An Investigation into Variability within Archaeologically Recovered Assemblages of Faunal Remains: the Influence of Pre-Depositional Taphonomic Processes.

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This thesis is dedicated to the memory of
Leslie Peter Wenham.

Bones of Contention

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DECLARATION

This thesis includes reference to the fish remains from Newcastle Queen Street and Crown Court. These have both been the subject of previously published reports by myself, as referenced. The fish remains from Viborg Sonderso, Thetford Redcastle Furze, Pool and Tofts Ness, Sanday, have all been studied and reported on during the period of this research. None have yet been published. An article based on chapter 4, on the burning of fish remains, is due to appear in the Proceedings of the Fifth International Congress for Archaeozoology, Fish Remains Working Group, from a meeting held in Gothenburg in 1989.

ABSTRACT

The effects on a variety of animal skeletal tissues of a range of pre-depositional processes were investigated. Skeletal tissues included bone, shell and insect cuticle from a selection of taxa. Experiments were conducted in the field and laboratory, and the effects of a number of biostratinomic processes including heating, physical force, sedimentary abrasion, sub-aerial exposure and digestion were examined. Observational data were also collected from bone assemblages recovered from mammal droppings and bird pellets. The organic:mineral ratio within bone, and bone density were determined for fish, small mammal and bird, and their use as explanatory variables for bone survival was explored. Archaeologically recovered assemblages of fish bone were used in several cases to examine the value of the information derived from the experiments and observations. The extent to which variability within archaeologically recovered assemblages of animal remains may be explained by the effects of biostratinomic processes is discussed.

It was found that, with regard to vertebrate skeletons, fish bone in general was much less resistant to physical force than mammal, bird and amphibian bone. The last proved to be particularly resilient. The bones of gadid fishes survived generally less well than the bones of the other fish species used, under most conditions of testing. Boiling dramatically weakens all bone, but fish bone more than others. Density did not prove to be a useful predictor of bone resistance to destruction, but bone element shape, and the amount and type of organic material appeared to be important in some cases.

CHAPTER 1. INTRODUCTION.

1.1 Taphonomy: A Descriptive Framework and Overview.

Archaeologically recovered remains of animals may not accurately reflect the skeletal assemblage originally deposited on the site, which in turn may not reflect the original proportions of skeletal elements present in the animal during its life.

The processes of dispersal and disintegration of skeletal material are numerous, and may conveniently be divided into cultural mechanisms (i.e. a result of human action) and "natural" mechanisms (i.e. not resulting from human action). Schiffer (1976) has discussed a number of the processes which may act on material objects and coined the terms "C-transforms" and "N-transforms" to describe cultural and "natural" modifications. While this distinction is useful as a means of defining the area of study it should be realised that human actions are also "natural", and it is not always easy to draw a hard line between cultural and "natural" mechanisms.

In more common usage, the term "taphonomy", defined by Efremov (1940), describes the field of research which studies the processes which act upon an organism between its death and the preservation of its remains into the fossil, or archaeological, record. Investigations into the processes which are reflected ultimately in the preservation (or lack of preservation), distribution and condition of animal remains in archaeology are an obvious prerequisite to any subsequent faunal analysis. Lawrence (1979, 903) discusses the requirement for a researcher to remove the "taphonomic overprint". This view implies that the overprint must be obscuring the information of relevance, which may not always be true: it is often the process(es) implied by the "taphonomic overprint" which can yield vital information about the human and non-human actions which have taken place and affected the animal

remains. Until recently, however, very few reports included any discussion of the history of the skeletal assemblage in question. This was in part due to a paucity of basic research into the mechanisms which selectively modify skeletal assemblages, a problem which still has not been rectified despite an increasing awareness by archaeozoologists in recent years of the importance of taphonomy.

Taphonomy, then, is the study of "the transition from the biosphere to the lithosphere" of organic remains (Efremov, 1940). Clearly there are many processes which may be involved in the transition, some prior to burial and some subsequent to it. Processes acting on remains after death but before final burial are termed biostratinomic (of the subdiscipline biostratinomy); processes acting after burial are diagenetic. Animal remains which went through the same taphonomic history from the moment of death until the recovery of the remains are termed a taphonomic group (Gautier 1987).

In the area of biostratinomy there are many possible processes causing modifications and attrition to a skeletal assemblage. It is in this sphere that the scope of the present research lies.

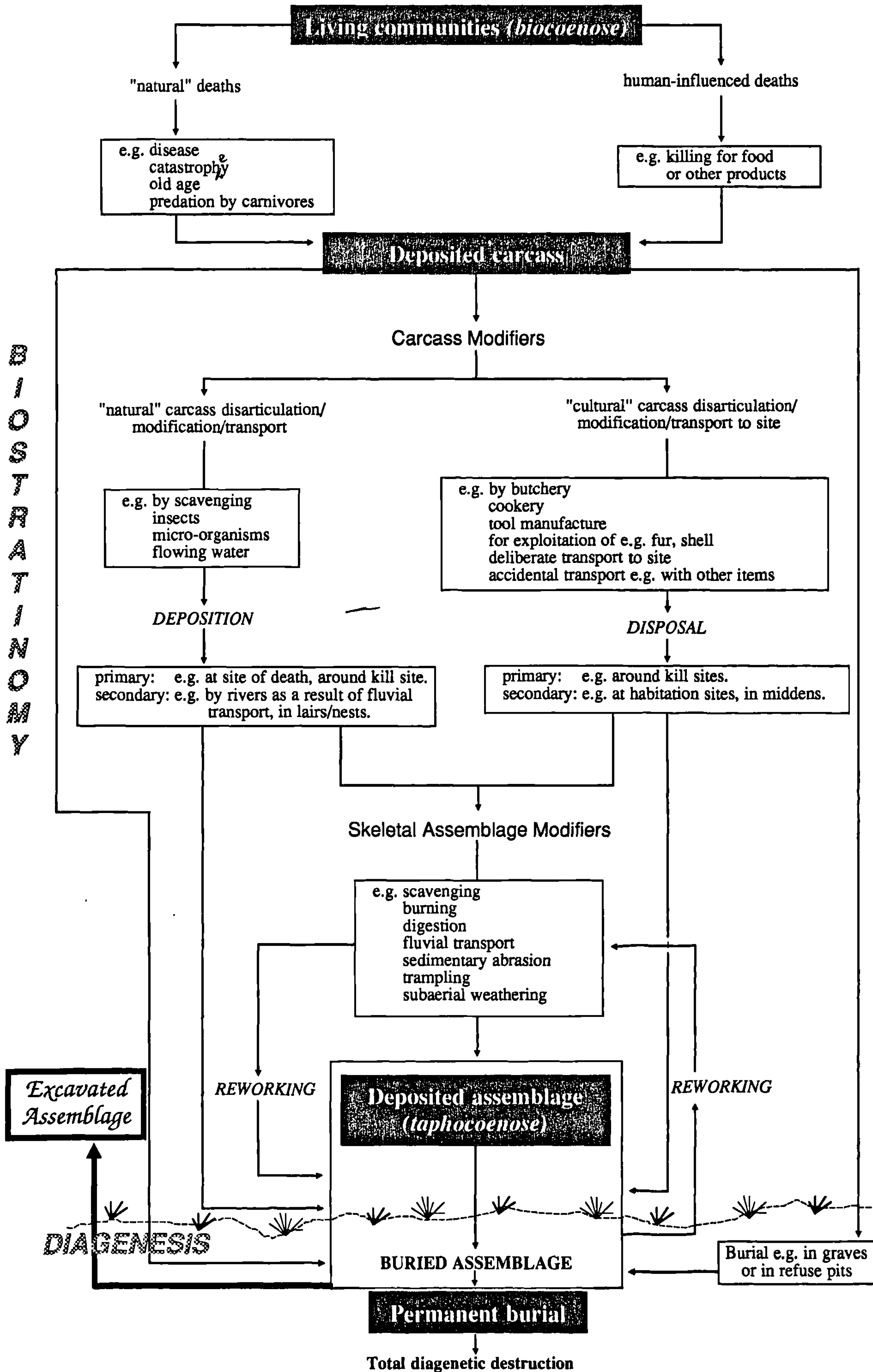
Taphonomic processes act on material remains during a period of time which may vary greatly. The means by which animal remains may be modified and accumulated prior to burial are numerous. Fig. 1:1 describes some of the possible ways in which the life assemblage (biocoenose) may be transformed into the depositional assemblage (taphocoenose) and ultimately the recovered assemblage retrieved during excavation. Various terms have been adopted to describe assemblages of fossils formed as a result of selective agents; some of these are described by Denys (1985). The term catastrophocoenose has been used to describe an assemblage of bones formed as a result of a catastrophic event; these assemblages may be rapidly buried

or the components subject to a similar taphonomic history. Denys (*ibid.*) has termed the collection of bones by a predator a necrocoenose while a coprocoenose describes a collection of animal remains concentrated in pellets or faeces directly as a result of feeding.

Secondary concentrations of animal remains by sedimentary, water or aeolian action has been termed a sedimentocoenose. It is very important for archaeozoologists to be able to distinguish between different types of death assemblages if reliable reconstructions of paleoenvironments or economies are to be made, although the possibility of several agents of collection and/or modification must be recognised.

Biostratinomic processes (also termed pertothaxic factors by Clarke *et al.* 1967) may include both physical and chemical attrition. The mechanisms by which faunal remains may be modified are summarised in Fig. 1:1. Corpses may be disarticulated either slowly by micro-organisms, or rapidly by humans or other animals. The remains may be transported by scavengers, humans, wind, water or the effects of gravity. The skeletal elements may be modified by one or a number of physical and/or chemical processes such as abrasion, burning, passage through an animal's gut and fracturing due to applied pressure. Exposure to the climatic elements may cause the physical and chemical breakdown of skeletal tissues, and micro-organisms may penetrate the structure, eroding channels through the tissue. Mounteney (1981, 80) refers to the processes causing flaking and cracking of bone after exposure to the natural elements as "physical weathering" and the processes causing leaching and pitting as "chemical weathering". Breakdown of the bone tissue as a result of exposure to rain and ultra-violet light is clearly related to chemical changes within the bone tissue, however, even though the effects may appear as flaking and cracking, so this distinction, though having useful application, is naïve in its definition.

Fig. 1:1 Flow diagram illustrating possible taphonomic pathways which cause modifications to skeletal assemblages and consequent loss of information.



After burial, remains may be fragmented by movement within the soil or cryoturbation (Wood and Johnson 1978), eroded and leached by acids within the soil and penetrated by soil micro-organisms and roots. These factors are diagenetic, but have also been termed taphic by Clarke *et al.* (1967). Remains may resurface, for example as a result of worm action or human interference (e.g. excavation) and be acted on by another suite of biostratinomic processes.

Understanding the effects of these processes may enable the archaeozoologist to strip off the "taphonomic overprint", or at least to recognise when assemblages of faunal remains may be a modified sample of the originally deposited whole.

Research into the causes and effects of variability in skeletal preservation has been less fashionable in European than in American archaeology. This is largely because firstly, many American archaeologists are trained anthropologists and have been concerned with analysing sites in terms of their value as indicators of human behaviour. Consequently investigations into the loss of material, and site formation processes have been important. Secondly, many North American and Old World sites are essentially paleontological and comprise assemblages of animal remains for which the principal question concerns possible hominid influence (e.g. Bonnischen 1973; Shipman and Phillips-Conroy 1977). It has therefore been important to determine how the effect of man may be distinguished from those of other organisms and environmental processes. European archaeologists have tended to focus more on animal remains as indicators of past animal husbandry and methods of exploitation. This has involved taking large samples for measurement and statistical analysis. Many European sites have also produced large quantities of well-preserved animal remains, for example from urban sites, where questions of primary interest concern butchery patterns and agricultural practises within a market economy (Mounteney 1981, 75). Methods of quantification and recording have

therefore taken priority in archaeological research. Thirdly, in recent decades archaeology in Britain has largely taken place under a "rescue" budget and timescale which does not allow for primary research into aspects not of immediate relevance to the overall interpretation of the site.

The following section summarises the major areas of study undertaken in the field of biostratinomy. More comprehensive literature surveys are given in the relevant chapters.

1.2 Recent Developments

In the last twenty years there has been an increasing number of investigations into various aspects of taphonomy, largely conducted by vertebrate paleontologists and mainly in Africa and North America. Much of this work, as well as earlier related studies, is reviewed in Behrensmeyer and Kidwell (1985), Kidwell and Behrensmeyer (1988) and Gifford (1981). As a result the following review will not attempt to be comprehensive, but rather to point to the more important studies. In particular the works of Shipman (1981), Behrensmeyer (1978), Behrensmeyer and Hill (1980), Hill (1979), Brain (1981) and Binford (1981) have demonstrated the value of experimental, ethnographic and observational (the last sometimes termed "actualistic") studies to the interpretation of archaeologically recovered remains.

With a few exceptions (e.g. Dodson 1973; Korth 1979; Jones 1984; 1986, forthcoming) research has concentrated on the remains of large mammals, aiming to distinguish between "naturally deposited", carnivore-modified and hominid-influenced bone assemblages. Other taphonomic studies have been concerned with modifications to human bone as a result of burial (e.g. Garland 1987; Piepenbrink 1986; Lambert *et al.* 1979; 1982; Hanson and Buikstra 1987). Several workers have been concerned with determining the way bones may be

transported by water. A geologist, Voorhies (1969) determined the settling velocities of sheep and coyote bones in an artificial flume and showed that fluvial transport of animal skeletal parts selectively sorts the remains dependent upon shape and size. Behrensmeyer (1975) examined the role of shape, density and size in the rate of settling, and devised a "quartz grain diameter equivalent" for the skeletal elements. Behrensmeyer and Hanson (Hanson 1980) examined bone movement in a river environment over a number of seasons, which produced similar results to the flume experiments for a range of large ungulate bones. Dodson (1973) examined the disarticulation and transport of small mammal and amphibian bones in water. Disarticulation patterns in large mammals have also been extensively studied, although mainly in Africa (e.g. Brain 1981; Hill and Behrensmeyer 1984; Gifford 1978). Andrews and Cook (1985) documented the disarticulation of a cow in a temperate environment (Somerset).

Archaeology tends to be concerned with the excavation of human habitation sites, so consequently many attributes of the recovered organic materials are explicable in terms of human actions. There are, however, a number of other processes which may result in accumulations of animal remains, or alterations to them. Determining the marks of humans from those of carnivores on bones and bone assemblages has become a popular research topic in recent decades. There have been a number of studies attempting to distinguish fragmentation patterns which are identifiable as caused by man from those that may be due to large carnivores, for example Binford (1981); Brain (1975; 1976; 1981); Bonnischen (1973; 1979); Haynes (1971) and Miller (1969; 1975). Of more relevance to European sites, Brothwell (1976) noted the modifications to bones inflicted by sheep, and Stallibrass (1986) investigated canid modifications to bones of sheep and red deer in Britain, applying the results of this observational research to archaeological bone assemblages. Several investigations relate fracture mechanics to the study of large mammal bone

fragmentation, as discussed by Johnson (1985). The collection of bones by agents other than man has been discussed in a number of papers and books. These agents include carnivores (e.g. Brain 1980; Binford 1981) birds (e.g. Andrews 1990) harvester ants (Shipman and Walker 1980) and porcupines (Brain 1976; 1980). Bone accumulations in predator droppings and pellets have been studied by several scholars including Dodson and Wexlar (1979), Mellet (1974), Korth (1979), Andrews and Nesbit-Evans (1983) and Andrews (1990). Assemblages of small fish bones may be accumulated in otter spraint or bird pellets as discussed by Colley (1982). Little has been said about the aggregation of insect remains in pellets and scats, although this is clearly an important concentrating mechanism (for one published study see Girling 1977).

There have been very few published pieces of work concerning the taphonomy of bird, fish, amphibian or reptile bone (apart from a literature on dinosaur bones), or of invertebrate remains. A few papers in recent years have attempted to apply a taphonomic approach to bird and fish remains (e.g. Jones 1984; 1986; Colley forthcoming a; Spenneman and Colley 1989; Livingston 1989; Erikson 1987) but although useful they have all been on a fairly small scale. Experiments into the erosion of shells in a marine environment have been discussed from a palaeontological viewpoint by Chave (1964), Driscoll (1967; 1970) and Driscoll and Weltin (1973). Carter (1990) studied the taphonomy of land snails in a chalk environment.

The investigation of reasons for variability in preservation between different animal taxa has been largely ignored, and statements have been made such as:

> *"Some bones have a better chance of survival than others. Those most at risk are the small or more porous and less dense fragments. Bird, small mammal and fish bones are particularly vulnerable ..."* (Maltby 1979, 4).

a view rejected by Jarman *et al.* (1982, 85) who state that:

"The assumption that fish bones are especially vulnerable to destruction, though commonly voiced, has little to recommend it."

Neither of these opinions is supported by much background research, although the latter is at least based on some observations by Gifford (1977; 1978) into the preferential burial of small compact bones. Very few studies have attempted to relate the findings of "neotaphonomic" studies to archaeological material, other than in a very simplistic, subjective way. Statistical applications of taphonomic studies to archaeological material are extremely rare, as pointed out by Denys (1985, 883) yet are clearly desirable in many instances.

In 1976 Schiffer proposed the concept of "behavioural archaeology", the principal aim of which is to create "laws" to explain the relationships between human behaviour and material culture. One of the methods he proposed was experimental:

"carefully contriving a situation in which to observe the interaction of several variables and boundary conditions by direct manipulation"

In effect this proposal encompasses both experiment and observation. It is only as a result of such investigations that the "laws" or "relational statements about non-cultural formation processes" ("N-transforms") which Schiffer envisages can be developed. These statements form what Binford (1981) has termed "middle-range theory" and the approaches used fall into his category of "actualistic research".

To relate the condition of a bone fragment to a single process which caused it, the researcher must be able to demonstrate that all other possible causes of the condition

have been considered and eliminated. This is the basis of Binford's rationale (Binford 1981) although his success in its application has been questioned by, for example Lyman (1984). At the root of any such application is the uniformitarian principle that the present is the key to the past. Although this premise may be untenable when applied to human cultures it is unlikely that the effects of environmental variables, for example, will have changed.

Different processes may result in the same or similar effects, however, and it may not always be possible to determine the exact taphonomic history, especially when assemblages have been subject to several attritional operators. In any taphonomic study the practitioner must therefore bear in mind the danger of drawing over-simplified conclusions.

Intrinsic characteristics of the skeletal tissue may control the way in which the material degrades, and similar results may be produced even when different taphonomic agents are involved, as a product of these constraints. It has been demonstrated, for example, that various measurements which have been termed density or specific gravity appear to control to a certain extent the way in which bone is transported in a fluviatile environment and the way it fragments or is lost due to a variety of attritional processes (for a review see Lyman 1984). Shape, mechanical strength and size also play a very important role in determining the preservation potential of a skeletal part. Therefore characteristics other than just the presence/absence of certain skeletal parts may be necessary in order to demonstrate a taphonomic pathway.

Archaeozoologists are increasingly trying to refine their methods of quantifying faunal remains. In the last decade or so there have been a number of papers and books concerned with quantification (see for example Watson 1972; Grayson 1984; Nichol and Wild 1984) with the aim of resolving questions concerning animal exploitation, dietary

input and trade. Specific questions concerning carcass use, for example, frequently rely on patterns of skeletal element distribution. In fish bone studies conclusions about fish processing have often rested on discussions of skeletal element frequencies (e.g. Heinrich 1986; Noe-Nyggard 1983). The lack of head bones of Nile catfish *Clarias gariepinus* has been seen as indicating beheading prior to importation (Gautier *et al.* 1980). For the same species Van Neer (1986) attributes the predominance of head bones to preferential destruction of vertebrae. In neither case are these somewhat contradictory conclusions tested against evidence from taphonomic studies.

If taphonomic processes can be shown to act selectively on different skeletal parts then conclusions based on anatomical element representation may be invalid. Heinrich's conclusions concerning stockfish (Heinrich 1986) is based on the absence of vertebrae in a small assemblage of fish bone. This determination could only be upheld if it could be shown that there was no other reasonable explanation for the absence (which has not been attempted). The smaller or more incomplete the assemblage the less easy it will be to determine which processes have acted upon it. Problems of assemblage composition may be exacerbated by poor retrieval during excavation, as demonstrated by Payne (1975), Levitan (1982) and Jones (1983) for example.

For these reasons it is unacceptable to base conclusions concerning human selection or intervention on the presence/absence of certain bones, without supporting evidence to demonstrate that the skeletal element distribution could not be the result of other agents. As the overall aim of archaeozoological studies is, in many cases, the determination of the ways in which humans have exploited animals, it is all the more unfortunate that so little work has been conducted into setting up a basic framework from which to understand better how skeletons fragment and decay.

1.3 Aims of the Current Research.

The principal aim of this project was to investigate reasons for variability in archaeologically recorded assemblages of faunal remains. The approach taken was to combine a laboratory and field-based experimental approach to examine the variability of response of different skeletal tissues, skeletal elements and different taxa to a number of common predepositional influences. It was hoped to be able to distinguish the effects of different taphonomic pathways on a variety of skeletal remains and so define ways in which different taphonomic groups might be recognised archaeologically. The scope of this research project is large, and much of the approach is of an exploratory nature.

More specifically, the object of this study was to examine the effects of a number of processes that may affect skeletal remains between the death of an animal and the incorporation of its remains in the ground, in order:

1. To investigate how assemblages of skeletal remains may be modified by the processes under investigation, whether the modifications are predictable and to what extent the archaeological record may be biased as a result. Specific questions addressed were:

a. Do all taxa stand an equal chance of survival?
b. Do all skeletal elements (of a given animal) stand an equal chance of survival?
c. If not, do different processes cause the same patterns of loss?
d. Can the results of these processes be recognised in archaeological material?

2. To determine whether the effects of the processes under investigation leave distinctive characteristics on skeletal

tissues and, if so, whether these characteristics can be recognised on contemporary material and remains recovered from archaeological excavations.

3. To investigate whether criteria used for identifying specific biostratinomic processes on large mammal remains can be applied to other vertebrate assemblages.

4. To assess the effects of cooking on bone, and the consequences for preservation.

The approaches taken are defined by Hill (1975) as "neotaphonomic", including both experiment and observation using modern material and encompassing a range of field and laboratory-based experiments. Each experiment or set of related experiments was designed to be performed in a relatively short space of time, as a result of the limitations imposed on a research project of this nature.

By the use of experiment the intention was to isolate the effects of specific processes and so to identify the effects of the process under investigation, under variously controlled conditions. In the field it is often difficult to distinguish modifications resulting from definable processes, as many different variables may interact to produce the observed result. Laboratory experiments were used where appropriate to examine the effects of single processes. In real life, however, multiple processes act to modify a skeletal assemblage, and over-simplified experiments will not represent the actual conditions obtaining in the field. Some experiments were therefore conducted outdoors, in conditions where the number of attritional processes were confined, but the conditions of the experiment were not so clearly definable.

Not all the experiments have been carried out to an equal standard of scientific rigour. In such a large field, where very little experimental work has been done, I felt it more appropriate for archaeological purposes to cover a

range of areas, pointing out potential avenues for further investigations, rather than covering a single area exhaustively. The intention was to assess the effects of a number of different processes by a selection of methods, and consequently some experiments proved to be more useful than others. The object was also to open up productive topics for future research by generating, as well as answering, questions about archaeological deposit formation.

The areas of pre-depositional taphonomy selected for study fall under four main headings:

1. **Burning**: experiments into the effects of burning bone, both in the field and under laboratory conditions. The potential for determining the temperature to which bone has been heated is assessed.
2. **External force**: experiments into physical abrasion and trampling as well as tests of the relative strengths of fresh, boiled and burned bone.
3. **Climatic factors**: experiments into pre-depositional weathering, freezing and thawing, wetting and drying.
4. **Digestion**: experiments and observations into the characteristics of faunal remains which have been ingested.

All these factors may modify animal remains after the primary deposition of the corpse, or, in the case of burning, during food preparation. A fifth important area, that of fluvial transport, is not dealt with but has been the subject of a number of research projects (see above). Although human rubbish discard patterns are an important aspect of archaeological deposit formation, the subject has been extensively discussed, for example by Schiffer (1972; 1976; 1983) and further investigation is not an aim of this research.

The criteria used in this investigation included all or a combination (depending on animal group and experimental

situation) of:

a. Skeletal element frequencies.
b. Surface patterning, including texture, erosion, exfoliation and cracking.
c. Fragment size.
d. Density.
e. Mineral:organic ratio.
f. Strength (heated vs. fresh bone only).

1.4 Reasons for this Study.

The research was prompted primarily by my general unease with the conclusions sometimes drawn by archaeozoologists based on the distribution of skeletal elements in an assemblage. This was particularly evident in fish bone work, where interpretations of fish processing have commonly been made on the presence/absence of skeletal elements (e.g. Wilkinson 1979; Johnsson forthcoming). Additionally, several pioneering studies indicated the direction in which this research could most usefully progress. Shipman (1981, 12) pointed out that "*the occurrence of a past event can be deduced only by demonstrating that its effects differed from those of other, similar events*". Gifford (1981, 398) suggested the need for taphonomic study of non-mammal remains. Influential practical applications to taphonomy included the work of Andrew Jones in trying to establish patterns of loss for fish bone and Pat Shipman's use of the scanning electron microscope as a tool for determining the taphonomic history of bones by examining the surfaces of bones subjected to various modifying factors.

CHAPTER 2. METHODS AND MATERIALS.

2.1 The Animal Remains Used in this Study

The animal remains chosen as the basis for this investigation were selected to cover a range of skeletal hard tissues and taxa frequently recovered in archaeology. The groups selected were mammals (small mammals and a selection of bones from large mammals), bird, fish, amphibian, mollusc and insects. It was clearly not possible, given the time available and the scope of this study, to investigate all animal groups in equal detail. Some types of skeletal hard tissue were ignored, for example horn, antler, ivory, hair and crustacean shell. Dentine and enamel have also not been investigated in any detail. The animal groups chosen were selected both to cover a range of different types of material and skeletal design and to include those frequently recovered archaeologically but neglected in taphonomic studies, at least in an archaeological context, in the past. A wider range of fish species than species from other animal classes were incorporated in the investigations for several reasons:

1. Fish bone has commonly been assumed to be fragile and so preferentally destroyed when compared with other bone.
2. Fish bone has been largely ignored in taphonomic studies to date. Gifford (1981, 419) states that *"taphonomic methods and findings of most use to archaeologists are those pertaining to the remains of terrestrial vertebrates, especially mammals"*.
3. There are over 30,000 different species of fish known to exist, and within this group there is a range of very different skeletal types. The types of calcified tissues involved, as well as the organisation and shapes of skeletal elements, is far greater than among any other group of vertebrates.
4. Conclusions are frequently drawn about processing fish based on the distribution of fish taxa, skeletal ele-

ments and sizes of fish.

5. Received wisdom and common sense suggested that fish bone would disintegrate more rapidly than mammal bone. In a programme which aimed to study degradation it was useful to incorporate animals whose remains were more likely to show evidence of decay in the time available for study.
6. The analysis of fish bone had been an interest of mine for several years, and I had acquired a level of competence in the identification of fish bone.

Insect remains and mollusc shells were included in some of the experiments because these groups have been neglected in the past, both in taphonomic and archaeological studies. In the early stages of this project it was apparent that the scope was too large for the time available, however. As a result the investigations using insects and molluscs are very limited, and the main aim has been to suggest where further investigations may prove fruitful.

2.2 Archaeological Assemblages Used in this Study.

The archaeological material used in this investigation originated from several sites in Britain and Denmark. The assemblages were selected to utilise the information accrued from the experimental data. All of the archaeological material was studied contemporaneously with the experimental aspects of this research, and all of the archaeological assemblages are of fish bone. Each will be described under the section to which it applies.

2.3 Basic Skeletal Anatomy of Mammals, Bird, Fish, Amphibian, Molluscs and Insects.

Details of the taxa and, where relevant, skeletal elements used in the experiments is given in the appropriate chapters. Individual experiment methodologies are also given in the appropriate sections. This chapter gives a brief resumé of the taxa used in the study as a

whole, and the methods employed.

Taxa

Figures 2:1a-f illustrate the basic anatomy of the vertebrate, mollusc and insect taxa used in the subsequent experiments.

A selection of complete skeletons and skeletal elements were used, from large mammal, bird, fish, medium-sized mammal, small mammal and amphibian. The species in the experiments included:

Large mammal: sheep (*Ovis* f. domestic) and cow (*Bos* f. domestic), lower limb bones only.
Medium mammal: rabbit (*Oryctolagus cuniculus* (L.)) stoat (*Mustela erminea stabilis* L.).
Small mammal: mouse (*Mus sp.*), field vole (*Microtus agrestis* (L.)), shrew (*Sorex araneus* L.), brown rat (*Rattus norvegicus* (Berkenhout)).
Bird: pigeon (*Columbia livia* Gmelin).
Fish: cod (*Gadus morhua* L.), haddock (*Melanogrammus aeglefinus* (L.)), whiting (*Merlangius merlangus* (L.)), plaice (*Pleuronectes platessa* L.), long rough dab (*Hippoglossus platessoides* (Fabricius)), herring (*Clupea harengus* L.), salmon (*Salmo salar* L.), dogfish (*Scylorhinus canicula*(L.)), carp (*Cyprinus carpio* L.).
Amphibian: frog (*Rana temporaria* L.).

Additionally a selection of **molluscs** were used for some experiments:

mussel (*Mytilus edulis* L.)
cockle (*Cerastoderma edule* (L.))
periwinkle (*Littorina littorea* (L.))
limpet (*Patella vulgata* L.)
dogwhelk (*Nucella lapillus* (L.))
common garden snail (*Helix aspersa* Müller)

and **insect** groups included:

adult *Tenebrio molitor L.* beetles and larvae (mealworms)
adult bluebottles (*Calliphora vomitoria* L.) and puparia.

The species chosen were selected to cover a variety of taxa commonly recovered archaeologically and readily available as corpses.

2.4 Sizes of Animals

The physical properties of bone vary as a result of age, nutritional status and health of an individual animal (Chaplin 1971). Mineralisation of bone proceeds through much or all of the life of a vertebrate, and increased mineralisation affects the physical properties of bone, making it stiffer but reducing its resistence to impact (Currey 1984, 93). For this study, where possible, individuals from the same species were of similar sizes and adult. This was not always possible in the case of the mammals where occasional sub-adults, with unfused epiphyses, were included in experiments. Where relevant the ages/sizes of individual specimens are noted. The means, medians and standard deviations for the total lengths of the fish commonly used in this study are detailed below, Table 2:1.

Table 2:1.

		Total length (in mm.)		
	No.	Mean	Median	Standard deviation.
Cod	17	570	580	24.3
Haddock	27	378	380	20.7
Plaice	22	361	358	20.7
Herring	18	298	288	34.8
Salmon	8	840	830	27.3
Dogfish	5	600	600	7.9
Whiting*	20	182	188	22.7
Long rough* dab	4	153	150	12.6

* = used in the experimental fires, Chapter 4, only.

Mollusc shells were represented by a variety of sizes for

each species. Very small shells were not included, but otherwise samples were obtained by numbering each shell and using a random number chart to select specimens.

It was not possible to ascertain easily the age of the insects used in the study, and only obviously newly emerged beetles, with untanned or lightly tanned cuticle, were excluded.

2.5 Preparation of Skeletons.

Individual corpses were frozen at -10 - -20 °C for periods of time ranging from a week to several months prior to use. Evans (1973, 56) quotes evidence indicating that freezing does not significantly affect the physical properties of bone.

For those experiments where selected skeletal elements were utilised, the bones were dissected from the corpse manually and cleaned by hand in cool tap water. The bones were dried at room temperature and humidity and stored until required, except where fresh bone formed part of the experiment (i.e. some of the freeze/thaw experiments) in which case the bones were used immediately following dissection.

For experiments where whole skeletons were required, the bodies were prepared by fly blowing with maggots followed by burial in a peat and sand mixture for a period ranging from three weeks to two months, depending on season and size of the corpse. The bodies were partially defleshed prior to burial, to speed up the decomposition. Full details of this method of skeleton preparation is given in C. Nicholson (in prep.). Following skeleton preparation the bones were stored dry at room temperature until required.

All the mollusc shells were collected from live animals, dried at room temperature and stored until required. Insects were frozen at -10 - -12 °C and whole corpses used.

