	-	-	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+
Radius, dist.	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	/	+	+
Ulna, prox.	-	-	-		-	-	-	-	-	-	+	+	+	+	+	/	+	+
Femur, prox.	-d	-d	-d		-	-	-		-	-		+	+	+	+	/	+	+
Femur, dist.	-	-	-		-	-	-		-	-	+	+	+	+	+	/	+	+
Tibia, prox.	-d	-d	-d		-	-	-		-	-	+	+	+	+	+	/	+	+
Tibia, dist.	-	-	-	-	-	-	-		/	+	+	+	+	+	+	+	+	+
Metacarpus fused	+/	+	+	-	+	+	+		+	+	+	+	+	+	+	+	+	+
Metatarsus fused	+/	+	+	-	+	+	+		+	+	+	+	+	+	+	+	+	+
Metacarpus, prox.	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+
Metacarpus, dist.	-	-	-	-	-	-	-		-	-	+	+	+	+	+	+	+	+
Metatarsus, prox.	-	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+
Metatarsus, dist.	-	-	-	-	-	-	-		-	-	+	+	+	+	+	+	+	+
Calcaneus	-	-	-	-	-	/	/		-	-	+	+	+	+	+	/	+	+
Phalanges	-	-	-	-	+	+	+		+	+	+	+	+	+	-	+	+	+

Table 2. The time in month of epiphyseal fusion for male *Capreolus capreolus*. - = not fused; + = fused; / = fused but with wide open suture; d = the epiphysis in question is divided into two.


ANIMAL
MONTH
Cervus elaphus
Capreolus capreolus
Sus scrofa
Lutra lutra
Martes martes
Erinaceus europaeus
Pelicanus crispus
Ciconia nigra
Grus grus
Pandion haliaetus
Milvus milvus
Mergus serrator
Fulica atra
Anas acuta
Aythya ferina
Anas platyrhynchos
Anas crecca
Anas penelope
Tadorna tadorna
Breeding period
Tooth eruption data
Epiphyseal fusion
Visiting period
Possible presence
Proved presence
JAN.
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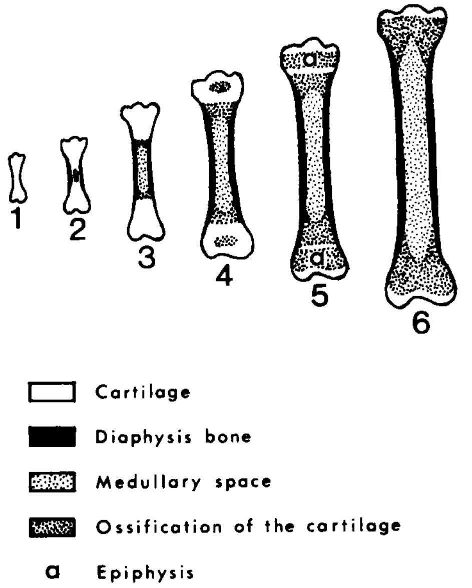


Fig. 6. Growth of long bones of mammals. During the growth of the cartilaginous bone (1) a collar of the hard bone of the diaphysis extends (2)–(3). At the ends there are formed ossified nuclei of the epiphyses (4), which increase to the epiphyseal line (5). Then the latter disappears (6). The bone has finished its longitudinal growth. The medullary space enlarges and the wall of the bone thickens by deposition of bony matter on the surface (modified from Schmid 1972).

sexual dimorphism the same skeletal element may fuse at different times in the two sexes. This has been shown to be valid for man also (Andersen 1968). With reference to animals, see also Lewall and Cowan (1963) and Watson (1978).

Epiphyseal fusion of modern roe-deer was examined by me on material collected from several places especially the neighbourhood of the game-biological station at Kalø, Denmark (fig. 4).

The day on which the animals were shot, and the ontogenetic age at the time of killing was known precisely as most of them were ear-marked at birth. Altogether 26 more or less complete skeletons were examined, comprising 18 males and 8 females, all of which aged under 2½ years (tables 1 & 2). For each animal the dentition was examined, and the degree of epiphyseal fusion was recorded for each bone. In case of bifurcation of the epiphyses their fusion was recorded as well.

The data showed that there is a marked difference in time for the fusion of the epiphyses of the various bone elements. Even within the same bone, e.g. humerus, the proximal epiphysis fuses at an age of 22–24 months, whereas the distal epiphysis fuses at an age of 3–9 months (tables 1 & 2). The hinge joints fuse earlier than the ball joints. As an example the hinge joint of the distal end of humerus and the proximal end of radius fuses at an age of approximately 3 months, whereas the proximal epiphysis of the ball joint fuses with scapula at an age of 22 months. It is thus possible to estimate at which time of the year a young roe deer was killed on the basis of the stage and nature of epiphyseal fusion (tables 1 & 2). For animals which have not yet reached the age of 2–2½ years it is possible to estimate the ontogenetic age of a bone within a range of 3 months. At the Danish Mesolithic site Præstelyngen (fig. 4) the ontogenetic age of roe deer bones was estimated on the basis of the stage of epiphyseal fusion. This can then be used as evidence of time of occupation of the site (fig. 5). After the age of 2½ years all the epiphyses are fused and no age estimation can be made on this basis. However, yearly growth rings have been described in the shaft of the long bones (Klevezal & Kleinenberg 1967; Morris 1972), but no attempts have yet been made to use this knowledge on subfossil material.

Tooth eruption and annular structures of dental cement are useful features in estimating both the ontogenetic age of a mammal and the time of the year at which the animal was killed (fig. 7). This has in Denmark been convincingly demonstrated by Grue and Jensen (1979) who also pointed out the limits of the method.

Young mammals are characterized by the possession of milk teeth. These are later replaced by permanent teeth and the eruption of the molars is initiated. The time of replacement of milk teeth and molar eruption is characteristic for each species. Red deer completes replacement and molar eruption within an age of 33–36 months (Strandgaard 1972) and Aitken (1975). It is thus possible to estimate the age of a red deer which has not obtained a full permanent dentition with the precision of two months. In Danish subfossil material the molar and mandibular tooth row is a common fragment of the skull. Ontogenetic age groups of 3–6 months, 6–12 months, 12–18 months, 18–24 months, and 24–30 months can be established on the basis of measurements of upper as well as lower tooth rows (Noe-Nygard 1969). After complete permanent dentition has been obtained age estimations can be made by evaluation of tooth wear (Lowe 1967). This method demands much experience, however, and gives rather inexact results.

◆ Fig. 5. Determination of the seasonal inhabitation period at the Mesolithic site Præstelyngen. All available seasonal indicators are used. Dotted signature indicates breeding period, as well as possible presence of the animal on the site. Thick horizontal lines indicate the proved presence of the animal on the site. Thin horizontal lines indicate time of occupation based either on tooth eruption or on epiphysial fusion. The two long horizontal lines delimit the season in which the habitation took place.

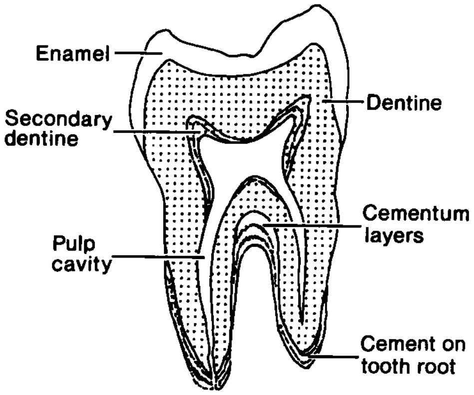


Fig. 7. Vertical section through a molar tooth of red deer showing major components and position of incremental lines in cement and secondary dentine (modified from Morris 1972).

A more effective method is to study annular increment lines in the dental tissue, in much the same way as growth increments can be measured in fish scales, fish otoliths, tree rings, and bivalve shells. Growth layers in the dental cement allow the establishment of age classes for fully grown deer. It is furthermore possible to determine at which time of year the growth layers were formed. Among the first to use the method were Sergeant & Pimlott (1959) in a study of elk, and Klevezal & Kleinenberg (1967) reviewed the whole subject of age related stratification in the structure of teeth and bone. Both Mitchell (1967) and Lowe (1967) have used this method with good results.

Both dentine and cement are characterized by appositional growth, being continuously formed around preexisting tooth material (fig. 7). The cement is laid down around the outer side of the roots to provide better anchorage in the jaw. The odontoblasts in the tooth pulp produce dentine which is deposited on the walls on the tooth cavity. The layers can be correlated with regular events in the animal's life and their number is a guide to the ontogenetic age (Morris 1972; Grue 1979).

Shed and unshed antlers. The yearly antler cycle of elk, roe deer, red deer and reindeer offers a good seasonal indication.

On the site Star Carr the time of habitation was established on the basis of the development of antlers of the various species (fig. 89 in Clark 1954). Juvenile bones were, however, not taken into consideration. By applying this procedure only one period of habitation was recorded, namely winter time. Estimation of the age of the juvenile bones by me indicated a further habitation period during late summer and early autumn (Noe-Nygaard 1975 b). This time of habitation agrees well with the considerable number of skulls of roe-deer with unshed antlers that were figured but not taken into consideration by Clark (1954, fig. 31).

It can thus be concluded that a relatively safe estimate of the period of habitation of a settlement can be reached through the combined use a number of different techniques. In fig. 6 the period of habitation of the Mesolithic settlement Præstelyngen is estimated by combining several of the methods mentioned.

The locus of death

The place where an animal dies is considered a thanatic factor (fig. 2). The various sedimentary environments have different preservation potentials. Important factors are sedimentation rate, pH, and the degree of oxygenation. Thus the locus of death greatly influences the possibilities of an animal body passing into a fossil assemblage from the death assemblage (defined by Clark *et al.* (1967) as the total sum of corpses present on the surface of a sedimentary unit ready for burial). Aquatic organisms and those living near water are more prone to rapid burial. Consequently they constitute the greater part of the fossil record. This includes in particular those organisms that live in the sea, but also those in or near streams, lakes and swamps.

In this paper only calcareous, eutrophic lake and bog deposits are dealt with in further detail, whereas shell-heaps and dry-land deposits are only briefly mentioned for comparative reasons. Some other types of depositional environments not influenced by man are listed below.

Dry land deposits. Most land-mammals die on dry land, but the preservation potential in this environment is very low due to the exposure to weathering and scavengers. The possibilities of rapid anoxic burial are few. Among dry land burial agents earth slides and wind blown sand may be mentioned, but even after burial the sediments are commonly well oxygenated thus allowing biological decomposition. Rapidly moving pore waters may cause chemical solution of bones. Terrestrial animals may in cases of drought gather around water holes resulting in concentration of bones (Conybear & Haynes 1984).

Bog deposits. Few larger mammals actually die in bogs, but the preservation potential may be very high. The animals will often have died by accident. Stagnant eutrophic water and a relatively high sedimentation rate will normally result in very good preservation. Oligotrophic acid bogs offer good preservation conditions for skin, hide and horn, whereas bone and woody material are commonly well preserved in more eutrophic, basic and neutral bog types.

Material from Danish bogs is described below.

Lake deposits. The number of larger mammals that die in lakes is limited, although hunted, wounded and old animals often seek the water, as may be the case with the aurochs from Vig (Noe-Nygaard 1973, 1974; Aaris-Sørensen 1984). Accidents constitute the major reason for accumulation of larger mammals in lakes. Thin ice cover is for example responsible for the death of many deer. The preservation potential is rather high, but variable due to the microbiological activity in the lake.

River deposits. Animals down in rivers because of flooding, thin ice, carelessness when drinking or during crossing. The preservation potential is variable and most of the material will be subjected to transport. The bone deposits commonly accumulate as lags in channel floor deposits of sand or gravel and may form bone beds.

Near-shore marine deposits. The preservation potential is variable depending on the rate with which the dead body is covered by water, sand or mud. If the dead animal is fat it may float in the waters for weeks aided by development of gas within the putrifying corpse. It will slowly disintegrate and the bones drop to the bottom one by one. Lean animals sink to the bottom more rapidly and thus have a higher chance for rapid burial, and thus a higher preservation potential (Schäfer 1972). Transport and redeposition are important taphonomic agents in high-energy environments.

Cave deposits. Many species of mammals are found in cave deposits where the preservation potential may be high. The faunal assemblages accumulated in caves represent a broad spectrum of the existing fauna often mixed with bone debris left by man. Stalagmitic limestone serves as the preservation medium. However, in some caves nothing is preserved or preservation is by mumification.

TAPHONOMIC FACTORS

Taphonomic factors, which can be described under the disciplines biostratinomy and fossil diagenesis, are those operating during the transition of a death assemblage into a total fossil assemblage until the moment of collection. The total fossil assemblage is defined by Clark *et al.* (1967, p. 155) as the sum total of fossil specimens entombed within any particular sedimentary unit in the area in question.

The first step from death assemblage to fossil assemblage involves taphonomic factors such as climate, degree of exposure, sedimentation rate, time intervals between episodes of sedimentation, lithology and grain-size, thickness of sediment cover, compaction, post-depositional action of roots and burrowing animals, permeability, and pH of permeating solutions.

The effect of some of these factors is described below, and special emphasis is placed on man as a taphonomic factor.

Climate and exposure

Climate and degree of exposure are of importance for the preservation potential of animal bones (Behrensmeyer 1978). Variable climatic conditions lead to selective destruction of bone and teeth owing to differences in resistance to weathering. It is well known that different bones of the mammalian body are preserved with different frequency in fossil and subfossil deposits (Voorhies 1969; Binford 1983). The various parts of the vertebrate skeleton have different functions and correspondingly have different structure and shape. Consequently there is a great variety of possible post mortem processes which affect the bones before burial. Knowledge of these processes and their results may be of considerable value in reconstructing aspects of the environments in which vertebrates were buried.

Experiments and observations of the weathering of bones under variable conditions have been carried out by Brain (1967), Behrensmeyer (1978), and Larsen & Noe-Nygaard (unpublished data on modern musk ox from East Greenland). Brain (1967) placed bones in sand and under leaves under arid and humid conditions. Bones exposed to weathering on a sandy substrate were bleached and developed a soft chalky surface. The bones were abraded by the action of cattle, and wind blown sand removed the soft surface by abrasion, resulting in the exposure of new surfaces of hard bone. Bones deposited covered by leaves in humid climate under well drained conditions revealed the same type of weathering. The bones found in kitchen-midden deposits from the Danish Mesolithic period is a good example of removal of the organic membranes exposing the inorganic bone material to both physical and chemical weathering. The sculpture of the bone surface, such as muscle attachment processes, is obliterated and the dimensions of the bones are altered due to the continuous removal of superficial bone material (fig. 8 c). Small fragments subjected to these conditions probably disappear completely. Teeth from medium sized mammals like red deer and roe deer exposed to weathering under semi-arid conditions crack and splinter very rapidly (Clark *et al.* 1967), whereas in bog deposits they normally comprise the most resistant and better preserved elements of the skeleton (Noe-Nygaard 1969). The high frequency of well preserved mandibulae containing teeth from subaquatic refuse heaps may indicate that only a short time elapsed between removal of the jaw from the body and its final deposition in the lake close to the site of habitation.

If the animal is subaerially or subaquatically exposed for some time after death, disintegration and scattering of the skeleton will start. Weathering, scavenging, current action and bacterial activity are important factors. The disintegration may be completed within weeks in a warm humid climate. In the arctic environment of East Greenland the disintegration of unburied skeletons of musk ox may last several hundred up to thousand years due to the cold, dry conditions (Larsen & Noe-Nygaard, in prep.).

Müller (1951, p. 40) summarized the course of disarticulation for marine mammals. The lower jaw is disarticulated first at an early state, followed by disarticulation of the phalanges. The other limb bones and the rest of the articulated elements are later stage disarticulations.

Experiments of skeletal disarticulation were carried out under semi-arid and desert conditions by Toots (1965). Five stages in disarticulation were recognized. The first step was the disconnection of the skull and some of the limbs. Then ribs became loosened from the front part. Limbs then started to disarticulate into smaller segments. The vertebral column then began to disarticulate. Finally weathering and disintegration of the individual bones commenced.

Some parts of the body contain a large amount of easily decomposed tissue. Where there is little flesh, ligament and hide tend to persist for long time and thus protect the bones. Metapodial bones are held together

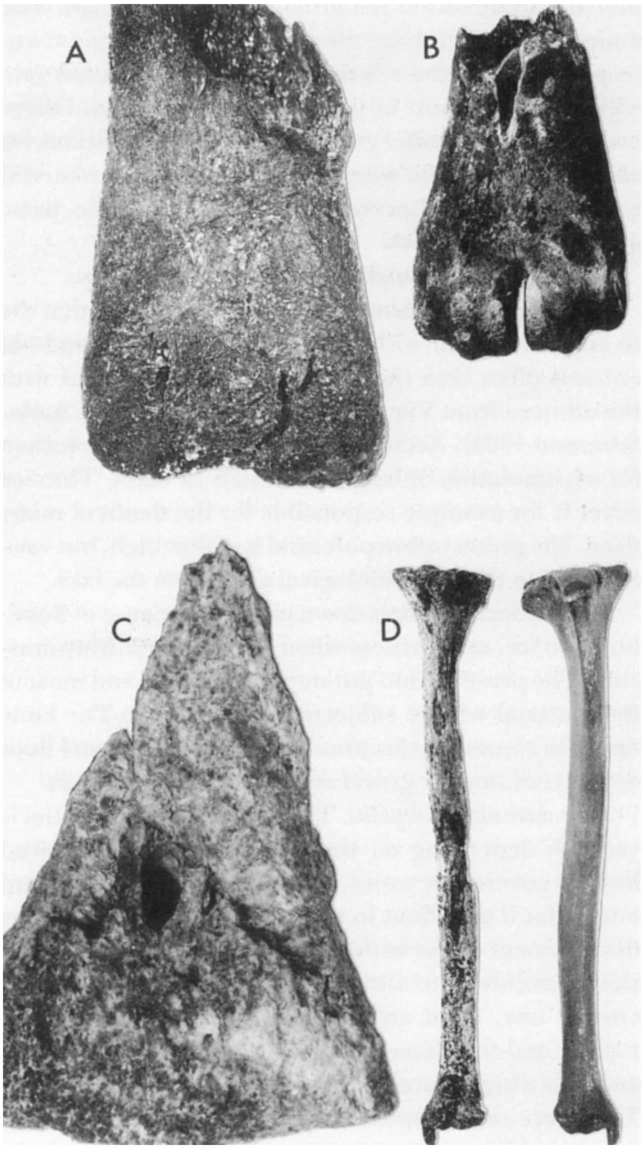


Fig. 8. A, C: Diagenetic decalcification of a metapodial bone of red deer from Star Carr. The bone fragment shown in A cannot be safely identified due to nearly complete decalcification in acid bog deposits, compare with B, a modern metapodium. Note the collagen fibres in the black bone on A. C is a metapodial bone from red deer from Brovst. The organic tissue has been removed by oxydation leaving the inorganic part unprotected. D: Two tibiae of dog from Præstelyngen, the left one deposited in peat, the other in gyttja (lime-rich organic mud). The dimensions of the bones indicate that they derive from animals of the same size – probably the same individual. Note the deformation and decalcified nature of the bone to the left; the weight of this bone is only 60% that of the bone to the right. Size: A × ⅔; B × ¾; C × 2; D × ½.

by remains of tissue after much of the skeleton has been disarticulated.