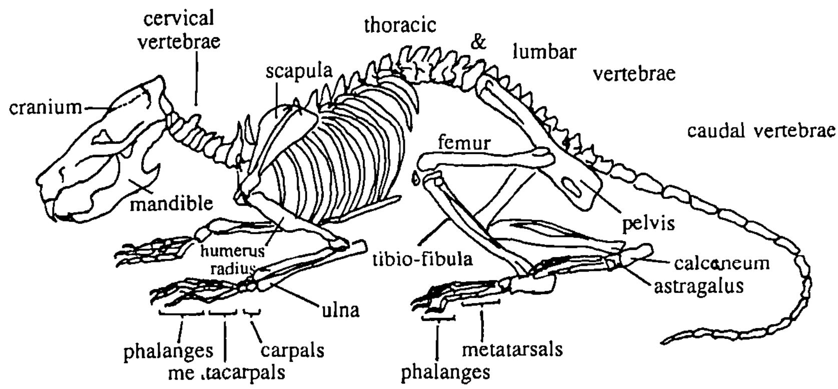


Fig. 2:1a Skeleton of the brown rat, *Rattus norvegicus.*

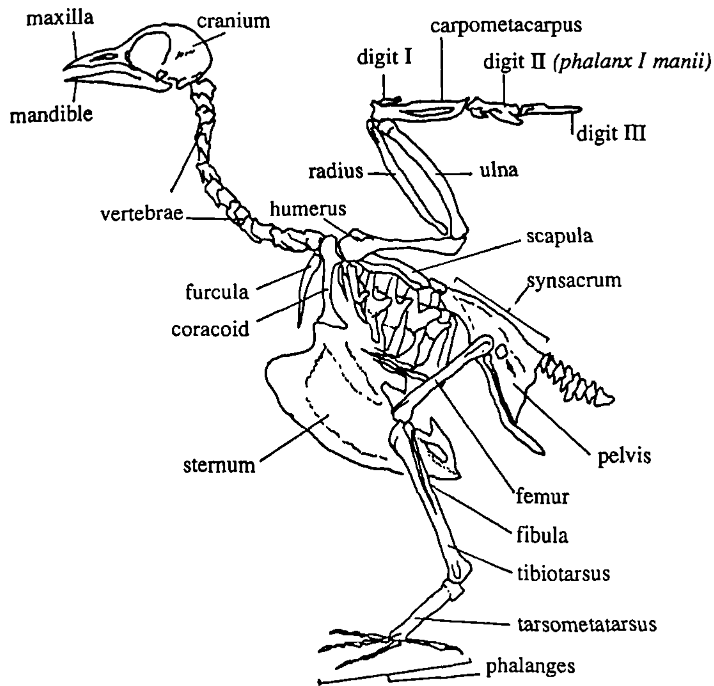
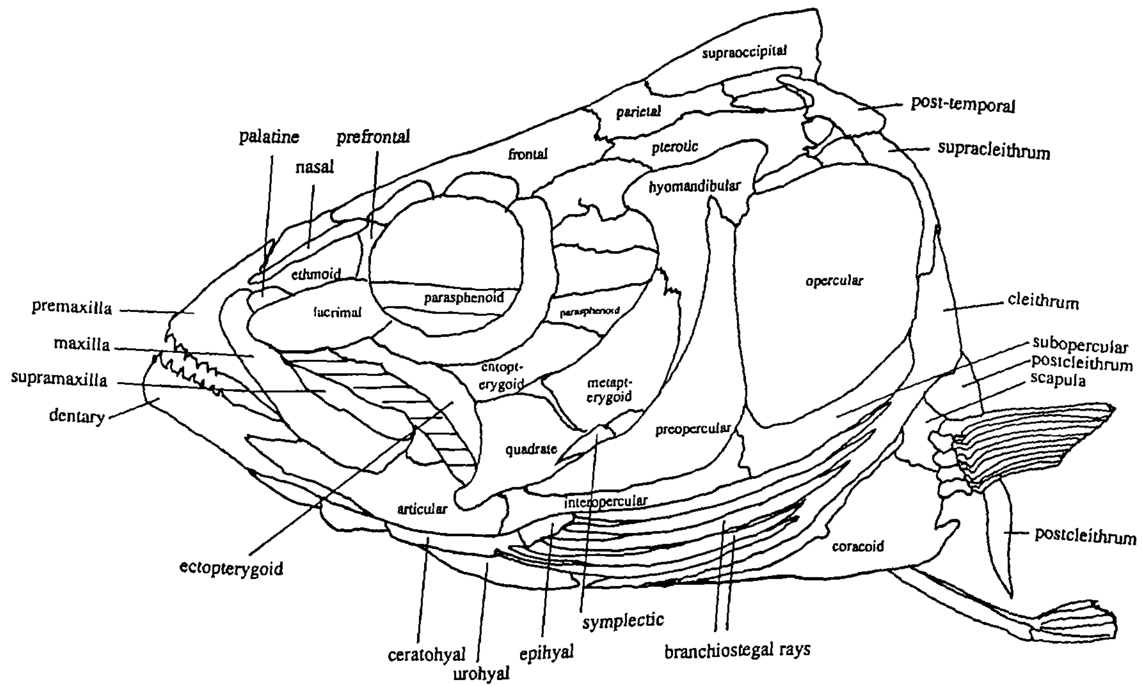


Fig. 2:1b Skeleton of the pigeon, *Columba sp.*



Generalised teleost skull. (after Gregory, 1933)

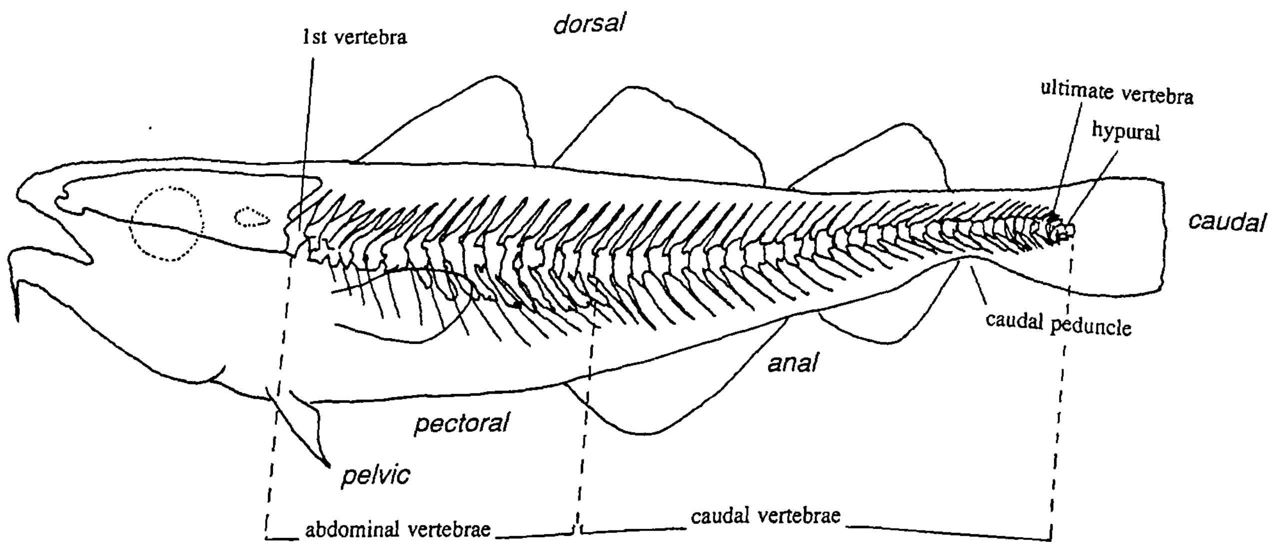


Fig. 2:1c Gadid skeleton illustrating the post-cranial elements. (after Wilkinson, 1981)

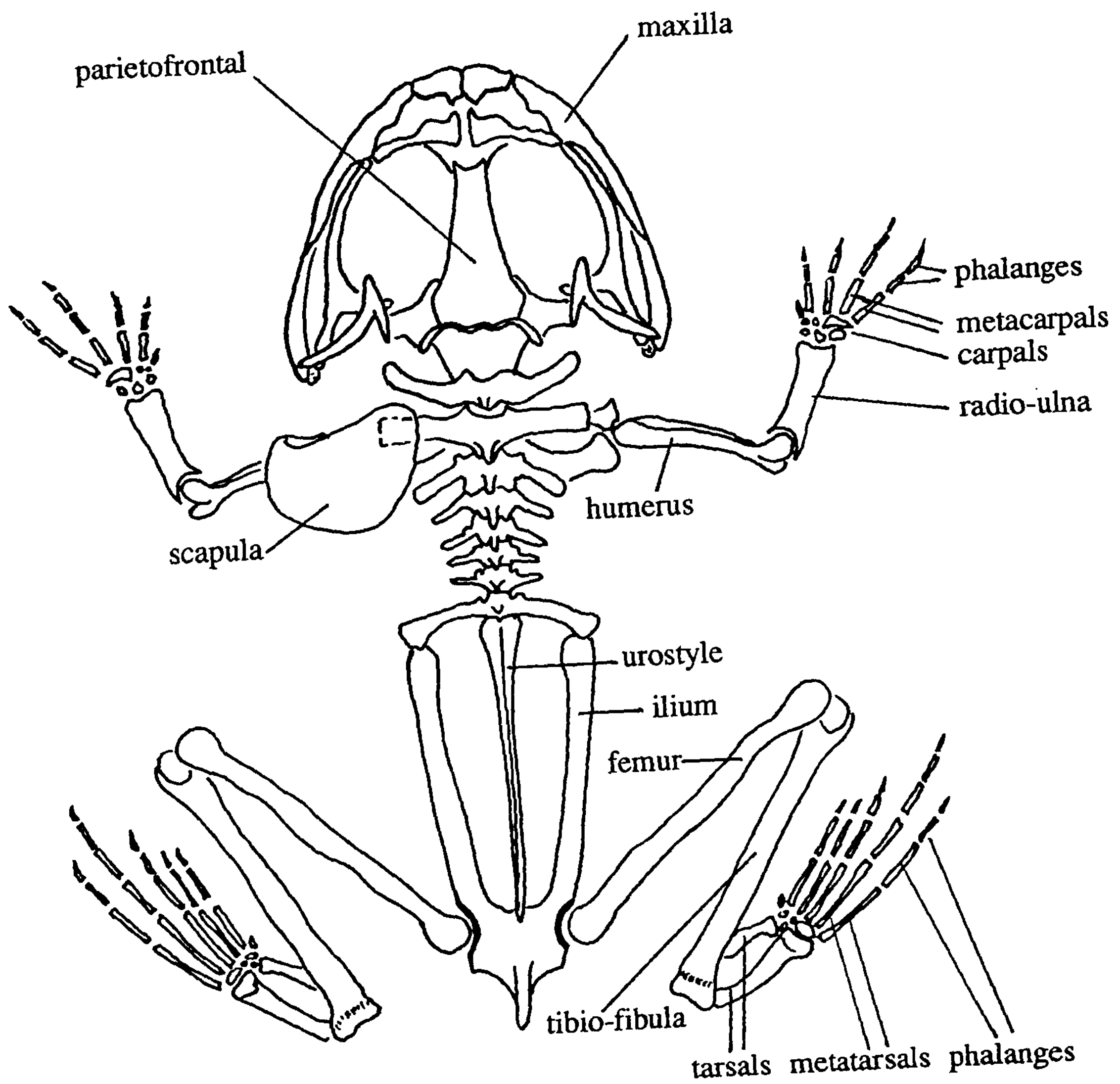


Fig. 2:1d Skeleton of the common frog, *Rana temporaria:* Dorsal view, right scapula removed

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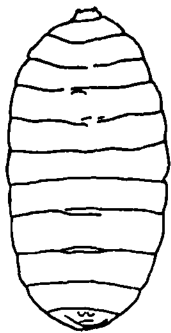
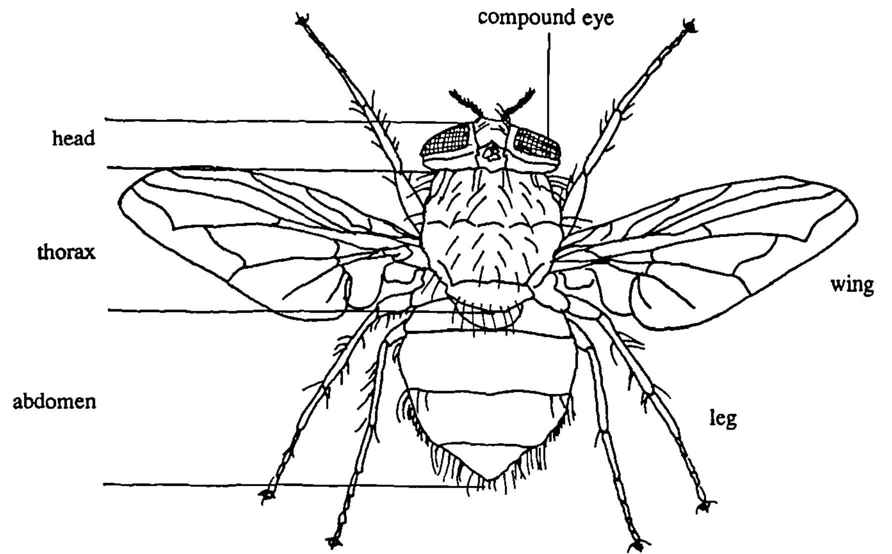
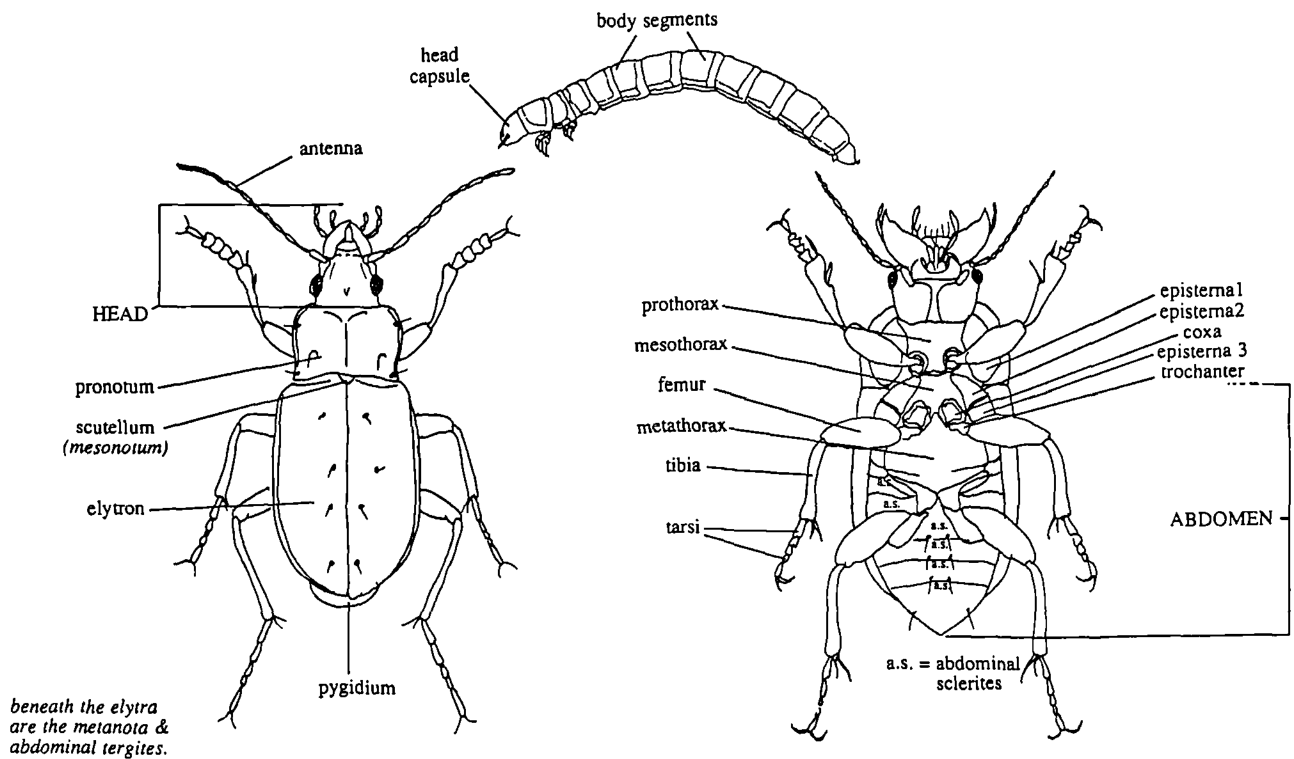


Puparium of the fly *Calliphora vomitoria.*

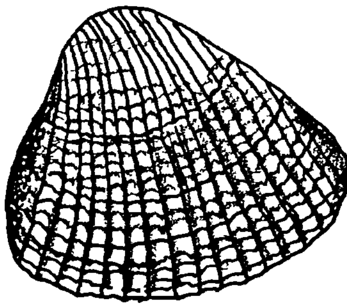
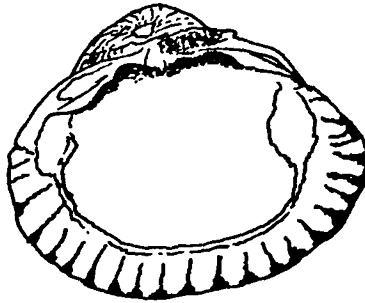


Adult fly, *Calliphora sp.*

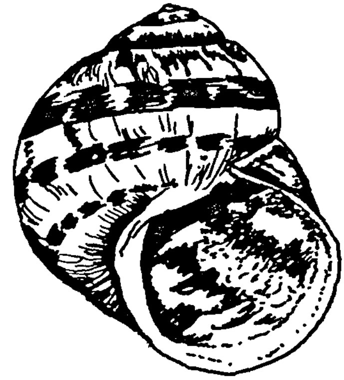


Below: dorsal (left) and ventral (right) views of an adult beetle. Above: larva of *Tenebrio sp.* (mealworm).

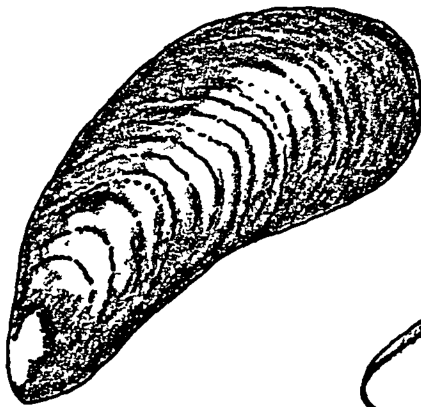
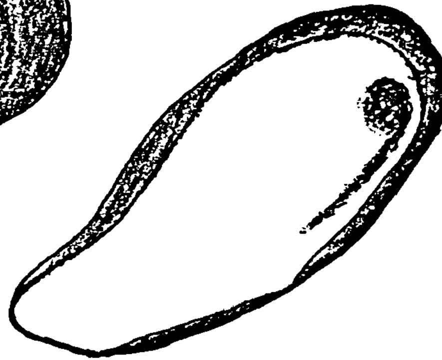
Fig. 2:1e The Insects

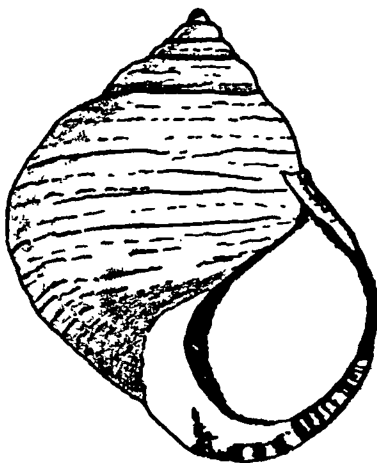
Common cockle, *Cerastoderma edule*



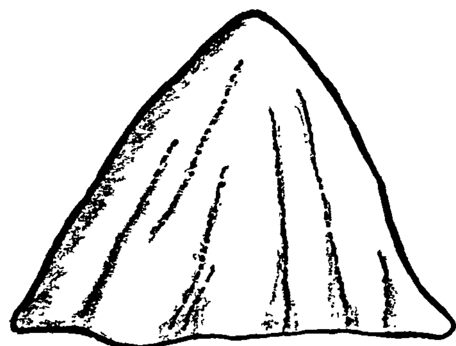
Common snail, *Helix aspersa*

Common mussel, *Mytilus edulis*



Common periwinkle, *Littorina littorea*



Common limpet, *Patella vulgata*

Fig. 2:1f The molluscs

2.6 General Recording Methods.

The principal methods of recording the information recovered from the experiments were by photographs, sketches, written descriptions and database records as described below. Examination of tissue surfaces was conducted in a laboratory, using a 60 watt bench lamp and a low powered (X10) dissecting microscope.

Investigation of a variety of different processes on a selection of different skeletal types inevitably means that recording methods vary to a certain extent depending on the properties being examined. As far as possible, however, standard recording techniques have been adopted for bones and insect remains, using the micro-based database package D-Base III plus (Ashton-Tate 1987). The aim of standardising recording methods was to enable the results of each experiment to be compared, and as far as possible to objectify the observations made. It should be noted, however, that not all the categories used are equally applicable to all the experiments. Table 2:2 (below) gives an example of the bone database records; the insect recording sheets, on which the records are based, are given in Appendix 2.1.

2.7 The Recording of Bone

The criteria which have been recorded as standard fields were:

Experiment Code: a code given to identify each experiment, where the experimental situation was not adequately documented by the file name.
Time: the duration of the experiment (e.g. in hours, weeks or number of cycles).
Treatment: a code to describe the state of the bone prior to the experiment (e.g. if boiled, fresh etc.).
Bone: the skeletal element name (abbreviated code).

Number: number of identical records (to save recording the same thing many times).
Side: the anatomical side.
Shape: a subjective classification by shape (see below).
Condition: the sum of texture, erosion and flaking: a scale of 1 (as fresh) to 15 (extremely poor).
Texture: recorded on a scale of 1 (as fresh) to 5 (extremely crumbly).
Erosion: recorded on a scale of 0 (none) to 5 (extreme)
Flaking: (surface exfoliation), recorded on a scale of 0 (none) to 5 (extreme).
Acid Erosion: recorded as present (1) to severe (3), only for relevant experiments.
Warping: recorded as present (1) to severe (3), only for relevant experiments.
Cracking: recorded as present (1) to severe (3), and the major direction of cracking noted (L=longitudinal, T=transverse, P=Parabolic, R=Radial, C=Circumferential).
Fragment Completeness: recorded as the proportion (%) of the whole bone that the fragment represents, to the nearest estimated 10%.
Area of Bone: (e.g. proximal, distal, medial, dorsal, ventral).
Colour: this section was used only for the burning experiments, but is relevant to archaeological samples.
Comments: this section may carry a number of observations about the fragment.

Where variables were recorded which relate to a specific experiment they are discussed in the relevant sections of the text.

2.7.1 Condition, Texture, Erosion and Flaking.

"Texture" describes the overall appearance of the bone, from greasy, through dry and brittle to crumbly or "biscuit-like". "Erosion" is caused by abrasion to the surface causing polishing followed by the exposure of areas of cancellous bone. In some circumstances bone may be eroded as a result of chemical weathering, in which case no

polishing occurs but areas of cancellous bone are exposed. Chemical weathering of bone in this way is reflected by an increasingly crumbly texture. "Flaking" or exfoliation has been described by Johnson (1985, 184) as the result of severe desiccation resulting in the delamination of the cortical surface. This delamination is usually propagated from the edges of the bone or from cracks which form on the bone surface, and flakes are produced.

The "condition" category combines the scores for "texture", "erosion" and "flaking" to give a figure which can usefully summarise the preservation state of the fragment and be used as a comparative tool. It is, however, obvious that these categories are not independent; an extremely eroded bone may not show surface exfoliation because the surface has eroded away! This fragment would therefore score less for "condition" than a fragment which showed less erosion but some exfoliation. The "texture" category in some cases ameliorates this problem, as the former fragment may score more highly for texture (i.e. is more crumbly) than the latter. For some inter-experimental or intra-experimental comparisons the scores in the "condition" category have been condensed into five groups representing states ranging from fresh bone to extremely friable bone. In cases where one of the components of the "condition" category (i.e. "erosion") was the dominant process observed during the experiment, this category has been used as the comparative class rather than using the less relevant "condition" category.

For greater clarity, each class for texture, flaking and erosion is described:

Texture:

1 = Greasy, as fresh
2 = Dry, non-greasy.
3 = Slightly crumbly, chalky or brittle in some areas.
4 = Crumbly and friable, or very brittle but remains intact when touched.

5 = Extremely crumbly/friable, a powdery deposit may be left on the fingers when the bone is touched, and the bone breaks up very easily.

Flaking:

0 = none.

1 = Slight peeling of the surface (<10% of the surface). These flakes are defined by cracks penetrating <1 mm. into the bone.

2 = Between 10 and 50% of the surface shows these small flakes, making the surface rough.

3 = Some areas (<25% of the total surface area) display larger flakes, propagated by cracks of 1 mm. or several mm. deep, these flakes may extend through several laminae.

4 = Between 25% and 50% of the surface area shows these larger flakes.

5 = Virtually the whole surface area (>50%) is characterised by large flakes.

Erosion:

0 = None

1 = Very slight. Occasional areas (<10% of the surface) usually on the edges of bones or upstanding parts appear worn.

2 = Between 10 and 25% of the surface appears worn or abraded. In small areas the upper layer(s) of bone have been removed, exposing the underlying tissue (often cancellous bone)

3 = Between 25% and 50% of the surface appears worn or abraded, edges and upstanding areas have been extensively reduced.

4 = The bone surface has been removed from up to 50% of the bone, exposing the underlying tissue. Some areas of the bone, usually edges or upstanding areas, have been completely worn away, and small holes may have appeared in the bone.

5 = Very severe erosion. Large areas of the underlying bone are exposed. A large part of the bone may have been worn away.

2.7.2 Shape

For several experiments the bones were classified subjectively according to shape. These categories were based on the overall appearance of the bone, and one bone may possess areas corresponding to different shape categories. It should be remembered that once broken the fragment may have a different shape from the complete element.

Four categories were used to describe fish bones:

1. **Robust**: Bones were classified as "robust" when the bone appeared dense, at least in parts; e.g. dentary, premaxilla, quadrate.
2. **Flat**: Bones which are of uniform thickness over much of the element with a large surface area in relation to volume; e.g. opercular bone.
3. **Spherical**: Bones which are approximately the same size in all directions, with a circular aspect; e.g. vertebrae, which have a cylindrical centrum despite having spiny processes.
4. **Irregular**: This category includes those bones which could not be placed in any of the above categories; e.g. cleithrum, gadid hyomandibular (some of these bones were robust in some parts, flat in others).

Six shape categories were used to describe the bones of mammals, birds and amphibians, of which the first four included most of the bones:

1. **Tubular**: This category includes long bones, with hollow interiors.
2. **Flat**: Bones with a large surface area in relation to volume, and of uniform thickness over much of the element; e.g. pelvis, mandible, scapula.
3. **Short** bones: squat bones; e.g. phalanges.
4. **Spherical**: Bones which are roughly the same size in all

directions and roughly circular; e.g. vertebrae, astragalus, calcaneum.

5. **Robust**: Bones were classified as "robust" when the bone appeared thick, at least in parts, but was not spherical e.g. sacrum.

6. **Irregular**: This category includes those bones which could not be placed in any of the above categories, e.g. bird mandibles, maxillae.

These groups are very crude, and individuals may wish to disagree with some of the classifications. Fish skeletal elements vary considerably in shape. Each species of fish was considered individually when classifying the bones into shape groups as the same skeletal element may have very different gross morphology in different species.

Alternative methods of classifying bones by size and shape have been proposed, and are given in Shipman (1984, 26-28). The shape index, defined as:

SI = maximum length / maximum breadth

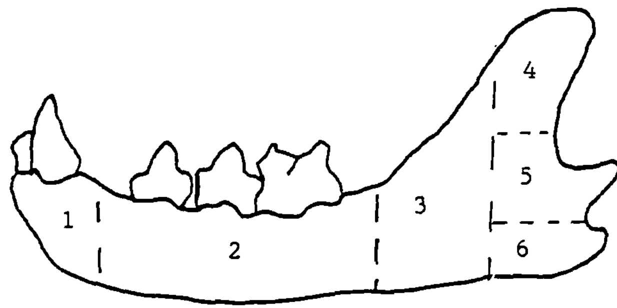
where maximum length and breadth are measured at right angles to each other, had the disadvantage of discounting the three dimensional property of bones. A cubic bone could end up with the same shape index as a flat bone. More accurate measurements of surface area to obtain a surface area:volume ratio would be very time consuming, especially for fish bones where many elements are irregular shapes. For these reasons I felt it more appropriate to use subjective rather than quantitative methods of defining shape.

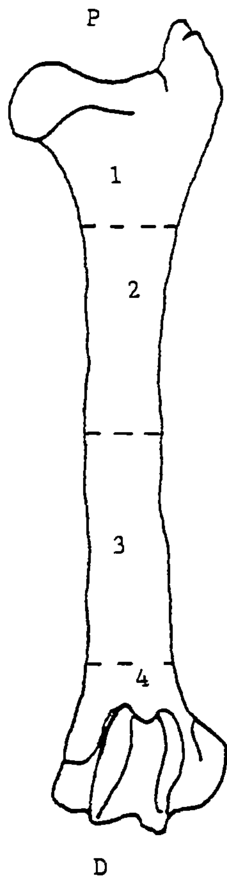
2.7.3 Fragment completeness

Fragment completeness was recorded as a percentage of the whole bone that the fragment represented, scored to the nearest estimated 10%. These scores were later grouped into wider categories, dependent on the experiment but frequently groups of a. 30% or less, b. 40-50%, c. 60-70%, d. 80-90% e. complete, i.e. 100%). The boundaries used for

the groups depended on the state of the remains after the experiment; for example if very few complete or nearly complete bones were recovered groups d and e would be merged.

Using the fragment completeness scores, a mean fragment completeness statistic was calculated in several cases, in order to compare the extent of fragmentation between taxa and skeletal elements. To enable this, the mean value for fragment completeness per bone was first calculated, necessitating the recording of the area(s) of bone represented by the fragment. Depending on the bone, the area was recorded as proximal, distal, medial, lateral, dorsal or ventral. Where these descriptions were insufficient to describe the fragment, a numeric code was given based on the anatomical position of the area(s) of bone represented. This was done for the major long bones of mammals and birds and for mammal mandibles and pelves. The codes used are illustrated for these bones in Fig 2:2. By this method, and by recording the anatomical side (left or right) of the element, it was possible to establish which fragments could have come from the same bone. A mean fragment completeness score for that bone was then calculated from the average of the fragment completeness scores. The figure obtained for each bone is therefore the mean identifiable fragment completeness score. The mean fragment completeness statistic for each skeletal element was then calculated from the total of the mean fragment completeness scores per bone divided by the expected number of that skeletal element (i.e. based on the number of bones at the start of the experiment).





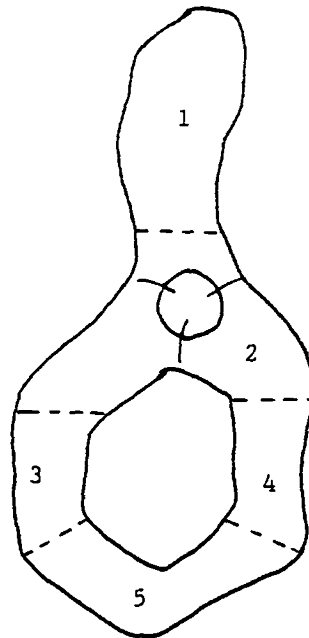


Fig 2:2 Illustrations of the areas of bones described by numerical codes. a) Mammal mandible, b) Long bone, c) Mammal pelvis.

Table 2:2 An Example of the Bone Database Record

REC TIME	TR	SPEC	BONE	NO	SD	SH	CN TX	ER	FL	WP	FC	A	CR	COMMENTS
1264109	B	COD	CL	1	R	I	9.04	0	5	2	90	-	-	
1265109	B	COD	CL	1	L	I	9.04	5	0	2	70	DO	-	
1266109	B	COD	D	1	R	R	10.04	4	2	0	90	-	-	
1267109	B	COD	D	1	L	R	14.05	5	4	2	50	DO	-	T. ROW EROD.
1268109	B	COD	A	1	R	R	10.04	5	1	1	90	-	-	
1269109	B	COD	A	1	L	R	12.05	5	2	2	80	-	-	
1270109	B	COD	PX	1	R	R	10.04	4	2	1	90	-	3L	
1271109	B	COD	PX	1	L	R	13.05	3	5	1	80	-	2L	
1272109	B	COD	VO	1	-	I	9.04	3	2	2	90	-	2	
1273109	B	COD	PAR	1	-	I	9.04	4	1	2	80	-	2L	
1274109	B	COD	MX	1	R	R	11.05	4	2	0	90	-	3L	
1275109	B	COD	MX	1	L	R	11.05	4	2	0	90	-	2L	GR.MOLD
1276109	B	COD	CH	1	R	F	10.05	4	1	0	90	-	2L	GR.MOLD

KEY.

Rec = Record no., TIME (measured in weeks in this instance) TR = Treatment (B = boiled), SPEC = Species, BONE = Skeletal element, SD = Side, SH = Shape, CN = Condition, TX = Texture, ER = Erosion, FL = Flaking, WP = Warping, FC = Fragment Completeness, A = Area represented by the fragment (DO = dorsal) CR = Cracking (severity and direction).

2.8 Statistical Analyses

The information was analysed using several different computer packages and techniques. Statistical tests were kept to the most robust non-parametric tests due to the limitations imposed by the nature of many of the experiments, which yielded non-normally distributed data. The two tests utilised most frequently were the chi-squared test and Spearman's rank order correlation analysis. By means of these tests it was hoped to test hypotheses and to identify distinctive patterns in the data, the reasons for which could then be further explored.

The chi-squared test highlights deviations from the expected values based on a null-hypothesis (usually of there being no difference between two groups other than

that expected by chance). Spearman's rank order correlation analysis indicates where the ranking of variables within a group are more similar to the rankings of the same set of variables in another group than would be expected by chance alone. All significant correlations were plotted to ensure that the relationships were linear.

Where Spearman's rank correlations were applied, they were limited to comparisons of similar groups; for example comparisons of skeletal element representation resulting from experiments using the same species or similar groups of species. Different fish taxa, for example, have different numbers of certain skeletal elements, and the design of some bones is also markedly different. Comparisons of skeletal element representation between different species would therefore be invalid.

The statistical packages used most often in the analyses were MINITAB and S.P.S.S.X. Additionally GENSTAT has been used in the calculation of the best fit lines for the experiments into bone composition described in Chapter 3. Graphs were drawn with the aid of the graphics package UNIRAS versions 5.4 and 6.1. All packages were run on the University of York Vax cluster mainframe computer.

2.9 The Recording of Insect Remains.

Insect remains were scored according to the degree of disarticulation and fragmentation, and any evidence of colour change was also recorded. Scoring was by counts of complete and fragmented elements, by body part or group of body parts. Appendix 2.1 shows the standard recording form used. Comparative material with which to compare the degree of colour change was obtained by experiments using various chemicals; these are discussed in Appendix 2.2. The insect records were used to construct disarticulation stages, which are given in Appendix 2.3.

2.10 The Recording of Mollusc Shell

The condition of mollusc shells was recorded by written descriptions, with sketches to illustrate fragmentation or cracking where appropriate. As little change apart from breakage was observed, more sophisticated methods of scoring were inappropriate.

2.11 The Structure and Composition of Bone, Shell and Insect Cuticle.

To define the materials which this study deals with, this section summarises, albeit very superficially, the more pertinent aspects of the present state of understanding of the structure of the skeletal tissues under investigation; bone, shell and insect cuticle.

2.11.1 Bone.

Bone is essentially a calcified tissue comprising protein fibres (collagen) embedded with calcium phosphate, mostly in the form of hydroxyapatite crystals [$Ca_{10} (PO_4)_6 (OH)_2$]. Also included are a number of polysaccharides and water, as well as blood vessels and living cells in most living bone tissue (Currey 1984, 24). Collagen forms the bulk of the organic matrix in bone, about 50% of the volume of the bone or one third of the dry weight (Wainwright *et al.* 1976, 169).

Mammalian bone may be divided into three basic types: woven, lamellar and parallel-fibred. The following descriptions are based largely on Currey (1984). Woven bone is laid down rapidly, and forms most of the bone of foetuses and around calluses. Lamellar bone comprises sheets of oriented collagen fibrils, with their associated mineral, consequently it is laid down more slowly than woven bone but confers greater strength. Parallel-fibred bone is an intermediate form between woven and lamellar bone. At a higher level of organisation bone may be

described as woven, lamellar, haversian (also lamellar, but containing secondary osteons) and fibrolamellar (also known as plexiform or laminar). These structures are described in detail by Currey (1984, 26-30). At a higher level still, bone may be described as compact and cancellous. The latter is highly vascularised and "spongey". The periosteal portions of the shafts of long bones are composed of compact bone, the epiphyses and in some vertebrates the endosteal part of the shaft, cancellous bone. Growth takes place at the ends of the diaphysis (shaft) of long bones; at the junction with the cartilage. Dermal bones, including the skull, jaws and shoulder girdle, are formed by mesenchyme cells in the skin, so growth takes place at the margins and bone is also laid down on the inner and outer surfaces (Romer and Parsons 1986).

Bone forming cells are mesenchyme cells termed osteoblasts; as bone formation proceeds, a process which takes place at the epiphysial plates in mammals and birds, the osteoblasts nearest to the newly formed bone become walled in (Halstead 1974, 44). These cells then undergo a number of changes, to become osteocytes, important in mineral homeostasis. Osteoclasts are large multinucleated cells responsible for destroying bone (*ibid.*).