The time necessary to cause complete disarticulation and disintegration of the various bones during transport in running water was estimated in a series of experiments by Dodson (1973). In his experiment dead bodies of mice and frogs were used. It took 77 days to disintegrate a mouse and 45 to disintegrate a frog. Tendons were far more durable than muscles. It also emerged that a small stream with weak currents was only able to remove the small bones, while the larger remained behind as a lag deposit. The light bones of birds and of small mammals were selectively removed by current action. The various bones of a skeleton have different hydrodynamic properties. With the lowest velocity vertebrae start to roll along the bottom, the thoracic ones being most easily rolled. Humerus, femur and tibia move next, whereas much stronger currents are required to move mandibulae and skulls. The buoyancy of a bone is also of importance to its susceptibility to transport. Bones which have been lying on dry land for some time and then later transferred to water are able to float over a long period. Dried specimens of radius, ulna, femur and tibia of a frog were able to float for a month. See also Behrensmeyer (1975).

On the basis of our knowledge of how the various bones act to current transport it is possible to estimate whether a bone deposit has been exposed to transport or whether certain types of bones have been selectively removed.

Experience with early Pliocene bone material shows that the degree of mechanical fragmentation of the various bones differs (Voorhies 1969). Metacarpus, metatarsus and radius have a low fragmentation potential, whereas tibia and femur have a medium, and the fragile humerus a high fragmentation potential. Cranial and metapodial bones occurred with a high frequency in this deposit, whereas femur and humerus together with scapula, atlas and ulna were poorly represented (Voorhies 1969, plate 3). The studied difference in relative frequency of the various bones may not alone be due to different degrees of fragmentation and sorting by current of the various bones. Activity of predators may also account for a considerable part of the biasing factors working upon a bone deposit. The disarticulation sequence of vertebrate skeletons can be estimated on the basis of the relative numbers of different intact joints in a bone assemblage. Hill (1979) demonstrated that the disarticulation pattern is very consistent. However, the disarticulation sequence is different on dry land and in environments influenced by the presence of water.

Predation

During feeding, predators and scavengers most often concentrate on the eyes, the thigh-bone, the upper part of the shin-bone, and the upper part of the upper arm. Carrion feeders show a great preference for the spongy bone tissue, probably because of its content of iron and fat.

In archaeological deposits the lower ends of tibia and humerus are often found to be over-represented relative to the upper ends of the same bones (figs. 9, 10). This may be due to several factors such as selective destruction, selective removal by man, or dog scavenging.

Lyon (1970) suggested that dogs had an influence on archaeological bone deposits on the basis of an investigation of the activity of dogs in a modern village in Peru. In the village the dogs were of medium size and in some cases they totally devoured the bones of small animals such as fish, birds and small mammals and destroyed identifiable portions of the bones of the medium sized animals leaving only the remains of large animals in an identifiable condition. Domesticated dogs may not only account for the differential representation of skeletal parts but they may also totally destroy the remains of certain species so that the archaeological picture may be highly distorted.

On the upper arm bones of an elk from Star Carr, England, and from an aurochs from Grænge Mose, Denmark, the upper joint had been removed (fig. 11). Tooth marks on the bones of the aurochs indicate that the upper ends were removed by scavengers. Such marks were not seen on the bone from Star Carr, but a find of a skull of a dog at the site shows that dog was present (Clark 1972).

It is well known that scavenging birds are selective in their choice of where to peck. I have observed peck marks of birds on the upper end of humerus of a modern roe-deer.

According to Shotwell (1955) the relative state of preservation of a bone assemblage in a given deposit, can be estimated on the basis of calculations of the ratio of the amount of fragments and the minimum number of individuals, assuming that this calculation is made for several species. This relationship has been widely dis-

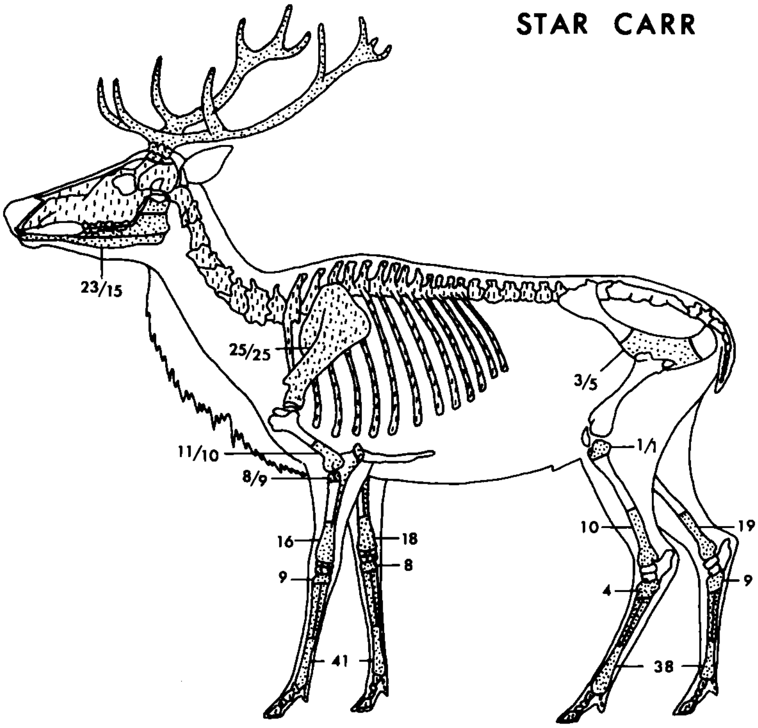


Fig. 9. Skeleton of red deer showing the type and amount of bones found at the Star Carr site. The bones subjected to systematic fragmentation are emphasized. Note the lack of certain bones and the differences in number of the various bones. Antlers are plentiful indicating October to January killing of the animals.

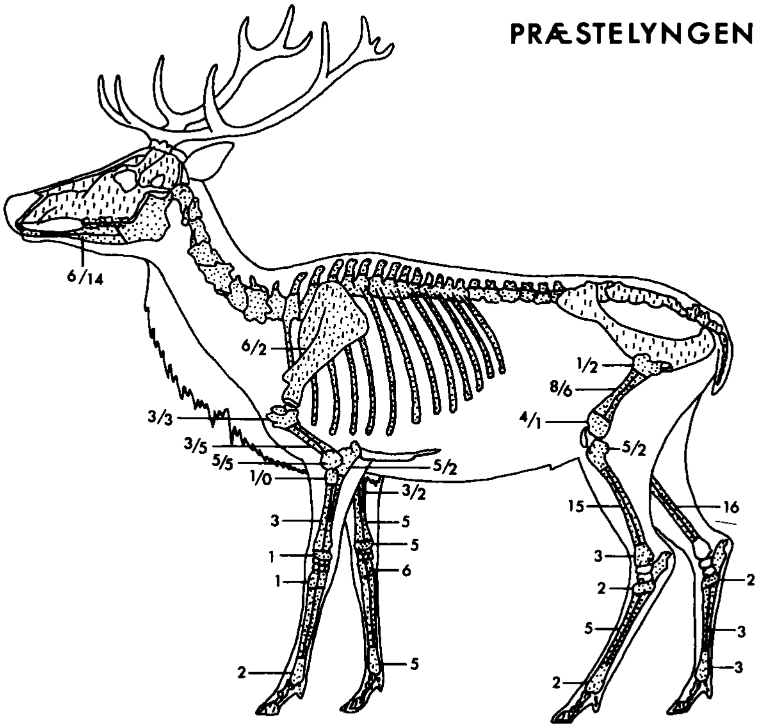


Fig. 10. Skeleton of red deer showing the amount of bones found at the Præstelyngen site. The bones subjected to systematic fragmentation are emphasized. Note the uniformity in numbers of the various bones and the absence of antlers. Lack of antlers may indicate inhabitation of the site within the period February to September.

cussed (*e.g.* Grayson 1978) and may be misleading depending on how prone the different types of bone are to fragmentation and current transport. In archaeological deposits the differences in fragmentation pattern for the various species (see below) will further hamper the possibilities of using this method alone for estimation of the relative degree of preservation. Shotwell (1955) further assumed that the skeletons of animals which lived closest to the site of deposition were better represented in the bone assemblage than skeletons from animals which lived further away from that site.

Sedimentary parameters

Post-burial alterations of chemical or mechanical nature can be ascribed to factors such as sediment permeability, changes in pH of the permeating water, and lowering of the ground-water level resulting from changes in drainage conditions.

Sediment permeability has a marked influence on the fossilization processes and on decomposition of the fossils. Sand and shell heaps present highly permeable media. Silt, clay and organic mud have very low permeabilities and offer protection for the organic remains which stand a better chance of final preservation.

Deformed bones have been shown by experiments to result from decalcification (Noe-Nygaard 1975 b). Examples of sub-fossil decalcified bones from the acid bog deposits of the Preboreal Star Carr Site are illustrated on fig. 8. The bones show various stages of shrinkage and deformation; some bones are so deformed as to preclude identification. On the surface of the bone the texture of the collagen fibres has been brought out.

In north and east Denmark the pH of the ground water has changed during the Mesolithic period, due to the outwash of $CaCO_3$ from the moraine soils. The early Mesolithic lake sediments were organic mud with a considerable content of $CaCO_3$. This is the case for the Aamose basin where the site Præstelyngen is situated (fig. 4). Towards the Neolithic period the pH was generally lowered in the depositional environments. Bones found in the more acid peat deposits are in a rather poor state of preservation. Two tibiae of dog were found at the site Præstelyngen, one in organic mud with a high $CaCO_3$ content, the other in $CaCO_3$-free peat (fig. 8). There is a marked difference in the outline, surface texture and weight of the two bones which probably belonged to the same animal. The differences are best explained by differences in pH values in the two types of sediment. Changes in chemistry of the percolating water during time may result in a downwards migration of the acid zone whereby bones originally deposited under conditions favourable for preservation are etched. Disintegration of the collagen fibres of bones reduces the preservation possibilities. Percolation of alkaline water in highly permeable sediments like sand and shell heaps will lead to this type of destruction. The $CaCO_3$ components of the bones dissolve and pass into solution. The sculpture of the bone, such as joints and muscle attachments, become smoothed and hinder proper identification. Smaller fragments may disappear completely. In some cases iron in solution is precipitated as iron oxides around the bone and within its porous structure, resulting in better preservation (Voorhies 1969).

Overgrowing of lakes together with modern agricultural drainage have lead to destruction of organic material in former water-logged sediment. Bones exposed to repeated moisturing and desiccation crumple and peel

Fig. 11. Right humerus of aurochs, single find from Grænge Mose. The proximal epiphysis is lacking. The tooth marks on 1 indicate that predators chewed away the blood-filled spongy tissue of the upper epiphysis. Size: × ⅙.

off like onions, resulting in total destruction of the bones within a short time. In Denmark many of the former bog areas have been turned into farm land of doubtful value, resulting in disappearance of the bones of numerous Mesolithic sites. The destruction is almost total, but at many sites the desiccation has only influenced the upper part of the deposit, destroying an unknown part of it and thus rendering a statistical treatment of the material impossible.

The taphonomic factors are manyfold and it is important to evaluate the effect of each factor especially in comparison of different achaeological deposits. In the next chapter a few of the taphonomic factors acting on Danish bog deposits are analysed.

TAPHONOMY OF SOME DANISH LAKE AND BOG DEPOSITS

Single bog finds and land mammals

The fossilised fauna from the deposits of Danish lakes, bogs or overgrown lakes stem from a variety of sources: 1) Skeletons of the animals which inhabited the lake bottom or water are embedded in the lake sediments. 2) Part of the natural population inhabiting the biotopes immediately around the lake and the near neighbourhood may accidentally fall into the lake, and in this way contribute to the bog sediments. 3) A human population may also contribute in several ways to the lake deposits. Animals may be driven into the lake during hunts, escaping their pursuers, but drowning; wounded animals seek the lake as a refuge; and animals may have been sacrificed and ceremoniously lowered into the lake to honour deities. Finally, refuse from lake side human settlements, including remains left over from meals, is also thrown into the water.

Natural death. It is in many cases impossible to separate fossil material representing the natural death of the animal population from material representing man's sample of this population. However, the isolated finds of complete skeletons most likely represent the accidental death of an individual belonging to the natural population provided that no weapons or unhealed injuries are to be seen, and that no observable sacrificial arrangements of the bones is recorded. Some complete skeletons have, however, been interpreted as representing a sacrificial arrangement e.g. Sørbylille, Åmosen (*e.g.* Troels-Smith, pers. comm. 1975). Isolated bog finds from Denmark number more than 10,000, but detailed information is unfortunately very rarely available. Only about a hundred finds are dated either by pollen analysis or ^{14}C analysis. The isolated bog finds consist of relatively large animals such as red deer, elk, aurochs. Commonly only the skull and a few bones are recorded, but complete skeletons are occasionally retrieved. Such a sample of the natural fauna is biased in many ways. Animals that have gone through the ice or have floundered in a quagmire are likely to be the heavier ones, and accidents of this type are likely to have happened more often to species living near a lake such as ox, elk, deer, and wild boar. These animals are heavy and having once broken through ice, they continuously will break the ice edge in their attempts to regain the ice surface. Their efforts to reach safe ground may result in their being buried quite rapidly in the soft lake sediment. Nevertheless, Collet (1912, p. 481) mentions that roe-deer often risk a thin ice cover and may drown or get stuck with their thin legs through the ice and starve to death. These animals will often be the target of predators such as wolf, fox and dog, and roe-deer is rarely recorded as single bog finds.

Another factor to be considered is a strong collection bias. Most of the finds from the bog deposits are recovered by non-scientists, giving the larger and more impressive finds a preference. Thus the number of finds of males of aurochs, roe-deer, and wild boar exceeds that of females by several times; this hardly proves that more males than females drowned in the lakes but that the horns, antlers and canine teeth respectively render the male skull more conspicuous than the female. Similarly, bird and fish remains occur abundantly in bog deposits; however, there are practically no records of single bog finds of birds and only a few complete skeletons of fish have been recorded at for example the Muldbjerg site. Most records of fish and birds are connected with archaeological excavations. Among birds, water fowl such as the various species of duck are the most common, but birds with other habitat requirements are also found. Nearly all the bird species recorded are only represented by a few bones, because of the light bone structure, fat and feathers, which keeps a carcase of a fowl floating for months leading to a scattering of the bones (Schäfer 1962, 1972).

Animals killed by man. Where isolated finds occur with flint embedded in the bones or with unhealed injuries it is obvious that the death of the animal was caused by man. In several finds such as the wild boar from Aldersro, the complete skeleton bears injuries and contains flint implements (Steenstrup 1889). The aurochs from Vig has several injuries, some healed and some unhealed (Hartz & Winge 1906). The unhealed injuries of this skeleton indicate that the animal did not live long after the last hunt, and the fact that it was found as a complete skeleton may be taken to indicate that the hunters never caught the deadly wounded animal (Noe-Nygaard 1973, 1974). An aurochs from Prejlerup found under similar circumstances was described by Aaris-Sørensen (1984).

Fragments retrieved from excavations may include bones of sacrificed animals, but these will in most cases be indistinguishable from the fragments derived from meals. There are, however, exceptions to this general principle. In rare cases it is possible to distinguish an offering from the rest of the deposited bone fragments. For example, in the Hamburgian Culture from Stellmoor several complete, non-transported skeletons of reindeer were found, weighed down by stones placed inside the rib-cage suggesting that the animals represent a sacrifice (Rust 1937, 1943). In other cases where only parts of the animals were sacrificed, a correct interpretation is more difficult. If, however, bones are broken following a certain pattern and if the fragments are collected at one place it is reasonable to class them with offering finds. A possible example is known from the early Neolithic settlement Store Lyng VI where four complete skulls of sheep/goat with similar fractures were found. One had a lesion in the frontal bone, and three had lesions in the back head (Troels-Smith, pers. comm. 1975). Møhl (1978) described six individuals of elk from the pre-boreal Skottemarke locality who appear to have been ritually killed.

The setting of the bones of the sacrificed animals from the Hamburgian Culture shows that if the carcase of an animal is buried in an articulated condition and is rapidly covered with sediment, all of the bones stand a good chance of preservation.

The place of sacrifice may, however, also be on dry land either at the living site or separated from it. The remains from such a place will be extremely difficult to distinguish from remains of meals and will in many cases never reach a lake.

Animals probably killed by man. It is difficult to prove the connection between barbed points or other projectiles and complete skeletons recovered from the same site, when the arrows are not embedded in the bones but just occur adjacent to the skeleton. A causal relationship between such an association between flint or bone implement and a skeleton have been suggested by several authors. As examples can be mentioned an elk from Taaderup dated to the pollen zone VI (Ødum 1920) and an elk from High Furlong dated to the Allerød period, pollen zone II (Hallam *et al.* 1973). In both cases there is no direct proof of a close causal connection between the skeletons and barbed points found nearby. The elk from Taaderup was found together with the basal part of a barbed point and no injuries were recorded on the skeleton. In this case the barbed point could very well have been deposited many years before or after the death of the animal, and no known dating method would be able to distinguish the difference in time. The object will be recorded as contemporaneous, and the obvious conclusion will then be that the elk was hunted and perhaps killed with the barbed point. Several damages of the skeleton were recorded on the elk from High Furlong but these are most likely of modern date (Noe-Nygaard 1975). Here again no real proof exists of contemporaneity between the barbed point found adjacent to the skeleton and the skeleton itself. The points could have been used as fish spears and dropped on a later occasion. The barbed points from High Furlong were very light and slender, much more suited as a leister or a fish spear than for elk hunting.

Deposits of mixed origin, Præstelyngen – a case study

The numerous fish remains recorded from archaeological sites commonly offer serious problems concerning their origin.

The fish bones found during an excavation are normally thought to represent meals left over by the inhabitants of the site. Most of the well preserved material stems, however, from that part of the refuse that was deposited in the water. The refuse from the site will thus run a risk of being mixed up with the carcasses from the natural population of fish in the lake.

The fish remains excavated from the Mesolithic site Præstelyngen in Denmark (fig. 4) are discussed in order to throw light on the questions if the fish remains represent left overs from meals, or carcasses of the naturally died animals, or both. Noe-Nygaard (1983) demonstrated by a combined population and seasonality study that it was possible to distinguish between the two main types of origin.

Accumulations of fish bones are in most cases interpreted to indicate that the culture was a fishing culture, while similarly, lack of fish bones at a site is taken to indicate that the inhabitants have not touched a fish (Brøndsted 1957).

Approximately 5000 fish bones were retrieved from the site of Præstelyngen (3280 ± 100 bc, K2049) (Noe-Nygaard 1983). Around 4000 were determinable and 78% of these belong to *Esox lucius*, the pike. The rest are distributed between the following species: tech *Tinca tinca*, perch *Perca fluviatilis*, crusian carp *Carassius carassius*, bream *Abramis brama*, roach *Rutilus rutilus*, rudd *Scardinius erythropthalmus*, spurdog *Squalus acanthias*, and catfish *Silurus glanis*.

The fish bones found on dry land around the site probably derive only from meals prepared by Mesolithic man, whilst the in-shore lake deposits may very well be composed of both refuse from the site and accumulations of fish which died naturally in the lake. A rim up to 5 m wide of dead floating fish with up-turned, air-filled bellies can commonly be observed in modern lakes. Such mass mortalities may have several reasons including lack of food, or more commonly suffocation beneath a thick late winter ice cover, or lack of oxygen, caused by biological overproduction and decay in warm summers.

At Præstelyngen it is clear, both from the large number of fragments and from the estimated minimum number of individuals (250) that pike was the dominant fish. Pike is a predator at the apex of the food pyramid whilst perch and the other fish species constitude its potential prey. Consequently, the ratio of the two groups does not reflect the composition of the natural fauna of fish in the lake. Several attempts have been made by poisoning a lake to retrieve the total population (Malin & Enros 1956; Berzins 1958; Larsen 1961). For comparative reasons the fish fauna of a modern lake poisoned by rotenone is pertinent to the problem presented here (Larsen 1961). The modern lake is comparable to the Aamose lake with regard to size, depth, pH and surroundings. Larsen counted 16,692 fishes from the lake, distributed as follows: roach, 13,731, perch 1,522, rudd 1,263, pike 111, tech 69, crucian carp 1, eel 5. The abundance of the various species is in accordance with a normal abundance of prey animals and predators. Larsen pointed out that probably not all the fish were caught and counted, but the number of missing fish would not markedly change the ratio between the two groups. It thus seems clear that the dominance of pike in the Aamose deposits does not reflect the composition of the natural fauna. The obvious explanation of the pike dominance is that it was the preferred fish for consumption by man, possibly because of a combination of flavour, ease of catching and type of fishing equipment. Pike is relatively easy to catch during spring and early summer when it inhabits the shallow, warm water zone near the lake shore, where the mating dance takes place. There are, however, other possible explanations for the large numbers of pike. Pike bones have a conspicuous shiny black surface which may lead to a collecting bias in black bog deposits. But the very careful excavation technique applied at Præstelyngen diminish collecting bias to a minimum. Few fragments will escape the excavator who is helped by the difference in colour between sediment and all preserved bone material. Furthermore, pike bones may be more resistant to scavengers, weathering, and diagenesis than bones of other fish. Finally, the dominance of pike may reflect an unstable monospecific fauna developed under abnormal conditions such as in isolated water-filled marl pits with no inlet or outlet. Individuals living under such conditions are commonly "Kummer Formen", that have large heads and may be cannibalistic. In the case of the Aamose Basin such conditions did not prevail. The faunal remains and the pollen spectrum from this period indicate an open lake with vegetation along the shore. Also the present day river Halleby Å ran through the area, as it does today. The lake thus had a fresh water inlet and outlet permitting immigration of fish.

In order to evaluate the influence of man on the deposition of fish in the Præstelyngen site in the Aamosen, it was compared with a Cromer interglacial age lake deposit, situated near Voigtstedt in the German Democratic Republic (Deckert, in Kahlke 1965). The possibility of human interference at Voigtstedt is negligible. Thousands of bones from various species of vertebrates were retrieved from the site. Apparently the shallow-water lake had a few deeper pools and had a small stream running through it. Among the bone remains there were about 550 identified fish bones distributed amongst eight species (fig. 12). More than half of the fragments were of pike. It is striking that pike is the dominant fish in the deposits of Voigtstedt and Præstelyn-

	% OF NUMBER OF FRAGMENTS		INDIVIDUALS %
	PRÆSTELYNGEN n = 2228	VOIGTSTEDT n = 550	MODERN POISEND LAKE n = 16693
Pike	75,80	52,6	0,7
Tench	1,88	29,1	0,4
Perch	21,70	6,4	9,1
Crusion Carp	0,20	3,8	0,1
Bream	0,18	0,4	—
Roach	0,20	0,8	82,2
Rudd	0,05	6,2	7,6
Spur dog	0,05	—	—
Spine loach	—	3,0	—
Wels	0,13	—	—
Eel	—	—	0,1

Fig. 12. Percentages of freshwater fish species found at Præstelyngen and Voigstedt compared to a modern poisoned lake.

gen. Furthermore, the distribution of the fragments of the various skeletal elements is very similar, at least for the five most common elements. The difference between the two deposits is that at Voigtstedt very few body skeletal remains were retrieved. This lack of the smaller and lighter part of the skeleton may be due to sampling bias or the small parts may have been removed by current action. Deckert (in Kahlke 1965) interpreted the distribution of bone fragments for the various species of fish as a response to differing resistance to mechanical wear.

The quantitative composition of the various species of the subfossil faunas in the Cromer lake and the Mesolithic lake are thus closely similar, whereas they differ markedly from the quantitative composition of the species in the modern lake described by Larsen (1961). This suggests that the distribution of the various species cannot simply be ascribed to a human factor, but may just as well be the result of mechanical and chemical biasing factors (cf. Deckert, in Kahlke 1965).

Thus, it is necessary to investigate other lines of evidence in order to directly associate fish bones at Præstelyngen with human activities at the site. This was attempted in two ways: 1) The population structure of the Præstelyngen pike was reconstructed. 2) The yearly season at which they had died was analysed by year-ring analysis.

The relation between distal height of the dental bone and the total length of 14 animals has been analysed in a material of 100 modern pikes (fig. 13). The correlation coefficient is very highly significant (r = 0.900). The size distribution of the pikes from Præstelyngen was calculated on the basis of the equation of the regression line (fig. 13) and the measurements of the distal height of the dental bone.

The size structure of the Præstelyngen population clearly differs from that of the modern poisoned lake (fig. 14). The dominance of individuals of a very limited size range between 30 and 70 cm suggests selective killing of fish and strongly implies that the accumulation of fish bone was due to human activity. The narrow size range of the selected fish may be a result of the method of killing. Several finds of Ertebølle fish spears, hooks and traps have been made from the lake area (Troels-Smith 1953). The use of fish spear strongly biases the catch in favour of the larger fishes, as they are easier to hit. Pike is approximately 2 years old before it matures, at which time it has reached a length of about 27–48 cm for males and 31–49 cm for females (Frost & Kipling 1967). The very large pike may have been too cunning to catch, or they may have inhabited less easily accessible parts of the lake. The pikes caught at Præstelyngen most likely represent mature individuals which

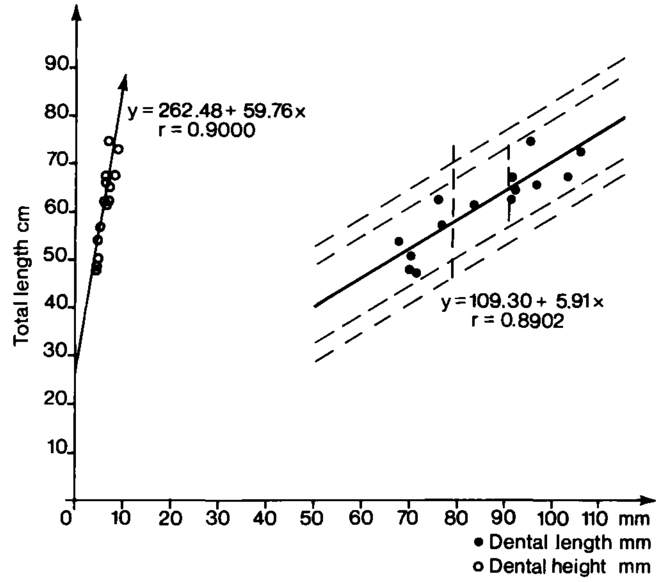


Fig. 13. Correlation lines between dental length and total length of modern pike (*Esox lucius*) (N=14), and between dental height and total length of modern pike (N=14).

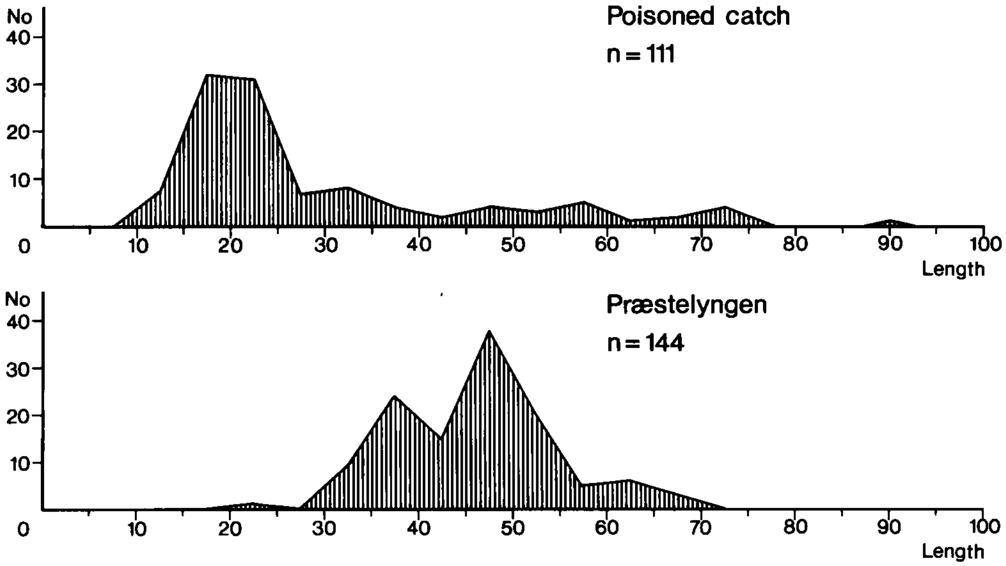


Fig. 14. Comparison between the population structure of pike catch from a modern lake, and the assemblage collected at Præstelyngen. Note the very narrow size range at Præstelyngen.

could easily be obtained at their spawning grounds at shallow water near the rim of the lake.

The size composition of pike at Præstelyngen might, however, be a result of a catastrophic mass mortality of specific age groups. This may have been brought about by anoxic conditions below winter ice or by biogenic over-production in the lake during warm stable summer conditions which would cause lack of oxygen or biogenic toxication (Noe-Nygaard *et al.* 1987).

In order to eliminate some of these natural factors, the season of death of the fossil pike was estimated by year-ring analysis of 79 well preserved vertebrae, following the method of Casteel (1976) and Voorhies (1969).

It is noteworthy that from about 3,000 pike bone fragments only some 120 vertebrae and very few other body skeletal elements were preserved. This may be due to the fact that more than about 90% of the bone material from the site was recovered from a human dump from the near shore lake deposits and thus may contain only the unwanted parts of the fish. A pike head is unattractive, has very little meat on it and has sharp teeth. The many bones from the pike head may thus represent the remains of the semi-product of the fish. This interpretation of immediate decapitation of the pike at the lake margin is supported by two points. The number of paired cranial bones is almost the same for the various skeletal elements indicating that the whole head was dumped at one time. Further, at a coastal site, Ølbylyng, of approximately the same age as Præstelyngen, the cranial bones only represent 1–2% of the total number of fish bones (Møhl 1970). The coastal people probably never brought the fish heads to the site itself, as they were dumped at the place where the fish were landed.

In order to estimate the season of death of the pike from Præstelyngen a sample of 100 modern pike was collected throughout one year. The development of the outermost annual increment on the atlas, on a praecaudal vertebra and the tenth caudal vertebra from behind was compared with the preceding fully developed annual layer of the same type. The white "summer" growth layer was divided into three segments. The annual increment of cleitrum and basihyale was tested as well for comparative reasons (fig. 15). The data on the fossil pike indicate that the major part of the fish were killed well within their season of growth. By direct comparison between fossil and modern pike it is apparent that the majority of the fossil vertebrae was derived from fish killed in the summer season, predominantly May, June, July, and August (fig. 16). From Williams (1955), Frost & Kipling (1967) and Casteel (1976) it is clear that the time of growth of pike depends largely on ontogenetic age, on the general condition of the individual and on the abundance of food available. Considering the possibility of false annulae, and a variation in the time of development of summer layers the only thing which is clear is that the fish were killed at a time within their main growth season. This season is in agreement with the season for habitation of the Præstelyngen site, deduced from other seasonal indicators (fig. 6).

The limited size range of the pike and their season of death suggest that human beings were responsible for their death, and also possibly for the death of the other species of fish. Consequently, fish constituted a major part of the food economy at the site.

From the faunal analysis of the seasonal occupation of the Mesolithic inland sites in the Aamose area it has been demonstrated that during the time of occupation all the available resources were exploited. But which resources the inland people utilized throughout the year is still unanswered. On one hand it has long been argued that the inland settlements were the summer hunting stations of migratory coastal people, and on the other that the inland people were an autonomous migratory group who did not permanently inhabit any one site (Andersen 1981; Mathiassen 1943; Noe-Nygaard 1971).

The pike bone assemblage consists almost entirely of skull bones. Annual ring analyses of vertebrae indicate pike mortality from May to August. This is in agreement with other seasonal evidence indicating the season when the Præstelyngen site was inhabited (fig. 6). The very narrow size distribution of the pike assemblage suggests that they were subject to a selective kill, probably by human beings.

These three lines of evidence indicate that the majority of pike bones and other fish dumped in the lake close to the Præstelyngen site represent the remains of catches made by people on the site. They decapitated the prey immediately, at the edge of the lake.

In addition to the important exploitation of fish at Præstelyngen the inland people also collected a great number of fresh-water mussels (Noe-Nygaard 1983).

The inference from the major role of fresh-water fish and mussels in the diet of inland Mesolithic people as part of the overall non-marine food intake is that two groups of Mesolithic people were in existence in Sjælland at the same time. One group exploited the whole range of prey species available along the coast, including marine fish, birds, mammals, and mussels, see *e.g.* Aaris-Sørensen (1980 b) and Enghoff (1983). This was supplemented with whatever non-marine birds and terrestrial mammals they could obtain. The inland people exploited the whole habitat around the larger lake areas

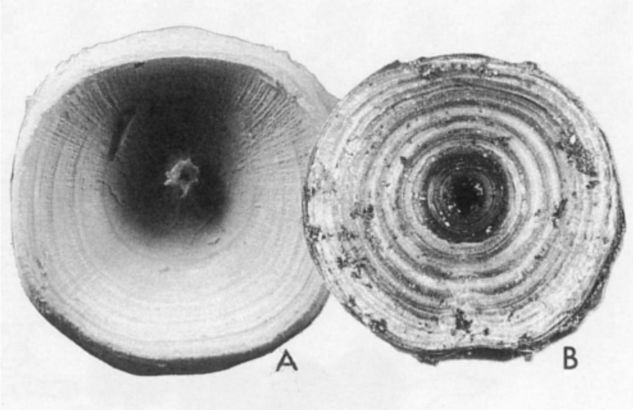


Fig. 15. Pike-vertebrae with clear year-rings which are useful as a seasonal indicator. A: modern pike; B: pike from Præstelyngen. Size: × 2.