Teeth are composed of an enamel capping to a dentine base. Dentine is morphologically similar to bone, but contains "dentine tubules" rather than cells. Enamel is the hardest and stiffest vertebrate skeletal material, and consists of large apatite crystals with a small amount of protein (Wainwright *et al.* 1976, 223-4)

There have been a substantial number of published works on the structure of mammal bone and its mechanical properties. Foremost in this area have been the books by Evans (1973) and Currey (1984) which have been used by archaeozoologists and paleontologists interested in bone fracture. Most of the experiments have been conducted using small samples of bone rather than whole elements, which

reduces their applicability to archaeozoological research. Even so, some general principles are useful, for example that the internal composition of bone affects the nature of fracture, and that bone is anisotropic (i.e. it has different properties when tested in different directions). The structural organisation of bone gives rise to lines of weakness, known as "split lines" (Tappen 1969; 1971; 1976) which may be exposed when bone exfoliates as a result of subaerial weathering, for example. The way in which a bone fragments is therefore partly determined by its shape and its internal structure.

Bone can vary in its levels of calcium, protein and fat as a result of factors such as age and nutritional state. Depletion of calcium is common in old age and may lead to osteoporosis, in which the resistance of the bone to withstand stress is reduced. Calcium depletion within bone is accentuated in salmon bone as a result of spawning. Weathering and chemical erosion (e.g. leaching) of bone will alter its physical characteristics. Drying out greatly alters the mechanical properties of bone; it becomes stiffer and more brittle (Currey 1985).

Cooking also affects the structure of bone, denaturing the collagen fibrils and, at high enough temperatures, melting and recrystallising the hydroxyapatite. Richter (1986) demonstrated that collagen fibrils in fish bone begin to denature at temperatures well below 100°C, and Snowden and Weidman (1976) found the same effects in sheep bone. Changes in the physical structure of bone will clearly have severe consequences for the mechanical properties.

Other types of bone, which are not relevant to medical applications, have been less well studied, though the histological structures of fossil and recent bone has been described in detail by Enlow and Brown (1956-58) from which most of the following descriptions are taken.

Bird bone is essentially similar to mammal bone, but the skeleton shows adaptations for flight. The bones of birds are light and hollow, and many are pneumatised by the addition of air sacs lined with epithelium (Cohen and Serjeantson 1986). Cancellous bone generally occurs only in the epiphyses and flat bones. Lamellation is indistinct in bird bone, but the bone compacta of large birds possess an outer and inner lamellar layer and a central vascular layer. Small birds may possess non-vascular bone.

Amphibian bone is characterised by its light, delicate thin walled structure. Limb bones have splayed ends, and in all but old individuals the ends of most bones are cartilaginous. Most amphibian bone, like reptile bone, is simple, non-vascular and composed of concentric lamellae.

Fish bone has been described as comprising lamellar and woven bone, but may be cellular (with osteocytes) or acellular (without osteocytes). In acellular bone the bone cells withdraw before they become trapped within the matrix to form osteocytes. More primitive families such as the Salmonidae appear to have cellular bone while more advanced teleosts such as the Gadidae have acellular bone, although there are some exceptions in both cases. X-ray diffraction of acellular (carp) and cellular (salmon) bone has indicated that acellular bone contains a higher organic component (Moss 1960) although this is questioned by the present study (see Chapter 3). It is not clear what, if any, advantage is conferred by acellularity, although Moss (1962) suggested that cellularity may be more expensive metabolically. New bone is laid down mainly at the edges of existing bone, and, unlike other vertebrate groups, growth continues throughout life, although at a diminishing rate. The appearance of most teleost bone is fibrous, even wood-like, as a result of the orientation of the collagen fibrils. The bone is light and vertebrae, in particular, are supported by means of struts to provide internal support. Fish, because of their aquatic existence, are not subject to the same external forces as terrestrial

vertebrates and their bone can be lighter as a consequence.

Otoliths, the balance organs in fish located in the inner ear, are paired structures composed of calcium carbonate, usually in the form of aragonite (Wheeler and Jones 1989, 114). The largest of the three pairs is the sagitta in most bony fishes. It is this which will be referred to as the otolith in the subsequent text. Otoliths are not equally developed in all fish groups. The elasmobranchs do not have well-formed otoliths, and otoliths are small and poorly developed in the Salmoniformes (*ibid.*).

Although frequently termed bone, the skeletons of elasmobranch fish (including the sharks and rays) is in fact composed of cartilage, which may become mineralised by the addition of calcium in the form of apatite crystals in later life. Cartilage is a hard gristle composed of protein and toughened by fibres. Sharks and rays have a large number of vertebral centra which contain calcified struts within the body of the centrum (Wheeler and Jones 1989, 80).

2.11.2 Mollusc shell

Mollusc shell is composed of calcium carbonate, generally in the form of calcite and aragonite, plus a small amount of protein and occasionally chitin (Wainwright *et al.* 1976, 211). These two forms are rarely found in the same layer; where both are found in the same shell usually calcite forms the outer layer, aragonite the inner (Rhoads and Lutz 1980, 71-2). Nacre (mother-of-pearl) occurs on the inside of many shells (e.g. the mussel, *Mytilus* sp(p)) and is composed of aragonite. The microstructure of shells may be classified as simple prismatic, composite prismatic, crossed lamellar, complex crossed-lamellar, homogeneous, foliated or cross foliated (Wainwright *et al.* 1976, 211-2). The most common combinations are 1. nacre inside, prismatic material outside; 2. foliated material with a little crossed lamellar material; 3. crossed lamellar material

alone or with a little homogeneous material. Thin shells tend to be made of prismatic material with nacre or foliated material; thick shells tend to be made of crossed lamellar material (Vincent 1982, 168). The former composition describes most of the shells used in this research. Limpets are an exception, having a foliated structure (Currey 1985). Currey has investigated the strength of nacre and crossed lamellar shell and demonstrated that the organisation of the material is the most important determinant. The nacre layer is arranged with its sheets parallel to the prismatic structure, thus diffusing any cracks which may travel through the prismatic layer (Vincent 1982, 173-4).

2.11.3 Arthropod cuticle.

Arthropod cuticle contains three main components; chitin (a polysaccharide), various structural proteins and calcium carbonate. The last is found mainly in Crustacea and Diplopoda. Insect solid cuticle, or sclerite, is a composite material composed of chitin fibres associated with a protein matrix. The protein matrix becomes progressively tanned or sclerotized following ecdysis or moulting, by a cross-linking of the protein chains via quinone links, the precise mechanism of which is still unclear. This makes the cuticle hard and stiff. Within the cuticle are two layers, the exocuticle (which becomes tanned) and the endocuticle (which may not be tanned). The chitin fibres confer high strength and stiffness, the matrix is more pliant (Wainwright *et al.* 1976, 164). The mechanical properties of insect cuticle will therefore depend on the ratio of chitin:protein, the organisation of the chitin fibrils, and the extent of sclerotization. Further details about the structure and properties of insect cuticle may be found in Neville (1975), Vincent (1980) and Vincent (1982).

CHAPTER 3. EXPERIMENTS TO INVESTIGATE THE PHYSICAL PROPERTIES OF SKELETAL TISSUES.

The skeletal tissue investigated in this section is bone and the chapter presents the results of two dissimilar approaches to the question of how the intrinsic properties of bone from various animal groups differ.

The first set of experiments described below investigates the loss of organic matter with heating, for bone from a number of taxa. The second set examines the property termed "density" and examines its usefulness as a predictive tool in biostratinomic studies.

3.1 Weight Loss on Heating

The motives for the investigation of weight loss on heating were:

1. To see at what rate organic matter is lost with increasing temperature, and to ascertain whether the rate of loss is constant irrespective of taxon.

2. To investigate the amounts of mineral and organic material within bone from different taxa, and to determine the extent to which the proportion of organic : mineral in bone varies between animal groups.

The organic component in bone degrades as a result of micro-biological activity, weakening the bone and making it much more susceptible to erosion and fragmentation. The proportion of organic material within a bone may therefore have an important bearing on the rate at which the bone will disintegrate.

Two sets of experiments were performed: the first using a range of bone types and temperatures, using weights taken for the bones heated in the muffle furnace during the experiment described in Chapter 4 to determine colour

change with increasing temperature. The second set of experiments utilised standard sets of bones and investigated the amount of lipid in the bones as well as the ratio of mineral:organic material. Experiment 2 was undertaken as a result of the findings of the first experiment which indicated that the bones of different taxa contained very different proportions of organic : mineral material.

3.1.1 Experiment 1.

Methods and materials.

The bones used in this experiment were those used in the heating experiments in the muffle furnace described in Chapter 4 (p.102). The animal groups included fish (cod, haddock, plaice, salmon, and herring), bird (pigeon), mammal (sheep) and amphibian (frog). The fish bones comprised one articular, one opercular, one hyomandibular and 8-10 vertebrae from each taxon for each temperature of burning. The sheep bones included six phalanges (a combination of first and second) and four sesamoids; the frog bones included ten limb bones. The pigeon bones included sets of ten comprising one or two humeri, one or two tibiotarsi, one coracoid, one scapula, one or two radii, one or two ulnae and two vertebrae.

The bones were prepared by scraping away as much flesh, cartilage and periosteum as possible by hand, and were dried for a minimum of 48 hours at room temperature. They were weighed at the start of the experiment, heated from cold for two and a half hours in a muffle furnace in open crucibles, and weighed again at the end after cooling to room temperature at room humidity. This enabled a comparison of rate of weight loss for the bone from each of the selected species and a comparison of the total weight loss after combustion of all the organic matter.

Results and Discussion.

The figures for the percentage weight loss at each temperature condition for each taxon are given in Appendix 3.1 and Fig. 3:1 illustrates the rates of weight loss with increasing temperature for each taxon.

Analysis of the percentage weight loss by temperature demonstrated that all the taxa studied showed a broadly similar pattern of weight loss, which was most rapid up to 300-400°C and generally stabilised at between 500° and 700°C. Weight loss up to about 300°C will be mostly of unbound water which is lost by evaporation (Duval 1963) after which bound water is removed and organic matter is combusted (Civjan *et al.* 1971). The organic matter is removed at temperatures up to about 700°C, at which point the weight stabilises.

The weight loss recorded in this study was consistently higher than expected from published figures. Most analyses of mineral in bone suggest a proportion of between 65 - 70% in dry degreased bone, with the remaining material being mainly (90%) collagen; other proteins, carbohydrate and fat being of minimal importance (Price 1989). The higher than expected weight loss in this study may in part be attributable to incomplete drying, as drying took place at room temperature and was sometimes of less than the week's duration suggested by Smith and Walmsley (1959, quoted in Evans 1973, 309) as necessary for complete drying. Combustion of fat within the bone probably accounts for the remaining excess weight loss.

Published figures of bone composition have been based on analyses of sections of mammal long bone shaft. The bones in this study are complete, and in the case of sheep and pigeon will have contained marrow fat in the cavity of the bone. All the bones in this experiment appeared to be from adult individuals, but some bones may have been incompletely mineralised. As dissimilar skeletal elements

were used in this study, the weight loss figures for mammal, bird and fish bone cannot really be usefully compared. The elements used from fish were the same for all species, however, with one articular, one opercular, one hyomandibular and 8 - 10 vertebrae used for each temperature of burning. The results are therefore comparable. The relatively high standard deviations are associated with differences in the percentage weight loss between different skeletal elements from the same animal. In all cases, for example, fish articulars showed a greater overall weight loss than vertebrae. In terms of total weight loss the gadid fish (cod and haddock) lost a smaller proportion of their total weight compared with the other species.

To test whether this difference was significant, non-linear regression curves were fitted to the percentage weight loss data as illustrated by Fig. 3:1 using the statistical computer software package "Genstat" (developed by the Rothhampstead experimental group). The slopes and asymptotes of the exponential regression curves for the weight loss data from the fish bones were calculated, and the temperature at which 50% and 90% of the total weight of the bones was lost was calculated for each taxon (Table 3:1). The maximum percentage weight loss was compared between taxa, using asymptotic confidence intervals (The Genstat 5 Committee 1988). The asymptotes (i.e. maximum weight loss values) were significantly different when the value of the interval did not contain 0.

$$(A\ species1 - A\ species2) \pm Z\sqrt{s^2 species2 + s^2 species1}$$

where A is the asymptote start point (i.e. maximum weight loss)
Z is the confidence interval used (95% = 1.96, 99% = 2.58)
s is the standard error.

The results at the 95% and 99% confidence interval are given in Table 3:2.

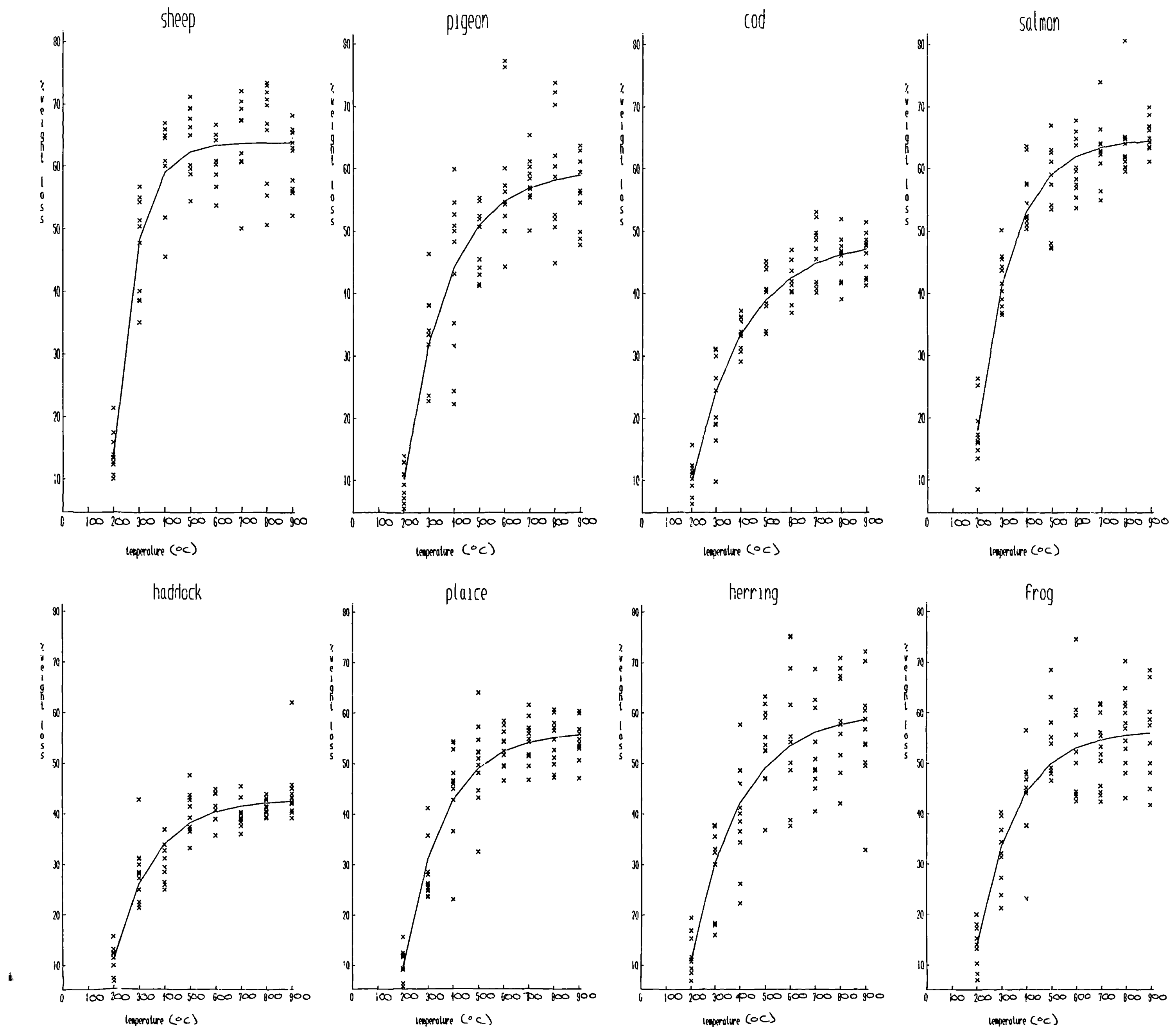


Fig. 3:1 Percentage Weight Loss With Temperature, By Taxon.

Table 3:2. Temperatures at which 50% and 90% of the original weight of bone is lost, by species (calculated values).

Species	50% weight lost	90% weight lost
Sheep	237.9°C	374.0°C
Pigeon	287.6°C	565.1°C
Frog	266.1°C	522.1°C
Cod	299.5°C	644.3°C
Salmon	253.2°C	484.8°C
Haddock	261.1°C	510.1°C
Plaice	280.8°C	536.8°C
Herring	297.1°C	619.4°C

Table 3:3. Confidence intervals and significance of the total proportion of weight lost on heating to 900°C.

To test null hypothesis is that there is no difference between the maximum weight loss between the pairs of species.

Species	Asymptotic Confidence Interval (95%)	Accept null hypothesis at 95%?	Accept null hypothesis at 99%?*
Cod and Haddock	5.59+/-4.78	No	Yes
Cod and Plaice	7.74+/-4.88	No	No
Cod and Herring	11.64+/-5.42	No	No
Cod and Salmon	16.53+/-4.72	No	No
Haddock and Plaice	13.33+/-3.88	No	No
Haddock and Herring	17.23+/-4.54	No	No
Haddock and Salmon	22.12+/-3.69	No	No
Plaice and Herring	3.90+/-4.64	Yes	Yes
Plaice and Salmon	8.79+/-3.80	No	No
Herring and Salmon	4.89+/-4.48	No	Yes

* using the confidence level of 99% Z, in the formula given on p.47 , = 2.58.

Looking at the rate of weight loss, all the species tested achieved 50% of the total weight loss at between 250 and 300°C (Table 3:1). Much of this is probably due to water loss (see above). The temperatures at which 90% of the weight loss had taken place varied more between species. The sheep bone samples had lost 90% of their weight before 400°C while salmon bones lost most of their original weight at just under 500°C, at which temperature the bones became grey. The rate of weight loss was slower for the other species, in particular the temperatures for cod and herring were in excess of 600°C for 90% of the weight lost. The reasons for this are not immediately clear. Differences in the size of specimens does not seem to have been a controlling factor, as might have been expected; the salmon bones were the largest fish bones used, yet most of the weight loss occurred at a lower temperature than for smaller boned species.

As illustrated by Fig. 3:1 and Table 3:2, the most significant differences in maximum weight loss as a proportion of the total bone weight was between both cod and haddock compared with the other three species (as indicated by the size of the confidence interval). At the 99% confidence level the total percentage weight loss values between cod and haddock and between herring and salmon were not significantly different, while the total percentage weight loss values for plaice and herring were not significantly different at 95%. At all temperatures the weight loss for cod and haddock were less as a proportion of the original dry bone weight than for the other species.

This result is surprising given that Moss (1960) concludes from X-Ray diffraction analysis on bones from Spanish mackerel (*Scomberomorus maculatus* L.) and carp (*Cyprinus carpio*) that acellular bone (the mackerel) contains more collagen than cellular bone (the carp). Moss's experiments included only the skulls of one individual from each of the two species of fish, of unspecified sizes and ages, however. The preparation

methods used included pulverising the hand-scraped specimens and drying over calcium chloride, followed by grinding by hand for X-ray diffraction. Whether the results he found were a product of the difference between acellularity and cellularity in bone is therefore open to question. Differences in the organic:mineral ratios in bone need not be related solely to the activity of osteocytes. Furthermore, the X-Ray diffraction patterns only indicated a greater amount of organic material in the mackerel bone than in the carp bone. Moss states that this organic component is probably collagen; however other organic materials such as lipids may have contributed, and mackerel are particularly oily fish.

The fish of the lower Orders tend to have cellular bone, those of higher Orders acellular, although there are some exceptions. Of the fish used in this experiment, cod, haddock and plaice have acellular bone; herring and salmon cellular (Moss 1961; Easom 1988; personal observation of cells on an unstained surface of herring dentary compared with the lack of cells in a haddock subopercular, both viewed under a compound microscope using transmitted light).

It is possible that variations in age of the individuals used in the experiment may explain some of the differences in the organic:mineral ratio in the bone. All the salmon used in the experiments were about 900 mm. total length, the cod and haddock were about 550 mm. and 400 mm. long respectively, the plaice were about 350 mm. and herring 250-300 mm. As fish grow throughout their lives, size is a reasonable guide to age, but obviously different species grow at different rates and attain different maximum sizes. As far as the salmon are concerned, the mineral content of the bones is also affected by spawning. All the salmon used in these experiments were female and about to spawn. The bones would have been depleted in calcium as a consequence.

The other most likely explanation for the large

difference in percent weight loss between the gadid fish compared with the other species is the different amounts of lipid stored in the bones. That salmon, plaice and herring bones are extremely oily can be observed at room temperature, when oil exudes from the bones turning them an orange colour. Cod and haddock bones remain white. On heating to 200 and 300°C the salmon, plaice and herring bones became swamped in oil, which turned to black peeling char at higher temperatures, while cod and haddock bones produced much less oil. The difference in lipid content may play an important part in bone preservation. Experiments conducted into weathering and the decay of bone (below, Chapter 6) indicated that bone decay progresses much more rapidly when the bone is degreased, and cod and haddock bones seem to decay more rapidly than the bones from other animals tested.

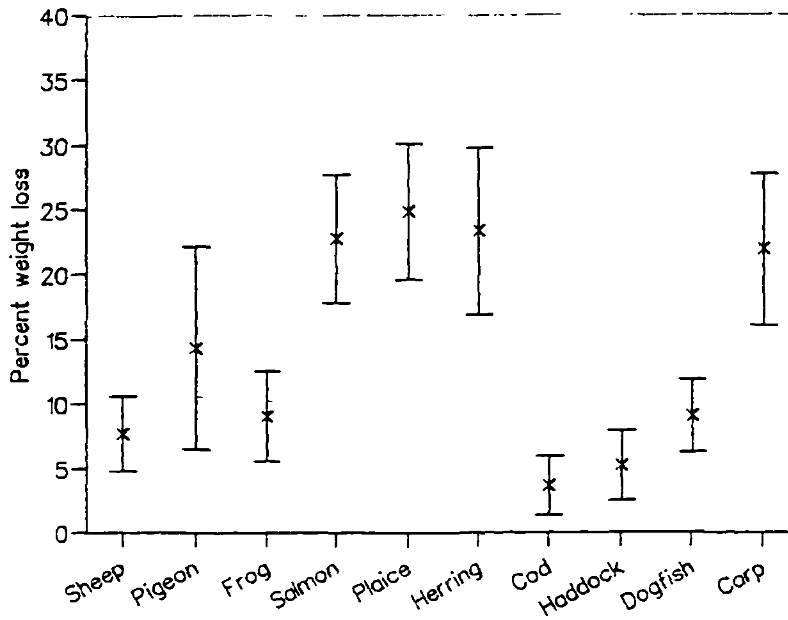
3.1.2 Experiment 2.

As a consequence of the findings of Experiment 1 further sets of bones were examined to investigate the extent to which the amounts of lipid and protein in bone contribute to the overall weight loss on ashing.

Methods.

Ten sets of bones from each of the animal groups used above, from three carp (*Cyprinus carpio*) of total lengths 250 mm., 180 mm. and 220 mm., and calcified vertebral centra from dogfish were utilised in this experiment. The sets of bone samples each comprised approximately 0.5 grams of dry bone from the shaft of sheep metapodials, pigeon femora and tibiotarsi, frog femora and tibio-fibulae and from fish vertebral centra (where complete centra weighed more than approximately 0.5 grams a longitudinal section was used). Each bone sample was weighed after drying for 24 hours at 40°C. One sample from each animal group was then degreased for three days in a 1:2 methanol:chloroform mixture, constantly shaken, with the liquid changed after

the first day. After redrying at 40°C, the specimens were reweighed and then ashed at 850°C for three hours from cold in a muffle furnace until a constant weight was achieved, followed by a final reweighing. This procedure was repeated for each of the ten sets of bone samples.



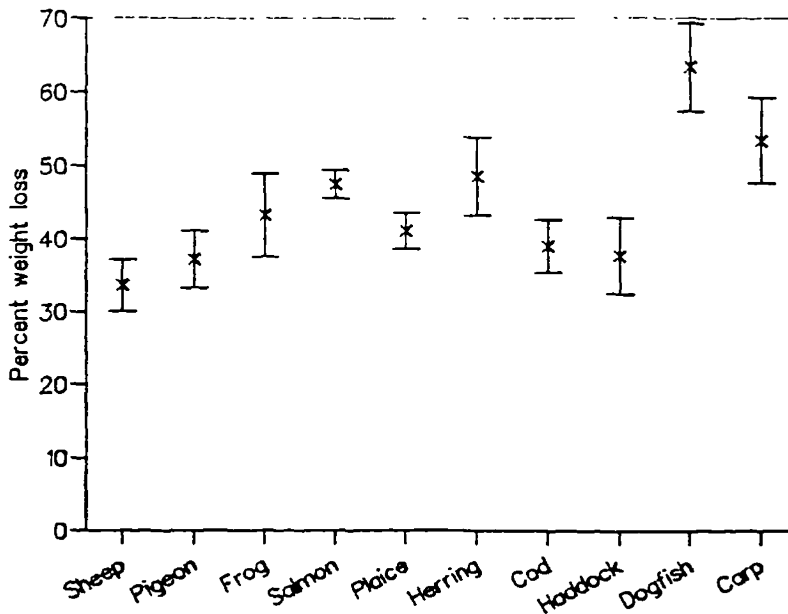


Fig. 3:2 Percentage Weight Loss for Bone Samples After Degreasing and Ashing, by Taxon.

Results and Discussion

Appendix 3.2 gives the weights and percentage weight loss of the bone samples at each of the stages described above, by species, while Fig. 3:2 summarises the results in graphical form. The percentage weight loss on ashing is derived from the difference in weight between the degreased bone and the ashed bone; i.e. it represents the non-lipid portion of the bone, the fat portion being represented by the percentage weight loss on degreasing.

The most greasy bones were those from salmon, plaice and herring, each losing between 22% and 25% of the total dry bone weight when degreased. The least greasy bones were from cod and haddock with a grease content of less than 5%. These results support the conclusions drawn from the earlier experiment; the larger weight loss on ashing of the salmon, herring and plaice bones is largely a result of a greater amount of lipid within the bone. The carp bones were also greasy, losing 22% of the dry weight on degreasing. The high standard deviation associated with the pigeon bones can be attributed to differences in the greasiness of the femur and tibiotarsus; the tibiotarsus samples account for the measurements at the top of the range. The sheep and frog bones contained between 5% and 10% lipid, and the dogfish calcified cartilage 9%. After ashing, only 36% of the dry degreased weight of the dogfish calcified cartilage remained. Carp showed the next highest loss of non-lipid organic material at 53%, followed by salmon, plaice, herring and frog at 40-50% loss. Cod, haddock, sheep and pigeon bone all contained between 33% and 39% non-lipid organic matter. The organic fraction removed from degreased bone on ashing will be mostly protein (collagen). The higher proportions of both lipid and protein indicated in the cellular salmon, herring and carp bones than in the acellular cod and haddock bones contradicts Moss's findings. Acellular plaice bone contained similar amounts of organic material (lipid and

protein) to the cellular-boned species, implying that the acellular or cellular property of fish bone is not related to the proportion of organic material within the skeletal tissue. The high organic component in the carp bones may be a result of the young age of the fish (carp may grow to over 0.5 m.) as mineralisation in bone increases with age.

3.1.3 Conclusions from Weight Loss on Heating Experiments

These experiments have shown that the mineral:organic ratio is not constant in bone but varies between animal groups, and notably between fish taxa. While samples from adult sheep metapodials contained 61.4% mineral, cod 58.3% and haddock 65.4%, other groups contained proportionately less mineral. The young carp bones contained only 38.5% mineral, while dogfish calcified centra contained only 33.3%. It is to be expected that these proportions will change depending on the age of the animal. There is no reason to suppose that the type of bone, i.e. cellular or acellular, is related to the amount of organic material within the bone. It is to be expected that calcified cartilage will contain a large organic component, however.

The amount of lipid in bone varied greatly and is probably animal-group dependent, as well as related to age, size and nutritional state. The proportion of organic material within a bone may determine the rate at which it degrades both above and below the soil, as a consequence of microbial and fungal activity.

The rate of weight loss with increasing temperature also varied significantly between taxa, presumably as a consequence of the varying proportions of the components of bone; different organic materials will be combusted at different temperatures. The oily salmon bones in particular lost a much higher proportion of their weight at under 500°C than did the bones of the other animal groups.

3.2 Density of skeletal elements.

3.2.1 Introduction

The relationship between bone density and the survival of skeletal elements during fluvial transport has been demonstrated by a number of studies concerning large mammal remains (e.g. Brain 1967a; 1969; Voorhies 1969; Behrensmeyer 1975; Binford and Bertram 1977). These attempts to quantify bone density, or specific gravity, are discussed by Lyman (1982, 1984) who points out the different properties of bone which have been measured in each study and defined the properties of true density, bulk density and total porosity used below. While the methods employed by most investigators utilised water displacement to obtain bone density, that used by Lyman (1984) involved photon densitometry. While this latter method has advantages in enabling precise comparisons between specific areas of bone (as opposed to values based on the average density value for the bone as a whole), the former method is simple to perform and does not require the use of sophisticated equipment. For this reason displacement in water is the technique employed in this study.

Within archaeological bird and fish bone reports analysts have argued for bone density as a likely explanatory variable in describing skeletal part survival in the absence of selection by man (e.g. Rich 1980; Livingston 1989; Wheeler 1977; Butler 1987; forthcoming). To date there are no published density measures for fish, bird or small mammal bone, to my knowledge. The density measurements of cod, plaice, rat and pigeon bone presented here are designed to contribute in a preliminary way in this area.

Lyman (1982; 1984) has discussed some problems with using density measurements; for example it is not always clear what property is being measured. The fact that there was no significant correlation between the mean density values

published by Behrensmeyer, Binford and Bertram, and Brain (*ibid.*) using different techniques and so measuring different properties, indicates the problems of relating obtained density values to recovered bone assemblages. Despite the differences, however, all the properties measured did appear to have some use in explaining bone survival, although true density appeared less useful than bulk density (Lyman 1984). Other difficulties arise when relating the properties measured for fresh bone to archaeologically recovered bone, however. As Nichol and Wild (1984, 43) point out, where decay is due to attrition the surface area:volume ratio may change, as will the mass; so density, as a function of mass and volume, may also be altered. Furthermore, when bone begins to exfoliate and is penetrated by invasive organisms (e.g. fungi) the density will similarly be affected. Organic matter will block pores and inhibit water uptake, affecting density measures. The age of the animal will also influence the density of the bone as demonstrated by Binford and Bertram (1977).

Despite the limitations of what has traditionally been termed "density" to describe a consistent property of bone, as a function of relative bone porosity the measure has potential as a predictive tool. For this reason the densities of small mammal (rat), bird (pigeon) and fish (cod and plaice) have been measured and the rankings of skeletal element densities obtained are assessed in terms of their value as predictors of relative destruction of parts of the skeleton throughout the experiments which follow. Density has been described by Shipman (1981) as the weight of the object divided by its volume. In this study several methods of obtaining "density" measurements are discussed. All will be referred to as density in this analysis, although each method measures a slightly different property.

3.2.2 Methods.

The species which have been used in this investigation

include those animals consistently used in the study as a whole, but with relatively compact bones; that is, the bones of herring, salmon and frog have not been used because their large surface area:volume ratio meant that the accuracy of measuring volume of water displaced was limited using the methods described below. These methods were used for simplicity of performance.

The bones of cod (total lengths 1.09 m., 0.63 m. and 0.62 m.), plaice (total length 0.64 m.), rat (adult) and pigeon (adult) were used. The skeletons had been prepared by boiling for varying amounts of time, enough to soften the flesh and ligaments but not to damage the bone, followed by cleaning of the skeleton by hand. This preparation technique had the effect of removing some, but by no means all of the grease. The plaice bones proved to be particularly greasy, a fact that has been observed by the author for flatfish bones generally when compared with gadid bones. Additionally two haddock cleithra from a fish of length 0.59 m. were used to compare with the density of cod cleithra. The haddock cleithra, with swollen ends, are often considered to be one of the most robust archaeological fish bones. All other bones from haddock are generally similar to cod.

All bones were air-dried after preparation and stored for varying amounts of time prior to use. The bones were again dried at 40°C for 24 hours at the start of the experiment, following which they were weighed. Volume was calculated by displacement in water of the bones, using measuring cylinders of varying sizes. The variation in sizes of the bones meant that not all fitted into the same size of measuring cylinder. This problem is greater for fish bones, many of which have irregular shapes and/or large surface areas: volumes. This resulted in varying levels of accuracy for different sizes of bones in reading the volumes of water displaced. Accuracy was greater for small compact bones than for flat or irregularly shaped bones. Pairs of skeletal elements were measured where possible, and the

mean values obtained. Density was calculated from the formula:

Density = Mass (g) / Volume (cubic cm)
True density = mass/volume excluding pore space
Bulk density = mass/volume including pore space

The volume measurement calculated here is a hybrid of bulk and true density as defined above, after Lyman (1984), as temperature and total pore space were not taken into account. As the bones were weighed dry, the method is the most similar to that used by Brain (1969; 1976). This measurement is presented as density measurement 1 (m1). The density of all three cod skeletons were measured in this way.

By examining the predictive value of the different methods of measuring bone density for interpreting recovered bone assemblages, Lyman (1984) concluded that bulk density was the most useful measure. To establish whether the relative density values for the skeletal elements was significantly altered by using a more precise measure of bulk density to that described above, bulk density was measured for the cod bones (fish of total length 1.09 m.) only, using the method given by Lyman (1984). To calculate the bulk density of bone, i.e. the density inclusive of pore volume, all bones were coated with a thin layer of wax, reweighed, and their volume and density calculated as before. The density measure so calculated is referred to as measurement 2 (m2) below. This property is an imprecise calculation of bulk density because the volume of wax is not included in the calculation. To ascertain the bulk density the volume of wax was calculated by the formula:

Vol. wax = mass wax/density of wax.
mass of wax = weight of bone + wax / weight of bone only
density of wax = 0.833

The volume of water displaced by the bone was then

calculated by subtracting the volume of wax from the volume of displaced water, allowing the calculation of true density, presented as measurement 3 (m3). This measurement is the bulk density as defined by Lyman (1984).

A further measure, that of total porosity, was also obtained for cod bones, this time using an individual of total length 0.62 m. The dry bones were weighed after 24 hours in a drying cabinet at 40°C (wa) and subsequently boiled in water for 2 hours to fill all the air spaces and reweighed in the saturated state (wsat). Total porosity (fp) was calculated by the formula:

$$fp = wsat - wa$$

This property is obviously related to the size of the bone, so that large bones will have a relatively large fp value. The proportion of bone : pore space was calculated (wa/wsat x 100) to give a standard measure of porosity for each skeletal element. This measure is referred to as m4.

3.2.3 Results

The three sets of density measurement m1 taken for cod were tested for their degree of similarity by Spearman's Rank Correlation tests. All three sets were significantly correlated at the 99% level (Table 3:3) so a set of mean density values was calculated from the three sets, and this is the group referred to as density measurement m1 in Table 3:7 and used for the statistical tests used elsewhere in this report. The low number of replicates invalidates the use of confidence intervals for the measurements, however.

The weights, volumes and density measurements obtained are given in Appendix 3.3 (for the individual cod measurements) and Tables 3:3 - 3:6 for the combined m1-m4 figures for cod and m1 figures for plaice, rat and pigeon.