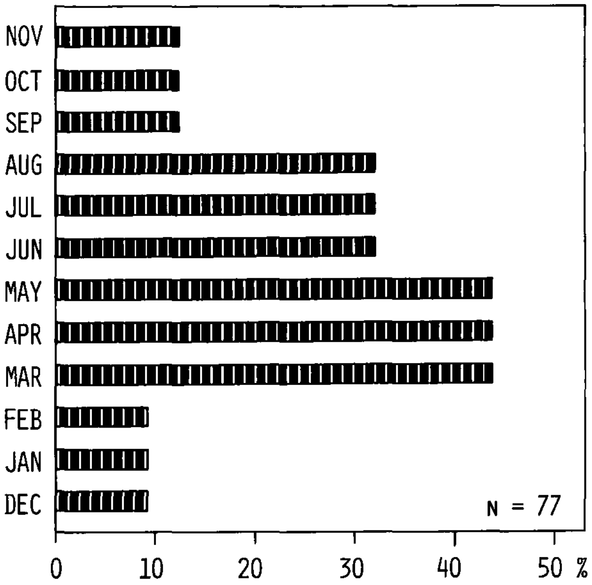


Fig. 16. Seasonal occupation of the site Præstelyngen deducted from year-ring analysis of pike vertebrae. Inset in the lower right shows a more detailed version of the quadrant in question based on direct comparison with year rings from monthly caught modern material.

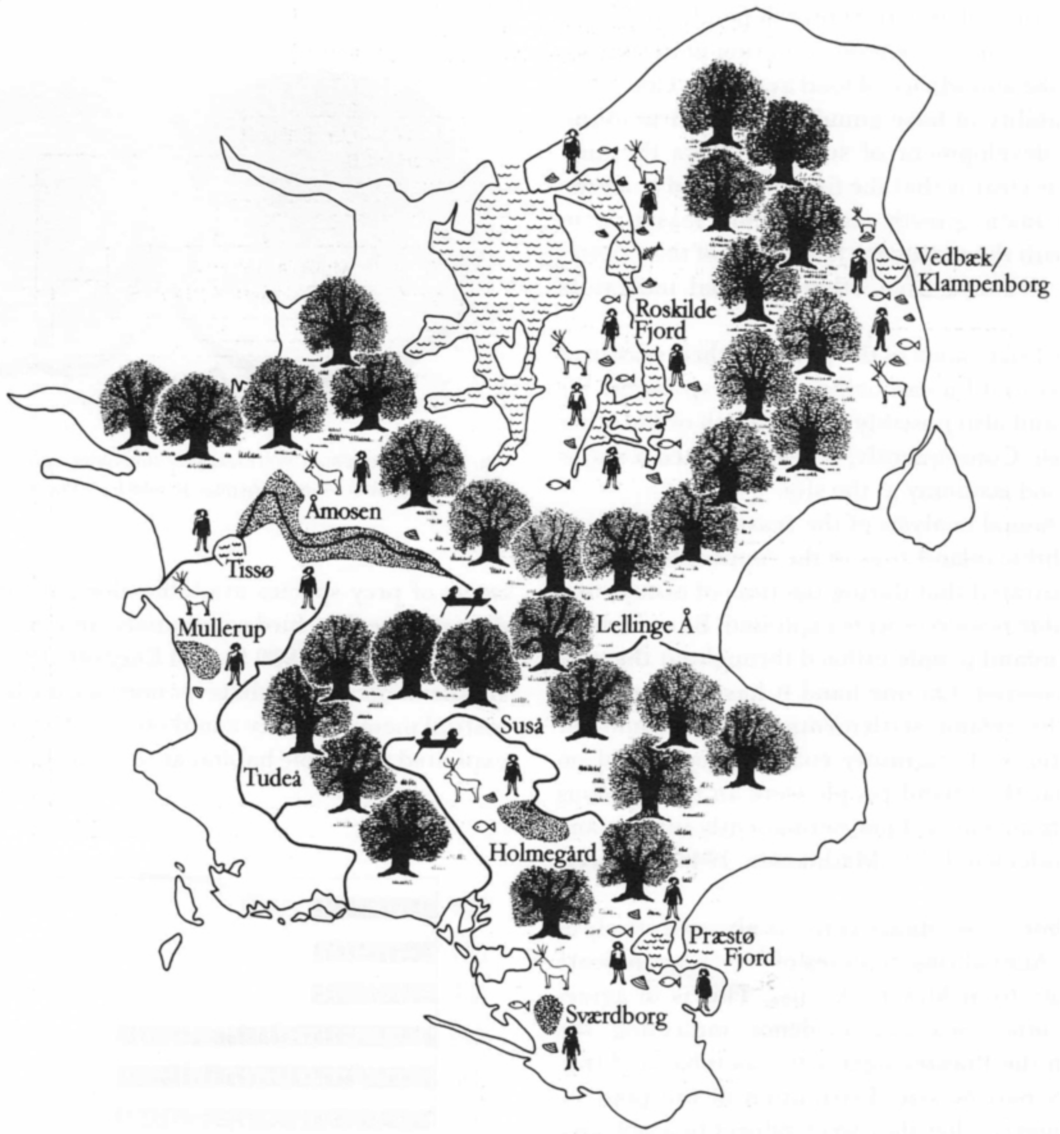


Fig. 17. Schematic map showing the main biotopes on the island of Sjælland during Mesolithic times.

which supported populations of mammals, birds, fish, and mussels. As both summer (e.g. Præstelyngen) and winter (e.g. Kongemosen) sites are known, the inland people seem to have exploited the whole habitat all year round. These two groups of people probably had some communication (Noe-Nygaard 1971), but were otherwise subsisting totally within their specific habitat (fig. 17).

This more stationary way of life in the late Ertebølle period might have facilitated the adaptation of the agricultural way of living in the early Neolithic.

Deposits of human refuse

Material embedded in bog deposits as a result of human activity is in some cases easy to recognize. The human habit of marrow fragmenting the long bones and breaking up the remainder renders identification of human

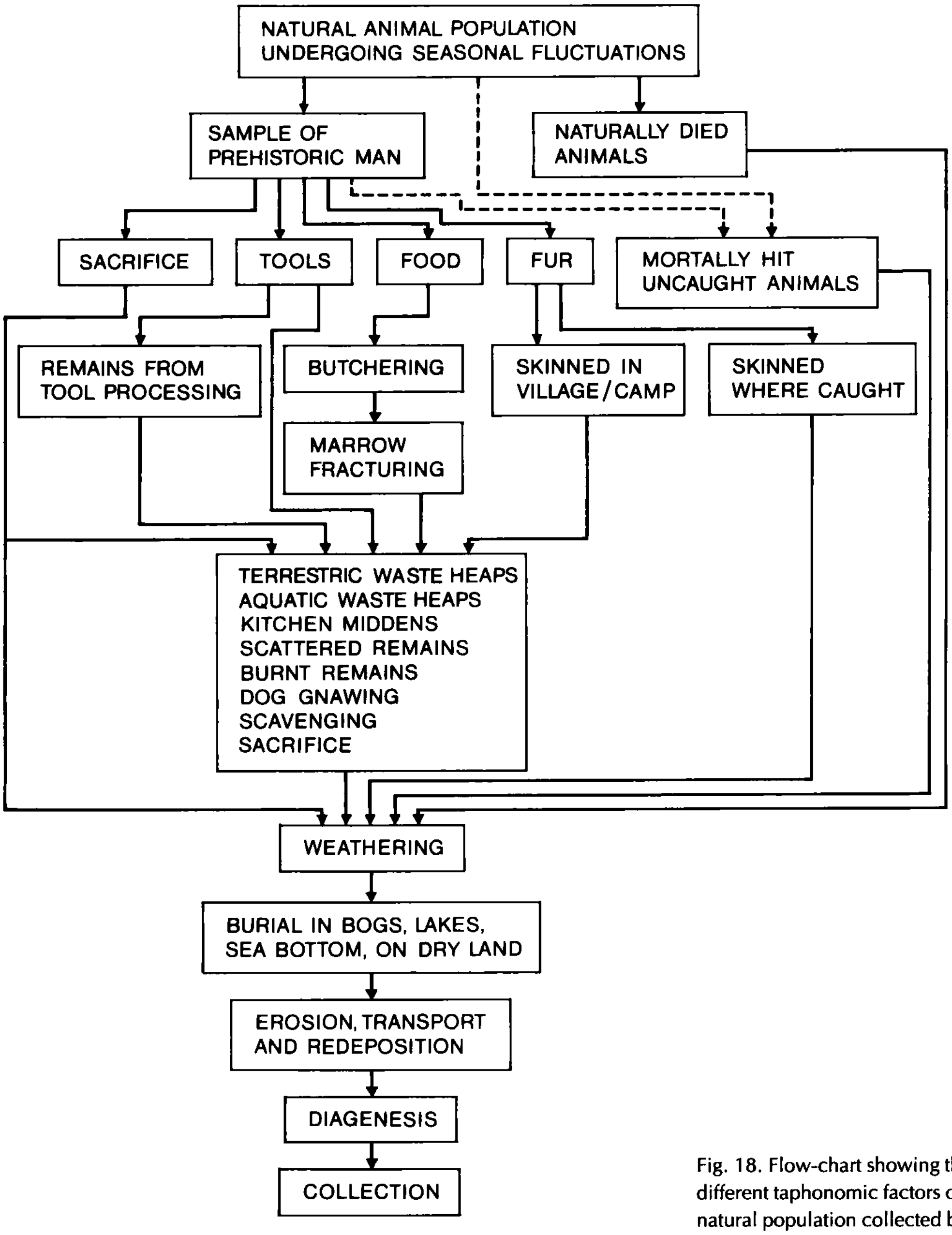


Fig. 18. Flow-chart showing the effects of the different taphonomic factors on a sample of the natural population collected by pre-historic man.

refuse possible. This fragmentation is an indicator of the use of the animals to man. Also the repeated patterns of the numerous cut, scrape and sawing marks are strong arguments for human activity (Noe-Nygaard 1969). The repeated pattern of the position of the cutmarks also diminish the obliteraty effect of *e.g.* trampling which in other cases may change or blurr clear cut marks (Behrensmeyer *et al.* 1986). Fig. 18 lists the taphonomic factors acting on a death assemblage the composition of which is determined by man. Food, tools and clothing are major purposes of killing the animals. In the following the results of the various procedures to which a killed animal may be subjected are analysed.

Food. When the butchering of a prey animal has taken place the odd pieces will probably be given to the dogs or just left where the animal was butchered as refuse. The rest of it, intended for consumption, would have to be prepared and eaten within a short time if it was not dried or smoked for later consumption. The bones from prepared food in most cases were exposed to marrow splitting before they were thrown away. This refuse may be deposited at several places (fig. 18). Firstly, in accumulations at a terrestric refuse heap, like the kitchen middens well known from Denmark (Madsen *et al.* 1900). Secondly, the refuse may be dumped in the neighbouring lake. Thirdly, the bones may be scattered around the site close to where they were eaten. Fourthly, the bones may have been thrown into the fire, where most of them would be totally destroyed. Only very few fire affected fragments are found on the sites. Burned bones are very fragile and porous and are easily destroyed. A considerable number is available only from burned bone tombs due to the immediate covering of the bones. If the bones are left either on a terrestric refuse heap or scattered around the site, scavengers like dogs, foxes and birds will have the opportunity of removing and destroying a greater part of the refuse. The refuse accessible but no longer attractive to scavengers and just lying around the site will be exposed to destruction by both mechanical and chemical weathering. Laboratory experiments showed that exfoliation was the first result of decalcification (Noe-Nygaard 1975 b).

The conclusion is that only the left-overs after meals that immediately are embedded in the lake sediments stand a chance of preservation. If the bones are uncovered for a period only a minor part of the fragments has a chance to reach the lake and the final embedding necessary for preservation for the benefit of the palaeobiologist.

Food and tools. The prey animals often serve multiple purposes to the stone age hunter. Raw material for tool processing is one of them. Antlers, metapodial bones, ribs and tibiae are the preferred bones for raw material. These parts will be removed from the rest of the animal either immediately after its death, i.e. the antlers, or after the meat has been eaten. The fragments resulting from tool processing consist of the finished implement, the waste products (Andersen 1971) and the unsuccessful attempts. The two last mentioned types of fragments would be exposed to the same destructive agents as the food remains mentioned above, while several alternative fates await the tool itself in addition to the above mentioned. It may be removed by its owner to a completely different place owing to his nomadic migrations or it could be used as a gift. The tool may be lost in a hunt or elsewhere; or it may be worn down and the stump thrown away. It is thus clear that the waste products and the discarded unsuccessful pieces stand a better chance of preservation at the site than the tool itself. Furthermore, the additional fragmentation owing to implement processing is likely to diminish the preservation potential making identification difficult or impossible.

In spite of the additional fragmentation it has been possible to retrieve and recognize waste products from

Fig. 19. Fragmentation pattern of metacarpus of aurochs from Star Carr. The view perpendicular to the long axis of the diaphysis of metacarpus shows the sawing marks made by Mesolithic man during the careful removal of the lower epiphysis. Note also the difference in outline of the fragments resulting from normal marrow fragmentation (figs. 21 and 24) and the outline of fragments resulting from tool processing.

the deposits. A good example is the fragments resulting from worked antlers described by Andersen (1971) and the often found lower joint neatly cut from the diaphyses of the metapodial bone (fig. 19). These types of fragments are found e.g. at Star Carr. The treatment of the various bones depends on the rôle they play for human beings. In cultures like the Hamburgian Culture where antlers are the only raw-material for implement processing, the treatment of the metapodial bones as well as the other bones will be very uniform. The fragmentation pattern of reindeer differs from that of the other deer (Møhl 1972). The special way of treating bones of reindeer is due to the very thin walls of the long bones which render them unsuitable as raw-materials for tools. The epiphyses are removed near the joint and the diaphysis remains as a tube from which the marrow is pushed or soaked out. In cultures where red deer, roe-deer and elk are the important game, the metapodial bones are treated in two ways depending on their use either as food or raw-material. When treated as food the bones are either broken rather carelessly as in Star Carr and Kongemosen (see below) or the joints are more carefully removed and the diaphyses are divided into two by series of laterally placed blows as is the case in Præstelyngen and Muldbjerg I (figs. 20 & 21). If the bones are treated as raw-material for tool processing the joints are removed and the diaphyses are parted carefully by groove cutting.

The various treatments give a variable number of fragments and increased possibilities for interpretations. From the Hamburgian Culture fragmentation produces three recognizable pieces and a few splinters. At the Kongemose and Star Carr sites fragmentation produces two recognizable fragments and a lot of splinters. In the Præstelyngen and Muldbjerg sites four recognizable pieces result from the fragmentation. If a bone such as metacarpus had been used for tool processing the recognizable fragments including the finished tool itself would be the same for all four sites, namely four.

Food and furs. Obviously fur and skin have been used for many purposes such as clothing, sleeping blankets and tent production. Skin has probably been used from both food animals and carnivores. It is difficult to prove this use of red deer, roe-deer, elk and aurochs because their remains always will have an overprint resulting from their main purpose as a food source. Bones of carnivores seldom show traces that can be interpreted as

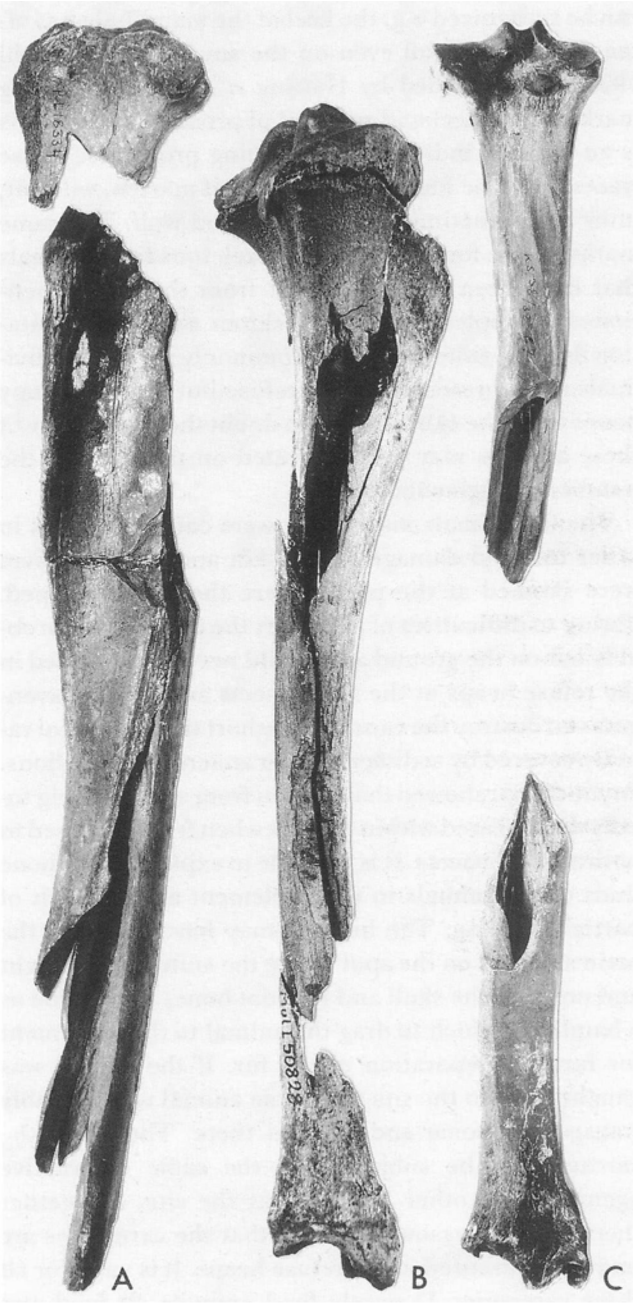


Fig. 20. Tibia from red deer from A: Præstelyngen; B: Muldbjerg; C: Kongemosen. Note the similarity in fragmentation pattern and resulting fragments in A and B as opposed to the fragmentation pattern in C. Size: A and B × ½, C × ⅔.

eating traces such as marrow fragmentation. However there are cases where repeated fragmentation pattern can be recognized e.g. the keel of the mandibula has often been broken off even on the small marten (Møhl 1972). As described by Hatting *et al.* (1973), cutting marks on the keel and removal of processus articularis is an obvious indication of skinning processes. These traces are to be found on craniums of marten, wild cat, otter and sometimes also on dog and wolf. The same marks can be found on modern skeletons from animals that have been skinned. Apart from the above mentioned examples carnivores seldom show fragmentation done by stone age man. Commonly very few individuals are represented in the refuse but often by many bones or by the skull alone. No doubt the importance of these animals may be underrated on the basis of the number of fragments alone.