Table 3:3

Mean Density (ml) of cod bones.
Fish total lengths (a) 1.09 m (except hyomandibular and frontal from a fish of total length 0.67 m.): (b) 0.63 m. and (c) 0.62 m.

	Density a	Rank a	Density b	Rank b	Density c	Rank c	Mean Density	Rank ml
Otolith	2.40	37	2.40	37	3.30	37	2.70	37
Ectopterygoid	1.48	36	1.80	34	1.12	17.5	1.47	30
Subopercular	1.38	35	1.30	26	2.00	3	1.56	31
Interopercular	1.33	33.5	1.11	17	1.66	28.5	1.37	25
Urohyal	1.33	33.5	1.25	24.5	2.30	36	1.63	36
Postcleithrum	1.31	32	1.20	22.5	1.24	24	1.25	24
Cleithrum	1.30	31	1.70	32	1.72	30	1.57	32.5
Maxilla	1.29	30	1.83	36	1.15	19	1.42	27.5
Ceratohyal	1.27	29	1.13	19.5	1.03	13.5	1.14	19
Dentary	1.25	28	1.43	30	1.57	27	1.42	27.5
Basipterygium	1.21	27	1.80	34	1.80	31.5	1.60	35
Parasphenoid	1.20	26	0.99	11	0.79	. 5	0.99	10
Epihyal	1.18	24.5	0.93	8.5	1.20	21	1.10	17
Palatine	1.18	24.5	1.25	24.5	0.96	11	1.13	18
Symplectic	1.16	23	1.03	12	1.00	12	1.06	14
Supraoccipital	1.15	22	0.81	5	0.63	1.5	0.86	4
Premaxilla	1.15	20.5	1.50	31	1.66	28.5	1.44	29
Prevomer	1.15	20.5	1.33	28	0.70	17.5	1.20	23
Hypohyal	1.14	18	1.38	29	2.20	35	1.57	32.5
Infrapharyngeal	1.14	18	1.04	13	0.87	9	1.02	11.5
Scapula	1.14	18	1.80	34	1.80	31.5	1.58	34
Ethmoid	1.08	16	0.93	8.5	0.63	1.5	0.88	5
Caudal vert.	1.07	15	1.17	21	1.22	22	1.15	20.5
Posttemporal	1.06	13.5	1.32	27	1.06	16	1.15	20.5
Quadrate	1.06	13.5	0.88	7	0.86	8	0.93	7.5
Lacrimal	1.05	12	0.76	3	1.40	26	1.07	15
Supracleithrum	1.04	10.5	1.20	22.5	1.04	15	1.09	16
Suprapharyngeal	1.04	10.5	1.07	15.5	1.36	25	1.16	22
Articular	1.03	9	1.12	18	2.01	34	1.39	26
Coracoid	1.00	8	0.83	6	1.23	23	1.02	11.5
Abdominal vert.	0.91	7	1.07	15.5	1.18	20	1.05	13
Basioccipital	0.88	6	0.96	10	0.83	7	0.89	6
Opercular	0.85	4.5	1.13	19.5	0.80	6	0.93	7.5
Preopercular	0.85	4.5	1.06	14	0.95	10	0.95	9
Hyomandibular	0.72	2.5	0.73	2	0.78	4	0.74	2
Frontal	0.72	2.5	0.70	1	0.71	3	0.70	1
Prefrontal	0.70	1	0.79	4	1.03	13.5	0'.84	3
MEAN							1.15	

Haddock cleithrum (fish 0.47 m)

	1.0	1.35	1.35

Spearman's Rank Correlations between replicates. 35 df.

density (a) against density (b). rho = 0.616. significant at 99%
density (a) against density (c). rho = 0.459. significant at 99%
density (b) against density (c). rho = 0.619. significant at 99%

Table 3:4

Mean Volume (cubic cms), Weight (g.) and Density (ml) of Plaice bones.

Bone	Volume	Weight	Density	Rank
Parasphenoid	0.50	0.86	1.72	33
Caudal vert.	0.21	0.36	1.71	32
Preopercular	0.60	0.97	1.62	31
Basipterygium	0.10	0.14	1.40	30
Abdominal vert.	0.33	0.42	1.27	29
Maxilla	0.28	0.35	1.25	28
Opercular	0.25	0.31	1.24	27
Subopercular	0.20	0.24	1.20	26
Posttemporal	0.30	0.35	1.17	25
Articular	0.40	0.46	1.15	24
Interopercular	0.50	0.57	1.14	22.5
Cleithrum	1.50	1.70	1.14	22.5
Supracleithrum	0.23	0.26	1.13	21
Anal pteryg.	2.10	2.27	1.10	20
Hyomandibular	0.55	0.59	1.08	19
Premaxilla	0.30	0.30	1.00	18
Urohyal	0.50	0.49	0.98	17
Suprapharyngeal	0.27	0.26	0.96	16
Ectopterygoid	0.10	0.09	0.90	15
Symplectic	0.10	0.08	0.80	13.5
Coracoid	0.10	0.08	0.80	13.5
Dentary	0.45	0.36	0.79	11.5
Quadrate	0.48	0.38	0.79	11.5
Supraoccipital	0.25	0.19	0.76	10
Palatine	0.20	0.15	0.75	9
Hypohyal	0.20	0.16	0.70	8
Infrapharyngeal	1.10	0.71	0.65	7
Basioccipital	1.00	0.60	0.60	6
Frontal	0.80	0.48	0.60	5
Ceratohyal	0.60	0.36	0.60	4
Epihyal	0.30	0.18	0.60	3
Prefrontal	0.70	0.41	0.59	2
Prevomer	0.50	0.24	0.48	1
MEAN			0.99	

Table 3:5

Mean Volume (cubic cm), Weight (grams) and Density (ml) of complete pigeon bones.

Bone	Volume	Weight	Density	Rank
Scapula	0.13	0.21	1.62	15
Phalanx IIm	0.10	0.12	1.20	14
Tarsometatarsus	0.29	0.32	1.10	13
Tibiotarsus	0.67	0.65	0.97	11.5
Radius	0.30	0.29	0.97	11.5
Pelvis	0.40	0.36	0.90	10
Femur	0.70	0.57	0.81	9
Carpometacarpus	0.50	0.37	0.74	8
Ulna	0.90	0.64	0.71	7
Coracoid	0.50	0.35	0.70	6
Synsacrum	1.00	0.69	0.69	5
Cranium	1.50	0.88	0.59	4
Humerus	1.75	0.95	0.54	3
Vertebra	0.13	0.069	0.53	2
Sternum	3.0	1.36	0.45	1
MEAN			0.83	

Table 3:6

Mean Values for Volume (cubic cm), Weight (g.) and Density (ml) for complete adult rat bones.

Bone	Volume	Weight	Density	Rank.
Radius	0.10	0.14	1.75	13
Pelvis	0.50	0.78	1.56	12
Ulna	0.25	0.23	1.53	11
Scapula	0.20	2.86	1.43	10
Cranium	2.20	3.04	1.39	9
Mandible	0.40	0.48	1.20	8
Femur	0.90	0.93	1.16	7
Humerus	0.50	0.46	1.15	6
Tibio-fibula	0.90	0.83	1.13	4
Sacrum	0.70	0.79	1.13	4
Cervical v.	0.08	0.09	1.13	4
Caudal vert.	0.17	0.19	1.12	2
Lumbar vert.	0.25	0.25	1.00	1
MEAN			1.28	

Mandible included all molars, no incisors.
Cranium included all molars and one incisor.

Table 3:7

Mean density measurements (m1-m4) for cod bones, with ranks and Spearman's Rank correlation coefficients.

	m1	Rank	m2	Rank	m3	Rank	m4	Rank
Urohyal	1.63	36	1.34	30	2.67	36	57.69	20
Basipterygium	1.60	35	1.20	16.5	2.25	34	42.50	2
Scapula	1.58	34	1.14	12.5	1.49	14	44.47	4
Hypohyal	1.57	32.5	1.14	12.5	1.44	10	60.73	24
Cleithrum	1.57	32.5	1.41	32.5	1.69	23.5	68.41	36
Subopercular	1.56	31	1.35	31.0	1.46	11.0	67.63	33
Ectopterygoid	1.47	30	1.33	29	2.35	35	66.28	32
Premaxilla	1.44	29	1.12	10	1.23	4.5	66.04	31
Maxilla	1.42	27.5	1.09	9	1.14	2	68.27	35
Dentary	1.42	27.5	1.31	26.5	1.59	18	67.71	34
Articular	1.39	26	1.13	11	1.25	6	64.13	28
Interopercular	1.37	25	1.43	34	1.65	21.5	65.49	30
Postcleithrum	1.25	24	1.30	24	1.65	21.5	64.37	29
Prevomer	1.20	23	0.92	2	1.69	23.5	61.54	26
Suprapharyngeal	1.16	22	1.21	18	1.86	30	48.57	9
Posttemporal	1.15	20.5	1.25	20.5	1.47	12.5	62.29	27
Caudal vert	1.15	20.5	1.41	32.5	1.77	26	51.34	14
Ceratohyal	1.14	19	1.07	7.0	1.23	4.5	51.89	15
Palatine	1.13	18	1.51	35	2.23	33	58.17	21
Epihyal	1.10	17	1.23	19	1.55	17	50.84	11
Supracleithrum	1.09	16	1.31	26.5	1.47	12.5	52.49	16
Lacrimal	1.07	15	1.20	16.5	1.50	15	59.48	22
Symplectic	1.06	14	1.06	5.5	1.28	7	51.32	13
Abdominal vert.	1.05	13	1.16	14	1.41	9	47.33	7
Infrapharyngeal	1.02	11.5	1.29	23	1.81	27.5	53.17	18
Coracoid	1.02	11.5	1.05	4	1.30	8	48.69	10
Parasphenoid	0.99	10	1.25	20.5	1.81	27.5	52.67	17
Preopercular	0.95	9	1.31	26.5	1.88	31	45.32	5
Quadrate	0.93	7.5	1.31	26.5	1.83	29	61.00	25
Opercular	0.93	7.5	0.90	1	0.93	1	60.00	23
Basioccipital	0.89	6	1.18	15.0	1.74	25	40.69	1
Ethmoid	0.88	5	1.26	22	1.53	16	51.02	12
Supraoccipital	0.86	4	1.64	36	1.89	32	54.26	19
Prefrontal	0.84	3	1.06	5.5	1.64	20	47.19	6
Hyomandibular	0.74	2	0.99	3	1.22	3	48.08	8
Frontal	0.71	1	1.08	8	1.61	19	42.96	3
MEAN	1.15		1.22		1.63		55.67	

Spearman's Rank Correlations, 34 df.

	m1	m2	m3
m2	0.235	-	-
m3	0.062	(0.645)	-
m4	0.497**	0.316*	-0.120

* = significant at 90% level of confidence
** = significant at 99% level of confidence
( ) = significant, but related values.

Spearman's rank correlations were also performed to test the correlation between the hybrid true/bulk density measures (m1 and m2) and bulk density (m3) obtained for the cod bones (Table 3:7). The results obtained, rho = 0.24 (m1 with m2) and 0.06 (m1 with m3) indicates that there is not a significant correlation between these measurements. The measurements m3 and m2 are related, as the latter is used in the calculation of the former, therefore the significant correlation between these two measures is not surprising.

Spearman's rank correlations indicated that the ranking of relative porosity of bones (m4) was significantly correlated with density measurement m1 (rho = 0.50, significant at the 99% confidence level) but was not significantly correlated with measurements m3 (rho = -0.12) and only at the 95% confidence level with m2 (rho = 0.32).

3.2.4 Discussion

The results obtained comparing the rankings of what may conveniently be termed density by the four different methods indicates that while similar results are obtained by displacement of dry bone in water (m1) and by calculating relative porosity (m4), attempts to measure bulk density (m3) lead to a completely different set of rankings. The possible reasons for this are both methodological and conceptual. On the conceptual level, these results support Lyman's findings, and indicate that different properties of the bone are being measured, not just between methods but also possibly between different bones by the same method. Each method has a slightly different relationship with porosity, and the porosity of fish bone is in any case hard to define owing to the "feathery" appearance of many fish bones, and their irregular design, with frequent folds and cavities. This variable design makes any measure of bulk density in particular very difficult. Any method (such as coating in wax) which aims to fill, or to isolate, the pores will also inevitably affect some of the folds or cavities. The extent

to which a coating or filling medium penetrates the pores or fills the cavities is difficult to control for "feathery" or folded bone, leading to the possibility of experimental inconsistencies. Flat or compact bones will be much less subject to this source of error.

A further methodological problem concerns the measurement of volume by displacement in water. As has already been mentioned, measuring displacement of water for bones with a large surface area:volume ratio and irregular shape is difficult, at least by the methods used in this study. Measuring the difference in water displacement between bones with and without a coating of wax is especially difficult, as the difference may be small. If the wax penetrates into the pores or cavities of the bone, where air had been trapped when the first volume measurement was taken (v1), the volume of water displaced (v3) may be very similar, but the mass of the bone with the wax will be much greater. With flatter or more compact bones the wax will tend to remain on the surface, so that its volume will be additional to that of the bone as measured without the wax (i.e. it will not replace air). In other words, the extent to which wax or water fills the air spaces will have a critical effect on the apparent porosity or density of a bone, and this will cause much greater inconsistencies with irregularly shaped bone than with flat or compact bone. A small difference in the mass/volume ratio has a large effect on the relative ranking of skeletal elements, thus the cod urohyal for example would move from the most dense to the 26th most dense were the volume of water displaced to be 0.6 cm^3 rather than 0.3. This sort of error is possible when using necessarily large measuring cylinders to measure displacement. Other methods of collecting displaced water would be subject to some error too, such as water loss from sticking to the sides of the collecting vessel.

3.2.5 Conclusions: The value of density measurements

To use any one measurement as a basis for ranking bone density and correlation with archaeologically recovered material is therefore of limited interpretative value, unless the property of the density measure being tested is fully understood. The correlation of the relative proportion of bone : pore space (m4) with density measurement m1 at least suggests that these methods are measuring a real property of the bone, however. The general similarity of the rankings of m1 and m4 with that intuitively expected from an examination of the bones (i.e. those bones which look most dense appear high up the ranking while the more "feathery" bones appear lower) also indicates that the property being measured is useful as an indicator of relative density. For this reason the rankings obtained for skeletal elements by method 1 will be used when density is referred to in the following chapters.

Contrary to Behrensmeyer's findings (Behrensmeyer 1973, 31) this study indicated that fish bones were less dense than mammal bones (mean density measurement m1 = 1.15 (cod), 0.99 (plaice), and 1.28 (rat)). Behrensmeyer (*ibid.*) quotes densities of between 1.3 and 2.3 for fish and reptile bones and between <1.0 and 2.0 for mammal bones. It would appear that generalisations about the relative density of bones from different classes of vertebrate are misleading, as there is substantial intra-class variation.

A low density measurement, and high rank, indicates a high volume: weight ratio, and so a porous bone with a relatively large surface area. Bones with large surface areas will be more vulnerable to attack by micro-organisms, and porous bones will absorb more water, so accelerating protein decay and leaching. Low density may also indicate light, thin-walled, air-filled bones such as bird long-bones, when the entire bone is used for the measurement. Thin walls may also make a bone vulnerable to destruction, as they too have a high surface area: volume ratio.

CHAPTER 4. INVESTIGATIONS INTO BURNING

4.1 Introduction

Having looked briefly at some of the intrinsic differences between bones from different animals, the next four chapters are concerned with the experiments undertaken in the laboratory and in the field, looking at the ways in which skeletal tissues and anatomical parts are affected by a range of very different biostratinomic processes.

This chapter investigates the effects on skeletons of heating to high temperatures and assesses the value of burnt animal remains for archaeology. The results of field and laboratory experiments are presented in which the effects of heating skeletal tissues are examined a) in a natural, variable environment and b) under more controlled and carefully monitored conditions, in the laboratory. Both types of experiment have important implications for the interpretation of archaeologically recovered burnt faunal remains.

Whole animals and animal skeletons were placed on fires which reached temperatures of up to 850°C, and the colour of the bones and representation of anatomical parts examined. Bones were also heated in a muffle furnace to temperatures ranging from 200-900°C and studied with regard to colour, strength and surface morphology, the last using the scanning electron microscope. The results were compared with archaeological material, which demonstrated that, within limits, the temperature which the bone reached during heating can frequently be determined from archaeological remains.

4.2 Background

Burnt bone is a common but little studied component of many archaeological sites. In some sites, where organic material is not preserved, it represents the sole evidence

of animal bone (e.g. Castell Henlys, (Gilchrist and Mytum 1986)). While many studies have been undertaken on the effects of burning human and other large mammal bones, largely because of an interest in human cremation (e.g. Baby 1954; Binford 1963; Parker 1985; McKinley 1989) to date little attention has been paid to the effects of burning other faunal remains. Exceptions include the work of Richter (1986) who looked at the effects of heating on fish bone collagen, and Spennemann and Colley (1989), and Colley (forthcoming a.) who undertook limited field experiments.

In many archaeological instances burnt bone represents the direct exploitation of animals by man as food. Bone displaying evidence of heating is unlikely to have become incorporated into archaeological deposits by "natural" events. In most cases burnt bone probably originated either intentionally, as a result of rubbish disposal of unpleasant objects, or accidentally, during cooking.

Interpretations based on assemblages of burnt bone are fraught with even more problems when extrapolating from an excavated assemblage to the originally utilised animal material than unburnt bone. Whether bone survives will depend not only on pre-burial and post-burial conditions but also on conditions obtaining between the death of the animal and the discarding of the remains, which includes conditions of burning. It is often assumed that bones will be easily destroyed or rendered unidentifiable by burning, and little regard has been given to the variable effects of heating on different categories of organic material.

The investigation of burning has important implications for the study of human development. Fire temperature is very variable depending on the construction of the fire and the materials used in its manufacture. Forest and grassland fires rarely reach temperatures above 700°C, and for most of the time are under 100°C, whereas man-made fires range in temperature from about 400°C (campfire) to nearly 1000°C

in the centre of a well constructed pyre (references in Shipman *et al.* 1984). If the presence of burning at temperatures suggesting man-made fires can be established then human influence can be demonstrated even in the absence of other cultural remains. The recognition of burnt bone also has important implications for determining the origins of the harnessing of fire by early hominids. Most studies of cremated remains to date have concentrated on this area (e.g. Oakley 1954; 1956; Brain and Sillen 1989) or, concerning human cremation, to determine the fire technology used and the condition of the body prior to and during cremation (e.g. the work of Baby 1954; Binford 1963; Wells 1960; and more recently McKinley 1989).

4.3 General Aims and Approaches

For the purposes of this study burnt remains have been examined from two standpoints; firstly, the extent to which skeletal assemblages are modified or destroyed by burning and secondly, the extent to which the conditions of burning may be identified from the surviving remains.

Field and laboratory experiments were undertaken using bones from a selection of taxa. The experiments were designed to investigate variability between different types of animal bone, including mammal bone, bird bone and fish bone, as well as between corpses subjected to different methods of preparation, for example filleting, boiling and baking. The effects of heating mollusc shells was also briefly examined, as mollusc shells which appear burnt are fairly commonly recovered on some archaeological sites. Insects were not included in this study as even if recovered, burnt insect remains would be unlikely to be of much archaeological significance.

The major questions which this chapter addresses are:

1. How much of the skeleton survives after burning? Do certain elements predictably survive or fail to survive?

2. Does the condition of the body before burning affect the way in which the bone will burn, and so can the state of the body be determined from the burnt remains?
3. How well does the colour/temperature scale proposed for human and other large mammal remains apply to non-mammal remains?
4. Are the bones of separate taxa differently affected by burning?
5. How much variation is there in the state of combustion of animal remains within a fire?
6. Can the temperature of burning be established from the surface morphology of fish bones, as is proposed for mammal bone by Shipman *et al.* (1984)?
7. If the answer to 6 is positive, then can the results be successfully applied to archaeological material?
8. How does heating affect the physical properties of skeletal material, and so the potential for preservation and incorporation into the archaeological record?

The approaches taken in order to answer these questions are diverse, and include burning remains on open fires (questions 1, 2, 4, 5) and in a muffle furnace (question 3); examinining fresh and burnt bone microscopically (questions 6 and 7); and using an Instron testing instrument to determine the force required to fracture uniformly sized specimens of burnt, fresh and boiled bone (question 8).

With regard to preservation: although burnt fragments are frequently recovered from archaeological sites, statements such as "burned bones are very fragile and porous and are easily destroyed" (Noe-Nyggard 1987, 32) is all the consideration that is usually given to them, unless the bone is of human origin. As burnt bone may represent all the directly available evidence of food debris from some sites, it is worth asking to what extent burnt material is likely to be destroyed relative to unburnt material. As a relatively rapid and straightforward way to approach this rather complex problem, bending tests were used to compare

the relative strengths, stiffness and brittleness of bone samples including fresh bone, boiled bone, and bone heated in the muffle furnace to 100°C to 900°C, inclusive, in steps of 100°C.

4.4 The Field-based Experiment.

4.4.1 Aims

The aim of this experiment was to examine the consequences to bone and shell of burning in the open on a fire of the type which may have been used for rubbish disposal in the past. Skeletons were burnt in various states to investigate whether the condition of the bone prior to burning would affect the way in which it burnt, for example whether it was fresh, covered in flesh or defleshed, dry or was in a weathered state (i.e. with reduced amounts of collagen). Another question concerns whether certain skeletal elements are more resistant to destruction than others, and if so whether this is related to their shape or density.

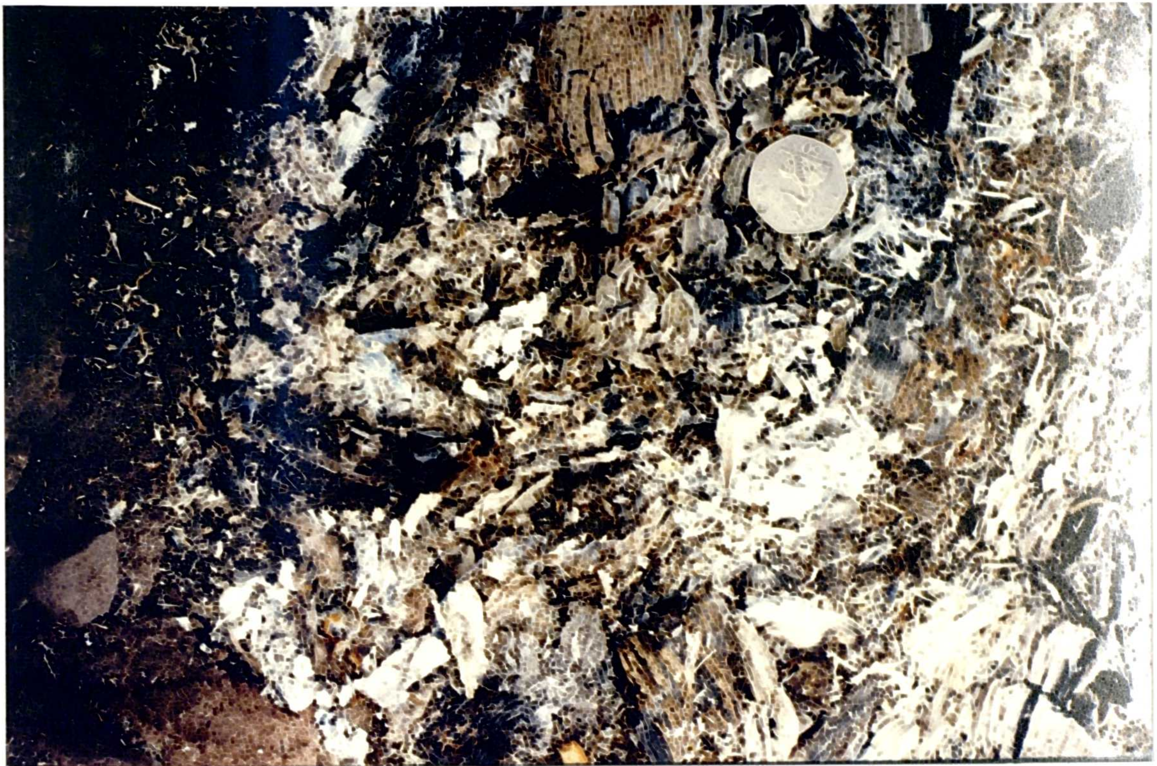
The colour and extent of mottling was examined with the intention of elucidating whether different treatment of the corpse or different densities of the bones had an effect on the colour(s) which the bone became after burning. The last point was complicated by the fact that natural fires do not burn at consistent temperatures over their entire area. Consequently the extent to which the animals combusted was dependent on their position within the fire and the maximum temperature and duration of that temperature at that locality.

4.4.2 Methods and Materials

Three fires were built, each in a shallow (50 -100 mm. deep) scoop of 1 m. x 1 m. area (Plate 4:1). The bases were lined with locally available sandstone slabs, and six glass marbles were placed at the base of each fire, one in each

a.

b.



<u>Plate 4:1</u> <u>The Open-Air Fires.</u>

a. General view of the fires before the addition of animal corpses, bones and shells.
b. Detail of the ash remaining after the fires had stopped burning.

corner and two in the centre. These were used as a very crude guide to the temperature at the base of the fire, as glass begins to melt at 500-550°C (Spennemann and Colley 1989). A more precise indication of the fire temperature was obtained by a digital readout thermometer, loaned by the Physics Department of the University of York, the probe of which was placed approximately in the centre of each fire. The wood used on the fires was from a variety of sources, and from a wide range of tree species. Each fire was allowed to burn for 15 minutes, after which time animal remains were thrown into the fire.

A variety of animals was used; for a list of taxa, size and treatments see Table 4:1. Both fresh complete corpses or parts of corpses, fresh partially defleshed corpses, cooked corpses, dry defleshed bones and a selection of dry weathered bones were included. The dry weathered bones were collected from the surface of a Victorian midden on the island of Great Cumbrae in the Firth of Clyde. The fires were constructed on the same island, on the same day, so the lack of an available bone reference collection meant that the species identifications of some of the dry bones is uncertain. To examine the hypothesis that certain skeletal elements are more likely than others to survive, twenty small whiting and four small long rough dabs were thrown on to Fire 3.

The weathered bones placed in Fire 3 included: a conger eel (*Conger conger* (L.)) dentary; a gannet (*Morus bassanus* (L.)) ulna; a herring gull (*Larus argentatus* L.) humerus; a smaller gull humerus and tibiotarsus; an immature ?gull (*Larus* sp.) ulna; a smaller bird (blackbird-sized) humerus; a chicken (*Gallus f. domestic*) humerus with chewed epiphyses; a rabbit humerus; two cow humeri mid-shaft fragments; a cow humerus proximal shaft and mid-shaft fragment; a cow radius proximal end; a sheep/goat metapodial mid-shaft fragment; a sheep/goat radius mid-shaft fragment; a sheep/goat proximal humerus shaft fragment and a sheep/goat metapodial shaft fragment. All the shaft

Table 4:1. Details of the Animal Remains put on the Open-Air Fires, 1-3

Fire 1.

1. One sheep's foot, separated at the proximal end of the metapodial, including flesh and wool.
2. One complete herring (total length 290 mm.)
3. One complete cod (total length 380 mm.)
4. One complete plaice (total length 350 mm.)
5. One complete adult brown rat.
6. One filleted haddock frame (total length 370 mm.)
7. One complete adult pigeon.
8. A selection of dry cod bones, from a fish of 600 mm. total length, including: the skull (including parasphenoid and basioccipital), one maxilla, two quadrates, two hyomandibulars, two palatines, one ectopterygoid, two ceratohyals, two epihyals, two hypohyals and one first vertebra.

Fire 2

1. One skinned and defleshed adult sheep's foot, separated at the proximal end of the metapodial.
2. One boiled cod (total length 395 mm.) boiled in water for one and a quarter hours.
3. One baked herring (total length 300 mm.) baked in an oven at 200°C for ten minutes.
4. One filleted plaice frame (total length 360 mm.)
5. One skinned and partially defleshed brown rat.
6. Dry bones from a complete pigeon.
7. Molluscs, as detailed in the text.

Fire 3

1. One filleted cod frame (total length 450 mm.)
2. One filleted herring frame (total length 290 mm.)
3. Four complete long rough dabs (lengths as in Chapter 2).
4. Twenty complete whiting (lengths as in Chapter 2).
5. One plucked and partially defleshed adult pigeon.
6. Dry "weathered" bone from the surface of a Victorian midden, as detailed in the text.

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fragments except the last included complete circumferences; the last was a longitudinal fragment from the lateral side of the bone. The large mammal bones were butchered and must have been components of the Victorian midden. The conger eel and bird bones may have been deposited at a later date, as animals which died at the site or were washed up onto the shore.

A collection of mollusc shells comprising twenty *Littorina littorea*; twenty *Nucella lapillus*; twenty *Patella vulgata*; twenty valves of *Mytilus edulis* and twenty *Helix*

aspersa were included in Fire 2, and the effects on them of exposure to elevated temperatures in a natural fire is described briefly below.

Three fires were used in order to keep separate individuals of the same species which had been prepared differently. With the exception of a complete haddock all the animals and animal remains were thrown in after the fire had been alight for 15-20 minutes. The haddock was added after the fire had been alight for one hour. Temperatures were read every 15 minutes, although problems with the digital readout thermometer caused some readings of the first fire to be missed (Fig. 4:1).

Each fire lasted from 200-230 minutes. After the fire had cooled completely the ashes were carefully collected and sieved to 1 mm.

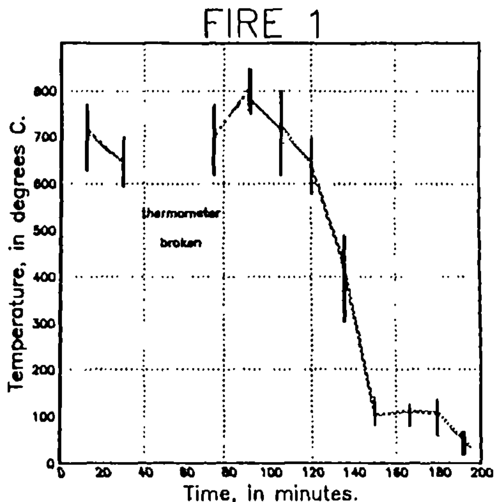
<u>Recording</u>

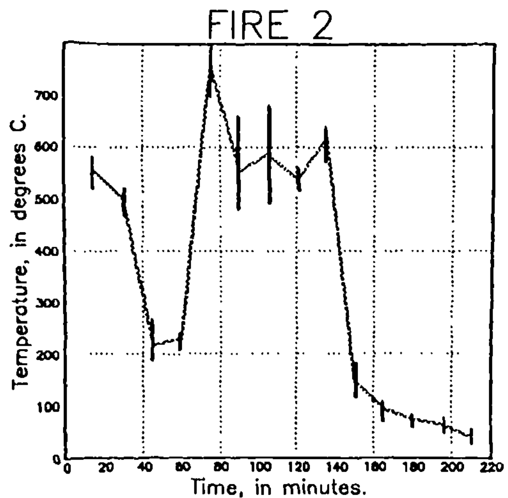
The bones were picked out in the laboratory and identified as far as possible. Records of bone identifications (element, species, anatomical side, fragment size, surface damage, major colour, extent and colour of mottling) as well as codes for the fire number were stored using D-Base III plus.

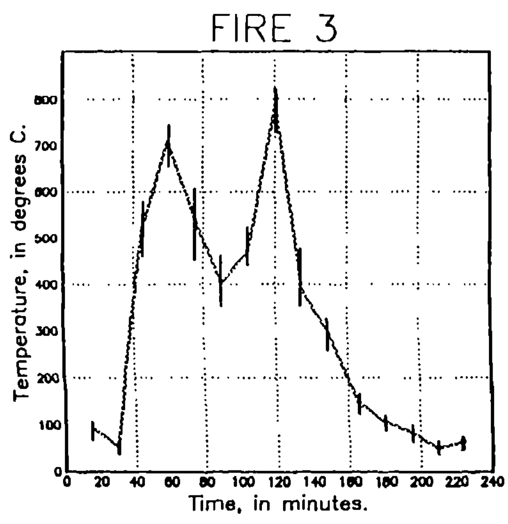
The bones recovered were identified to skeletal element and species (terminology for fish bones here, as elsewhere in this text, after Wheeler and Jones 1989) and the numbers of bones recovered were compared with the number of bones in the fresh animal. With the exception of the sheep's feet for which all bones were counted, the small undistinctive bones such as ribs, sesamoids, carpals, some tarsals, spines, small branchial bones, rays and the less distinctive cranial bones were ignored, as identification to species is frequently very difficult or impossible.

FIG.4:1 FIRE TEMPERATURES FOR EXPERIMENTAL BURNINGS

(Vertical lines give the range of temperatures during one minute)







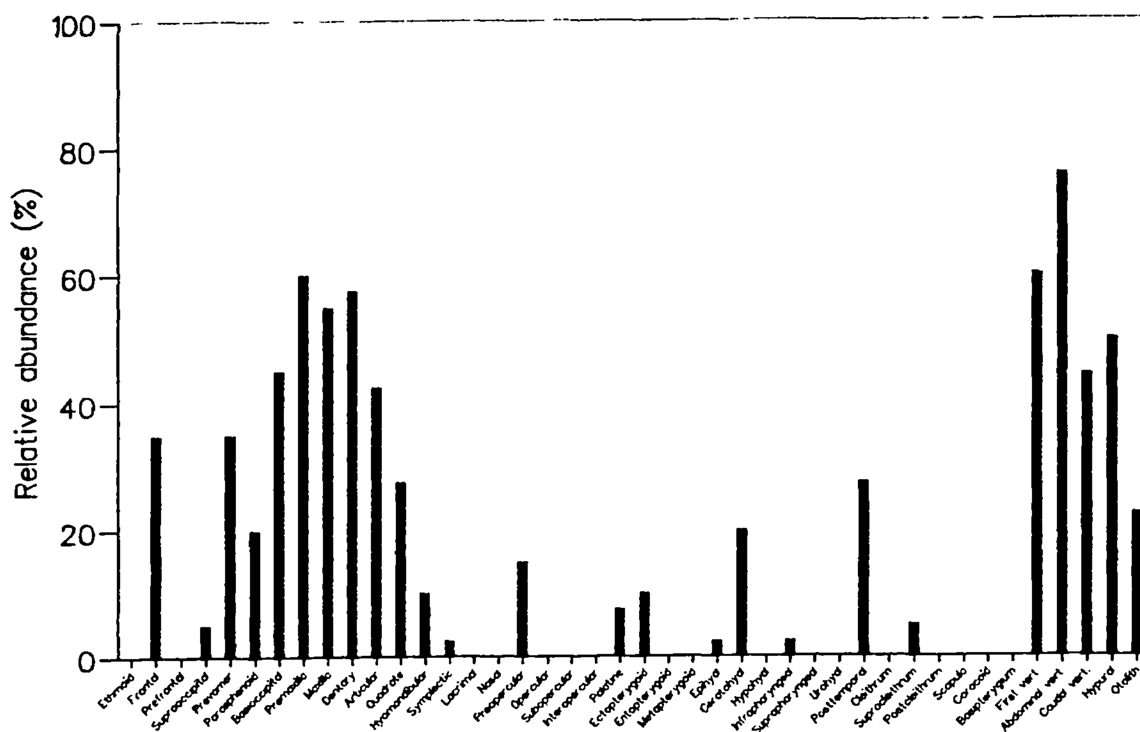
4.4.3 Results and Discussion

Temperature.