The fur animals most likely were caught in traps in order to avoid damage to the skin and many of them were skinned at the place where they were trapped. Owing to difficulties of transport the carcase was probably left on the ground and would never be recorded in the refuse heaps at the site. Insects and other scavengers can destroy the carcase in a short time if it is not rapidly covered by sediment under anaerobic conditions. Payne (1965) showed that carrion from a juvenile pig totally disappeared within 24 days when freely exposed to both air and insects. It is possible to explain single bone finds of fur animals in the settlement as the result of partial skinning. The hunters may have removed the main skeleton on the spot where the animal was caught and only left the skull and the foot bones in the hide as a handle by which to drag the animal to the settlement for further preparation of the fur. If the animal was caught close to the site the whole animal was probably transported home and skinned there. Thereafter the carcase may be subjected to the same destructive agents as the other left-overs at the site. Altogether there is good reason to believe that the carnivores are under-represented in the refuse heaps. It is valid for all three categories 1) purely food animals, 2) food and implements processing, and 3) food and skinning, that the only part of the remains standing a good chance of preservation is the material that enters the lake without delay. If the bones are left around the site on dry land the chances for preservation are very greatly reduced. It is unlikely that the remains from the different activities were evenly scattered around the site; different places

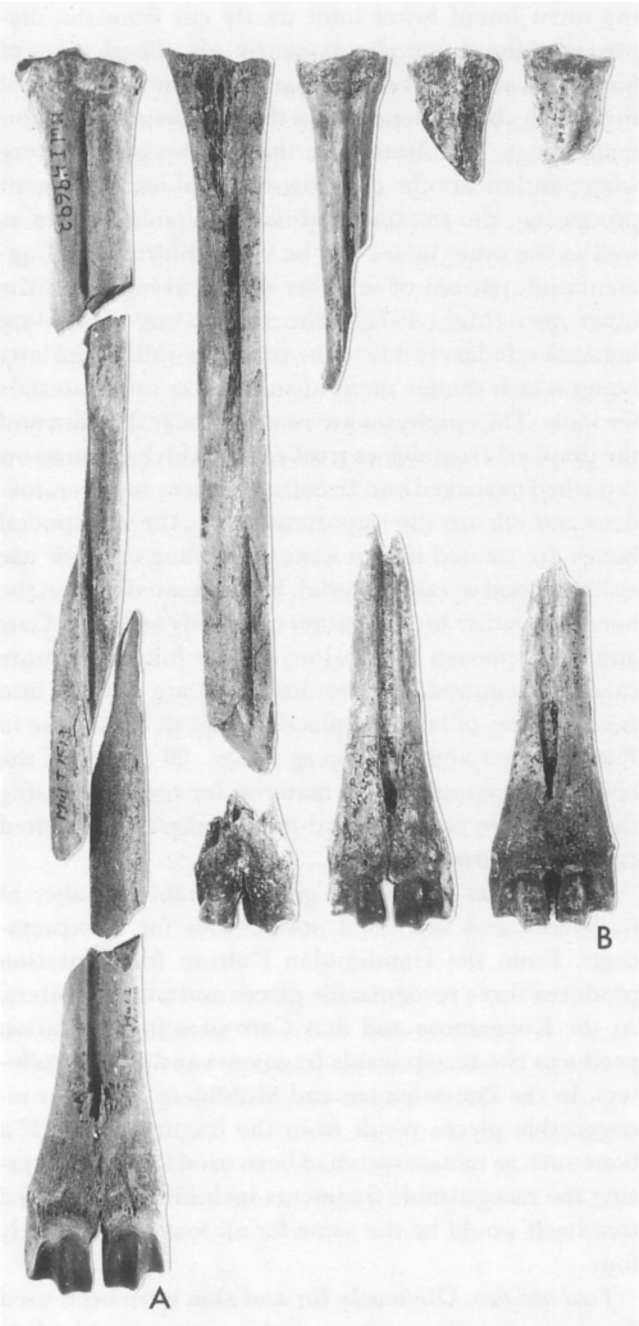


Fig. 21. Fragmentation pattern of metatarsus of red deer at Muldbjerg; A: Compare with the fragmentation pattern shown on fig. 24 and Præstelyngen; B: Compare also with the experimentally fragmented metapodium of roe deer (fig. 29). Size: × ½.

were probably used for different types of refuse. This seems to be the case of a number of settlements, *e.g.* Brovst.

When it has been killed, the common game animal is exposed to several different processes, two of which are butchering and marrow fracturing. First the prey is butchered, and later the bones are subjected to marrow fracturing, together with other destructive processes such as gnawing by dogs and burning. The refuse from the butchering probably went either directly into a lake or perhaps to the dogs. The nature of the applied marrow fracturing techniques and the relative importance of the processes are major factors in the preburial taphonomical history of the skeleton.

An analysis of marrow fracturing from various Mesolithic settlements from different periods is presented in the following section. Furthermore an evaluation is made of the taphonomic significance of different types of butchering and marrow fracturing techniques used by different cultures. This is particularly relevant since several authors (e.g. Uerpmann 1971, 1973; Clason 1967, 1972, 1974) have tried to estimate the original number of prey individuals on the basis of number of bone fragments without seriously taking the different butchering and marrow fracturing techniques into consideration. The various types of marrow fracturing found seem to belong to cultures at different technical levels. It would seem to be possible within a limited area such as northern Europe to establish a chronology using marrow fracturing type as an ecostratigraphic tool.

Before going any further it is necessary to define the three terms butchering, marrow fracturing and marrow splitting, as the last term especially has been applied to nearly all types of fragmentation.

Butchering is the cutting up of the animal while the meat is still attached to the bones, while marrow fracturing covers all the various processes by which the marrow is extracted, e.g. by cutting, beating, breaking, and crushing. Marrow splitting is a special case within the frame of marrow fracturing describing a process by which the bone is split longitudinally in two. The splitting is performed by a series of blows along the bone diaphysis after the meat has been scraped away. The term marrow fracturing carries no implication as to when the process took place in relation to the cooking of the meat.

The taphonomic model presented predicts that the number and kind of bones entering the burial stage at a site will depend on the butchering and marrow fracturing techniques applied by the inhabitant of the site. A further prediction is therefore that different cultures will produce different bone assemblages (Noe-Nygaard 1977).

MARROW FRACTURING IN THE MESOLITHIC

Material and methods

In the following account marrow fracturing techniques are compared from four Mesolithic bog deposits. These sites are: Star Carr (7500 ± 120 bc), Kongemosen (5600 ± 100 bc), Præstelyngen (3280 ± 100 bc), and Muldbjerg I (2900 ± 80 bc) (fig. 4), (Tauber 1970, 1972). The excavated material from the four sites was originally deposited in a lake close to the various habitations, embedded in gyttja (organic mud) with a minor content of calcium carbonate and drifted pieces of wood. The material is refuse from the settlements and was thrown into the lake which served as a dump. The bones do not seem to have lain scattered around the habitation for very long, since they bear little sign of physical destruction and wear. Gnawing marks occur on all four sites but few in quantity on the older sites. The bones seem have been thrown into the lake shortly after their use by humans ceased.

In the Danish material the state of preservation is extremely good, especially in the more calcareous layers of the bog deposits. Most of the bones are dark, hard and heavy and a large number of smaller fragments are preserved. However, where later postglacial humification has taken place, the bones have undergone some degree of decalcification and are very light and brittle and a light brown colour. In the Star Carr material many of the bones were in a very bad state due to decalcification and had to be impregnated with preservative simultaneously with excavation. In deposits where there has been decalcification, small fragments are almost lacking. The smaller the size of the fragments from the various marrow fragmentation processes the lesser the chance they stand of preservation in humified bog deposits. Their larger surface area exposed to dissolution leads to their more rapid dissolution. In Star Carr where the state of decalcification was most advanced very few small fragments were recorded. Also the

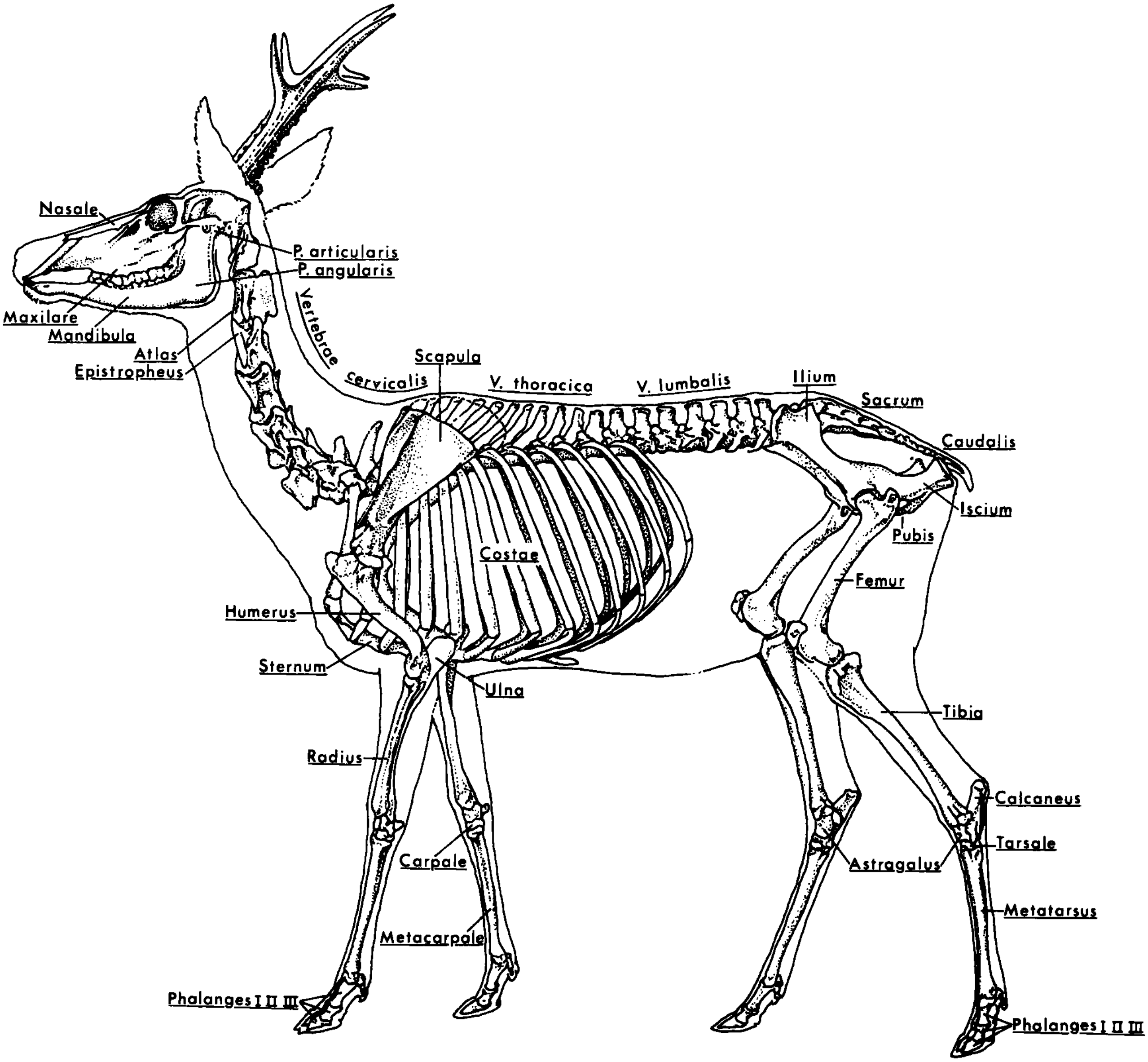


Fig. 22. Skeleton of roe deer with latin names on the various bone elements mentioned in the text.

possibility of overlooking small fragments is considerable, unless sieving techniques are used (Payne 1972). Even after the smaller fragments have been extracted, the possibility of identifying them to species and specific bone is limited and very time-consuming. Lyon (1970, p. 214) states that the destruction of bones by dogs on a site is the more complete the smaller the fragments. However, chewing marks are seen on the material from all four sites, so this can hardly be the only reason for the differences in number of small fragments recorded from the sites.

The fragments found in the refuse from the different sites are composed of a mixture of remains from meals, waste from implement production, and carcasses from skinned animals. The way in which the bones are reduced to fragments is determined by their use to man and to a certain extent by the structure of the bone. An example is illustrated by the material from the Palaeolithic Jaguar Cave (Idaho, USA) (Sadek-Kooros 1972, 1975). The outline of the illustrated bone fragments of metatarsus is very similar to that of the fragments found at both Star Carr and Kongemosen. In my opinion all of the fractures on the metatarsus described as primary from the Jaguar Cave (Sadek-Kooros 1975) and the similar fractures on the Kongemosen and Star Carr material were intentionally made in order to break the bone and get access to the marrow – in other words, were caused by marrow fracturing. The secondary fractures described by Sadek-Kooros (1975, p. 141), supposedly made to shape the primary fractures to some sort of an implement, do not alter the potential number of fragments per bone, nor do they unequivocally indicate the use of the fragment as a tool. A polish may be obtained in several ways, e.g. by serving as pavement on a floor.

Whether it is butchering, marrow fragmentation or implement production that determines the outline of the fragments is not so important, but fragmentation often seems to be uniform within a specific cultural group, and this may have wider implications.

The names of the various bones described below are shown in fig. 22.

Discussion and material of shed and unshed antlers from Starr Car has not been included in order to facilitate the comparison with Præstelyngen.

Bone material from Star Carr and Kongemosen

In the bone material from Star Carr (Clark 1954) which I had the opportunity to re-examine in 1974, the butchering technique and marrow fracturing was very uniform for the important game such as giant ox, elk, red deer, and roe-deer, whereas wild boar seemed to be butchered in a different way. The analysis of the technique used on the different bones will be exemplified by red deer.

Mandibles. – Forty-eight identified pieces, 23 from the right side, 15 from the left side, and from adult animals, plus two right fragments from juveniles. All of the mandibles were fragmented into 3–4 pieces (fig. 23). The fragment type most commonly found among the identified bones in the tooth-bearing part of the horizontal ramus, but several examples of the other fragment types occur among the unidentified bones.

Proceeding to the limb-bones, a characteristic pattern again emerges.

Humerus. – Twenty-three fragments including 2 which were decalcified and desiccated beyond further recognition, 10 dextral distal epiphyses, and 11 sinistral epiphyses. With very few exceptions (e.g. roe-deer), the humerus is represented by the distal part, the epiphyses, to-

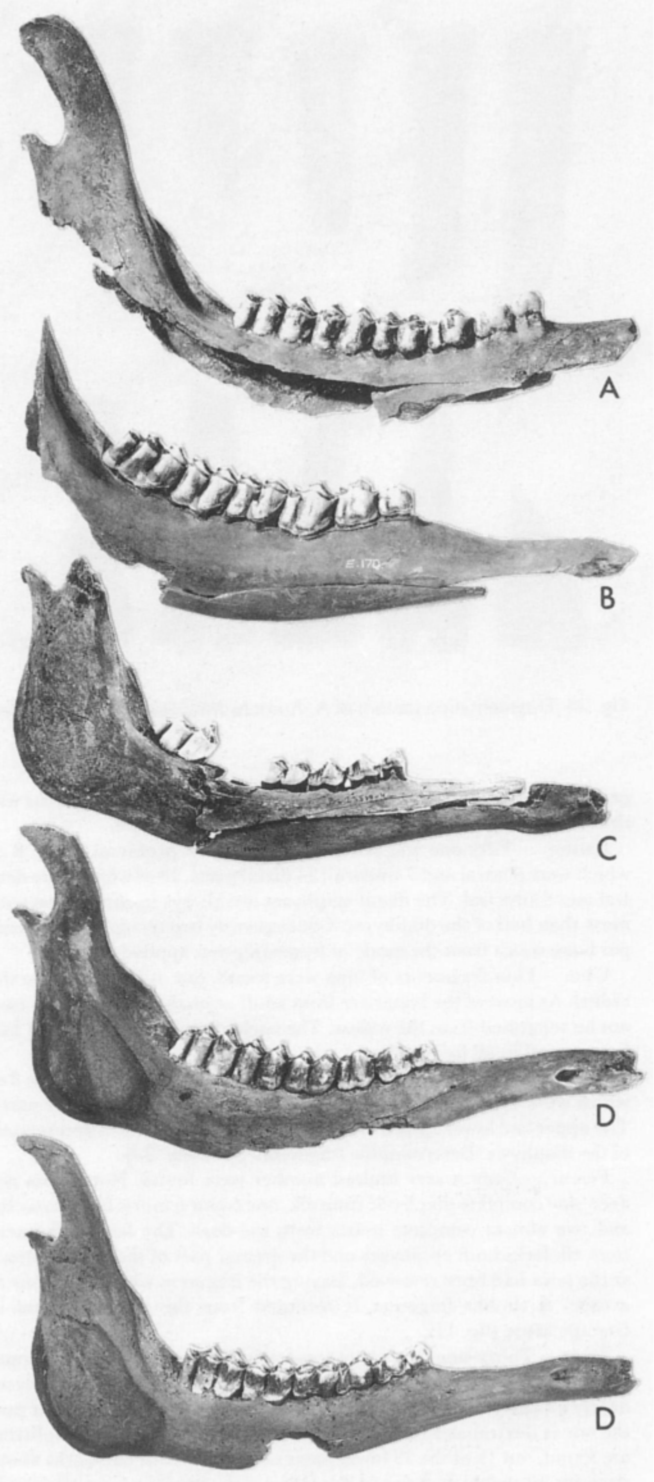


Fig. 23. Fragmentation pattern of the mandible of red deer from A: Kongemosen; B: Star Carr; C: Præstelyngen; D: Muldbjerg. For further explanation see the text. ⅓.