The temperatures in Fires 1-3 are given in Fig. 4:1. The vertical bars show the temperature ranges given by the digital readout thermometer during one minute of reading. The temperature varied locally during a very short space of time due to the movement of the flames. All the fires were lit when the air temperature was 19°C and there was a slight breeze. Each fire burned for three to three and a half hours, with additional wood added as necessary to keep the fires alight. The maximum temperature reached by all the fires was in the range 750-825°C, although this temperature was not sustained for more than 15 minutes in any case. Only the glass marbles from the centre of Fire 3 showed evidence of surface melting, indicating that in all other cases temperatures at the base of the fires were never, or only briefly, in excess of 550°C.

Skeletal Element Representation.

Fig. 4:2 shows the proportions of skeletal elements recovered from the twenty whiting (*Merlangius merlangus*) and four long rough dab (*Hippoglossoides platessoides*) after burning, based on the expected numbers of bones. Tables 4:2 and 4:6-4:7 give the numbers of identified skeletal remains for all the formerly complete corpses after burning. It should be noted that not all corpses burnt completely; in several cases all or part of the body rolled towards the periphery of the fire and remained only charred. The numbers of identified skeletal elements do not include those bones adhering in a charred mass, as they were impossible to identify owing to the covering of charred flesh.



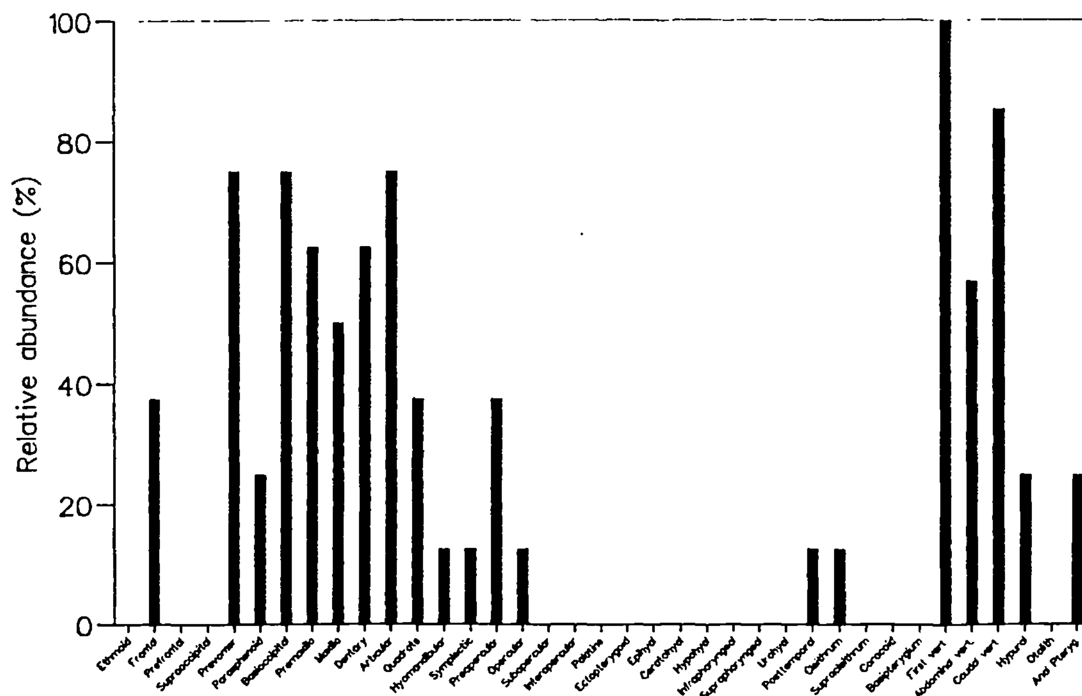


Fig. 4:2 Percentage Relative Abundance of Skeletal Elements from 20 Whiting and 4 Long Rough Dab, after Burning on Fire 3.

Fish

Table 4:2 details the number of identifiable fish bones recovered from the fires, compared with the number of bones in one fish. It is evident that a similar selection of skeletal elements are commonly represented in the burnt assemblages, irrespective of species or treatment of the corpse. The bones commonly recovered from all but the herrings were the jaw bones and jaw supports: dentary, premaxilla, quadrate, and articular as well as the vertebrae. Appendicular bones such as the supracleithrum and post-temporal, as well as the palatine and ectopterygoid also survived reasonably well. Most of the flat bones, for example the opercular series, basipterygium, scapula, coracoid, lacrimal and urohyal (except for the flatfish urohyal) were destroyed. Otoliths tended to fragment, but several recognisable pieces of the larger gadid otoliths were recovered; these would be identifiable as gadid but not to species if recovered archaeologically. In general herring head bones did not survive well, but vertebrae did. The complete haddock from Fire 2 was added to the centre of the fire later than the other fish, after one hour when the temperature had dropped, in a deliberate attempt to investigate the effect on the skeleton of incomplete incineration. As a result the majority of the head remained intact and charred but the vertebrae had completely separated, and most were blue in colour.

In some other fish not all parts of the skeleton were completely burnt. Lumps of black charred material represented parts of the corpse in several cases. These lumps sometimes contained dark brown, oily bones, but in many instances bones within the lumps were black, fragile and extremely difficult to separate or discern from the mass of charred flesh. The charred remains of skulls were particularly difficult to recognise, and if found archaeologically would be unlikely to be identified as fish. Looking at the whiting and long rough dabs,

Table 4:2
Numbers of identified skeletal elements from experimental fires 1-3, compared with the expected numbers of bones in a complete fish (excluding dry cod bones).

		Fire 1				Fire 2				Fire 3			
Species		Cd	Had	Her	Pl	Cd	Had	Her	Pl	Cd	Her	Wh	LRD
Condition		C	F	C	C	BO	C	BA	F	F	F	C	C
	No. in one fish.											(n=20)	(n=4)
Ethmoid	1	0	0	0	0	0	0	0	0	0	0	0	0
Frontal**	1/2	0	0	0	2	1	1	0	0	0	0	7	3
Prefrontal	2	0	2	0	0	0	0	0	0	0	0	0	0
Supraoccipital	1	0	1	0	0	0	0	0	0	1	0	1	0
Prevomer	1	0	1	1	0	0	1	0	0	1	0	7	3
Parasphenoid	1	0	1	1	1	0	0	0	0	0	0	4	1
Basioccipital	1	1	1	1	1	1	1	0	0	0	1	9	3
Premaxilla	2	2	2	0	0	0	1	0	0	2	0	24	5
Maxilla	2	2	0	1	1	0	1	0	1	1	0	22	4
Dentary	2	2	2	1	2	0	1	0	0	2	0	23	5
Articular	2	2	2	2	0	1	0	0	1	0	1	17	6
Quadrate	2	0	1	0	0	0	0	0	0	2	0	11	3
Hyomandibular	2	0	1	0	1	1	0	0	0	0	1	4	1
Symplectic	2	1	0	0	0	1	0	-	1	1	-	1	1
Lacrimal	2	0	0	-	-	0	0	-	-	0	-	0	-
Nasal	2	0	0	-	-	0	0	-	-	0	-	0	-
Preopercular	2	1	1	0	1	1	0	0	1	0	0	6	3
Opercular	2	1	1	0	1	0	0	0	0	0	0	0	1
Subopercular	2	0	0	0	0	0	0	0	0	0	0	0	0
Interopercular	2	1	0	0	0	0	0	0	0	0	0	0	0
Palatine	2	1	0	0	0	0	0	0	0	1	0	3	0
Ectopterygoid	2	0	0	0	0	0	0	0	0	1	0	4	0
Epihyal	2	0	2	0	1	0	0	0	0	1	0	1	0
Ceratohyal	2	0	1	0	0	0	0	0	0	1	0	8	0
Hypohyal	4	0	0	-	0	0	0	-	0	0	-	0	0
Infrapharyngeal	2	0	2	0	2	0	0	0	0	0	0	1	0
Suprapharyngeal	6	0	1	-	2	0	0	-	1	1	-	0	0
Urohyal	1	0	0	0	1	0	0	0	1	0	0	0	0
Posttemporal	2	0	2	0	1	0	1	0	1	2	0	11	1
Cleithrum	2	1	2	0	1	0	1	0	2	0	0	0	1
Supracleithrum	2	2	2	0	1	0	2	0	2	2	0	2	0
Postcleithrum	2	0	0	-	-	0	0	-	-	0	-	0	-
Scapula	2	0	0	0	0	0	0	0	0	0	0	0	0
Coracoid	2	0	0	0	0	0	0	0	0	0	0	0	0
Basipterygium	2	0	0	0	0	0	0	0	0	0	0	0	0
First vert.	1	1	1	1	0	1	0	0	0	1	0	12	4
Abdominal vert*	17	16	19	29	13	17	13	22	12	14	15	258	25
Caudal vert.*	30-33	22	18	33	25	12	24	18	21	13	22	295	99
Hypural	1	0	0	0	0	0	0	0	0	0	0	10	1
Otolith	2	0	0	0	0	1	0	0	0	2	0	9	0
Otic bulla (HER)	2	-	-	-	-	-	-	2	-	-	2	-	-
Anal pteryg.(PL)	1	-	-	-	1	-	-	-	1	-	-	-	1

n.b. for the cod and herring in fire 1 and the herring in fire 2, the heads, or parts of the heads, were charred and incompletely burnt, making recording the bones impossible.

KEY:
Species: Cd = Cod; Had = Haddock; Her = Herring; Pl = Plaice; Wh = Whiting; LRD = Long Rough Dab.
Condition pre burning: C = Complete; F = Filleted; BO = Boiled; BA = Baked.
The number of individuals is one unless otherwise indicated (n=x)

** Gadid fish have one frontal bone, the other species have two.
* The number of vertebrae in fish varies: the figures refer to cod and whiting. Haddock have 19 abdominal and 29-32 caudal vertebrae; plaice and long rough dab have 12 abdominal and 28-30 caudal vertebrae and herring have between 51 and 58 vertebrae (morphologically similar abdominal and caudal)

Table 4:3
Mean fragment completeness of skeletal elements from experimental fires 1-3.
(figures calculated from the expected number of bones, except for b)

		Fire 1					Fire 2				Fire 3					
Species		Cod	Cod	Had	Her	Pl	Cod	Had	Her	Pl	Cod	Her	Whiting		L.R.Dab	
Condition		D	C	F	C	C	BO	C	BA	F	F	F	C(n=20)		C(n=4)	
pre burning	SHAPE												a	b	a	b
Ethmoid	I	80	0	0	0	0	0	0	0	0	90	0	0	0	0	0
Frontal	F	40	0	0	0	45	10	0	0	0	0	0	5	50	30	80
Prefrontal	I	60	0	55	0	0	0	0	0	0	0	0	0	0	0	0
Supraoccipital	I	70	0	60	0	0	0	0	0	0	70	0	5	90	0	0
Prevomer	R	100	0	90	90	0	0	30	0	0	40	0	30	70	70	95
Parasphenoid	I	60	0	50	40	60	0	0	0	0	0	0	10	55	10	70
Basioccipital	S	80	100	90	0	90	80	100	0	0	0	100	40	85	70	90
Premaxilla	R	-	55	65	0	0	0	20	0	0	50	0	50	65	55	85
Maxilla	R	75	30	0	30	30	0	35	0	50	35	0	40	70	30	65
Dentary	R	-	30	40	40	25	0	35	0	0	20	0	35	55	40	60
Articular	R	-	50	55	25	0	45	0	0	15	0	20	30	75	65	85
Quadrate	R	85	0	20	0	0	0	0	0	0	30	0	20	65	35	95
Hyomandibular	I	75	0	20	0	20	30	0	0	0	0	15	5	50	5	50
Symplectic	F	-	35	0	0	0	15	0	-	20	40	-	5	50	10	90
Lacrimal	F	-	0	0	-	-	0	0	-	-	0	-	0	0	-	-
Nasal	I	-	0	0	-	-	0	0	-	-	0	-	0	0	-	-
Preopercular	F	95	10	35	0	15	20	0	0	15	0	0	10	70	20	50
Opercular	F	-	30	35	0	20	0	0	0	0	0	0	0	0	10	100
Subopercular	F	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Interopercular	F	-	30	0	0	0	0	0	0	0	0	0	0	0	0	0
Palatine	R	90	15	0	0	0	0	0	0	0	35	0	5	95	0	0
Ectopterygoid	F	40	0	0	0	0	0	0	0	0	50	0	5	60	0	0
Epihyal	F	80	40	80	0	50	0	0	0	0	45	0	5	100	0	0
Ceratohyal	F	30	0	30	15	0	0	0	0	0	20	0	15	70	0	0
Hypohyal	R	0	0	0	-	0	0	0	-	0	0	-	0	0	0	0
Infrapharyngeal	I	-	0	100	0	100	0	0	0	0	0	0	5	100	0	0
Suprapharyngeal	I	-	0	10	-	40	0	0	-	20	15	-	0	0	0	0
Urohyal	F	-	0	0	0	70	0	0	0	70	0	0	0	0	0	0
Posttemporal	R	-	0	75	0	30	0	20	0	50	65	0	20	80	10	90
Cleithrum	I	-	15	55	0	15	0	20	0	50	0	0	0	0	5	30
Supracleithrum	R	-	90	95	0	50	0	65	0	100	60	0	5	90	0	0
Postcleithrum	F	-	0	0	-	-	0	0	-	-	0	-	0	0	-	-
Scapula	F	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coracoid	F	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Basipterygium	F	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
First vert.	S	100	80	90	90	0	80	0	0	0	60	0	50	85	80	80
Abdominal vert.	S	-	55	80	80	85	55	45	55	85	55	45	65	85	40	80
Caudal vert.	S	-	40	45	80	85	25	60	55	50	15	45	20	70	70	80
Hypural	S	-	0	0	0	0	0	0	0	0	0	0	10	100	30	80
Otolith	F	-	0	0	0	0	20	0	0	0	40	0	15	75	0	0
Otic bulla (HER)	S	-	-	-	-	-	-	-	100	-	-	100	-	-	-	-
Anal pteryg. (PL)	I	-	-	-	-	50	-	-	-	15	-	-	-	-	25	90

a = value calculated from expected number of elements; b = value calculated from recovered number. All other values are calculated from the expected values (see Table 4:2), but if a bone is represented by more than one fragment the mean fragment completeness for that bone is obtained first and used in the calculation.

n.b. for the cod and herring in fire 1 and the herring in fire 2, the heads, or parts of the heads, were charred and incompletely burnt, making recording the bones impossible.

Shape: F = Flat; R = Robust; I = Irregular; S = Spherical (refers to gadids, some are different shapes in herring and flatfish).
Condition pre burning: D = Dry; C = Complete; F = Filleted; BO = Boiled; BA = Baked.
The number of individuals is one unless otherwise indicated (n=x)

separating the head bones by side and counting only fragments which included the articular end, gave a minimum number of individuals of 14 whiting (based on the dentary) and of 4 long rough dabs (based on the first vertebra; a MNI of 3 was obtained from the dentary, premaxilla and articular).

The only fish bones to show substantial cracking and warping were the head bones of the filleted cod on Fire 3. These were also, with the exception of the dry cod bones, the largest fish bones used for the experiment. Whether the distortion was a result of the higher temperatures, the rate of heating on Fire 3, or the larger bones is unclear, but it is notable that the bones of the herring, small dab and whiting recovered from Fire 3 were not extensively distorted or cracked.

Density, shape and size as determinants of bone preservation.

The mean fragment completeness scores for each fish group are given in Table 4:3. Mean values were obtained as detailed in Chapter 2 (p. 34) by first calculating the average fragment completeness for each bone (made possible by a record of the area of bone represented by the fragment and the relative completeness of the fragment), summing these mean values for each skeletal element and dividing by the expected number of that element. In general the small fish bones were not represented by more than one identified fragment each. These mean fragment values were calculated for all groups of fish. This figure, then, does not accurately represent the actual size of the recovered fragments but takes into account bones which were rendered unidentifiable by the fire, thus making it possible to use the figures to rank the skeletal elements in terms of their resistance to destruction. A second mean fragment completeness value (b) is given for the whiting and dab bones only, based on the recovered bones rather than the expected number of bones, giving a better indication of the

actual size of the fragments as a proportion of the whole bone but not giving an indication of the extent of bone loss. The actual figures for the number of identified bones per fish group are given in Table 4:3, which also details the shape categories assigned to the skeletal elements, as discussed in Chapter 2.

The values for mean fragment completeness of the skeletal elements recovered and identified from the filleted cod and complete whiting were compared with the density measurements (ml) obtained for cod (see Chapter 2, p.61). These two groups were selected because: firstly, the individuals had all reached a similar stage of combustion, in which all the skeletal elements had separated; secondly, all were on the same fire for the same time duration. Thirdly, only gadid remains can properly be compared with density measurements taken on cod bones. The main difference between these two gadid groups was in the size of the individuals, the cod being 450 mm. long, the whiting between 145 and 200 mm.

As illustrated in Table 4:4, there was no significant correlation between either species with density (rho = -0.08 and 0.14 at 34 degrees of freedom) although there was a significant correlation between the two species at the 99% confidence level (rho = 0.45). This suggests that the preservation of bones was not just a result of chance but that some factor or factors govern which elements will survive best; but clearly density is not the most important determining factor. The number of zero scores for the mean fragment size of whiting and cod elements should be considered, however. The high number of these tied scores affects the correlation to a great extent. If some of the smaller and less easily identified bones are excluded (e.g. the coracoid, basipterygium, scapula, lacrimal, post-cleithrum, prefrontal, nasal, hypohyal) the significance of the correlation between the two species declines (to rho = 0.29, not significant at 95% in this case) but the correlations with density do not significantly improve.

While the correlation indicates that the representation of skeletal elements after burning between whiting and cod are more similar than could be expected by chance alone, the presence/absence of elements is probably more important in the statistic than the mean fragment completeness score.

Table 4:4.
A Spearman's Rank Correlation Analysis of the mean fragment completeness of burned gadid bones from Fire 3 with density measurement ml for cod.

	ml	whiting	cod	Rank ml	Rank whiting	Rank cod
Ethmoid	0.88	0	90	5.0	7.5	36.0
Frontal	0.71	5	0	1.0	19.0	10.0
Prefrontal	0.84	0	0	3.0	7.5	10.0
Supraoccipital	0.86	5	70	4.0	19.0	35.0
Prevomer	1.20	30	40	23.0	30.5	27.5
Parasphenoid	0.99	10	0	10.0	24.5	10.0
Basioccipital	0.89	40	0	6.0	33.5	10.0
Premaxilla	1.44	50	50	29.0	35.0	30.5
Maxilla	1.42	40	35	27.5	33.5	25.5
Dentary	1.42	35	20	27.5	32.0	22.5
Articular	1.39	30	0	26.0	30.5	10.0
Quadrate	0.93	20	30	7.5	28.0	24.0
Hyomandibular	0.74	5	0	2.0	19.0	10.0
Symplectic	1.06	5	40	14.0	19.0	24.0
Lacrimal	1.07	0	0	15.0	7.5	10.0
Preopercular	0.95	10	0	9.0	24.5	10.0
Opercular	0.93	0	0	7.5	7.5	10.0
Subopercular	1.56	0	0	31.0	7.5	10.0
Interopercular	1.37	0	0	25.0	7.5	10.0
Palatine	1.13	5	35	18.0	19.0	25.5
Ectopterygoid	1.47	5	50	30.0	19.0	30.5
Epihyal	1.10	5	45	17.0	19.0	29.0
Ceratohyal	1.14	15	20	19.0	26.0	22.5
Hypohyal	1.57	0	0	32.5	7.5	10.0
Infrapharyngeal	1.02	5	0	11.5	19.0	10.0
Suprapharyngeal	1.16	0	15	22.0	7.5	10.0
Urohyal	1.63	0	0	36.0	7.5	20.5
Posttemporal	1.15	20	65	20.5	28.0	34.0
Cleithrum	1.57	0	0	32.5	7.5	10.0
Supracleithrum	1.09	5	60	16.0	19.0	33.0
Postcleithrum	1.25	0	0	24.0	7.5	10.0
Scapula	1.58	0	0	34.0	7.5	10.0
Coracoid	1.02	0	0	11.5	7.5	10.0
Basipterygium	1.60	0	0	35.0	7.5	10.0
Abdominal vert.	1.05	65	55	13.0	36.0	32.0
Caudal vert.	1.15	20	15	20.5	28.0	20.5

Spearman's Rank Correlation Coefficients, at 34 df:

density and whiting -0.137, not significant at 95% confidence
density and cod = -0.075, not significant at 95% confidence
whiting and cod = 0.449, significant at 99% confidence

Table 4:5
Shape of cod, long rough dab and whiting bones by mean fragment completeness, after burning on Fire 3: a chi-squared analysis.

COD

SHAPE	Count / Row % / Column %	Fragment Completeness 0%	10-50%	60-100%	Row Total
Flat	Count	16	1	3	20
	Row %	80.0	5.0	15.0	16.5
	Column %	32.0	2.9	8.1	
Irregular	Count	24	0	3	27
	Row %	88.9	0.0	11.1	22.3
	Column %	48.0	0.0	8.1	
Robust	Count	3	13	5	21
	Row %	14.3	61.9	23.8	17.4
	Column %	6.0	38.2	13.5	
Spherical	Count	7	20	26	53
	Row %	13.2	37.7	49.1	43.8
	Column %	14.0	58.8	70.3	
Column Total		50	34	37	121
		41.3	28.1	30.6	100.0

Chi-Square	Value	DF	Significance
Pearson	68.7	6	<.001
Minimum Expected Frequency -	5.6		

WHITING

SHAPE	Count / Row % / Column %	Fragment Completeness 0%	10-50%	60-100%	Row Total
Flat	Count	536	7	17	560
	Row %	95.7	1.3	3.0	23.3
	Column %	32.3	8.8	2.5	
Irregular	Count	379	5	4	388
	Row %	97.7	1.3	1.0	16.1
	Column %	22.9	6.3	.6	
Robust	Count	291	48	81	420
	Row %	69.3	11.4	19.3	17.4
	Column %	17.6	60.0	12.1	
Spherical	Count	452	20	568	1040
	Row %	43.5	1.9	54.6	43.2
	Column %	27.3	25.0	84.8	
Column Total		1658	80	670	2408
		68.9	3.3	27.8	100.0

Chi-Square	Value	DF	Significance
Pearson	807.2	6	<.001
Minimum Expected Frequency -	12.9		

LONG ROUGH DAB

SHAPE	Count / Row % / Column %	Fragment Completeness 0%	10-50%	60-100%	Row Total
Flat	Count	64	2	2	68
	Row %	94.1	2.9	2.9	17.2
	Column %	27.9	15.4	1.3	
Irregular	Count	68	2	2	72
	Row %	94.4	2.8	2.8	18.2
	Column %	29.7	15.4	1.3	
Robust	Count	57	5	22	84
	Row %	67.9	6.0	26.2	21.2
	Column %	24.9	38.5	14.3	
Spherical	Count	40	4	128	172
	Row %	23.3	2.3	74.4	43.4
	Column %	17.5	30.8	83.1	
Column Total		229	13	154	396
		57.8	3.3	38.9	100.0

Chi-Square	Value	DF	Significance
Pearson	177.6	6	< .001

Cells with Expected Frequency < 5 - 3 OF 12 (25.0%)

Table 4:5 gives a breakdown of the fragment completeness scores by bone shapes, for the cod, long rough dab and whiting from Fire 3 taking into account the numbers of missing bones. These fish were used for the analysis because all skeletal elements were separate, as the remains had burnt completely, and in the case of the long rough dab and whiting replication gave the results more validity. Due to the relatively low numbers of recovered bones for some of the shape groups (e.g. flat) the fragment completeness groups used are 0% (i.e. proportion not recovered), 10-50%

and 60-100%. Chi-squared tests indicated that in all cases there was a significant difference in the extent to which bones fragmented, dependent upon shape. As illustrated, spherical and "robust" shaped bones survive far better than flat and irregular shaped bones.

The influence of size is harder to ascertain from this series of experiments, but if the incompletely combusted animals are ignored, then there does not seem to have been an appreciable difference in the extent of bone loss between small fish (e.g. whiting and long rough dab) and large fish (e.g. cod and plaice). It appears that larger bones fragment into a greater number of pieces, many of which are unidentifiable. The vertebrae of all sizes of fish survived reasonably well, although in several cases the smaller caudal vertebrae preserved less well than the larger abdominal vertebrae.

Mammal and bird.

Tables 4:6-4:9 detail the numbers of bones identified and the mean fragment completeness scores for the skeletal elements recovered from the fires, compared with the numbers expected in one animal. The low numbers of mammals and birds used in this investigation make interpretations of skeletal element representation difficult, however bearing this limitation in mind there do seem to be some general trends apparent. The bone parts which survived best in both mammals and birds were the ends of the long bones; shaft fragments were frequently distorted and identifiable only as large, medium or small-sized mammal or bird. Bones of the skull, with the exception of a few elements of the rabbit cranium, did not survive in an identifiable state in any of the fires. Pigeon maxillae and mandibles were also rendered unidentifiable. Flat bones such as mammal pelves, scapulae and mandibles remained recognisable in a number of cases, but frequently were represented by small fragments. The pigeon sternum, a thin bone with a large surface area, did not survive. Many of the small, short bones (phalanges

and metapodials) remained intact. The larger rabbit bones proved to be more resistent to destruction in the fire than the smaller rat and pigeon bones.

Table 4:6
Numbers of identified rat bones recovered from fires 1 and 2, and rabbit bones from fire 2, compared with the expected numbers of bones from one animal.

	Expected no.	Rat Fire 1 C	Rat Fire 2 DF	Rabbit Fire 2 B
Mandible	2	2	2	2
Scapula	2	0	1	2
Humerus	2	1	2	2
Radius	2	0	2	2
Ulna	2	2	2	2
Pelvis	2	0	2	2
Femur	2	2	1	2
Tibio-fibula	2	2	2	2
Sacrum	1	0	0	1
Astragalus	2	2	2	1
Calcaneum	2	2	2	1
Cervical vert.	8 (7)	0	0	5
Lumbar/Thoracic v.	26 (19)	5	2	19
Caudal vert.	21 (10)	0	3	2
Metapodials	20 (14)	17	2	14
Phalanges	56 (48)	4	12	17

numbers in parentheses refer to rabbit.

Table 4:7
Numbers of identified skeletal elements of pigeon recovered from the experimental fires, compared with the expected numbers of the same skeletal elements in one bird.

	Expected No.	Fire 1 C	Fire 2 D	Fire 3 DF
Mandible	1	0	0	0
Maxilla	1	0	0	0
Scapula	2	0	0	1
Coracoid	2	0	2	2
Humerus	2	2	2	2
Radius	2	2	2	2
Ulna	2	2	2	2
Carpometacarpus	2	1	2	1
Phalanx I manii.	2	2	2	2
Sternum	1	0	0	0
Pelvis	2	0	0	1
Synsacrum	1	0	1	0
Femur	2	2	2	1
Tibiotarsus	2	2	2	2
Tarsometatarsus	2	2	2	2
Vertebrae	19	6	11	3
Phalanges	28	12	4	13

n.b. some parts of the body, including the wings, were partially unburnt in Fire 1, and individual elements were not identifiable.

C = Complete corpse; D = Dry Bones; DF = Partially defleshed.

Table 4:8
Mean fragment completeness of rat bones from Fires 1 and 2, and rabbit bones from Fire 2.

		Rat		Rabbit
		Fire 1	Fire 2	Fire 2
	Shape	C	DF	B
Mandible	F	40	30	25
Scapula	F	0	25	60
Humerus	TU	50	95	40
Radius	TU	0	80	40
Ulna	TU	50	30	40
Pelvis	F	0	30	60
Femur	TU	40	40	45
Tibio-fibula	TU	35	65	40
Sacrum	R	0	0	80
Astragalus	S	100	100	45
Calcaneum	S	100	100	50
Cervical vert.	S	0	0	70
Lumbar/Thoracic	S	20	20	80
Caudal vert.	S	0	20*	20
Metapodials	TU	90	10*	60
Phalanges	SH	5*	20*	35*

The values were calculated from the expected values (see Table 4:6).

Table 4:9 Mean fragment completeness of pigeon bones from Fires 1-3.

		Fire 1	Fire 2	Fire 3
	Shape	C	D	DF
Mandible	I	0	0	0
Maxilla	I	0	0	0
Scapula	F	0	0	20
Coracoid	F	0	45	60
Humerus	TU	20	30	30
Radius	TU	40	50	40
Ulna	TU	25	40	40
Carpometacarpus	TU	90	45	40
Phalanx I manii	F	100	80	75
Sternum	F	0	0	0
Pelvis	F	0	0	10
Synsacrum	R	0	80	0
Femur	TU	75	50	45
Tibiotarsus	TU	70	30	65
Tarsometatarsus	TU	80	40	60
Vertebrae	S	30	30	10
Phalanges	SH	40	20*	50*

* all recovered bones were complete.

n.b. some parts of the body, including the wings, were partially unburnt in fire 1, and individual elements were not identifiable.

Values were calculated from the expected values (see Table 4:7), but where a bone was represented by more than one fragment, the average value for the fragment completeness of the bone is obtained first and that value used in the calculations.

C - Complete corpse; D - Dry bones; DF - Partially defleshed
Shape: I - Irregular, F - Flat, TU - Tubular, S - Spherical, SH - Short
R - Robust.

Colour.

Fig. 4:3 and Table 4:10 give a summary of the major colours of the bones from Fires 1-3, by species. The proportions given are percentages of the total number of recovered bones which displayed the major colour. The numbers of mottled bones from Fires 1-3 are also illustrated (Fig. 4:4).

A wide range of colours were displayed by the experimentally burned bones. The colours seemed to relate more to the position of the remains within the fire than to species or treatment of the corpse. In general, however, all the bones in the centre of the fire tended towards white or light grey, which is the expected colour based on the maximum fire temperatures of 750-825°C. Mottling did not seem to be a function of the amount of flesh on the bones, as may be suspected due to uneven heating owing to the presence of flesh; the dry bones were equally likely to display mottling. This discussion of mottling is continued below, where it is suggested that mottling may be the result of locally varying atmospheric pockets. The blue colouration observed in particular on the boiled rabbit bones is also considered to be the result of burning in a limited supply of oxygen (p.107).

Experiments by Spenemann and Colley (1989) suggested that the colour of bone is related to the shape and density of the bone, with thin head bones becoming a lighter shade than the vertebrae (the term "density" as used by Spenneman and Colley here is a subjective one and bears no relation to the density measures described in Chapter 2 or in the preceding paragraphs). This trend was not generally apparent from the experiments described here, although the low numbers of flat bones which survived when compared to the numbers of denser spherical bones (vertebrae) make a statistical comparison impossible.

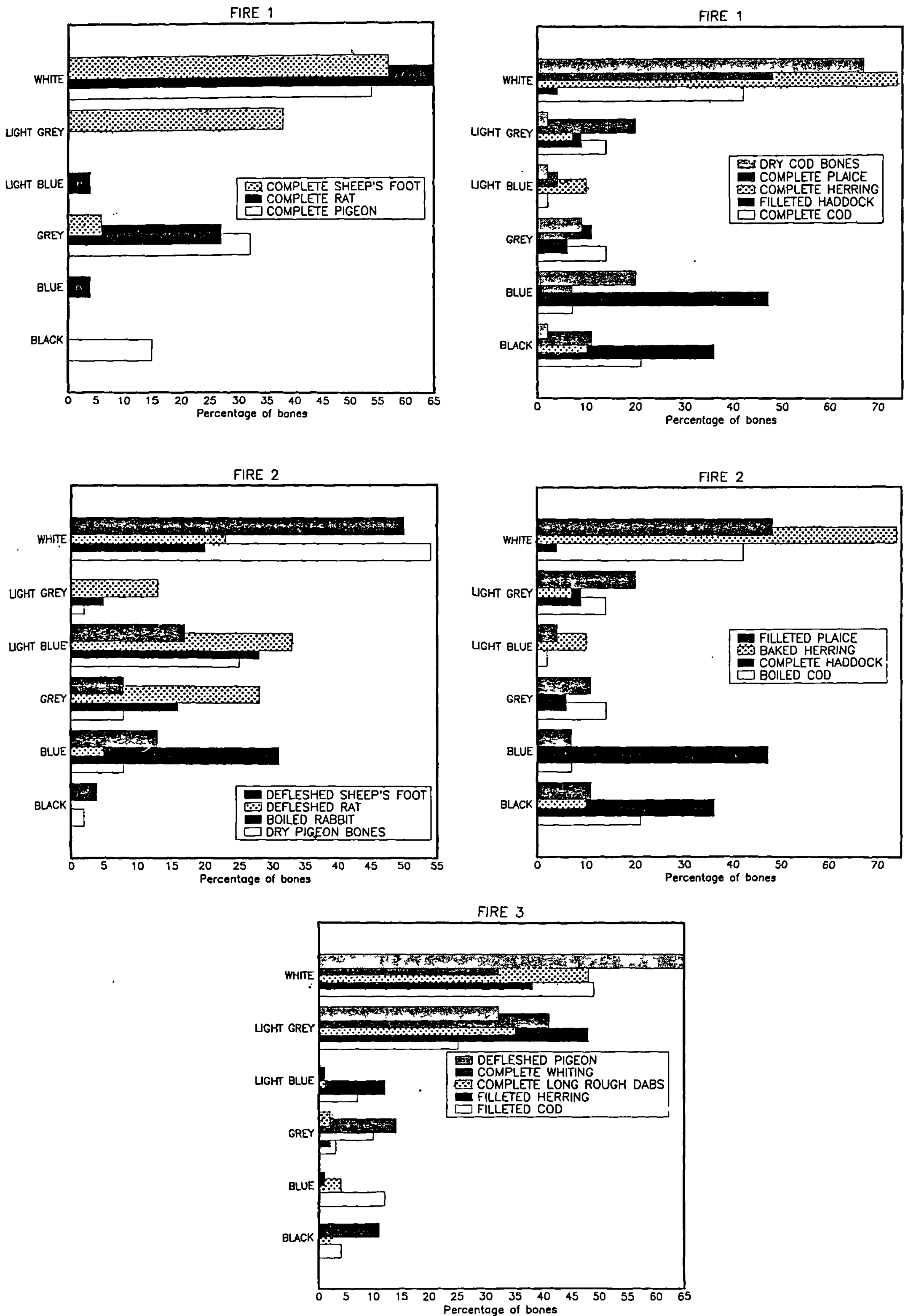
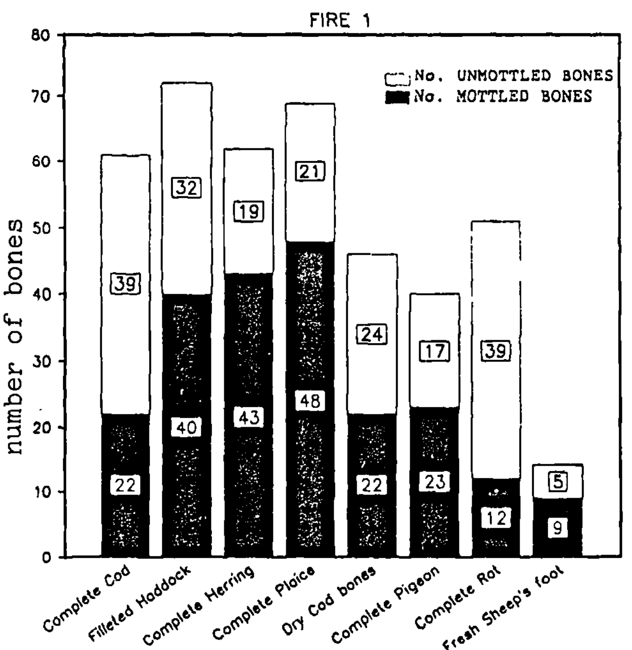
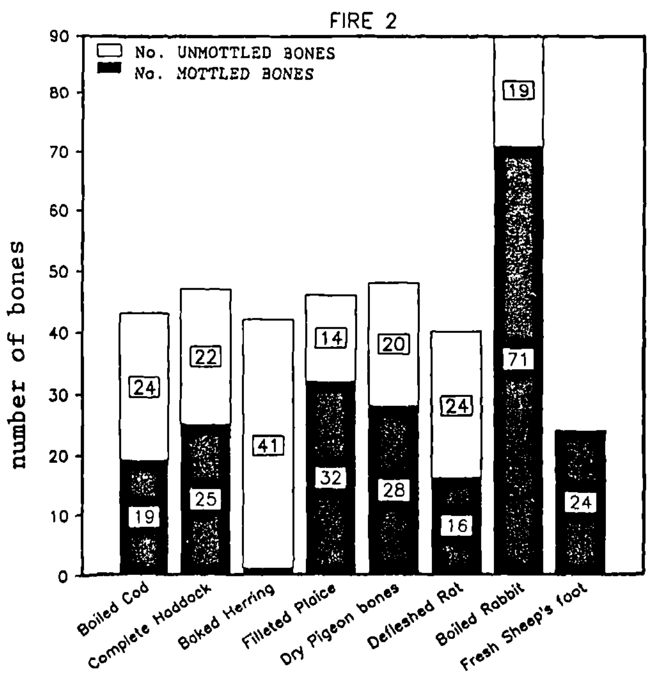


Fig. 4:3 Major Colours Exhibited by the Bones of Taxa Burnt on the Open-Air Fires.





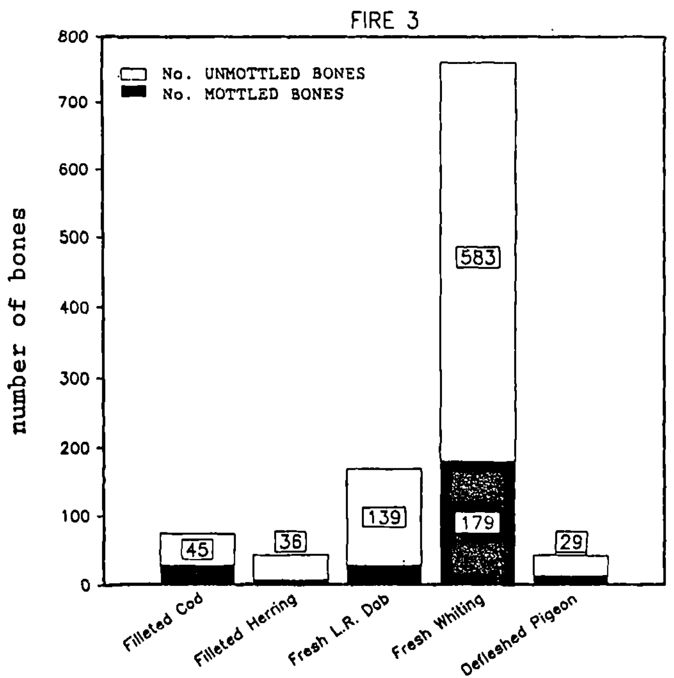


Fig. 4:4 Numbers of Mottled and Unmottled Bones of Taxa After Burning on Open-Air Fires.

Table 4:10 Percentages of predominant colours exhibited by bone fragments of the taxa burned on Fires 1-3, by shape of skeletal element.

	shape	Dk Brown	Black	Blue	Grey	Lt Blue	Lt Grey	White	no. of bones
Complete Cod	R	0	14.3	0	0	0	0	85.7	14
	S	0	60.0	2.5	0	0	5.0	32.5	40
	I	0	100.0	0	0	0	0	0	1
	F	0	25.0	0	0	0	0	75.0	4
Boiled Cod	R	0	0	0	0	0	0	100	1
	S	0	24.2	6.1	3.0	18.2	0	48.5	33
	I	0	100	0	0	0	0	0	100
	F	0	0	33.3	0	0	33.3	33.3	3
Dry Cod Bones	R	14.3	0	42.9	14.3	0	0	28.6	7
	S	0	0	50.0	0	0	0	50.0	2
	I	0	0	0	0	0	0	100.0	8
	F	0	0	42.9	0	14.3	0	28.6	7
Complete Haddock	R	0	85.7	0	0	0	0	14.3	7
	S	0	26.3	55.3	7.9	0	10.5	0	38
	I	0	0	100	0	0	0	0	1
Filleted Haddock	R	0	0	7.7	23.1	0	23.1	46.2	13
	S	0	0	0	5.1	0	30.8	64.1	39
	I	0	0	0	72.7	0	27.3	0	11
	F	0	0	0	50.0	0	16.7	33.3	6
Complete Herring	R	0	0	40.0	20.0	20.0	0	20.0	5
	S	0	10.9	5.5	47.3	7.3	0	29.1	55
	I	0	0	0	0	0	0	100.0	1
Baked Herring	S	0	9.5	0	0	9.5	7.1	73.8	42
Filleted Herring	S	0	0	0	2.5	10.0	50.0	37.5	40
	F	0	0	0	0	50.0	0	50.0	2
Complete Plaice	R	0	0	0	42.9	0	14.3	42.9	7
	S	0	0	0	12.5	0	4.2	83.3	48
	I	0	10.0	0	50.0	0	30.0	10.0	10
	F	0	0	25.0	25.0	0	50.0	0	4
Filleted Plaice	R	0	40.0	0	0	0	0	60.0	5
	S	0	0	6.1	15.2	3.0	21.2	54.5	33
	I	0	50.0	25.0	0	0	0	25.0	4
	F	0	25.0	0	0	25.0	50.0	0	4
Complete L.R.Dab	R	0	0	7.4	0	3.7	7.4	81.5	27
	S	0	2.3	3.8	12.2	0.8	42.2	38.6	132
	I	0	25.0	0	0	0	0	75.0	4
	F	0	0	0	0	0	0	100.0	4
Complete Whiting	R	0	1.6	0.8	3.1	0.8	27.1	66.7	129
	S	1.5	12.8	1.7	16.0	0.3	44.4	23.3	588
	I	0	0	0	0	0	22.2	77.8	9
	F	0	0	0	0	0	50.0	50.0	24

	shape	Dk Brown	Black	Blue	Grey	Lt Blue	Lt Grey	White	no. of bones
Complete Pigeon	TU	0	26.3	0	36.8	0	0	36.8	19
	SH	0	0	0	7.1	0	0	92.9	14
	S	0	0	0	83.3	0	0	16.7	6
Defleshed Pigeon	TU	0	0	0	5.3	0	0	94.7	19
	SH	0	0	0	0	0	76.9	23.1	13
	S	0	0	0	0	0	0	100.0	3
	F	0	0	0	16.7	0	50.0	33.3	6
Dry Pigeon Bones	TU	0	0	0	0	40.9	4.5	54.5	22
	SH	0	11.1	11.1	0	11.1	0	66.7	9
	S	0	0	27.3	36.4	9.1	0	27.3	11
	I	0	0	0	0	100.0	0	0	1
	F	0	0	0	0	0	0	100.0	5
Complete Rat	TU	0	0	0	16.0	0	0	84.0	25
	SH	0	0	25.0	50.0	0	0	60.0	5
	S	0	0	0	22.2	0	0	77.8	9
	F	0	0	0	33.3	0	0	66.7	3
Defleshed Rat	TU	0	0	0	66.7	0	16.7	16.7	12
	SH	0	0	0	0	58.3	0	41.7	12
	S	0	0	0	11.1	44.4	22.2	22.2	9
	F	0	0	20.0	40.0	20.0	20.0	0	5
Boiled Rabbit	TU	0	0	34.4	12.5	37.5	0	15.6	32
	SH	0	0	35.3	35.3	17.6	5.9	5.9	17
	S	0	0	39.3	0	10.7	10.7	39.3	28
	R	0	0	0	0	0	100.0	0	1
	F	0	0	30.0	20.0	20.0	0	30.0	10
Complete Sheep's Foot	TU	0	0	0	0	0	0	100.0	2
	SH	0	0	0	12.5	0	62.5	25.0	8
	S	0	0	0	0	0	16.7	83.3	6
Defleshed Sheep's Foot	TU	0	11.1	0	0	0	11.1	77.8	9
	SH	0	11.1	22.2	11.1	0	11.1	33.3	8
	S	0	20.0	0	60.0	0	0	20.0	5

Looking at the results from the burnt whiting from Fire 3 (Table 4:10), there does seem to be a trend for a higher proportion of the spherical bones to be darker in colour than the other bones, however. Being encased in flesh, the vertebrae would be insulated from the full heat of the flames until the flesh was burnt away. The chemical changes which account for the morphological states observed during burning can not take place in the absence of oxygen (McKinley 1989). It is to be expected that the greater the covering of flesh the shorter the period of time that the bones would be exposed to the maximum fire temperature. This pattern was not observed for all of the fish, however. The caudal vertebrae towards the caudal peduncle of the boiled cod on Fire 2 were black, but the abdominal vertebrae were predominantly white or light blue. The vertebrae of the complete haddock were mainly blue while most head bones were black. In other cases the vertebrae showed a very mixed range of colours.

Clearly, very local fire properties were more important than the physical structure of the bone in many cases. The density or thickness of the bone will affect the speed at which the chemical changes which produce the characteristic colours in burned bone take place, but all densities of bone will eventually reach the same colour stage for a given temperature. The dry bones passed from black through blue to grey and white within about five to ten minutes of being exposed to the flames, while those bones encased in flesh remained white or brown until the flesh was burnt away.

Determining the history of the burning of a specimen from the colour achieved is clearly only useful as an indication of the maximum temperature achieved by the specimen, and not of the maximum temperature of the heat source. Bone at the periphery of a fire may be heated to a far lower temperature than bone exposed to the flames in the centre. As an extreme example of this, in so-called cases of spontaneous human combustion the torso may be completely

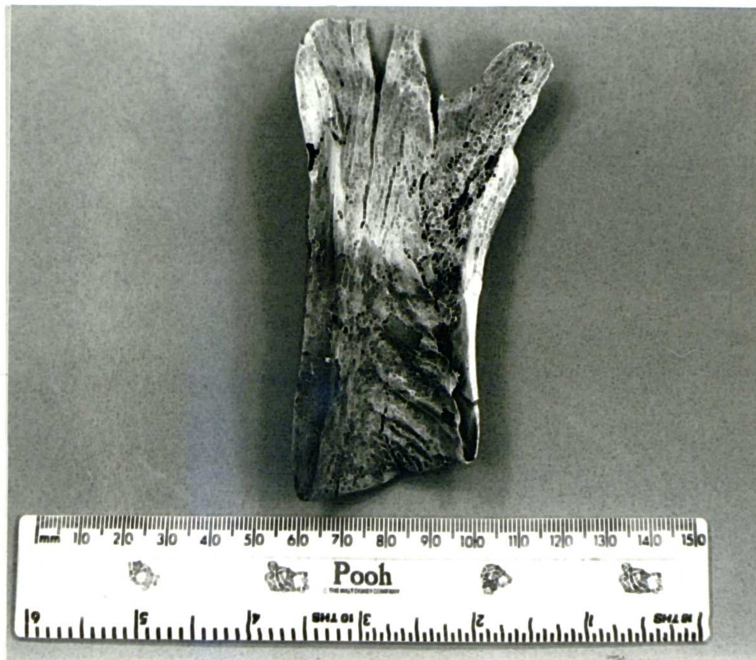
incinerated, while the limbs remain unburnt (from the television programme "Q.E.D.", Channel 4 April 1989). Studies of modern cremations by J. McKinley (1989 and pers. comm.) show that fleshed bone generally burns to a greater degree than defleshed or sparsely fleshed bone once oxygen reaches it, as a result of the higher temperatures generated by burning fat.

Weathered bone

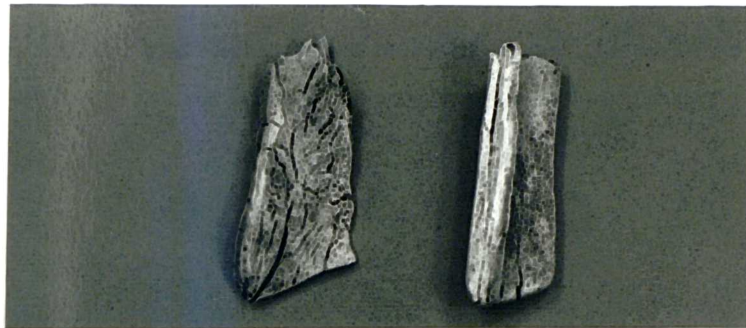
Weathered bone was distinguishable after burning both by the way in which it fragmented and cracked and by its colour, in many cases. The mammal bones were more easily distinguished as having been weathered prior to heating than the bird bones, which may be a consequence of a shorter period of weathering and exposure that the bird bones have been subjected to. The bird bones did not appear very much changed by burning, as the white colouration and ceramic-like appearance which was obtained was similar to fresh bone.

Most of the large mammal bones were fragmented into several pieces in the fire. Breaks and cracks were most frequently along the long axis of the bone and could be extensive with distortion of the bone leading to a fibrous "woody" appearance (Plate 4:2a) This "woody" appearance was only observed on weathered mammal bone. Transverse and parabolic cracks were also observed. The outer surface of bone sometimes exhibited superficial "crazed" cracking. Several of the shaft fragments were also split circumferentially, along the lamellae, separating the outer layers of cortical bone from the internal surface; these layers had subsequently warped (Plate 4:2b). This form of fragmentation was not observed for the fresh mammal bones. The weathered exfoliating surfaces of bones were still recognisable after heating and edges broken on heating and cooling were rough, as opposed to the smoother edges observed on old breaks.

a.



b.



c.

<u>Plate 4:2</u> <u>Weathered Bones After Burning on Fire 3.</u>

a. Cracking: the "woody" appearance.
b. Cracking: separation of the outer and inner layers of bone.
c. Orange colouration and mottles.

Although placed centrally in Fire 3 the conger eel dentary remained incompletely calcined, appearing dark brown in colour with a black area towards the proximal end of the bone. This dark brown colouration was observed on the other dry weathered bones as the stage immediately preceding grey. No predominantly black stage with bubbly char was observed for the dry weathered bones, unlike fresh bones which rarely appeared predominantly dark brown. After a grey/light blue stage many of the dry bones became cream in colour, not a colour observed on the fresh bones in this experiment, but described by Parker as a major colour observed on previously fresh burnt pig bone. Frequently the internal surfaces of the weathered mammal and bird bones were orange in colour, in contrast to the cream, light grey or white exterior surface (Plate 4:2c). This orange colouration was also observed on the inner surfaces of the defleshed pigeon long bones after burning and may be a consequence of a chemical reaction at high temperatures involving iron originating from haemoglobin. Bright green mottles were also observed on a few of the weathered mammal bones only. Green, pink and orange colours were observed on fresh bones burnt in the muffle furnace at high temperatures (700°C and above) however (see below), so can not be attributed to a lack of flesh or to chemical changes in the bone as a consequence of weathering. Beneath the surface the internal structure of the bone of some of the larger mammal fragments, as viewed in section, was often a darker shade than the external surface, but this may be a function of the bone thickness rather than its previously weathered state (see below, p.107). Parker (1985) observed this graded colouration through the bone on pig bones burnt in the flesh, but did not see it on previously defleshed bones. She interpreted the colour gradation as a function of high surface temperatures due to the burning of fat, however as weathered bone also shows the pattern it clearly can not be attributed to a prior covering of flesh.

The lack of organic material within the bone probably accounts for some of differences in colour stages observed,

for example the lack of a predominantly black stage. These experiments indicate that it is unlikely that previously dry or weathered bone could be determined from the colour of the bone fragments in the absence of distinctively weathered surface morphology, however.

Molluscs

Of the twenty specimens of each taxon put into Fire 2, 17 limpets, 15 periwinkles, 15 dogwhelks, 8 mussel valves and one apex of *Helix aspersa* were recovered. Apart from the destruction of virtually all the garden snails, the most extensive damage was to the mussels, most of which were identified from small fragments. The most resilient part of the mussel valve was the hinge portion. The identifiable parts of the valves were generally extensively cracked in all directions, and the inner nacre surface was missing in most cases. Except for three complete valves which were brown in colour all the other valves were grey or grey and white and extremely fragile/crumbly. Of the limpets, nine had the outer circumference of the shell separate, either whole or in pieces, and all were grey or grey and white and chalky. Circumferential cracks were visible on most of the limpet shells and penetrated the whole shell. In four cases the external surface was flaky. The shiny nacreous inner surface was missing in all but one limpet shell. Most of the periwinkles and dogwhelks were complete but cracked, although in the case of one dogwhelk and three periwinkles the apices had separated from the remaining body whorls, and one dogwhelk syphon was missing. Cracks could be in any direction, straight or parabolic (curved), and usually penetrated the entire shell. Four dogwhelks and one periwinkle appeared only slightly burnt, as indicated by a slightly brown colouration, the rest were dark or medium grey and fragile. Apart from the shells from the edge of the fire, which appeared only slightly burnt, it is unlikely that the surviving burnt mollusc shells, especially the mussel valves, would survive if subjected to much physical force.

4.4.3 Conclusions : the field experiment

Referring to the questions posed at the start of this chapter, the experimental fires have yielded information on six major points.

1. Some skeletal elements, in particular flat bones, are more susceptible to destruction than others; the spherical and "robust" fish bones and tubular mammal and bird bones survived best. Shape seems to be a more important factor than density of bone in determining which elements will survive.

2. Although the overall patterns of destruction were similar in all vertebrate taxa, the herring head bones were particularly vulnerable in the fire and the bones of smaller mammals survived less well than those of larger animals.

3. The condition of the body before burning did not seem to have much effect on the chances of survival of the bones, though fleshed bones were exposed to the heat at a later stage than defleshed bones. Pre-cooking of bones did not appear to affect their chances of survival. Further experiments involving greater numbers of replicates in different states would be needed to validate this conclusion, however.

4. The colour of the bones seemed to be determined more by local variations in temperature, temperature duration and possibly the atmosphere in which the bone was burnt than the taxon or condition of the animal. For this reason, while bones at the extremities of an animal, i.e. mammal and bird lower limb bones may be lighter in colour than areas covered with more flesh, this trend is not always observable.

5. Previously weathered bones may be distinguishable from

their burnt remains as the cracks and exfoliation which typifies weathered specimens before burning is observable on burnt bones. This has particular relevance to the determination of the condition of human cremated bone before burning.

6. Quite considerable amounts of skeletal material may survive burning to be incorporated into the archaeological record, but the assemblages which survive are likely to be a modified group, for the reasons given above.

4.5 The Laboratory-based Experiments.

Following on from the field experiments, in which temperature and atmosphere of burning could not be controlled, a series of laboratory experiments were undertaken to try to investigate further the effects of temperature and atmosphere on a selection of skeletal remains. The taxa used were similar to those used in the field experiments, but a more limited range of skeletal elements were selected.

4.5.1 Heating and Colour Change

Aim

To investigate further the questions of whether the temperature to which a bone has been exposed can be recognised, and whether the conditions of burning can be identified, the validity of the "colour/temperature" scales put forward by several workers, notably Baby (1954), Binford (1963), Ubeläker (1978) and Shipman *et al.* (1984) were examined. This scale relates temperature of burning to colour of bone, with bones passing from brown to black to blue/grey, through grey, blue, light grey and finally white. Most workers agree in principle to the stages observed, but there are discrepancies in the determinations

of the temperatures at which each stage is reached. Shipman *et al.* indicate that specimens become predominantly white at temperatures of over 645°C, while Ubeläker suggests temperatures of 900°C and above, for example. Previous workers in this area have only examined human and other large mammal bones. In line with the scope of this research the application of the colour/temperature scale was examined to see if it applied to non-mammal bone.

Methods and Materials.

Bones from sheep, pigeon, cod, haddock, plaice, herring, and frog and calcified vertebral centrum from dogfish were cleaned manually, and as much adhering cartilage and periosteum removed as possible. The bones were dried for a minimum of 48 hours at room temperature and then heated in a muffle furnace for two and a half hours from cold, as Buikstra and Swegle (n.d., quoted in Shipman *et al.* 1984) showed that neither fleshed or defleshed remains reach the maximum temperature of the furnace in under two hours. In trials during which bones were heated for two and five hours, it was established that generally no further colour changes occurred after two hours, indicating that the specimens had reached the maximum oven temperature. The furnace took up to half an hour to reach the maximum temperature. All bones were placed centrally in the muffle furnace to try to prevent uneven heating due to unequal heat distribution in the furnace, which had been observed in trials.

The experiments were conducted at temperatures from 200°C to 900°C, at 100 degree intervals. A similar selection of skeletal elements from each animal was used in each experiment and comprised six sheep phalanges and four sesamoids; ten pigeon bones (including one or two humeri, tibiotarsi, ulnae, and radii, one coracoid, one scapula and two vertebrae); ten frog limb bones; six dogfish calcified vertebral centra, two gadid otoliths; and, from cod, haddock, plaice, salmon and herring, one articular, one

hyomandibular, one opercular and 8 - 10 vertebrae. All represent species and skeletal elements commonly recovered archaeologically.

As oxygen is necessary for combustion to take place the effect on bone colour of burning in a very limited supply of oxygen was investigated. In real life it is extremely unlikely that a completely reducing atmosphere would obtain. For skeletons burnt "in the flesh", or for elements buried in ash, incompletely oxidising conditions may prevail, however. To simulate this a reduced range of skeletal elements were heated in crucibles covered with at least 30 mm. of silver sand and a lid. These experiments also lasted two and a half hours, but a second series was heated for five hours to ensure that the specimens had reached maximum furnace temperature. The bones were examined in day-light and the colours compared with a Munsell Soil Colour Chart (1973) to give consistency and objectivity. Both predominant colours and mottles were recorded.

Results and Discussion

Table 4:11 gives the predominant and minor colours observed on the bones and otoliths heated in open crucibles for two and a half hours, and Table 4:12 the colours for the bones heated for two and a half and for five hours under sand.

Although it seems that in general terms the colour/temperature scale is applicable to non-mammal bone, there are some important differences. In particular, the colours achieved by fish bones (particularly cod, haddock and plaice) at 500-700°C were consistently darker than those displayed by the sheep and pigeon bones heated under the same regime. Some darker colours were recorded for bones heated under sand at temperatures of 700°C and below, and the colours tended to be more variable than for assemblages of bone heated in open crucibles. Blue

Table 4:11 Major and Minor Colours for Bones and Otoliths Heated in the Muffle Furnace.
(Colours identified using the Munsell Soil Colour Chart in daylight).

Bones heated in open crucibles for two and a half hours

Temperature in degrees C	Predominant Colour	Minor Colours
Sheep		
20	White 5Y 8/2	5Y 8/1
200	Strong Brown 7.YR 5/8	10YR 5/8, 6/8, 10R 2.5/1, 2.5/4
300	Black 2.5Y 2/0	5YR 5/8
400	Grey 2.5Y 6/0	
500	Light Grey 10YR 7/1	N4, N8, 5B 7/1
600	Grey/light grey 10YR 6/1	10YR 7/1, 5B 7/1
700	White 2.5Y 8/0	2.5Y 7/6, N6
800	White N8	
900	White N8	
Pigeon		
20	White 2.5Y 8/2	
200	Reddish Yellow 7.5YR 6/8	10YR 5/6, 2.5Y 5/4, 7.5YR 5/8
300	Black 2.5Y 2/0	5YR 4/1, 4/2, 2.5/2
400	Black 2.5Y 2/0	
500	Light Grey 10YR 7/1	2.5Y 7/2, 10YR 7/2, 6/3, 4/2, 5/2
600	Light Grey 2.5Y 7/2	10YR 6/2, 5/2, 4/2, 5B 7/1
700	White 2.5Y 8/0	5Y 4/1, 7.5YR 7/8, N7, N6, 5B 7/1
800	White N8	2.5Y 7/6, 7.5YR 7/8, 10R 5/3, 5G 6/2
900	White N8	
Frog		
20	White 2.5Y 8/2	
200	Yellow 10YR 7/6	7.5YR 6/8, 5YR 4/6, 2.5YR 2.5/2
300	Black 2.5Y 2/0	
400	Black 2.5Y 2/0	
500	Brown 10YR 5/3	2.5Y 2/0, 10YR 5/1, 7/6, N7
600	Greyish Brown 10YR 5/2	10YR 4/2, 5/2, N3, N8
700	Greenish Grey 5G 6/1	5G 7/1
800	White N8	
900	White N8	
Salmon		
200	Strong Brown 7.YR 5/8	7.5YR 5/6, 2.5YR 5/8, 5YR 3/4, N2
300	Black N2	5YR 3/2,3/3, 5B 6/1
400	Black N2	
500	Black N2	10YR 3/2,4/2,6/2, 5YR 3/3, 5B 5/1, N4, N5
600	Black N2	10YR 3/2,5/2,3/1,4/2,5/1, 5B 6/1,7/1, N6, N7
700	Grey 2.5Y 6/0	5Y 3/1,6/1, 5B 7/1, N5, N8
800	White N8	
900	White N8	10R 6/3
Cod		
200	Yellowish Red 5YR 5/8	7.5YR 5/8, 2.5Y 8/2, 10YR 7/6
300	Black N2	
400	Black N2	
500	Black N2	10YR 3/1,4/2,5/1, 5YR 3/2, 5B 6/1
600	Very Dark Grey N4	10YR 3/2,4/2, N2, N5, N6, N7
700	White N8	N4, N5, N6, 5B 6/1, 7/1
800	White N8	
900	White N8	10R 6/3, 5G 7/2

Temperature in degrees C	Predominant Colour	Minor Colours
Haddock		
200	Yellowish Red 5Y 5/8	5YR 4/6,3/3,3/6, N2, 10YR 6/8
300	Black N2	
400	Black N2	
500	Black N2	5YR 3/3, 2.5/1, 10 YR 7/2,4/1, 5B 7/1,
600	Dark Greyish Brown 10YR 4/2	10YR 3/1,3/3,4/2,4/1,4/3, N5, N6, N8, 5B 6/1,7/1
700	White 2.5Y 8/1	N6,N7, 5B 6/1,7/1
800	White N8	
900	White N8	
Plaice		
200	Brownish Yellow 10YR 6/6	5YR 3/2, N2, 10YR 5/8, 2.5YR 2.5/4
300	Black N2	
400	Black N2	
500	Black N2	10YR 3/3,4/1, 5YR 3/4,2.5/2
600	Black 10YR 2/1	10YR 2/2,3/1, N2, N4, N6, N8, 5B 6/1,7/1
700	White 2.5Y 8/0	5B 6/1, 7/1, N6, N7, 5Y 4/1
800	White N8	
900	White N8	
Herring		
200	Very Pale Brown 10YR 7/3	10YR 7/6, 5YR 2/1,4/4, 2.5YR 3/6
300	Black 5YR 2/1	
400	Black N2	2.5YR 3/6
500	Very Pale Brown 10YR 8/4	10YR 7/3,6/2,4/3,4/4,2/2,3/2
600	Dark Greyish Brown 10YR 4/2	10YR 4/1,3/2,2/1, N8, 5B 6/1
700	White 5Y 8/1	5Y 6/1, 7/1
800	White N8	
900	White N8	
Dogfish		
200	Yellow 10YR 7/6	5YR 4/4, 2.5YR 2.5/2,2/0,3/4
300	Black N2	5Y 3/2
400	Black N2	
500	Black N2	5YR 3/4, N7, 5B 7/1
600	Dark Greyish Brown 10YR 4/2	N2, N8, 5B 7/1
700	White 2.5Y 8/0	N6,N7
800*	White N8	
900*	White N8	
Otoliths		
20	White 10YR 8/1	
200	White 10YR 8/2	7.5YR 7/6, 6/6, 6/8
300	Yellow 10YR 7/6	7.5YR 6/8, 6/6, 5YR 5/8
400	Light Brownish Grey 2.5Y 6/2	N2, 2.5Y 7/4, 10YR 7/6
500	Grey	N4, N2, 5B 7/1, 10YR 4/1, 3/1 10YR 4/2, 5B 6/1
600	Dark Grey 2.5Y 4/0	5B 6/1, 10YR 4/1, 3/1, N6
700	Dark Grey 2.5Y 4/0	N8
800*	White N8	
900*	White N8	

* : crumbled in the oven at this temperature.

Table 4:12 Major and Minor Colours for Bones Heated Under Sand.
(Colours identified using the Munsell Soil Colour Chart in daylight).

	Bones heated under sand for two and a half hours.		Bones heated under sand for five hours.	
Temperature.	Predominant Colour.	Minor Colours.	Predominant Colour.	Minor Colours.
Sheep				
200	Dark Reddish Brown 5YR 3/2	5YR 2.5/1	Black 5YR 2.5/1	
300	Black N2		Black N2	
400	Black N2	5YR 4/1	Dark Grey N4	N5
500	Dark Grey 5YR 4/1	5YR 4/2, 5/1, 6/1, N2	Mid Grey N5	N4, 10YR 5/1
600	Grey N4	N5, 5B 5/1, N8	Mid Grey N5	N6, 10YR 5/1, 5B 6/1, N8
700	Grey N7	N6, 5B 4/1, 5YR 2.5/1	White N8	
800	White N8	5Y 5/1, 5B 7/1	White N8	
900	White N8		White N8	
Salmon				
200	Yellowish Red 5YR 4/6	5YR 3/3, 2.5/1	Yellowish Red 5YR 4/6	5YR 2.5/1
300	Black N2		Black N2	
400	Black N2		Black N2	
500	Grey 5YR 5/1	5YR 4/1, 5/3, N2, 5B 7/1	Grey 10YR 5/1	10YR 4/1, 5B 7/1, N8
600	Grey N5	5YR 2.5/1, 5B 4/1, 5/1, 7/1, N4	Bluish Grey 5B 6/1	N6.N5, 5B 5/1, N8
700	White N8	5B 5/1, 6/1, 4/1, 5YR 2.5/1	White N8	10YR 5/1
800	White N8	N6, N7	White N8	
900	White N8		White N8	
Cod				
200	Dark Reddish Brown 5YR 3/2	5YR 2.5/2, N2	Dark Reddish Brown 5YR 3/2	5YR 2.5/1
300	Black N2		Black N2	
400	Black N2		Black N2	
500	Dark Grey 5YR 4/1	5YR 2.5/1, 2.5/2	Dark Grey N4	5YR 2.5/2
600	Dark Grey 5YR 4/1	5B 4/1	Grey N5	5B 5/1, 6/1, 7/1, N4, N8
700	Dark Bluish Grey 5B 4/1	5B 5/1, 6/1, 7/1, N8	Light Bluish Grey 5B 7/1	5B 6/1, N8, N7, N6
800	Bluish Grey 5B 5/1	5B 6/1, 7/1, N8, 5Y 5/1	White N8	5B 7/1, 6/1
900	White N8		White N8	
Haddock				
200	Dark Reddish Brown 5YR 3/2	5YR 2.5/2, N2	Dark Reddish Brown 5YR 3/2	5YR 2.5/1
300	Black N2		Black 5YR 2.5/1	
400	Black N2		Black N2	
500	Dark Grey 5YR 4/1	5YR 2.5/2, 2.5/1	Dark Grey N4	10YR 2.5/2
600	Dark Grey 5YR 4/1	5B 5/1, 5YR 2.5/1	Grey N5	N4, 10YR 5/1, 5B 6/1
700	Dark Bluish Grey 5B 4/1	5B 5/1, 5YR 2.5/1	Bluish grey 5B 6/1	5B7/1, N8
800	Bluish Grey 5B 5/1	N8, 5Y 5/1	White N8	
900	White N8		White N8	

colouration in particular was more evident on bone heated under sand. A covering of sand may lead to reducing and oxidising atmospheric pockets and possibly localised temperature variations, and this could explain the greater amount of mottling observed on some of the bones. In some cases both black and white areas were found on the same bone, as well as intermediate blues and greys, a condition observed on the bones burnt on open fires (see above p. 90) and frequently observed on archaeological bone. This multi-coloured state was particularly noticeable on bones heated under sand for two and a half hours, when the bones had not reached the maximum colour, as indicated by comparison with those bones heated for five hours under sand.

Once the bones had reached the maximum temperature set on the muffle furnace no further colour change seemed to occur, and when heated in open crucibles bones were generally unmottled; the minor colours observed were generally differences in colour between specimens, or fairly minor graduations in hue or chroma. Trials during which bones were taken out at intervals (as a means of establishing the time needed for the bones to reach the furnace temperature) indicated that flat bones and smaller bones tended to reach the maximum colour for that temperature first.

Incomplete oxidation probably accounts for bones which were darker on the inside than the outside, a form again commonly represented by archaeological material. A covering of flesh will inhibit combustion of the bone while it remains, and burning fat will lead to localised high temperatures. Duration of exposure to the maximum temperature is another obvious source of variability. Trial experiments, in which samples of bone were heated in open crucibles in an initially cold furnace for periods ranging from one hour to five hours, demonstrated that after a maximum of two hours no further change of colour occurred. Removing the samples before they had reached the maximum furnace temperature obviously did affect the colour

achieved, however. It is likely that in the experiments where bones were covered in sand they did not reach the maximum temperature in two and a half hours.

At temperatures of 800°C and above some bones were mottled with pink, bright green or orange, presumably due to chemical reactions occurring within the bone mineral.

Otoliths heated in open crucibles showed a different colour-temperature scale to bone. The otoliths did not appear heated until they had been subjected to temperatures above 200°C, and no black stage was observed. At less than 500°C otoliths were intact and uncracked, but at higher temperatures, when the otoliths had become grey, they became extensively cracked. Above 700°C the white otoliths crumbled to powder.

Clearly colour is an important indicator of the temperature which the bones have reached, but does not necessarily indicate the maximum temperature of the heat source. As several investigations have shown (e.g McKinley 1989 and the field experiments described above) time of exposure to the maximum temperature, supply of oxygen and condition of the bone are also critical factors in determining bone colour. Bones which have been buried may also have been coloured as a result of factors other than burning, including post-mortem funerary rites, and soil conditions after burial, as discussed by Franchet (1933). Gejvall (1963, 381) quotes the case of second world war human cremations which were initially interred in paper pulp containers but later reburied. He notes that the cremated bones had assimilated colour from the soil. As Franchet realised, organic acids in the soil may turn bone brown, dark blue or blue-grey, while iron and manganese can turn bone black (see also Oakley 1954 and 1956). Iron oxides are responsible for orange and yellow tones, and iron phosphate for light blue and green.