Fig. 24. Fragmentation pattern of A: Aurochs from Star Carr, and B: Red deer from Kongemosen. Size: A × ⅕–⅙, B × ¼.

gether with a greater or smaller part of the diaphysis. The humerus was thus divided into 2 to 3 recognizable fragments per bone.

Radius. – Fifty-one fragments comprising 17 proximal parts, 8 of which were dextral and 7 sinistral; 34 distal parts, 18 of which were dextral and 6 sinistral. The distal epiphyses are always in connection with more than half of the diaphyses. Consequently two recognizable pieces per bone result from the mode of fragmentation applied.

Ulna. – Four fragments of ulna were found, one still attached to the radius. As most of the bones are from adult animals, the diaphysis cannot be separated from the radius. The neck of the head of the ulna had been cut off in all four cases.

Metacarpus. – Fifty-eight fragments comprising 17 upper parts, 8 of which were dextral and 9 sinistral, and 9 sinistral, and 41 lower parts. The upper and lower epiphyses are always connected with a greater part of the diaphysis. Determinable fragments per bone: 2–3.

Femur. – Only a very limited number were found. None from red deer, one complete diaphysis from elk, one caput femoris from aurochs, and two almost complete bones from roe-deer. The femur fragment from elk lacks both epiphyses and the greater part of the spongy tissue at the joint had been removed, leaving the fragment with the outline of a tube. A similar fragment is recorded from the aurochs found in Grænge Mose (fig. 11).

Tibia. – Thirty-one fragments comprising 29 lower parts and 2 upper parts. The lower parts comprised 19 dextral and 10 sinistral epiphyses nearly all carrying a large part of the diaphysis. Of the two upper part the one is dextral and the other sinistral. No traces of marrow splitting are found, but 17 of the 29 lower parts carry numerous cut marks above the joint, probably deriving from cutting of the tendons in an attempt to separate the metatarsal bone from the tibial bone. There are two to three identifiable fragments per bone (fig. 20).

Metatarsus. – Fifty-seven pices, 38 of which are from the lower part and 13 from the upper parts (4 dextral and 9 sinistral). Six identifiable fragments of the diaphysis are recorded. Three of the lower parts belong to juveniles with loose epiphyses. All the upper or lower parts are connected with a greater part of the diaphysis. Maximum identifiable fragments are 2–3 per bone.

Rather few fragments of ribs and vertebrae are among the identified bones and no butchering or marrow fragmentation pattern is observed. The pelvic bones are all broken in the same way, and only the fragments around the acetabulum are found.

In the bone material from the early Atlantic settlement Kongemosen (5600 ± 100 bc), the butchering and the fragmentation technique employed was much the same as the one used at Star Carr (7500 ± 120 bc), compare fig. 24 and fig. 21. However, a few exceptions should be mentioned. The fracturing blow in the Star Carr material was placed on the lateral side of the diaphysis, while in the Kongemosen material the blow marks are most commonly situated on the front side or on the back side. The mandibles in the Star Carr material were fragmented in a basically uniform way (fig. 23), whereas the Kongemose mandibles were rarely fragmented, and when fragmentation occurred it was done in what looked as a casual manner. Later examinations revealed three types of repeated pattern of jaw fragmentation (Noe-Nygaard in press). The remains of the Star Carr wild boar are extremely fragmented and very few are identifiable: in total only 30 pieces, distributed over an estimated minimum number of five individuals. The only pattern observed is on the lower jaw bones where the incisional part of both left and right sides was cut off in the diastem between the canine teeth and the incisors. In the Kongemose material of wild boar the degree of fragmentation is much reduced compared with that of Star Carr. Furthermore, the modes of butchering and marrow fragmentation were the same for all of the game animals.

Bone material from Præstelyngen and Muldbjerg I

In the late Mesolithic (3280 ± 100 bc) site, Præstelyngen, the patterns of butchering and marrow fragmentation are different. The fragmentation technique employed on roe-deer follows that used on red deer, whereas the bones from the wild boar are extremely fragmented. In addition to the high degree of fragmentation of wild boar rather few fragments were retrieved; only 155 out of an estimated minimum number of 4 individuals. For comparison it should be mentioned that red deer is represented by 766 identified fragments with an estimated minimum number of 9 individuals. The most important game at Præstelyngen is red deer, roe-deer and wild boar. Red deer will again serve as an example.

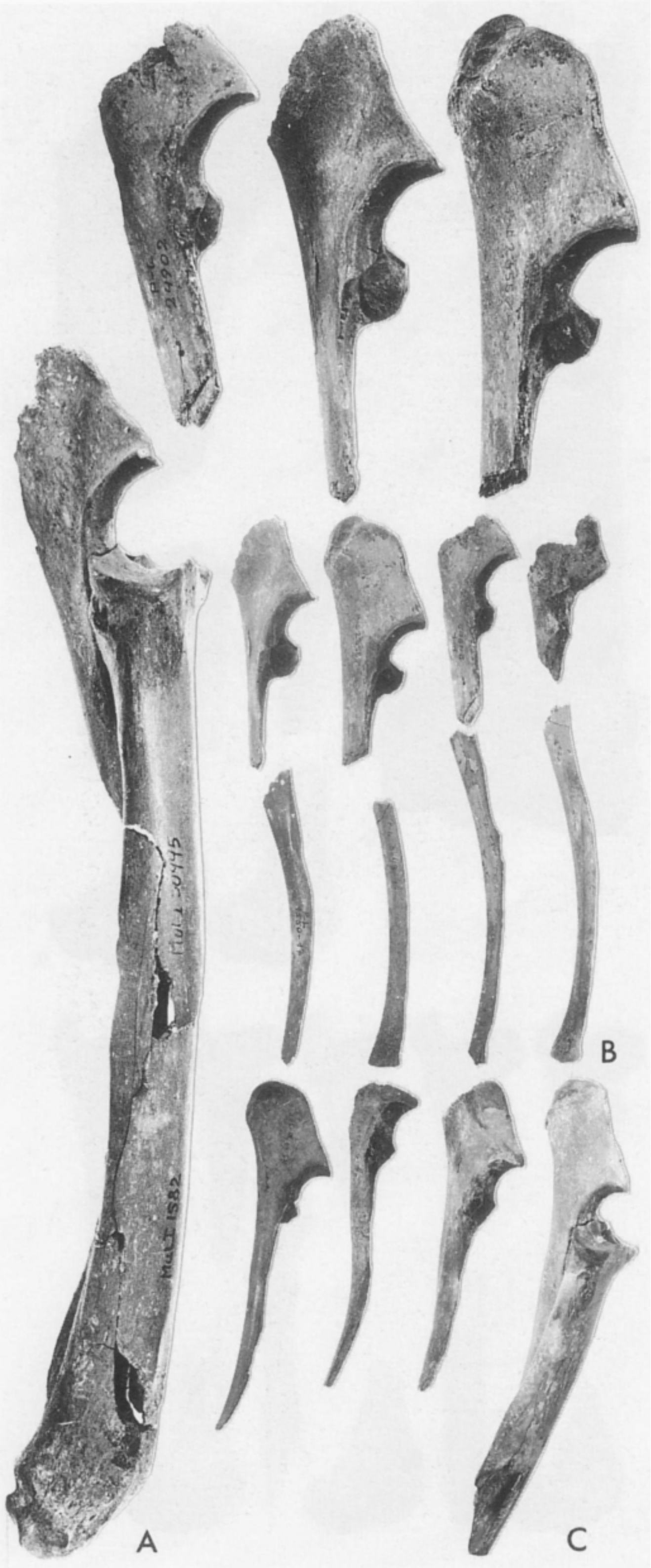
Mandibles. – Twenty-eight fragments, many of which should be reassembled, comprised dextral, 6 sinistral and 6 fragments which cannot be left/right identified. The mandibular bones were always broken into 3–4 pieces by a hard blow on the horizontal ramus just below the second and third molars. One typical fragment comprises the processus articularis together with the jaw containing the last two molars (fig. 23).

There is a second type in which the horizontal ramus is divided horizontally into two pieces and finally, in a few cases, the incisor region is broken off. Reassembling and gluing the fragments together leads to a better understanding of the mode of fragmentation. The jaw bones belong to animals ranging in age from 3 months to fully grown.

Humerus. – Twenty-seven fragments comprising 6 proximal ends (3 dextral and 3 sinistral), and 10 distal ends (5 dextral and 5 sinistral) together with 11 fragments of the diaphysis, 8 of which can be identified as to side (5 dextral and 3 sinistral). The number of determinable fragments per bone is 3–4. These had been produced by removal of the proximal and the distal epiphyses and division of the diaphysis laterally into two by blows along the shaft of the bone (fig. 25).

Radius. – Seventeen fragments comprising 6 distal parts (5 dextral and 1 sinistral) and 1 proximal part from the left side. From the diaphysis 10 fragments are identified, 8 of which comprise 3 dextral and 5

Fig. 25. Fragmentation pattern of humerus of red deer from A: Kongemosen; B: Præstelyngen. Note the difference in outline of the fragments. Size: The enlargement × ¾, A and B × ¼.



sinistral pieces, and two fragments which cannot be specifically assigned to a side. The radius was fragmented by removal of the proximal end and then splitting along the diaphysis which was still attached to the distal epiphysis. Traces of the splitting, which took place by means of a series of blows along the shaft of the bone, can still be seen on the fragmenting leaves us with 3 identifiable pieces.

Ulna. – Eleven fragments comprising 7 proximal ends (2 dextral and 5 sinistral) and 5 fragments of the diaphysis (2 dextral and 3 sinistral). The ulna is normally represented by two types of fragments, the head and the shaft. Juvenile ulnae are separated from radii whereas adult diaphyses remain fused with the radii (fig. 26).

Metacarpus. – Fifteen fragments comprising 7 proximal ends (6 dextral and 1 sinistral) and 7 distal ends with diaphyses (5 dextral and 2 sinistral) plus 1 fragment of the diaphysis. The normal number of fragments per bone is 2–3 and the fragmentation was carried out in the same way as in the material from Kongemosen; the distal epiphysis was removed and the diaphysis and proximal epiphysis were split. Clear striking marks are seen along the diaphysis.

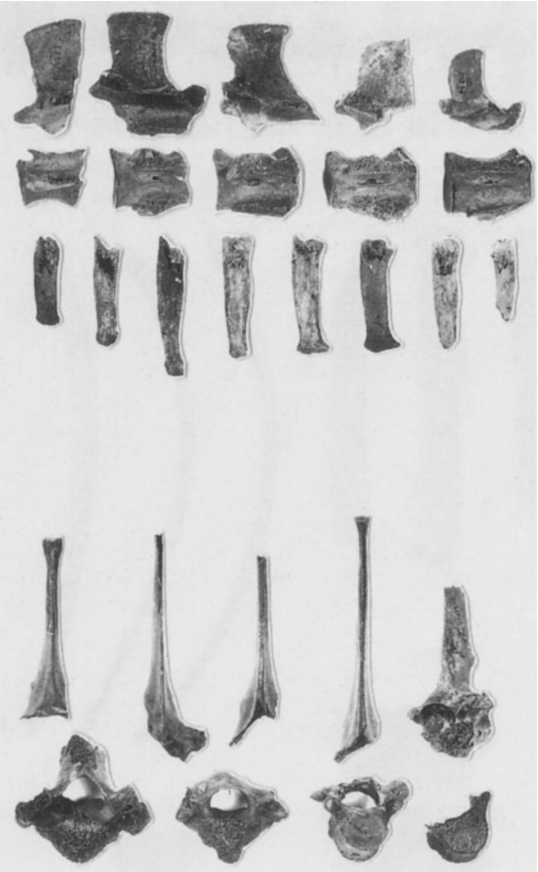
Femur. – Twenty-seven fragments comprises 3 proximal ends (1 dextral and 2 sinistral), 5 distal ends (4 dextral and 1 sinistral), and 14 fragments of the diaphyses (8 dextral and 6 sinistral) together with 5 pieces that cannot be classed with a specific side. The femur was parted into 4 identifiable fragments: a distal end, a proximal end, and two laterally split fragments of the diaphysis.

Tibia. – Fifty-one fragments comprising 7 proximal ends (5 dextral and 2 sinistral) and 5 distal ends (4 dextral and 1 sinistral). In addition 31 fragments of diaphyses (15 dextral and 16 sinistral) and 10 fragments of diaphyses, which cannot be assigned to any specific side, are recorded. The tibia was divided into 4 identifiable fragments: upper and lower ends and two longitudinally split fragments from the diaphysis (fig. 20).

Metatarsus. – Eighteen fragments comprising 4 proximal ends (2 dextral and 2 sinistral) and 5 distal ends (2 dextral and 3 sinistral). 9 diaphysial fragments, 5 from the dextral side and 3 from the sinistral side, with one not assignable to either side. The metatarsal bone was parted into 3–4 identifiable pieces as opposed to the metacarpal bone. In many cases both the upper and lower ends were cut off.

At the settlement Muldbjerg I, 200–300 years younger, which was inhabited in the period just at the Mesolithic/Neolithic transition, we find a pattern of butchering and marrow fragmentation which is very similar to the pattern found at Præstelyngen. The same pattern also applies to the skeletal part of the few fragments of domesticated animals found at Muldbjerg I. The similarity in butchering technique might indicate that no major change in food preparation took place at the Mesolithic/Neolithic transition and the people inhabiting the two sites may have belonged to the same ethnic group. However, the material is too limited to allow this conclusion before more dated settlements have been examined.

Fig. 26. Fragmentation patterns of ulna of red deer from A: Muldbjerg; B: Præstelyngen; C: Kongemosen. Note the completeness of the reconstructed radius and ulna from Muldbjerg. Size: A × ⅗, B and C × ½.



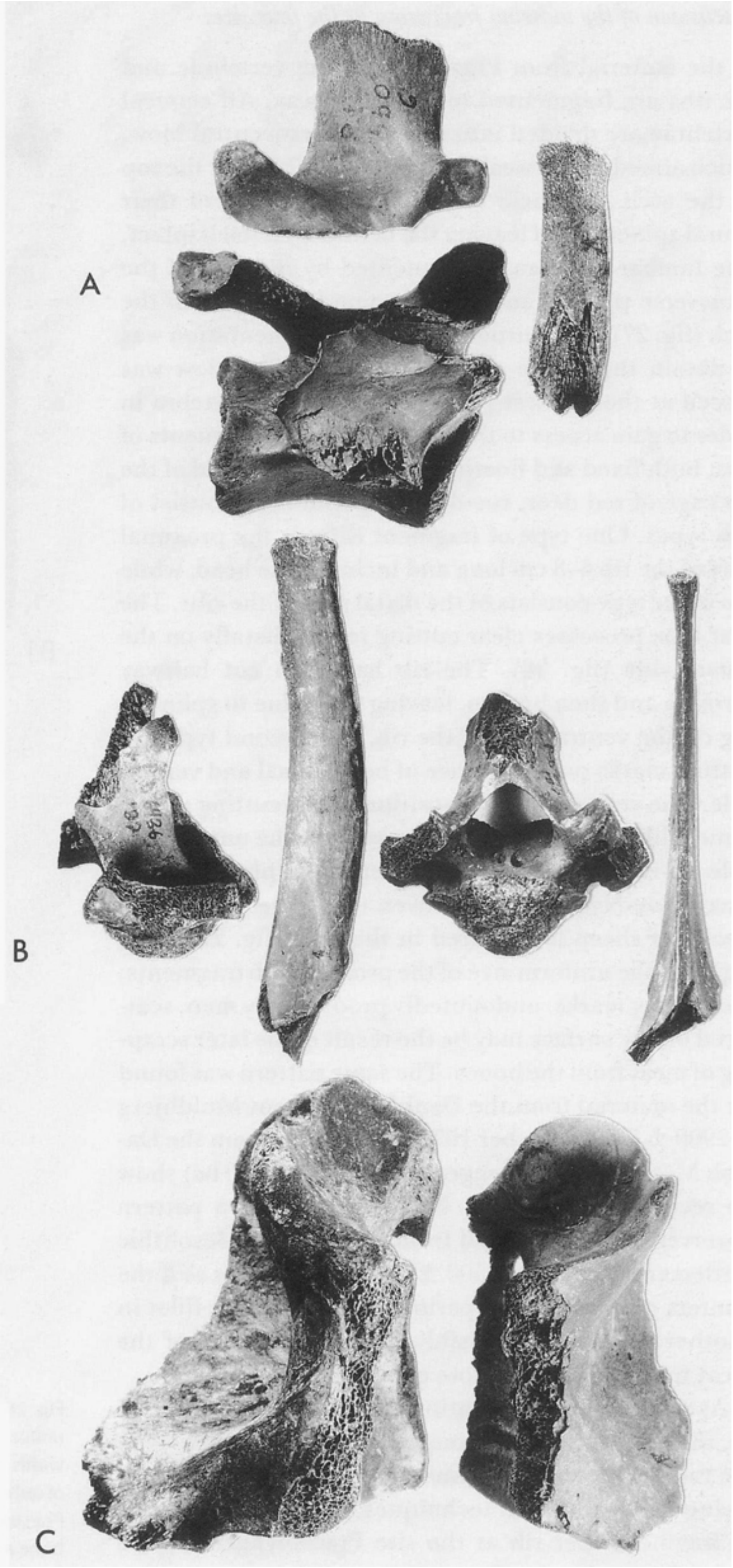


Fig. 27. C: Fragmentation pattern of vertebrae cervicalii of red deer from Præstelyngen. B: Fragmentation pattern of vertebrae thoracicae of red deer from Præstelyngen. C: Fragmentation pattern of vertebrae lumbalii of red deer from Præstelyngen. Size: C × 1.

Discussion of the marrow fracturing at the four sites

In the material from Præstelyngen the vertebrae and the ribs are fragmented in a specific way. All cervical vertebrae are divided into two by a dorsoventral blow, which aimed at the weakest point of the bone at the top of the arch. Thoracic vertebrae are relieved of their neural spines, often leaving the neural arch itself intact. The lumbar vertebra is fragmented by removal of the transverse process and neural spine together with the arch (fig. 27). The purpose of all this fragmentation was to obtain the edible medulla spinalis. The blow was placed at the weakest point of the specific vertebra in order to gain access to the spinal marrow. Fragments of ribs, both fixed and floating, from the caudal end of the rib cage of red deer, roe-deer and wild boar consist of two types. One type of fragment is from the proximal part of the rib 6–8 cm long and includes the head, while the other type consists of the distal part of the ribs. The first type prosesses clear cutting marks distally on the dorsal side (fig. 28). The rib has been cut halfway through and then broken, leaving scars due to splintering on the ventral side of the rib. The second type has cutting marks on the surface of both dorsal and ventral side. The very consistent position of the cutting marks is most likely due to the need to remove the unmanageable rib-ends just beyond the fillet before preparing the meat (Noe-Nygaard 1969). Even today the "back bone steak" of sheep is prepared in this way (fig. 28). This explains the uniform size of the proximal rib fragments; the cutting marks, undoubtedly produced by man, scattered on the surface may be the result of the later scraping of meat from the bones. The same pattern was found on the material from the Danish settlement Muldbjerg I (2900 ± 80 bc; Tauber 1970, 1972). Ribs from the Danish Mesolithic site Kongemosen (5600 ± 100 bc) show no recognizable pattern. Neither was such a pattern observed on the material from the English Mesolithic settlement Star Carr (7500 ± 120 bc). It seems as if the hunters of these earlier periods prepared their fillet in another way, which possibly involved removal of the meat from the bones before cooking.

As no actual fragmentation of the ribs has taken place, the fragments from Kongemosen and Præstelyngen are rather large and determinable to species. However, owing to the different techniques applied, the number of fragments per rib at the site Præstelyngen will be twice that at the site Kongemosen.

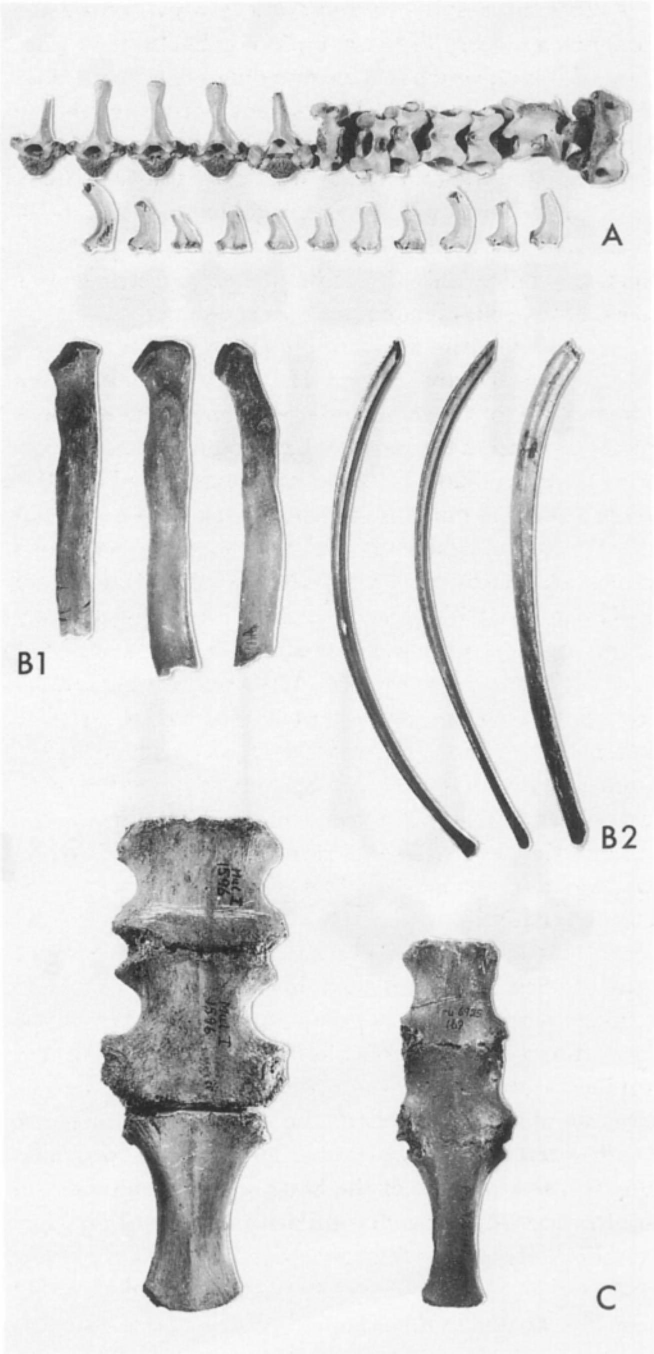


Fig. 28. A: Left over of meal year 1986 of sheep neck and back. Note the uniform length of the rib fragments. The length of the ribs indicate the width of the sirloin along the backbones. B: Fragmentation pattern of ribs of red deer from Præstelyngen. C: Sternum of red deer and roe deer from Præstelyngen. Note the uniform position of strong cut marks on both bone elements resulting from similar butchering techniques at the two sites. Size: $B_1 \times \frac{1}{2}$, $B_2 \times \frac{1}{4}$, $C \times \frac{1}{2}$.

A possible result of butchering is provided by the common recovery of the complete collections of phalangeal bones, which may be due not only to their more solid structure but also to the butchering technique applied; one of several possible explanations is that the distal ends of the limb bones were removed at an early stage of the cutting-up of the animal and were thrown away into the adjacent lake. The head had probably been cut off at an early state as well; cutting marks across the occipital condyles may indicate this.

To sum up, the marrow fracturing technique employed at Star Carr (7500 ± 120 bc) and Kongemosen (5600 ± 100 bc) is very similar while it differs in nearly all respects from the pattern found in the material from Præstelyngen (3200 ± 100 bc) and Muldbjerg I (2900 ± 80 bc). No real marrow splitting of the limb bones has taken place at Star Carr and Kongemosen. The long bones are nearly all represented by upper and lower ends together with greater parts of the diaphysis; fragments of diaphyses were recorded in only a very few cases. These fragments either were not produced by marrow fracturing, were lost during diagenesis, or escaped recovery because of small size. Nevertheless, even if all the fragments had been found, for example by use of the unusually detailed and meticulous excavation methods practised by Troels-Smith (1957) or by sieving methods, they would have been extremely difficult to identify.

At Præstelyngen and Muldbjerg I the limb bones are each divided into 3–4 identifiable parts, often as a result of marrow splitting: an upper, a lower, and at least two larger fragments of the diaphysis. In contrast to this dissimilarity of fragmentation of most bones, one exception should be mentioned: the metapodial bones are fragmented in a similar way at all four sites, probably due to the structure of the bone and its usefulness in tool processing. The dissimilarity between Star Carr and Præstelyngen in fragmentation of ulnae is merely a question of the ontogenetic age of the captured animal (fig. 26). Fusion of the ulna to the radius takes place after 36 months in red deer. The fact that the average age of the animals at Star Carr seems to be higher than the average age of the animals at Præstelyngen fits well with the supposed different targets of the people of the two settlements. Star Carr is considered to be primarily an autumn/winter settlement and/or hunting site where the hunters concentrated on antlers as raw material for tool processing and, of course, on a meat supply (Clark 1954, 1972; Noe-Nygaard 1975a), whereas Præstelyngen was a summer hunting and fishing settlement, which produced a number of juvenile red deer bones (Noe-Nygaard 1969, 1977).

Although the number of investigated sites is limited, it seems to be confirmed that 1) the number and kind of bones entering the burial stage at a site depends on the butchering and marrow fracturing technique applied, and that 2) the style of marrow fracturing and butchering do change between the different cultures whereas they are almost uniform within the same culture. Therefore, the patterns of marrow fracturing and butchering have considerable potential as ecostratigraphical tools. Binford (1981) suggested that the difference in marrow fracturing at the four sites exclusively was due to differences in the function of the sites.

Experimental marrow fracturing

In order to throw light on the differences and similarities in marrow fracturing at the four sites some experiments with modern material have been undertaken.

A roe-deer carcass was butchered and the limb bones were separated at the joints. The majority of the experiments were performed before any cooking took place and while most of the meat was still attached to the bones. The front limb bones were marrow fractured by blows inflicted with a stone having the shape of a *coup de point*. The hind limb bones were fractured by holding the bone by one end and beating it against a hard object of wood or stone using it as a club. It turned out to be difficult to place the blows on the stone accurately within a definite area owing to the protection of the meat and sinews and the elasticity of the fresh bone. The position of the break on the humerus was furthermore rather unpredictable. The radius and ulna were strongly fused along the diaphysis and only the proximal end of the ulna could be broken off. Later, when cooked and dried, marrow splitting of the radius was attempted by a series of blows along the diaphysis, but produced negative results. Similarly it was attempted to marrow-split the fresh metacarpal bone with a series of blows along the diaphysis, but it was found almost impossible to place the blows precisely on the bone as the stone slipped on the bone membrane. When the bone finally broke, the position of the fracture was unpredictable. The femur was fractured by striking the bone on a hard object. In this case the position of the fractures was easier to determine and the break was predictable (fig. 29). The tibia was broken in a similar way, placing the impact of the blow just below the attachment of the larger muscles. The fracturing resulted in two fragments, an upper end and a lower end in connection with a larger part of the diaphysis and a few minor fragments (fig. 29). The metatarsal bone was broken in a similar way (fig. 29). Many of the metapodial bones at the four above-mentioned sites were split along the diaphysis and included splitting of the upper epiphysis. Splitting of modern metapodials of roe-deer and sheep was therefore attempted by means of a blow placed on the surface of the upper joint. This resulted in a splitting of the bone into two fragments with an outline similar to the fossil fragments.

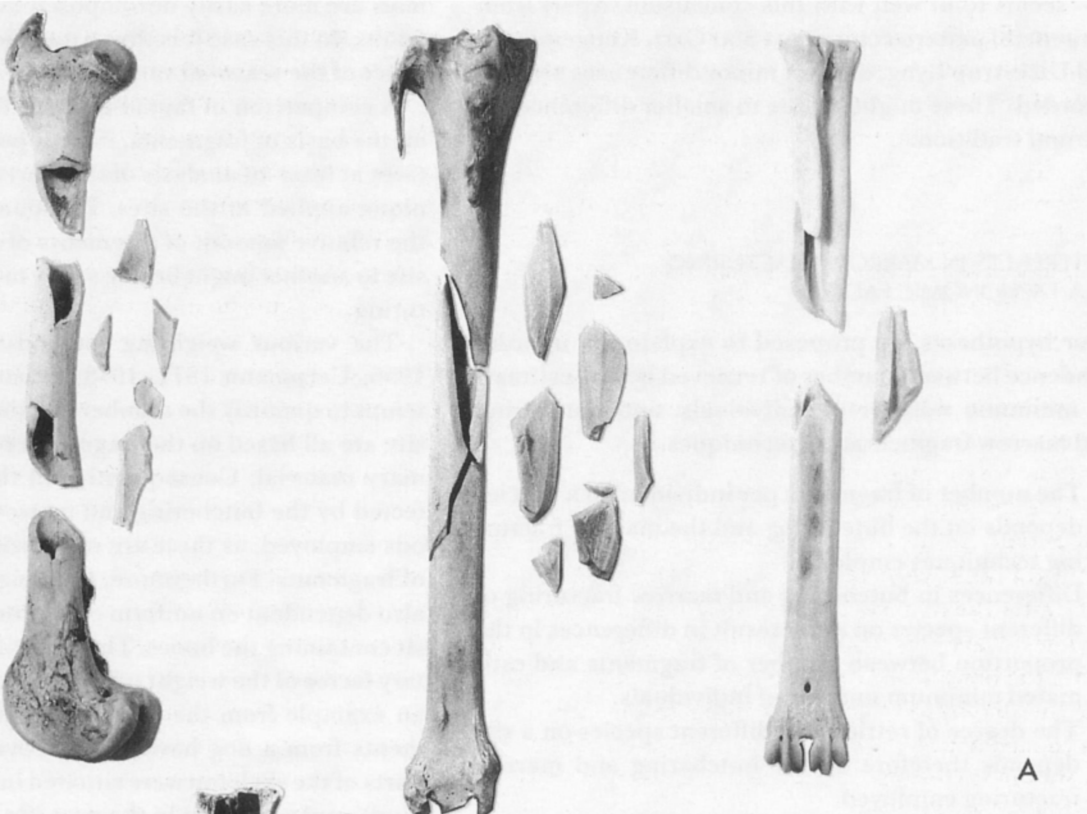
The experiments led to the following conclusions. The actual splitting of the bone of the diaphysis as found at Præstelyngen and Muldbjerg I most likely took place after the removal of the meat, for this would have been necessary to get access to the diaphysis in order to divide the bone along its full length. The habit of splitting the diaphysis might then indicate that the meat was cooked before dividing the bone. When cooked, the membrane surrounding the marrow tends to adhere to the inner side of the bone wall. To split the bone would therefore be a reasonable way to gain access to the marrow of the diaphysis in order to scrape it out. When reindeer bones are fractured, the large diameter of the marrow cavity renders it unnecessary to break the diaphysis as the marrow can be pushed out of the tube (Ulrik Møhl, pers. comm. 1972). The fragments from Star Carr and Kongemosen show no sign of splitting and are composed of lower ends and upper ends with larger parts of the diaphysis much like the fragments derived from the experiment. They could have resulted from removal of part of the bone before cooking. Breaking of the bone before cooking has two advantages, firstly the raw marrow is easy to pull out and secondly the steaks will be of a more manageable size without the lower, sparsely meat-covered end.

Assuming that the above hypothesis for the genesis of the fragments produced at the four sites is acceptable, it would then be interesting to know if differences in the marrow fracturing were consistent within an ethnic group and different from that of other ethnic groups. In this connection it is of great importance that both cases of assumed pre-cooking fracturing belong to cultures with no recorded ceramics. In contrast the assumed post-cooking fracturing was found in cultures possessing ceramics. In cultures without ceramics, roasting of meat has probably been the more common way of food preparation although the small number of burnt fragments including epiphysial parts of the bones from the excavations might indicate application of other methods in food-processing, such as boiling, drying and smoking. Cooking could have taken place by heating stones and dropping them into water held in a skin bag or a wooden container. The insignificant number of burnt bones at the sites might be due to other reasons: they are less resistant to weathering and in some cases they might have burnt away completely. Therefore, lack of burnt bone material does not necessarily indicate boiling as a food preparation method, but roasting is not likely to have been the only method employed at the sites Star Carr and Kongemosen.

If we assume that boiling has been one way of cooking in the aceramic periods, and if boiling has taken place by use of hot stones, the size of the steak will have a certain importance. Firstly, the size of the container in which the cooking takes place determines the size of the meat to be boiled, and secondly, it is easier to heat water in small containers. A reasonable way to reduce the size of a steak containing a bone such as a tibia, femur or humerus would be to remove before cooking the part of the bone which is sparsely covered with meat. The resulting fragments from such a procedure would correspond to many of the fragments found at Star Carr and Kongemosen. A number of the fragments will even have the outline of fragments resulting from modern butchering.

I conclude that the main pattern of marrow fracturing at Star Carr and Kongemosen was determined by pre-cooking marrow fracturing to reduce the size of the steak suitable for cooking. A superficial examination of the bone material from Ulkestrup Lyng – a Danish bog site from the Maglemosian culture dated to 6100 bc (fig.