4.5.2 Surface Morphology

Aim

To assess whether the temperature of burning can be established from observations of surface morphology on a selection of vertebrate remains.

Background

To try and determine whether burning had taken place in cases where bone colour was equivocal several analyses have been proposed, including X-Ray diffraction studies (Shipman *et al.* 1984); thermogravimetric analysis (Bonucci and Graziani 1975); electron spin resonance (Robbins *et al.* (1989); histological analysis (Brain and Sillen 1988); carbon:nitrogen ratio analysis (Brain and Sillen 1988) and study of surface morphology using the scanning electron microscope (Bonucci and Graziani 1975; Shipman *et al.* 1984; Shipman 1988). Of these the only analysis which claimed to successfully determine temperature of heating from 200°C to 1000°C, using equipment available in most universities, was microscopic analysis using conventional light microcopy and scanning electron microscopy. As a reasonably straightforward technique microscopical analysis of bone surfaces offers a simple way of obtaining information about burning from archaeological specimens, especially since conventional light microscopy does not require the specimen to be damaged, and resin casts can be used instead of the actual specimens for S.E.M. work (Shipman 1981) again conserving the specimen. It is for these reasons that the following analysis concentrates on the study of surface modifications to bone as a result of heating.

The only works published on microscopic surface morphology of burnt bone are by Bonucci and Graziani (1975) and by Shipman *et al.* (1984, and summarised in Shipman 1988). Of these the latter is much the more extensive and straightforward, as it uses intact bones rather than thin

sections. In their work sheep astragali and mandible samples were analysed, and stages illustrated for temperature-related surface modifications to bone and teeth, using the S.E.M.; the present study is therefore an extension of their work, designed to investigate whether bones from other animals show the same temperature-related stages.

Methods and Materials

The bones examined in this study included sheep phalanges and sesamoids, pigeon humeri, haddock otoliths and vertebrae from cod, salmon, plaice, haddock, herring and dogfish. The specimens were prepared and heated in the muffle furnace as described above. For the preliminary analyses all were heated for two hours, from cold, at temperatures from 200°C to 900°C inclusive, at intervals of 100°C, and cooled rapidly. Later, experiments cooling bones slowly were performed.

Specimens were prepared for examination using the ISI 100A scanning electron microscope (S.E.M.) by cleaning with mild detergent in an ultrasonic tank, followed by brushing with alcohol and acetone, as recommended by Shipman *et al.* (1984). Fresh bones and bones heated to below 600°C were first shaken in a 1:2 mixture of methanol:chloroform for at least 12 hours to remove the extensive surface grease. Specimens were then mounted on stubs, coated with gold in a Polaron coating unit to render them conductive, and viewed under the S.E.M. at magnifications from 25X to 15000X. The most useful magnifications were found to be between 1000X and 10000X.

Archaeological samples of sheep, cow and fish subchondral bone from the archaeological sites of Freswick Links, Caithness; North Cave, North Humberside; and Stakis, Wellington Row, York were also examined using the S.E.M.. The samples were cleaned in sodium pyrophosphate for 5 minutes in an ultrasonic tank to remove adhering particles prior to mounting and coating.

Results

Bones

Tables 4:13-4:15 and Plates 4:2-4:5 detail the stages observed for mammal and fish bones and otoliths under the light microscope and S.E.M. Table 4:16 and Plates 4:3-4:4 give the appearance of archaeological bone similarly examined, with an interpretation of temperature to which the bone has been heated, based on its appearance. The stages used in this study are based on observations of the articular surfaces of bone. Shaft samples from mammal and bird bones showed less clear differences, a fact also noted by Shipman and collegues. For fish, vertebral centrum articulating facets were examined. Following the above work, the classifications here are given for the most advanced stage seen on specimens. Plates 4:2-4:5 illustrate the forms described in the Tables.

Examination by eye, using the light microscope and using the scanning electron microscope gave results similar to those seen by Shipman and colleagues, but with some important differences.

To summarise, the major features apparent in the present study were that, in general, after exposure to temperatures above 200°C to about 400°C (depending on species) a black, vitreous, bubbly and peeling surface was apparent on all bones without recourse to magnification. Examination by eye and at low magnifications showed the polygonal cracking described by Shipman *et al.* on the articular surfaces of sheep and pigeon bones heated to between 400 and 800°C (Plate 4:2). The same cracking was not observed on the fish vertebrae, but examination of the articular surfaces of burnt cod and salmon articular elements revealed similar cracking. The polygonal or crazed pattern is distinctive and is caused by the propagation of cracks between vascular canals as a result of shrinkage. This form of cracking seems to be only present on bone which has been heated. The

cracks became deeper with increasingly curled edges from 400 to 700°C, but were less pronounced at higher temperatures, as all but the largest cracks closed. Similarly, as seen under the light microscope (Plate 4:2) the vascular canals became increasingly prominent after exposure to temperatures from 400 to 700°C, while at higher temperatures they appeared to be infilled. By 900°C the surface of bone seemed smooth and ceramic-like, while at 600-700°C the surface appeared granular.

These changes were not visible on fish vertebrae, where cracking, if present, was circumferential and radial, forms also apparent on unburnt fish vertebrae which have been weathered (see below, Chapter 6, p.268). Turning to the S.E.M. observations, examination of the specimens proved less straightforward than expected. The range of forms apparent on the same specimen, as well as between them, made simple grouping difficult. As a result the descriptions of each stage represented on the heated bones are more varied than those suggested by Shipman and colleagues.

There was therefore general agreement between this research and that of Shipman *et al.* (*ibid.*), in that stages of surface morphology on the articular surfaces of bones burnt experimentally can be recognised and related broadly to the temperature to which the specimen had been exposed. However, there were also important differences both general and related to taxon.

In the present study, while there were differences between the surface appearances of fresh bone compared with bone heated to 200°C, fresh bone which had been weathered appeared more similar to bone heated to 200°C than to fresh bone (Plate 4:3, b2). Examination of archaeological samples for which there was no evidence of heating also showed a surface morphology more similar to that observed on the 200°C experimental samples (Plate 4:4, b2).

Table 4:13 Heating stages in bone: Sheep phalanx and Pigeon tibiotarsus macroscopic and microscopic surface morphology.

Temperature	Macroscopic appearance	Microscopic appearance through the light microscope at up to X50.	Microscopic appearance, through the S.E.M.
Stage 1			
20°C.	Gently undulating, continuous surface.	Gently undulating, continuous surface, penetrated only by vascular canals.	Gently undulating, continuous surface. Vascular canals occasionally visible.
200°C.	Very similar to fresh bone, but the greasy, almost glassy surface on the articular ends is very difficult to remove completely.	Where the glassy surface has been removed the articular surfaces are rougher and more granular than fresh bone, and the vascular canals are more prominent.	The surface appearance is rougher than for fresh bone, with tiny grains sitting on the surface and small pores and cracks apparent. Vascular canals are prominent.
Stage 2			
300°C	Large areas are covered with a vitreous, bubbly layer of char.	Large areas are covered with a peeling, bubbly layer, beneath which is a granular surface with clear, regular vascular canals.	The layer of char on the surface forms a glassy layer beneath which the surface is granular or particulate.
Stage 3			
400°C	The vitreous surface has largely combusted, revealing a flat, granular, occasionally cracked surface.	The surface is flat and granular, and vascular canals are numerous and clearly visible. Polygonal cracking can be seen on and around the articular surfaces.	The spherical particles visible on the surface have become rather frothy and less regular in some areas. At lower magnifications polygonal cracking can be seen clearly.
500°C.	The articular surfaces show extensive polygonal cracking and many areas appear powdery.	The surfaces show extensive polygonal cracking, with the edges of the cracks beginning to curl upwards. The bone appears pitted and granular.	The bone on the articular surfaces appears pitted lower magnifications, and at higher magnifications (X1000 and above) frothy.
600°C.	The surface appears powdery and extensively polygonally cracked.	The surfaces of the bone are similar to 500°C, with the edges of the cracks curled upwards. Individual particles sit on the bone surface.	The pitted surface has become less regular, and the articular surface appears highly frothy.
Stage 3/4			
700°C.	The bone surface is extensively cracked, but some cracks seem to be superficial. Some powdery areas.	The articular surfaces are extremely variable in colour and appearance. Some surfaces appeared pitted and very granular while others appear smooth, this seems to be related to the colour of the bone.	The surfaces of the bones examined were highly variable, with frothy areas and areas where the particles have melted and recrystalised into various nodular and rod-like forms, as seen at higher temperatures.
Stage 4			
<800°C - >900°C	The bone appears chalky and smoother than before. Much of the cracking has disappeared.	The bone appears smooth, and most of the cracks have become infilled, making them shallower and more rounded at the edges. The vascular canals are less prominent than at lower temperatures.	At lower magnifications (<1000X) the surface appears pitted, with raised areas surrounding the vascular canals. At higher magnifications the crystals of hydroxyapatite have coalesced to form a variety of structures including nodules (on the shaft) and rod-like structures of about 1 micron in length, as well as less regular, roughly spherical forms, or a mixture of these. These crystals form donut-shaped raised areas around the vascular canals. Hexagonal plate-like crystals may also be seen, similar to artificially sintered hydroxyapatite (illustrated by Shipman et al. (1984).

Plate 4:2 Bone Surfaces Observed under the Light Microscope. (scale bar = 1 mm.)

A. Contemporary fresh sheep phalanx articular surface.

B. Mid brown sheep astragalus articular surface, from North Cave (NC87/289 APQ).

C. Contemporary sheep phalanx articular surface heated to 300°C.

D. Black sheep astragalus articular surface, from North Cave (NC87/289 APQ) showing char.

E. Contemporary sheep phalanx articular surface heated to 400°C, layer revealed beneath peeling char.

F. Dark brown and black sheep astragalus articular surface, from North Cave (NC87/289 APQ).

G. Contemporary sheep phalanx articular surface heated to 600°C.

H. Mid-grey and blue sheep naviculo-cuboid, articular surface, from North Cave (NC87/289 APQ).

I. Contemporary sheep phalanx articular surface heated to 900°C.

J. White cow long bone epiphysis, from North Cave (NC87/289 APQ).

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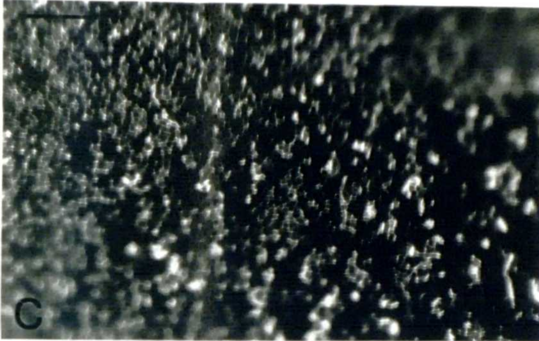
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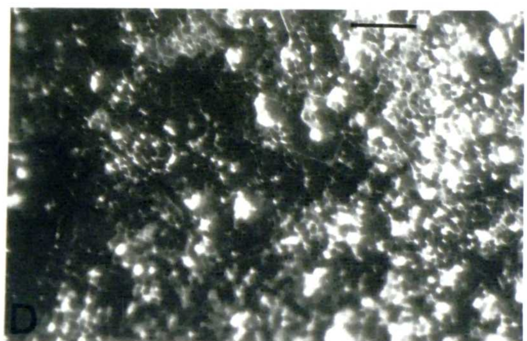
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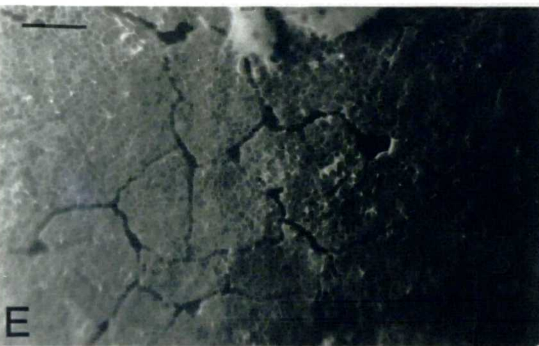
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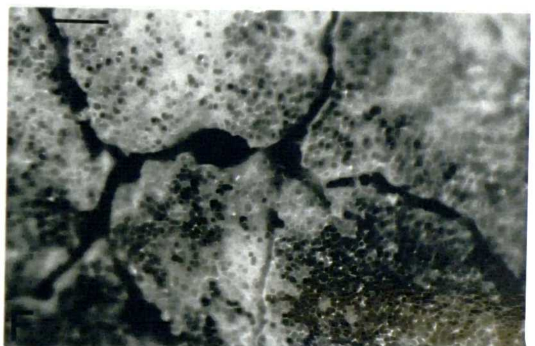
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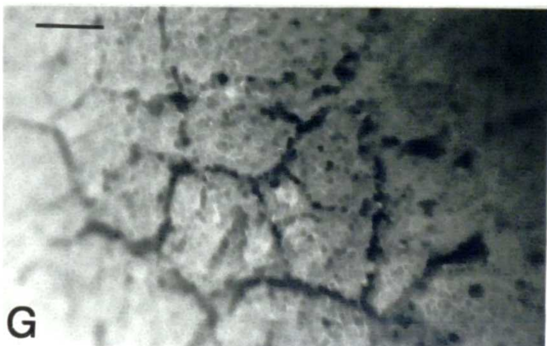
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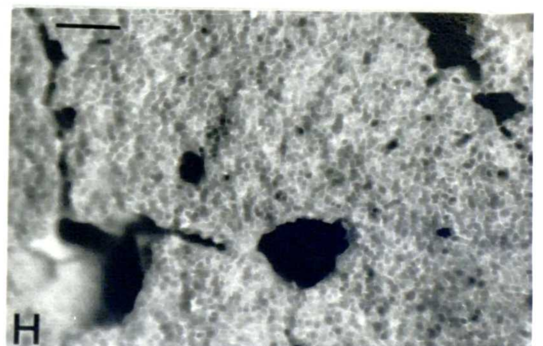
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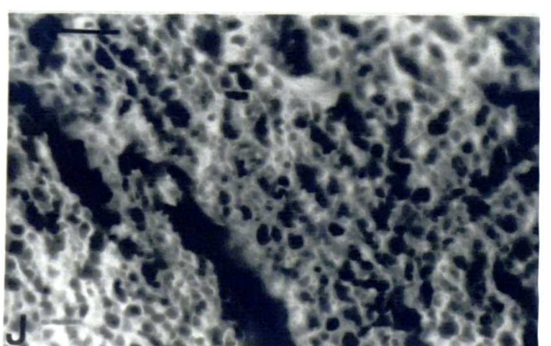

J

Plate 4:3 Mammal and Bird Articular Surface Morphology (and a Weathered Cod Vertebra) Viewed Through the S.E.M., (scale bar = 1μm, except for L)

A. Contemporary fresh sheep phalanx articular surface.

B1. Contemporary sheep phalanx articular surface heated to 200°C.

B2. Contemporary, unheated, weathered sheep metapodial articular surface.

C. Contemporary sheep phalanx articular surface heated to 300°C, the vitreous char.

D. Contemporary sheep phalanx articular surface heated to 400°C, area from which the vitreous char had been burnt away.

E. Mid-grey sheep astragalus articular surface, from North Cave (NC87/289 APQ).

F. Contemporary sheep phalanx articular surface heated to 600°C.

G. Light blue, light grey and white sheep phalanx articular surface, from North Cave (NC87/289 APQ).

H. Contemporary sheep phalanx articular surface heated to 700°C.

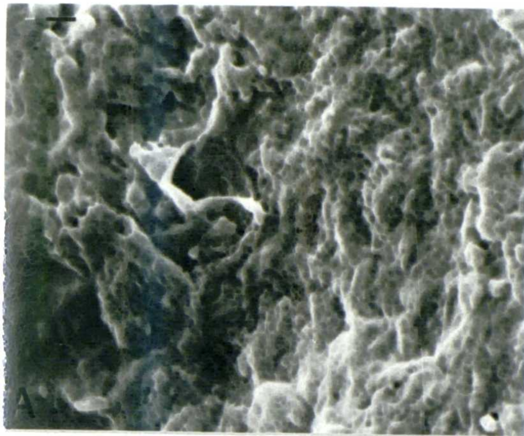
I. White sheep naviculo-cuboid articular surface, from North Cave (NC87/289 APQ).

J. Contemporary sheep phalanx articular surface heated to 900°C.

K. Contemporary pigeon tibiotarsus articular surface heated to 900°C, lower magnification.

L. Cracking on the articular surface of a sheep phalanx (scale bar = 1.5 mm.)

M. Weathered bone, unheated: a boiled cod vertebra, articulating facet.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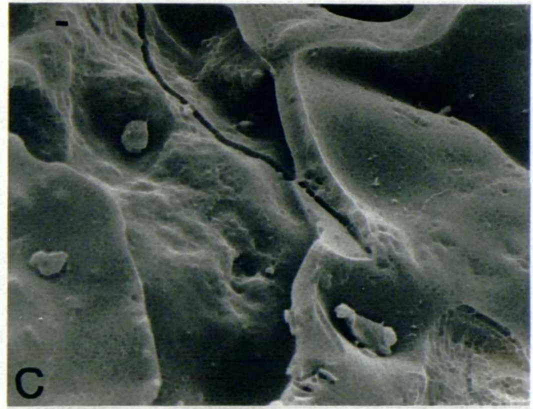
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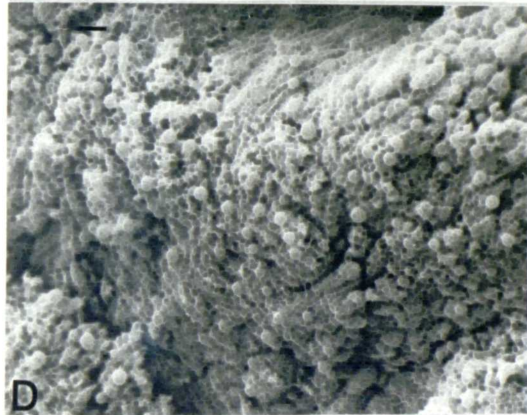
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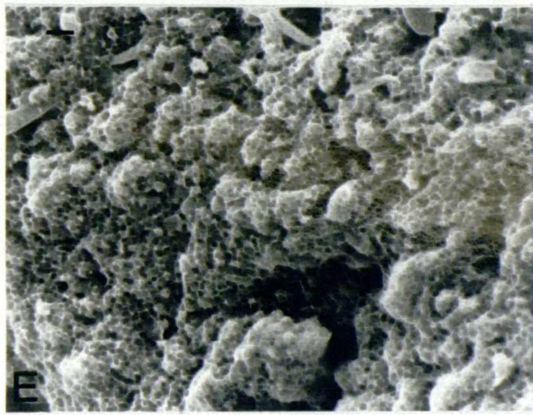
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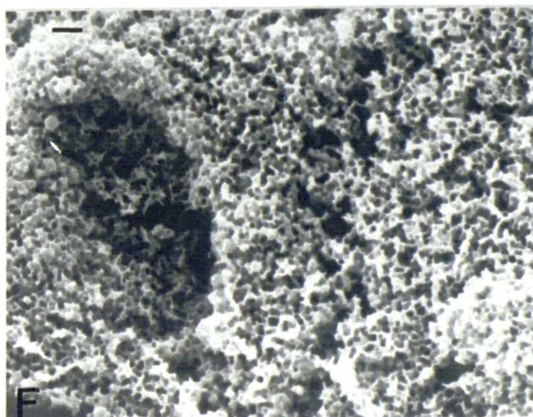
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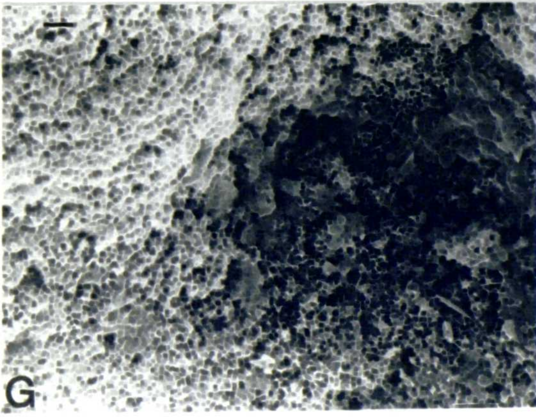
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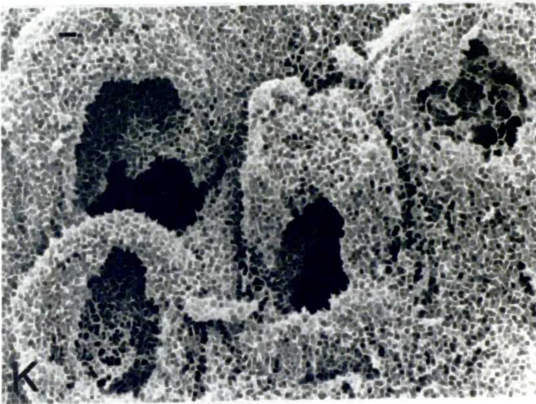
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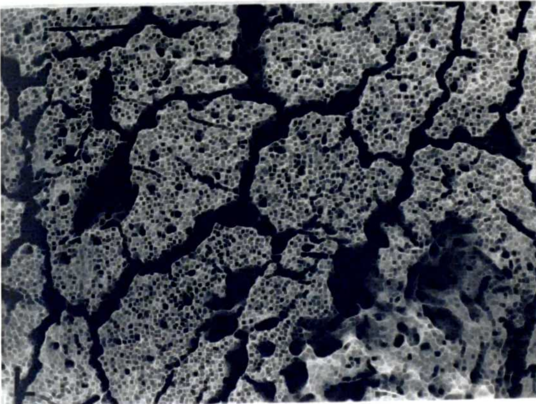
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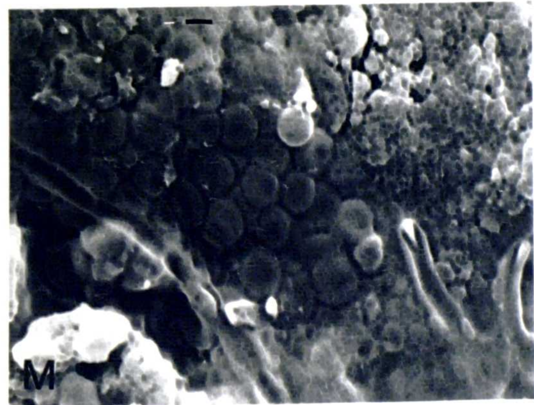
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Table 4:14 Heating stages in bone : fish bone surface macroscopic and microscopic morphology

Temperature	Macroscopic appearance and Microscopic Appearance, through the light microscope.	Microscopic Appearance, through the S.E.M. (vertebrae only)
Stage 1		
20^{0}C	The surface of all bones is gently undulating and continuous.	The surface of all bones is gently undulating and continuous.
200^{0}C	The surface of the bone is similar to fresh bone. The flat areas of the head bones are brittle and cracked.	The surface of the bone is undulating and continuous, and similar to fresh bone underneath the glassy, organic layer which was very difficult to remove from the surface. Where this surface was removed a rougher surface was observed than for fresh bone, with small fissures and asperities.
Stage 2		
<300^{0}C >400^{0}C	The surfaces of all bones are covered with a black peeling char, which is particularly thick and bubbly on the articular surfaces.	The surfaces of all the vertebrae are obscured by peeling char which forms an undulating, vitreous layer on all the surfaces, even after cleaning. Beneath this layer the surface is irregular and granular or "lumpy". The layer of char was continuous over many bones, especially those heated to 300^{0}C.
Stage 3		
<500^{0}C - >700^{0}C	Most bone surfaces are extensively cracked. The articular surfaces of the articular bones and opercular bones are, where not covered in char (generally at temperatures above 500^{0}C) extensively cracked. All but the herring bones exhibit radial cracks. On all vertebrae not covered in bubbly char the growth rings are clearly visible.	It is difficult to categorise the range of surface forms observed on the bones in this stage, due to the extreme variability in form between species. In general, the surfaces of the vertebrae seem to have formed continuous, undulating but rather irregular "lumpy" or "nodular" surfaces at 500^{0}C. This surface becomes "particulate" and then "frothy" at 500^{0}C and 700^{0}C. It is not clear to what extent variations in appearance may be related to species. The dogfish calcified centra show a very fissured and irregular, lumpy surface. At or before 700^{0}C the bone appears frothy.
Stage 4		
< 800^{0}C - > 900^{0}C	All surfaces are smooth, chalky and featureless. All but the very deep cracks have disappeared.	At these high temperatures sintering of the mineral phase of bone produces distinctive enlarged crystals, the shape of which varies. On many bones the pattern exhibited could be decribed as regular and "nodular" but flat polygonal plates were also observed on a salmon vertebra. Cod, haddock and herring vertebral centra exhibited a regular "knitted" appearance on the specimens studied.

Plate 4:4 Fish Vertebrae, Surface Morphology of the Articulating Facets, Viewed Through the S.E.M. (scale bar = 1μm).

A. Contemporary cod, fresh.

B1. Mid-brown gadid vertebra from Freswick (FL80 JJ 56 4 sq1).

B2. Same sample as B1, different area.

C. Contemporary cod, heated to 200°C.

D. Contemporary cod, heated to 400°C.

E. Black and dark brown *Molva cf. molva* vertebra from Freswick (FL80 JJ 52 4 sq1).

F. Contemporary salmon vertebra heated to 700°C.

G. Light blue, white and grey gadid vertebra from Freswick (FL80 JJ 60 4 sq1).

H. Contemporary haddock, heated to 900°C

I. White gadid vertebra from Freswick (FL80 JJ 56 4 sq1).

J. Contemporary salmon vertebra heated to 900°C.

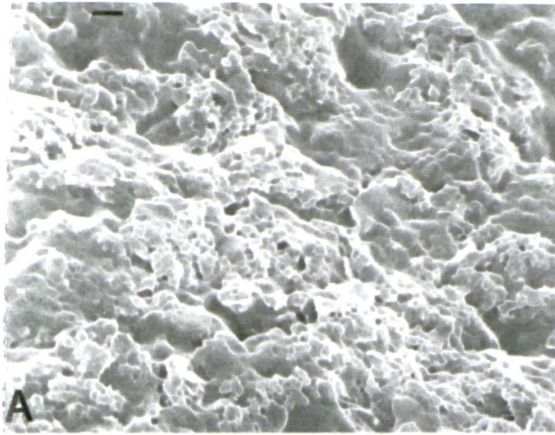
K. White gadid vertebra from Freswick (FL80 JJ 56 4 sq1)

L. Contemporary herring, heated to 900°C.

M. White gadid vertebra from Freswick (FL80 JF 39 4 sq1).

N. Contemporary cod, heated to 900°C.

O. Contemporary salmon vertebra heated to 900°C, same sample as J. different area.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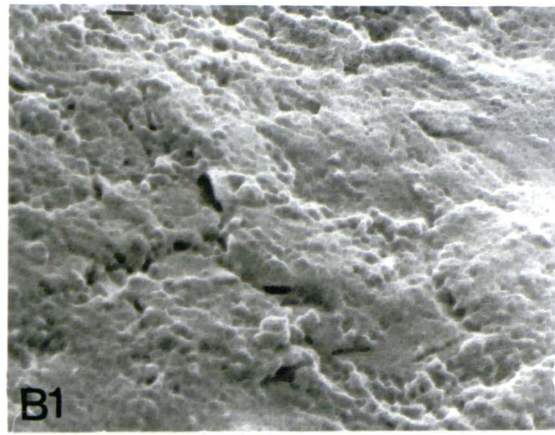
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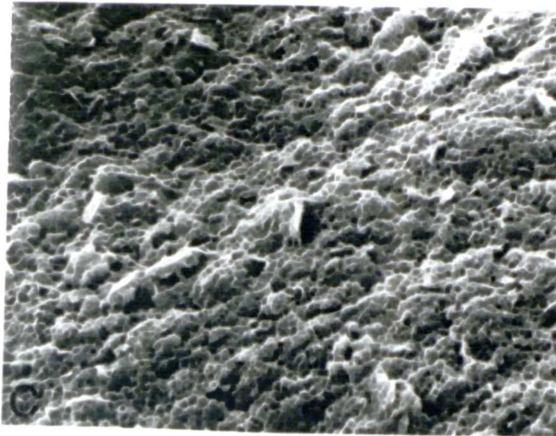
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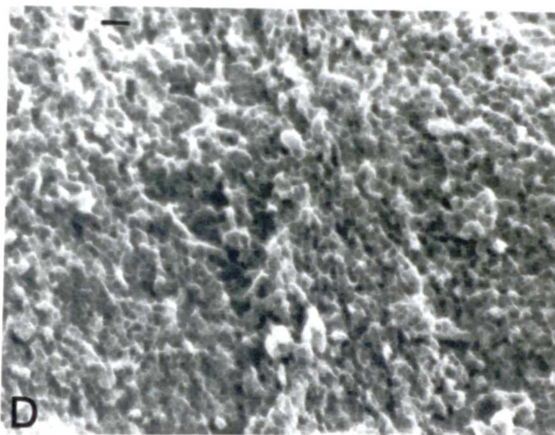
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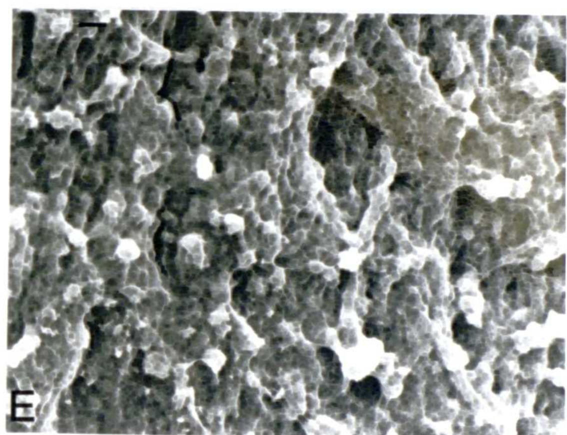
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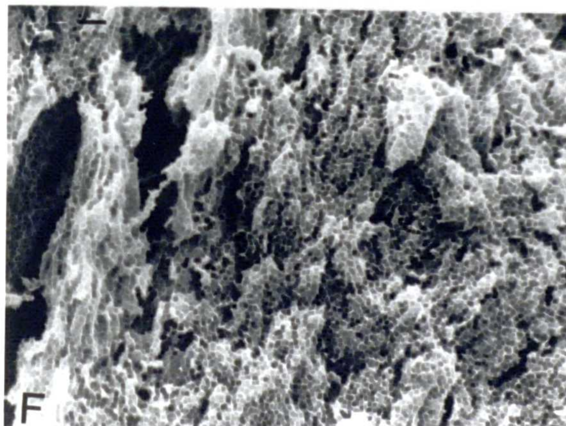
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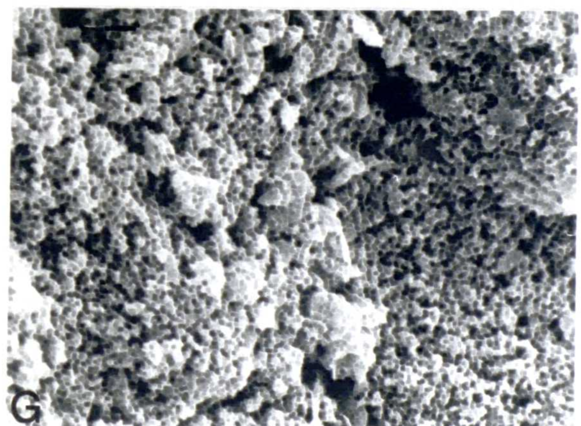
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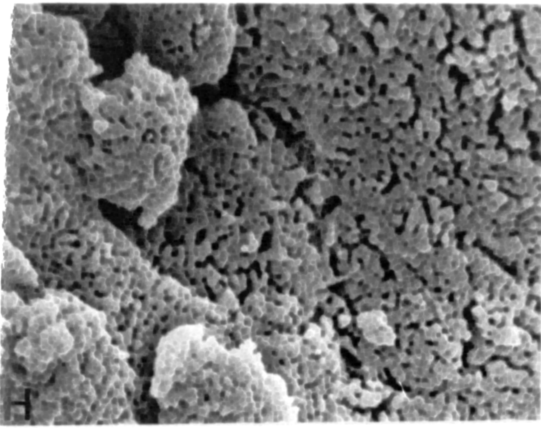
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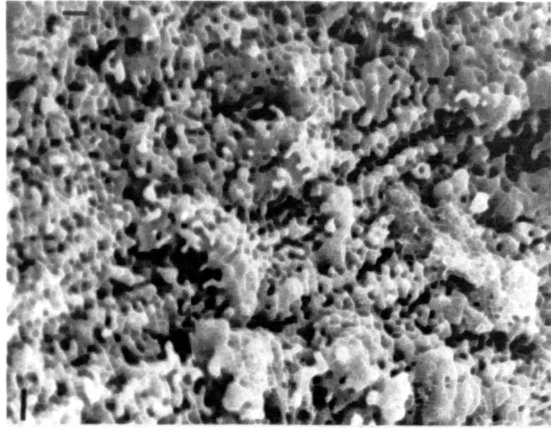
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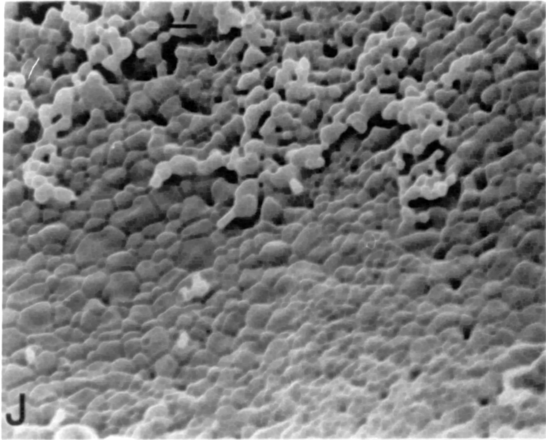
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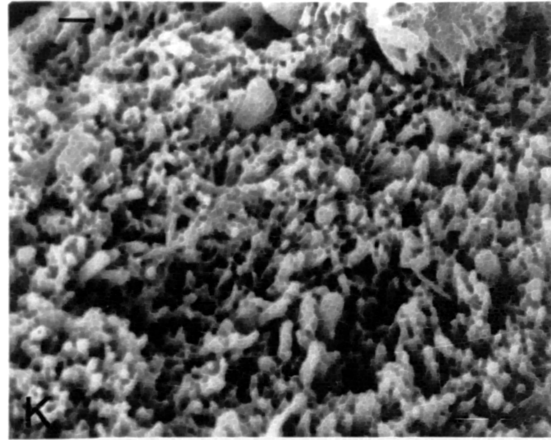
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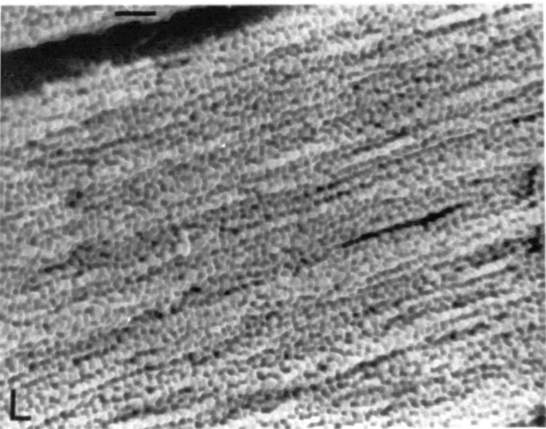
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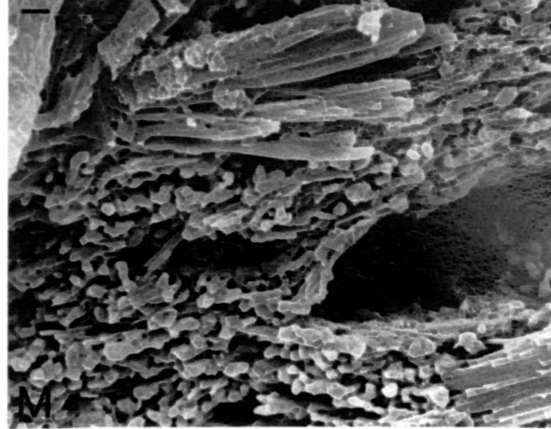
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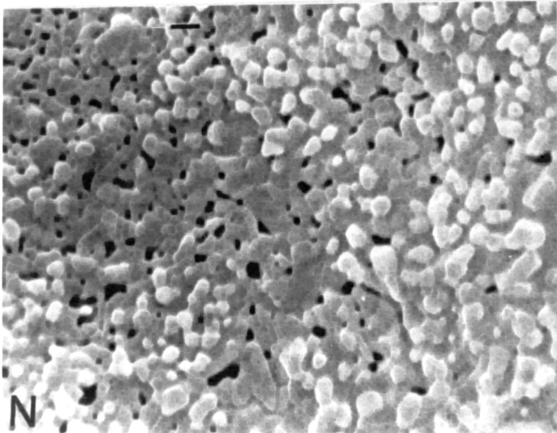
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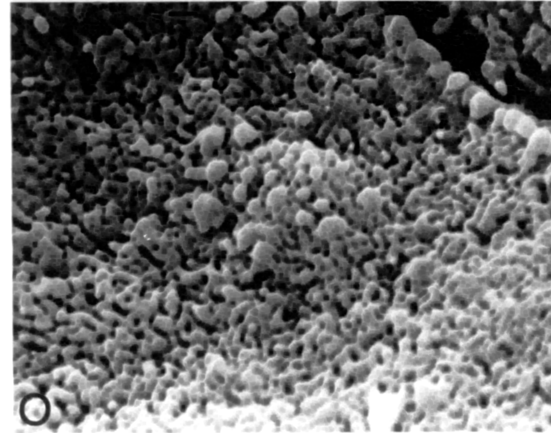
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Plate 4:5 Contemporary Gadid Otoliths, Surface Morphology Viewed Through the S.E.M. (scale bar = 1μm).