Fig. 29. A: Femur, tibia and metatarsus of a modern roe deer fragmented by striking it on a hard table. Note the type and number of possible identifiable fragments. B: Humerus, metacarpus, ulna and radius of a modern roe deer fragmented by a chisel-pointed stone. Note the number and outline of identifiable fragments. Size: × ½.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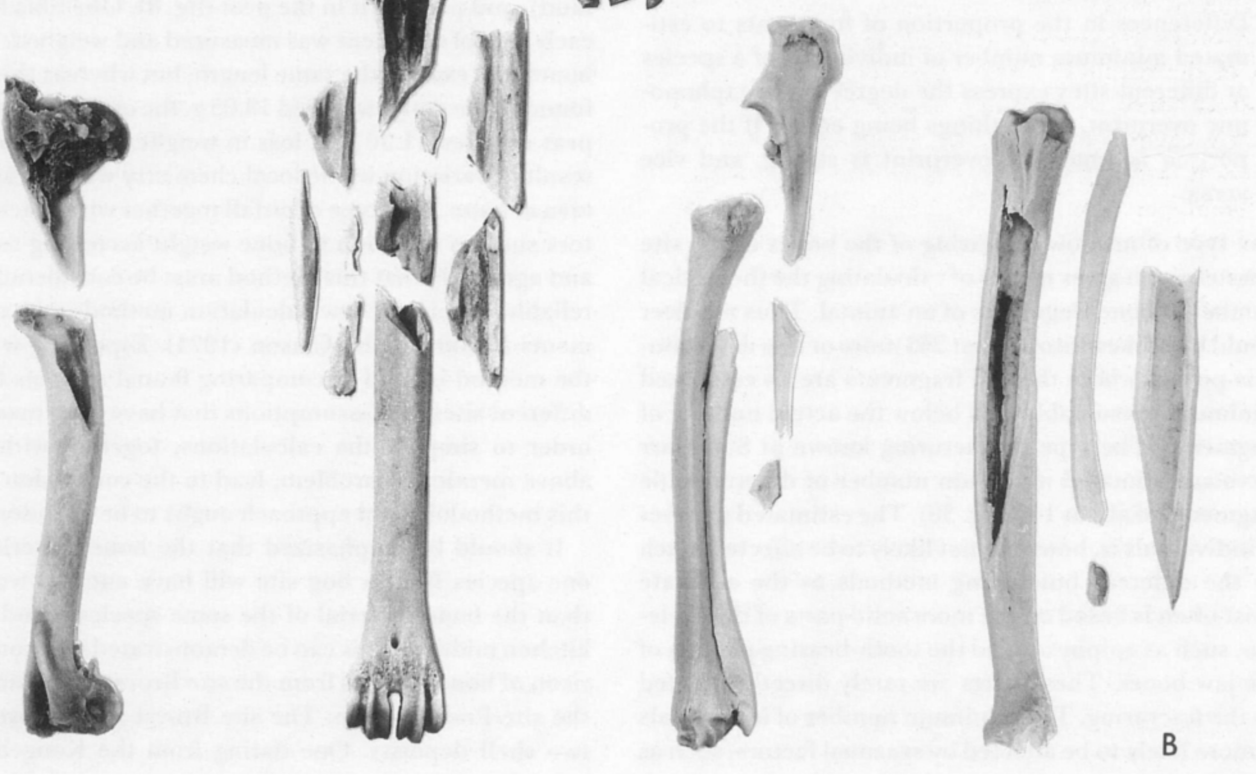
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4) – seems to fit well with this conclusion. Apart from the general pattern common at Star Carr, Kongemosen, and Ulkestrup Lyng, distinct minor differences are also recorded. These might be due to smaller differences in cultural tradition.

DIFFERENCES IN MARROW FRACTURING AS A TAPHONOMIC FACTOR

Four hypotheses are proposed to explain the interdependence between number of retrieved bones, estimated minimum number of individuals, and butchering and marrow fragmentation techniques.

1. The number of fragments per individual of a species depends on the butchering and the marrow fracturing techniques employed.
2. Differences in butchering and marrow fracturing of different species on a site result in differences in the proportion between number of fragments and estimated minimum number of individuals.
3. The degree of retrieval of different species on a site depends therefore on the butchering and marrow fracturing employed.
4. Differences in the proportion of fragments to estimated minimum number of individuals of a species at different sites express the degree of the taphonomic overprint, other things being equal. If the proportion is small the overprint is strong, and vice versa.

The type of marrow fracturing of the bones at the site Præstelyngen gives means of calculating the theoretical number of bone fragments of an animal. Thus red deer would be broken into at least 263 more or less determinable pieces, where the 263 fragments are an estimated minimum presumably well below the actual number of fragments. The type of fracturing known at Star Carr gives an estimated minimum number of determinable fragments of about 146 (fig. 30). The estimated number of individuals is, however, not likely to be affected much by the different butchering methods as the estimate most often is based on the more solid parts of the skeleton, such as epiphyses and the tooth-bearing portion of the jaw bones. These parts are rarely directly affected by the fracturing. The minimum number of individuals is more likely to be affected by seasonal factors, such as differences in age of the animals. Bones from young animals are more easily decomposed than the bones from adults. In this case it is thus a question of analyzing the effect of the seasonal variation.

A comparison of faunal remains from different sites on the basis of fragments, if at all permissible, necessitates at least an analysis of the marrow fracturing technique applied at the sites. Pronounced differences in the relative amount of fragments of a species from one site to another might be due solely to differences in fracturing.

The various weighting methods (*e.g.* Kubasiewicz 1956; Uerpmann 1971, 1973; Clason 1971) which attempt to quantify the number of animals butchered at a site are all based on the fragments retrieved as the primary material. Consequently, all the methods are affected by the butchering and marrow fracturing methods employed, as these are responsible for the number of fragments. Furthermore, the weighting methods are also dependent on uniform conditions within the deposit containing the bones. The influence of this sedimentary factor of the weight of bones can be illustrated with an example from the site Præstelyngen. Skeleton elements from a dog have been recovered from the site. Parts of the skeleton were situated in the gyttja (organic mud), and parts of it in the peat (fig. 8). One tibia from each type of sediment was measured and weighed. The bones had exactly the same length, but whereas the one found in the gyttja weighed 18.05 g, the one found in the peat weighed 11.30 g. A loss in weight of 83% is thus a result of variation in the local chemistry within a small area at a site. This type of pitfall together with other factors such as variation in bone weight according to sex and age imply that this method must be considered unreliable in spite of new calculation methods and arguments introduced by Clason (1974). Especially where the method is used in comparing faunal remains from different sites, the assumptions that have to be made in order to simplify the calculations, together with the above mentioned problem, lead to the conclusion that this methodological approach ought to be abandoned.

It should be emphasized that the bone material of one species from a bog site will have another weight than the bone material of the same species found at a kitchen midden. This can be demonstrated by a comparison of bone weights from the site Brovst with those at the site Præstelyngen. The site Brovst is composed of two shell deposits. One dating from the Kongemose culture and one from early Ertebølle culture (Andersen

	No.	Præstelyngen	Star Carr
Calvarium	1	1 x 10 = 10	1 x 10 = 10
Mandibula	2	2 x 4 = 8	2 x 1 = 2 (8)
Vertebrae	24	3 x 12 + 2 x 12 = 60	24 x 1 = 24
Costae	28	2 x 28 = 56	1 x 28 = 28
Femur	2	2 x 4 = 8	2 x 2 = 4
Tibia	2	2 x 4 = 8	2 x 2 = 4
Humerus	2	2 x 4 = 8	2 x 2 = 4
Radius	2	2 x 3 (4)= 6-8	2 x 2 = 4
Ulna	2	2 x 2 = 4	2 x 2 = 4
Fibula	2	2 x 1 = 2	2 x 1 = 2
Acetabulum	2	2 x 3 = 6	2 x 1 = 2 (6)
Sternum	1	1 x 1 = 1	1 x 1 = 1
Scapula	2	2 x 1 = 2	2 x 1 = 2
Sacrum	1	1 x 2 = 2	1 x 1 = 1
Metacarpus	2	2 x 3 = 6	2 x 3 = 6
Metatarsus	2	2 x 4 = 8	2 x 3 (2)= 4-6
Tarsal	5	5 x 2 = 10	5 x 2 = 10
Carpal	5	5 x 2 = 10	5 x 2 = 10
Phalanges	12	12 x 4 = 48	12 x 2 = 24
Total		263	146

Fig. 30. The calculated number of fragments of each type of bone of a *Cervus elaphus*, at Præstelyngen and at Star Carr. The difference in number of fragments at the two sites is due to the difference in marrow fracturing technique used at the two settlements.

1971). The bones from Brovst are about half as heavy as the bones found in gyttja at Præstelyngen and Kongemosen whereas the bones found in the peat at Kongemosen have more or less the same low weight as those from the shell deposit at Brovst. At the Brovst site the organic collagen fibers have been removed, and in spite of the calcium rich milieu, the inorganic calcium hydroxyl apatite is decomposed by transport of material and mechanical weathering. The exchange of material and transport of $CaCO_3$ in solution is a well-known process causing problems when shells are used for ^{14}C dating. In that case, removal of up to 50% of the outer part of the shells is necessary to minimize contamination with modern CO_2. The surface of the bones becomes porous and chalky and the characteristic features like muscle attachments and joints are obliterated, rendering identification difficult.

However, in cases of careful excavation or where the sieving method is applied, it might be of interest to know the weight of the identified bones as opposed to the weight of unidentified bones. The percentage weight of unidentified bones to identified bones gives a better impression of their relative importance than does their number. The tiny, mostly unidentified fragments retrieved by the sieving method will constitute in terms of number of fragments a considerable percentage of the total number of identified fragments. The figures from Præstelyngen will serve as an example. The total number of identified fragments from mammals is 1,185, and the number of unidentified fragments is 357, amounting to 30.1% of the total number of fragments – a rather high proportion. Using the weight of bones, the percentage is very different. The total weight of fragments of identified mammal bones is 11,368 g while the weight of unidentified bones is 540 g. The percentage of unidentified bones is 4.5%. The two percentages show that the unidentified fragments are very small, but that they occur in great numbers. Both percentages ought to be given in order to present a full picture of the excavated material.

At the two sites – Star Carr and Præstelyngen – the degree of fragmentation of the wild boar bones was much higher than that of cervid bones. At Præstelyngen the proportion of NF (number of fragments) to EMNI (estimated minimum number of individuals) for wild boar is 39 (NF 155: EMNI 4) as opposed to 85 (NF 766: EMNI 9) for red deer (fig. 32). At the Muldbjerg I site this proportion for red deer of the same age is 81 (NF 243: EMNI 13), whereas only one pig bone has been recorded so far. Turning to Star Carr the proportion for red deer amounts to 23 (NF 588: EMNI 25), and only six for wild boar (NF 30: EMNI 5). As the depositional environments were much the same at Præstelyngen and Star Carr, and as the bone structures of wild boar and red deer do not differ very much, the small number of wild boar bone fragments at both sites cannot be ascribed to diagenetic factors. No obvious explanation can be given, but a few hypotheses will be discussed.

The relatively short, curved diaphysis of the limb bones of the wild boar does not make them suitable for implement processing; this could have resulted in a more careless fragmentation of the bones. Furthermore, the bones are at least as solid as the bones of red deer and being shorter than those of red deer they are more difficult to break. This might have led to a more violent fracturing of the bone, resulting in smaller fragments. The bones might have been smashed up for fat extraction by boiling. If we assume that wild boar bones really were more strongly fragmented than bones from other animals, the loss of bone material might be greater owing to the easier decalcification of the smaller fragments. Finally, the cartilaginous parts of wild boar bones comprise more of the total bone as compared to cervid bones. These soft part of the bone in particular were subjected to chewing by dogs, just as may be observed in modern cases where dogs often eat almost the whole of a pig bone, leaving only small parts of the diaphysis.

Another explanation worthy of consideration is selective meat storage for later consumption. This might lead to removal of meat from the site. But often the excavated fragments are so few in number that no indication of selective meat removal can be found. In addition, it should be emphasized that decomposition is accelerated by fat. The boar is a fat animal as opposed to red deer and roe-deer (Rolfe & Brett 1969). The absence of brittleness of bones in and around adipose tissue in preserved fossils has been explained by decalcification brought about by the fatty acids (Rolfe & Brett 1969). Thus, deficiency of wild boar bones and the small fragments in which they are found might be the result of accelerated decomposition owing to fatty tissue around and within them. Often there is a total lack of ribs and vertebrae, except for the first cervical ones, and very few parts of diaphyses of the femur and humerus.

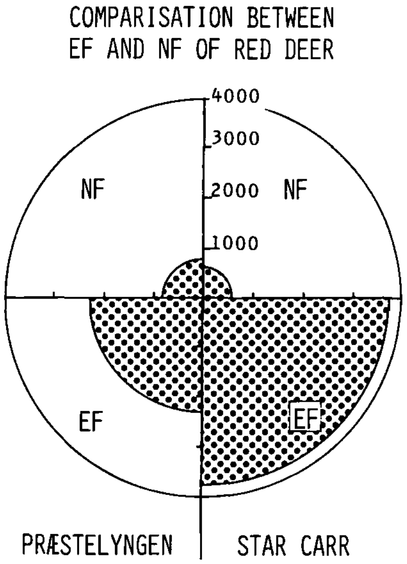

Fig. 31. Comparison of the sites Star Carr and Præstelyngen on the basis of the estimated number of fragments (EF) of red deer and the number of fragments (NF) of red deer actually found at the site. The estimated number of fragments (EF) is based on an estimation of the amount of fragments derived from one red deer subjected to a specific marrow fracturing pattern. The estimated number of fragments per animal (EF) were calculated to 146 at Star Carr and 263 at Præstelyngen.

The number of fragments per estimated minimum number of individuals (EMNI) is one way of indicating taphonomic overprint (fig. 31). It is obvious that Præstelyngen with 85 fragments per EMNI of red deer has a higher degree of retrieval than Star Carr with only 24 fragments per EMNI if the expected number of fragments per individual is the same at both sites (calculated on the basis of the fracturing technique). As an example the estimated production of fragments of a red deer at Star Carr (146) is only 5/9 of the estimated amount of Præstelyngen (263). For comparative reasons the number of bones at Star Carr therefore ought to be multiplied by 5/9, which results in a comparable number of 45 fragments per EMNI. Still, the degree of retrieval at Præstelyngen is less than twice as large as that of Star Carr, but nowhere near four times as high as indicated by the first uncorrected number.

Another way of illustrating the taphonomic overprint would be by a comparison of the total number of fragments of a species calculated from the estimated minimum number of individuals and the expected number of fragments indicated by the fracturing technique, and the actual number of fragments retrieved from the site. Fig. 31 shows, as expected, that the taphonomic loss in Star Carr is higher than at Præstelyngen.

A good indication of material having suffered taphonomic interference is differences in number of left and right side bones and upper and lower ends of the same bone (fig. 9). Compared with fig. 10 lower and upper ends show a more even distribution than left and right side.

CONCLUSIONS

The reconstruction of the palaeoecology of early man is one of the major aims of the analysis of archaeological deposits. Faunal remains especially yield valuable information in such reconstructions, and taphonomic considerations are a prerequisite in palaeoecological studies.

The aim of the present paper is to illustrate some of the numerous pathways leading from the subfossil death assemblage to the sample of the palaeobiologist. Meaningful reconstructions of ancient communities can only be made on the basis of well preserved and untransported fossil assemblages representing death assemblages uninfluenced by man. These death assemblages should again be the result of normal death rate of a stable population. Any fossil assemblage that has undergone selective destruction or transport is of limited value in any kind of population or community analysis. Nevertheless, seasonality, marrow fracturing techniques, ontogenetic variations and changes in growth have proved to be of outstanding importance in the evaluation of how, where, and why our ancient predecessors selected their prey.

Thus a thorough study of the taphonomic history and population characteristics of a fossil assemblage may offer substantial information on the subsistence economy of pre-historic man.

Marrow fracturing is here considered to be an important taphonomic factor. Great similarity is observed in the applied marrow fracturing techniques as found at Star Carr and Kongemosen in the one case and the younger Præstelyngen and Muldbjerg I in the other.

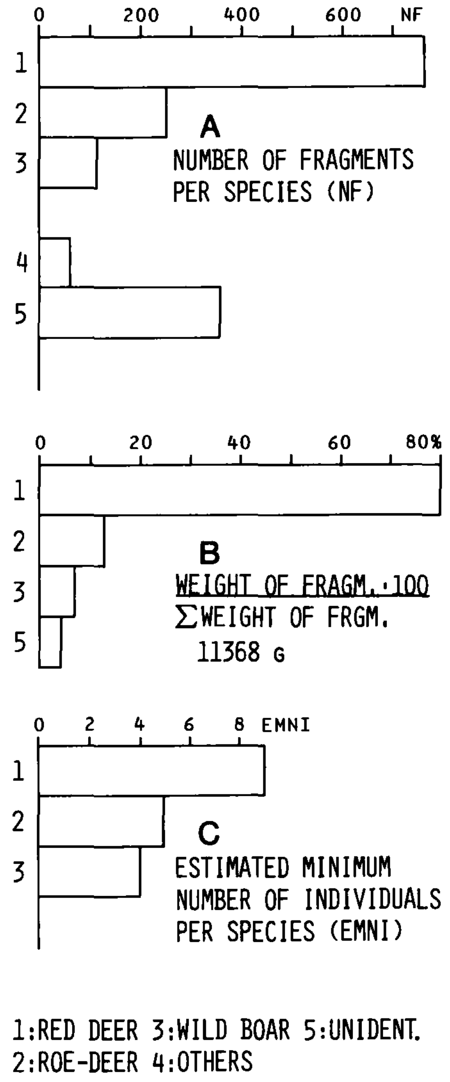

Fig. 32. Number of fragments of the three most important prey animals at the Mesolithic site Præstelyngen. The figures show the pronounced differences in relative abundances when calculated on the basis of different fragment parameters.

Differences in marrow fracturing technique between various cultures may reflect different methods of preparing food and may therefore reflect differences in cultural level, such as aceramic as opposed to ceramic cultures. It may thus be possible to use the character of bone splitting as an ecostratigraphical tool.

Different marrow fracturing techniques result in different numbers of fragments in a given type of bone. This has a considerable influence on the hypothetical total number of fragments at a site calculated by extrapolation from the excavated material. The number of fragments retrieved from a site as a fraction of the number of fragments calculated from the estimated minimum number of individuals, taking the marrow fracturing technique into consideration, may give an indication of the degree of taphonomic loss. Comparisons of the faunal composition and number of individuals from different sites can only take place after consideration of a number of taphonomic factors, of which one of the more important is the marrow fracturing technique.

The degree of fragmentation of bones in a deposit uninfluenced by man expresses the resistance of the various bones to mechanical destruction. The degree of fragmentation where human factors are predominant expresses, in addition, the activities of man as a taphonomic factor. In both cases the degree of fragmentation may be used as an indicator of the taphonomic overprint.

The study of marrow fracturing is therefore a fundamental part of the taphonomic analysis of an archaeological deposit. Furthermore it gives valuable information about many aspects of the daily life of early man; and finally may prove to be a potential ecostratigraphical tool within limited areas.

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