A. Fresh

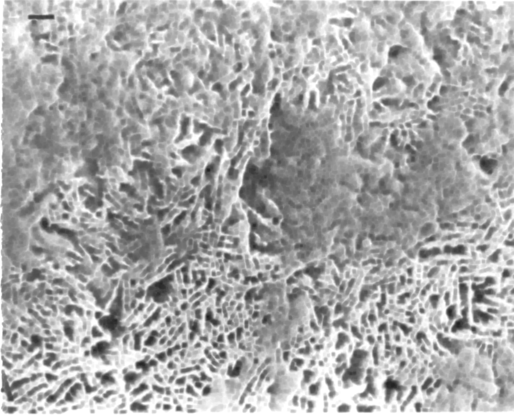
B. Heated to 200°C

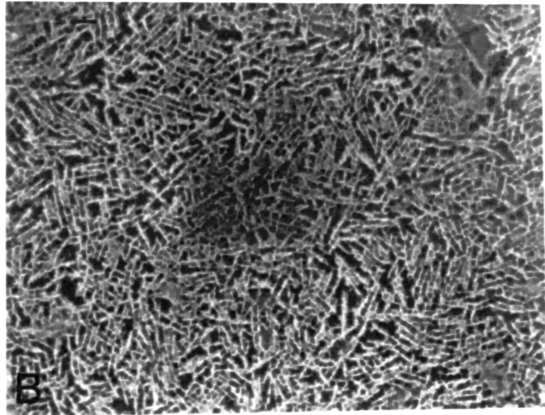
C. Heated to 300°C

D. Heated to 500°C

E. Heated to 600°C

F. Heated to 700°C

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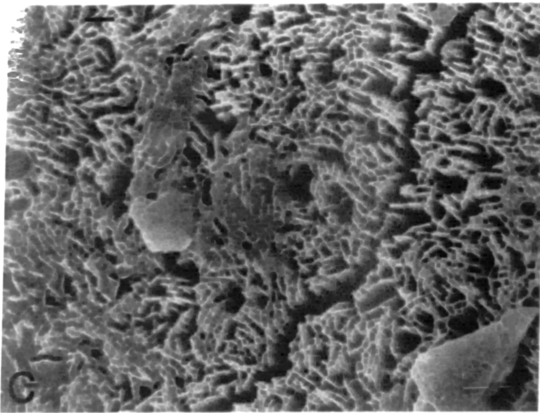
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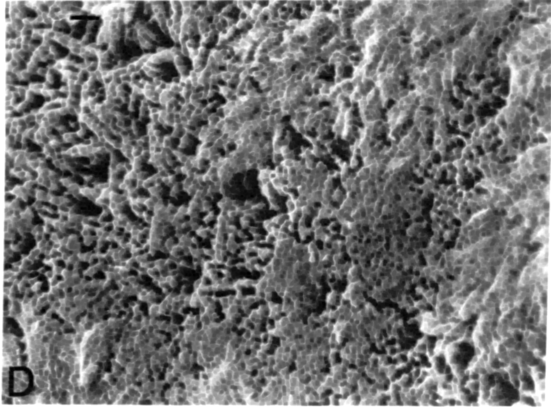
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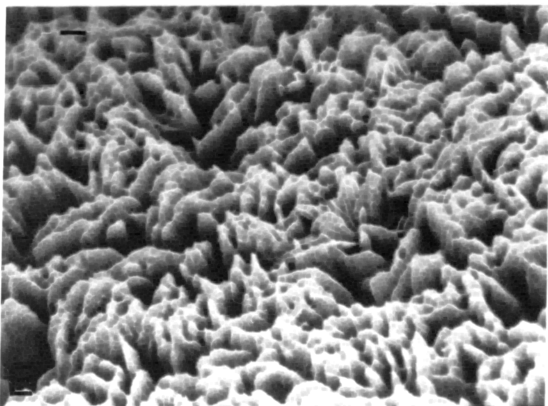

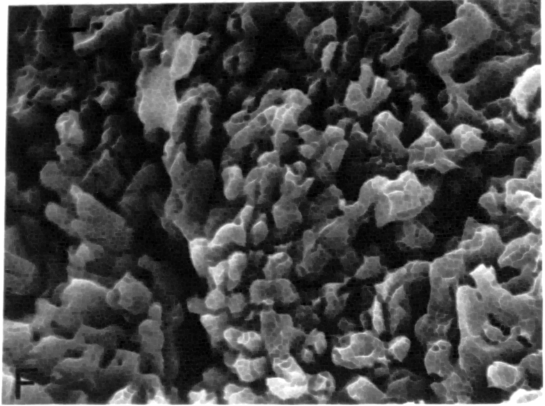
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Although Shipman and colleagues state that their observations relate to the most advanced stage, in the case of the vitreous surface illustrated in Shipman's article as stage III (285-<440°C) it was my observation that although a vitreous surface was common, it could frequently be easily peeled off, especially on bone heated to 400°C, to reveal a granular surface beneath, more characteristic of bone heated to Stage IV in the classification by Shipman *et al.*. This point is in keeping with observations by Bonucci and Graziani (1975), who looked at surface thin sections of burnt bone and noted that specimens heated to below 300°C show no significant differences to fresh bone, while specimens heated to 350, 450 and 550°C showed similar ultrastructural changes, with thicker crystallites than in normal bone.

This study also demonstrated much more variability in the form of surface structure on bone heated to 800°C and above than described by Shipman *et al.* and Bonucci and Graziani. While these authors describe the occurrence of hexagonal plates (Shipman *et al.*, subchondral bone), nodules (Shipman *et al.*, cortical bone) and irregular polygonal crystallites (Bonucci and Graziani, area unspecified), the current study revealed a much larger range of forms (see below for details and Plates 4:3-4:4).

While all the stages recognised on sheep bone could be broadly recognised on most of the pigeon and fish bones examined there was a great deal of inter-species variability, especially in bone heated to below 600°C, which was possibly related to differences in colour achieved as well as to bone morphology. In the case of cod and haddock, the bone surface at 500°C was very similar to fresh bone, while salmon had a nodular appearance characteristic of bone heated to a much higher temperature. Again, the most advanced stage seen on bone heated from between 200°C and 500°C was very much dependent on whether the upper, vitreous surface had peeled off to reveal the granular surface beneath. Perhaps the most distinctive

difference between the bones of fish from those of pigeon and sheep (and also from the descriptions given by Shipman *et al.* (*ibid.*)) was in the case of bones heated to above 700°C. All osteological samples exposed to these high temperatures showed distinctive enlarged crystals, but in only one case (a sheep sesamoid heated to 700°C) was the hexagonal pattern observed by Shipman and colleagues for stage V subchondral bone (shown to be similar to the crystal structure of artificially sintered hydroxyapatite) seen. Several distinctive patterns were observed, including enlarged rod shaped crystals, regular spherical crystals forming a "knitted" pattern, and more irregular, globular crystals, as well as combinations of these and irregular sized and shaped crystals.

Otoliths

The surface forms exhibited by the otoliths after heating (Plate 4:5, Table 4:15) show some similarities to the stages observed for the osteological samples and for dentine samples examined by Shipman *et al.* (1984). While cracks were observed in otoliths heated to above 200°C, under the S.E.M. little alteration was observed before about 500°C, at which point the needle-shaped crystals appeared to have begun to melt and coalesce, forming a less regular surface. At 600°C-700°C the crystals appear greatly enlarged and more rounded than previously, and this is most pronounced by 800°C. After exposure to temperatures of above 700°C the otoliths are extremely crumbly and would be unlikely to survive archaeologically.

Archaeological Samples.

The archaeological bones used in this analysis are detailed in Table 4:16, and archaeological samples are compared with the experimentally burned bones in Plates 4:2 - 4:4.

Table 4:16 Archaeological Samples : Surfaces examined under the S.E.M.

Site Name	Code	Bone Type	Colour	Appearance	Interpretation
Freswick Links	FL80 JF 39 4 sql	Otolith	Light grey	Irregularly orientated crystals	Heated to 600 - 700°C.
Freswick Links	FL80 JJ 52 4 sql	Vertebra of *Molva cf. molva*	Black + Dark brown	Gently undulating, vitreous, small nodules lie on the surface	Heated to 300 - 400°C
Freswick Links	FL80 JJ 52 4 sql	Vertebra of *Molva cf. molva*	Black	Irregular, continuous.	Unclear if heated.
Freswick Links	FL80 JF 39 4 sql	Gadid Vertebra	White	Enlarged needle-shaped and and nodular crystals.	Heated to 700°C or above.
Freswick Links	FL80 JF 39 4 sql	Gadid Vertebra	White	Gently undulating, continuous	Unclear if heated
Freswick Links	FL80 JM/R 4 sql	Gadid Vertebra	Black	Continuous, gently undulating	Unclear if heated
Freswick Links	FL80 JJ 60 4 sql	Gadid Vertebra	White + grey	Frothy	Heated to 500 - 700°C
Freswick Links	FL80 JJ 60 4 sql	Gadid Vertebra	Grey, White, Lt Blue	Frothy	Heated to 500 - 700°C
Freswick Links	FL80 JJ 56 4 sql	Gadid Vertebra	White	Highly particulate, some areas nodular	Heated to 600 - 700°C
Freswick Links	FL80 JJ 56 4 sql	Gadid Vertebra	Brown	Gently undulating, continuous	Not heated
Freswick Links	FL80 JJ 56 4 sql	Gadid Vertebra	White	Enlarged, irregular crystals	Heated to 700°C or above
Freswick Links	FL81 2ae 132 H01	Otolith	Brown + White	Slightly melted rod like crystals	Heated to around 500°C
Freswick Links	FL81 2ae 132 H01	Gadid Vertebra	Black	Some areas viscous, some irregular	Heated to 300 - 400°C
Freswick Links	FL80 JJ 52 4 sql	Gadid Vertebra	Mid Blue	Particulate	Heated to 500 - 600°C
Freswick Links	FL82 1128 3E YM	Gadid Otolith	Brown, Grey + Black	Irregular, flowing surface	Heated to 400 - 500°C
North Cave	NC87/289 APQ	Sheep distal fibula	Black + Dk Brown	Irregular, "lumpy" surface some areas vitreous.	Heated to 300 - 400°C
North Cave	NC87/289 APQ	Sheep second phalanx epiphysis	White, Lt grey Lt Blue	Particulate to frothy, in some areas nodular.	Heated to 600-700°C
North Cave	NC87/289 APQ	Sheep naviculo-cuboid	White	Some areas frothy, others nodular.	Heated to 700°C and above.
North Cave	NC87/289 APQ	Sheep astragalus	Mid Grey	Particulate to frothy	Heated to > 500 - <700°C
Stakis, York	1988-24 71025 2542 BS	Large mammal epiphysis fragment	Black	Particulate	Heated to 300 - 400°C
Stakis, York	1988-24 71025 2542 BS	Large mammal epiphysis fragment	White, Grey, Blue	Frothy, some enlarged crystals	Heated to 600 - 700°C
Stakis, York	1988-24 71025 2542 BS	Large mammal epiphysis fragment	Brown, Grey, White, Blue	Frothy, some enlarged crystals	Heated to 600 - 700°C

Areas of bone which appeared to have an uneroded surface were selected, and S.E.M. examination demonstrated that the stages suggested by the experimental work could be recognised on archaeological bone and correlated in a general way with the specimen colour. Unfortunately in some cases specimen colour and surface morphology did not agree, because despite colours indicative of burning (white and black) the micro-morphology resembled that expected for fresh bone. It is unclear whether this is due to diagenetic changes in the bone, either by modification of the surface structure or resulting from staining of unburnt bones. The best interpretation that can be given is that there is no clear evidence of burning from the surface morphology, in these cases. The three ambiguous samples were all fish vertebrae.

Observations under the light microscope revealed that on almost all the black bones examined areas of charring were visible, additionally, shiny black peeling areas were visible on the surface of bones which were a lighter colour. Where this char is visible it provides a simple and cheap method of determining that burning has taken place. Some of the white bones examined appeared highly pitted under the light microscope, and the exposed trabeculae had a melted appearance. This was more generally seen on mammal epiphyses and again suggests heating to high temperatures. These bones, under the S.E.M. showed the enlarged crystal structure expected in bone heated over 700°C. Not all white bone showed this rough surface under the light microscope; frequently in the case of fish bone the surface was intact and smooth, yet S.E.M. work again revealed the enlarged crystals.

Light microscopy also demonstrated the heterogeneity of bone surfaces, even in apparently non-burnt bone. Frequently the surface appeared granular, as did the surface of bones coloured black and grey, again suggesting modification to the surface of non-burnt bone.

Under the S.E.M. it was evident that archaeological samples which it was assumed had not been heated appeared more similar to bone heated to 200°C than to fresh bone. As this was also noted for weathered bone (see above) it is probably the result of sub-aerial weathering or diagenetic changes in the bone attributable to loss of organic matter, rather than to heating. The determination of bone burnt to temperatures below about 300°C may not be appropriate using surface morphology, and further work is necessary to determine the range of forms exhibited by weathered bone. Examination of several samples of weathered bone (in the last months of this research programme) also revealed, on one sample, an area of enlarged crystals, similar to that observed for sintered bone in this study and to that illustrated by Shipman *et al.* (1984, fig. 6f). This sample is illustrated by Plate 4:3 (M) and is discussed further in Chapter 6. As the area exhibiting the crystal changes was small, and on only one sample (a boiled cod vertebra) it does not seem to invalidate the conclusion that large areas of enlarged crystals indicate heating to high temperatures. It does argue for a cautious approach, however, and interpretation based on as wide a range of criteria as possible, as well as examination of several areas of the specimen.

While cleaning did remove most of the organic matter, examination through the light microscope often revealed embedded mineral particles and areas of staining. In this respect light microscopy was a very useful adjunct to S.E.M. work, as the former enables the bone structure to be viewed in colour.

Atmosphere of heating versus rate of cooling.

To investigate whether rate of cooling or the atmosphere to which the bone was exposed during sintering were responsible for the variation in crystal structure observed, a range of sheep sesamoids were examined. These

included bones cooled rapidly and slowly and bones burnt in sand and in open crucibles.

No clear pattern emerged relating crystal size and shape to rate of cooling or oxygen supply, although in the case of oxygen supply it is recognised that the muffle furnace atmosphere would always have been slightly reducing. To a certain extent the patterning seemed to be distinctive within animal groups, i.e. sheep and pigeon showed similar forms, including the rod or needle-like pattern as well as more irregular patterns, while among the fish the gadid and herring centra seemed to show the "knitted" pattern, while salmon bones had a more "globular" or "nodular" appearance. This may be related to the shape of the bone surface and the orientation of the mineral crystals. Much more work would be required to sort out the causes of variation in crystal form on heating, and is beyond the scope of this research.

4.5.3 Discussion

Sintering

By reference to ceramics literature it is clear that sintering, or chemical and physical changes as a result of heating to high temperatures, is by no means a straightforward process, and that to compare the surface morphology of cremated bone with sintered artificial hydroxyapatite is far too simplistic.

Investigations into the effects of firing on clays during pottery manufacture provides useful comparative material, and the following information is based on Rice (1987) and Hlavác (1983). During firing ceramics undergo several well defined stages, starting with the drying out of the pottery and movement of water and organic material to the surface, at temperatures up to 300°C. Carbon is burnt off from the surface from about 300°C onwards, and generally this process is not complete until 600-700°C. During this

process carbon dioxide is liberated and the atmosphere may become smokey and reducing. At 800-900°C or so, depending on the material, sintering and vitrification take place, filling in the available pore spaces. At 500-800°C some minerals migrate to the surface and volatilise or react to form new substances and bring about colour changes. Above 800°C, during sintering, recrystallization occurs, forming new crystal shapes. Some workers maintain that in bone heated to this temperature hydroxyapatite is transformed into tricalcium phosphate (e.g. Civjan *et al.* 1971; Bonucci and Graziani 1975, Grupe and Hummel 1991), but the X-Ray diffraction patterns illustrated by Shipman et al. (1984) do not appear to support this theory. The shape these new crystals take is probably dependent on many factors, including atmosphere during heating, rate of heating and cooling, duration of heating and the surface form of the object, especially curvature. Changes to the chemical composition of bone brought about by heating are discussed in much greater detail by Grupe and Hummel (1991).

4.5.4 Conclusions : The laboratory-based heating experiments

Some overall principles are clear from the results described in this section.

1. The colour of bone as a result of heating is closely correlated with the maximum temperature achieved by the bone, not necessarily that of the oven or fire. Also, the relationship between the colour of the bone and the maximum temperature reached by it varies with the type of bone, presumably related to the chemical composition of the bone.

2. The atmosphere in which the bone is heated has some effect on the colour/temperature relationship, and mottles are more frequently encountered on bone heated in an oxygen-limited environment, possibly related to pockets of varying temperature and/or atmosphere.

3. Turning to surface micro-morphology, the chemical changes which take place in the bone as a result of heating do seem to be closely correlated with the crystal structure of the bone and maximum specimen temperature can be deduced from the surface micro-morphology of the bone within the ranges given in Tables 4:13-4:15. Although it seems unsafe to attribute a single form to identify bones heated to 700°C and above, regular enlarged crystals covering a majority of the bone, of whatever form, do appear to be restricted to bones which have reached these high temperatures.

4. The temperature-related surface forms observable on mammal bones do seem to be generally applicable to non-mammal bones, but there are some differences in the crystal structures observed at higher temperatures. Whether the forms are related to taxon is not clear from this work.

5. The temperature-related surface forms are visible on some archaeological specimens, however in cases of ambiguity further analysis is necessary, for example by X-Ray diffraction, in order to demonstrate whether colours are due to burning or other factors. Weathering may cause an enlargement of crystallites in bone, as demonstrated by Tuross *et al.* (1989a.), so analysis by x-ray diffraction alone is clearly not satisfactory. The presence of intact collagen fibrils, visible under the Transmission Electron Microscope (after the appropriate preparation) could indicate when bone has not been heated, but further work is required to investigate collagen de-naturing as a result of diagenetic effects. The absence of intact collagen fibrils can not yet be taken as proof of heating. Brain and Sillen (1988) argue that heating to 300-400°C or thereabouts will leave a residue of char which can be detected by an enhanced carbon:nitrogen ratio in bone. Investigations by DeNiro *et al.* (1985) have demonstrated that collagen residues from charred bone do contain a significantly higher carbon: nitrogen ratio than fresh bone. However, the

analysis of archaeological bone by DeNiro (1985) which Brain and Sillen (*ibid*) used to support their findings, indicated that of the burned bones examined (only five specimens) one did not show a carbon: nitrogen ratio outside that expected for unheated bone. Furthermore, some specimens not thought to have been heated had enhanced carbon: nitrogen ratios. Further work is clearly also needed to determine the possible effects of diagenesis on isotopes in collagen. As all these methods indicate, conclusions based on single samples using one method of analysis must be treated with caution.

From the work discussed here it is evident that further study could be productive, in particular to investigate whether variations in crystal structure can be related directly to the atmosphere in which the bone was heated. This knowledge would be extremely valuable for archaeology, as it could help to resolve problems concerning methods of human cremation (e.g. on or under a pyre) and rubbish disposal (e.g. on an open fire or in a rubbish pit).

4.5.5 Burnt Shell

As an adjunct to the experiments detailed above, five valves from *Mytilus edulis* and shells of *Littorina littorea* were also heated for two and a half hours from a cold oven to 200°C, similar assemblages were each heated to 300°C, 400°C, 500°C, 600°C, 700°C, 800°C and 900°C. The effects of heating were immediately obvious, with the shells taking on a light brownish colour at temperatures from 200-400°C, becoming grey at 500-600°C and then becoming white. The internal nacre layer became matt white. Deep cracks occurred on the shells burnt to 300°C and over, and after being exposed to temperatures of 300-800°C many shells fragmented on handling. The mussels in particular were extremely fragile, with the upper aragonite layer cracking, leaving the nacreous material exposed. Cracking and crumbling increased with temperature upto 800°C, when many fragments had degraded into powder. At 900°C all shells

were less cracked and rather more robust. As many of the shells crumbled on touch I deemed further investigations into the physical properties of shell after heating unrealistic. Fragments of burnt shell are frequently recovered from sites where calcareous material is preserved, however these experiments demonstrate that when heated to temperatures in excess of about 300°C most shell will crumble to powder.

4.6 Static Bending Tests.

4.6.1 Aim

The aim of this investigation was to determine how the mechanical properties of bone are affected by heating. Weaker bone will be liable to be destroyed by forces applied to it, for example by trampling. Bones which have greatly reduced mechanical strength may therefore be under-represented with respect to stronger bones in archaeological assemblages.

4.6.2 Methods and materials

The method used in this study is a static bending test, as described in Currey (1984) and Battaglia (1985). Samples were cut using the bandsaw from the compact bone of the shaft of three adult cattle metapodials (more details on methods of obtaining samples are given by Battaglia 1985) and filed down using carborundum paper to a standard size of about 30 mm. length, 3.5-4.0 mm. breadth and 3.0-3.5 mm. depth. These samples are slightly deeper than those recommended for static bending tests (Brear pers. comm.) but this was felt to be necessary due to the fragility of burnt bone; thinner specimens snapped in the oven. Five samples, two from the posterior side and three from the anterior side of the metapodials, were tested for each temperature condition, which included heating to temperatures from 100°C - 900°C in a muffle furnace, at

100°C intervals, and boiling in water. Samples from the anterior and posterior sides of the shaft have different bending strengths (Brear pers. comm.). The bones were heated in a muffle furnace for two hours from cold, in open crucibles, while the boiled samples were boiled in water for one hour. The static bending tests were performed using the Instron model 1122 table testing instrument, using a load cell which incorporates highly sensitive strain gauges for determining the load applied to specimens in tension or compression. The test results are presented using a single pen chart recorder, which gives a trace showing the load applied with time, and the failure point of the specimen.

The samples were tested dry, fresh samples, used as a control, being dried at room temperature for two days, as were the boiled samples. Although wet samples give slightly less variation when tested it was felt safer to use dry samples in this case, as wetting would tend to make the more porous and already fragile burned bones susceptible to crumbling. Bones from archaeological deposits would be unlikely to be dry for all or most of the time, however.

Values were calculated for: firstly, modulus of elasticity, also known as Young's modulus (E) which is the stress divided by the strain and is measured in newtons per square metre (pascals); secondly, modulus of rupture (MR) which is the bending strength or the value of the stress acting on a material when it breaks and also measured in newtons per square metre; and thirdly, modulus of work (MW) which indicates the amount of plastic deformation undergone by the specimen, measured in joules per square metre.

4.6.3 Results and discussion

The results of the bending tests are given in Table 4:17. Figure 4:5 shows the relationship between log MR (modulus of rupture) and log E (stiffness) for fresh, boiled and burned bone, and E against temperature for all the conditions of burning. Figure 4:6 illustrates the

relationship between log MR and log MW (modulus of work) for fresh and burned bone and the relationship for fresh, boiled and 100°C and 200°C burned bone.

The general trends exhibited by the data are clear. As temperature increases so stiffness and strength decrease in a log-linear fashion from fresh bone to bone heated to 500°C (for definitions of strength and stiffness see Currey 1984). The two exceptions to this trend are the 100°C burnt bone samples, which have a lower MR value than expected from this model and a higher E value, and air-dried boiled bone which retains approximately the same properties of strength and stiffness as air-dried fresh bone. After 500°C the values for strength and stiffness remain similar, both being very low (see Table 4:17) until at 900°C the measurements for both parameters show a slight increase. The values for MR and MW are closely related, indicating decreased elasticity with increasing temperature and decreased strength, with the same slight increase in modulus of work at 900°C as compared with 800°C. The exception to this trend is boiled bone, which has a much greater modulus of work than fresh bone, indicating greatly increased plasticity presumably as a result of water swelling the protein collagen, although the precise role of water in the mechanics of biomaterials is not fully understood (Vincent 1982, 27).

These trends suggest a close link between the physical properties of bone and the chemical stages which occur in bone as a result of heating, with the degradation and combustion of the collagen causing the structure of the bone matrix to break down. Once the collagen and mineral bonding is broken the bone becomes brittle, and "will break catastrophically from some pre-existing flaw when the energy balance is right" (Currey 1984, 49). Alteration to the hydroxyapatite crystal structure causes a further change in the mechanical properties of heated bone, but the results from the present study suggest that the sintering process which takes place at 800°C and above, leading to

coalescence of mineral crystals and a decrease in porosity also has the effect of slightly increasing all parameters of strength, stiffness and toughness.

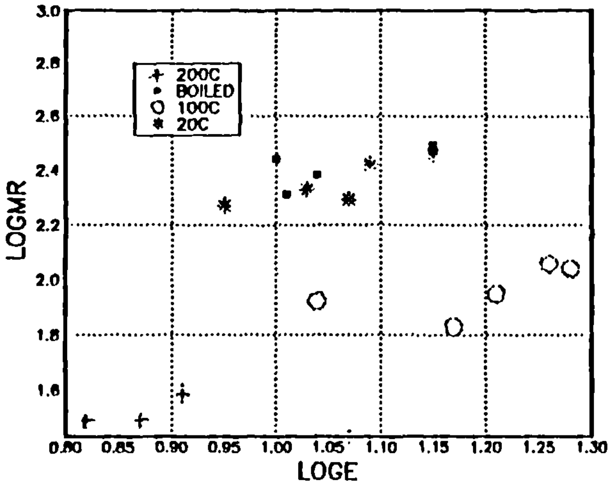
Subsequent to this work, I discovered references in Evans (1973) to reports by Smith and Walmsley (1959) and Sedlin (1965) who looked at the effects of boiling, oven drying and cooling on bending parameters. They conclude, in summary, that while heating bone to within the normal body range for humans gives an approximately linear, inverse relationship between the modulus of elasticity and temperature which are completely reversible; above normal body temperature the opposite is true. The combined effects of heating and drying have a greater effect on the mechanical properties of bone than heating or drying alone, and the modulus of elasticity is higher for cortical bone oven-dried at 105°C than for wet cortical bone, although energy absorbed to failure and total deflection are lower for the dried specimens. They found that in wet boiled bone, deflection also decreased, but to a lesser extent than in oven-dried bone. Bone dried at room temperature likewise shows the same trends, but to a lesser degree than the oven-dried bone.

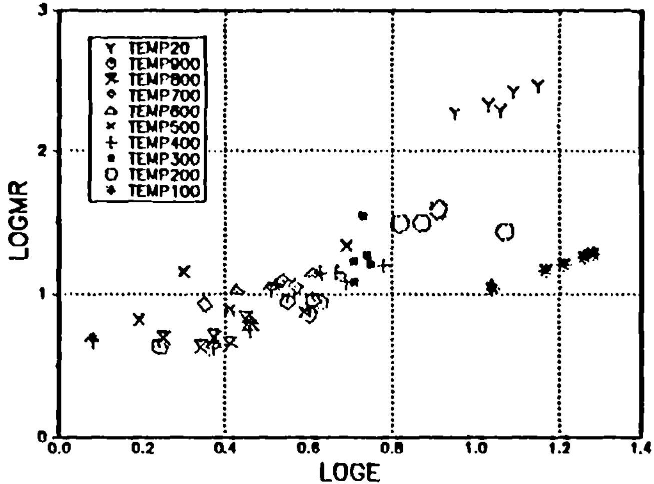
Experiments by Bonfield and Li (quoted in Evans 1973) examined the effects of temperatures from -196°C to 900°C on bone, the results of which show that ultimate tensile strength is temperature dependent, with maximum failure stress at 0°C. Reducing or raising the temperature causes a decrease in the magnitude of failure stress, but this is more rapid as the temperature is increased to 200°C, when it is approximately zero. At this point brittle fracture occurs. Below this temperature the breakage profile is more serrated. They note that at temperatures from 50-90°C there is non-equilibrium recovery, as an irreversible change in bone structure has taken place (Evans 1973, 75). This is probably due to melting of the collagen fibrils, which takes place from around 50°C (Richter 1986). At temperatures from 200°C to 900°C the magnitude of energy

absorbed to failure remains approximately zero, and is completely irreversible, due to the permanent decomposition of bone. Studies into microhardness of bone by Amprino (1958 and 1961, quoted by Evans 1973, 80) show that removal of moisture from bone by oven-drying at 38°C, 60°C, and 120°C produces progressive and consistent increases in micro-hardness. A marked decrease in micro-hardness occurs after carbonisation and more so after ashing at 300-500°C. At higher temperatures, however, the micro-hardness increases dramatically, until at 800 and 900°C it is greater than at 120°C.

Table 4:17 Mean Values and Standard Deviations for Modulus of Rupture (MR), Modulus of Elasticity (E) and Modulus of Work (MW), by Temperature

Temperature	MR	S.Dev.	E	S.Dev.	MW	S.Dev
20°C	230.4	45.3	11.52	1.88	8070	2502
100°C	93.04	19.14	15.83	3.17	774.6	219.5
200°C	33.08	5.19	8.42	2.04	234.8	144.6
300°C	19.59	8.78	5.31	0.21	54.93	17.27
400°C	13.95	1.21	4.81	0.74	43.63	4.95
500°C	11.62	6.47	3.01	1.39	43.60	31.2
600°C	11.11	1.94	3.25	0.76	38.16	6.51
700°C	6.34	2.62	2.43	0.96	22.06	15.71
800°C	5.01	0.93	2.34	0.39	11.93	3.42
900°C	7.59	2.03	3.54	1.04	18.81	5.66
Boiled Bone	264.80	43.50	11.93	2.14	10165.0	2938.0





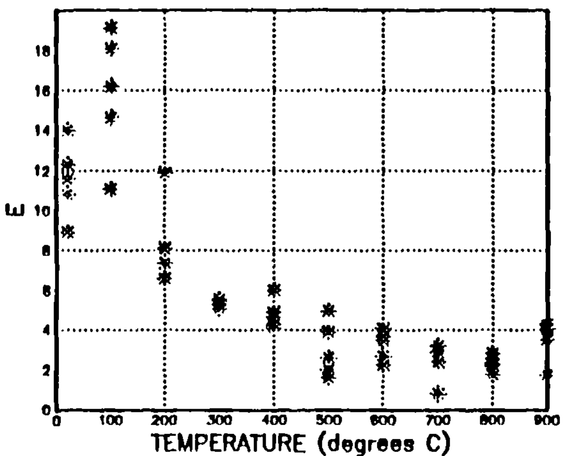
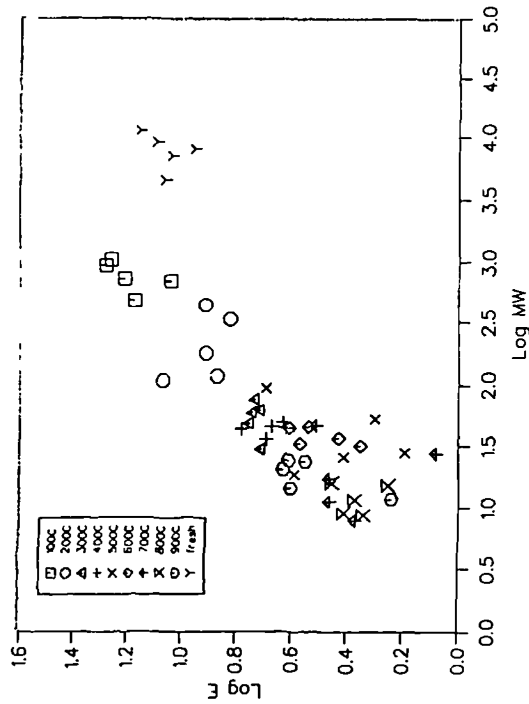
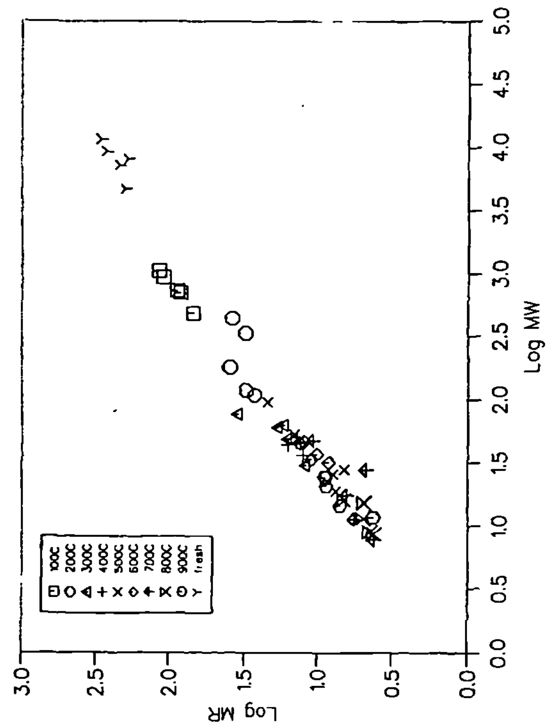
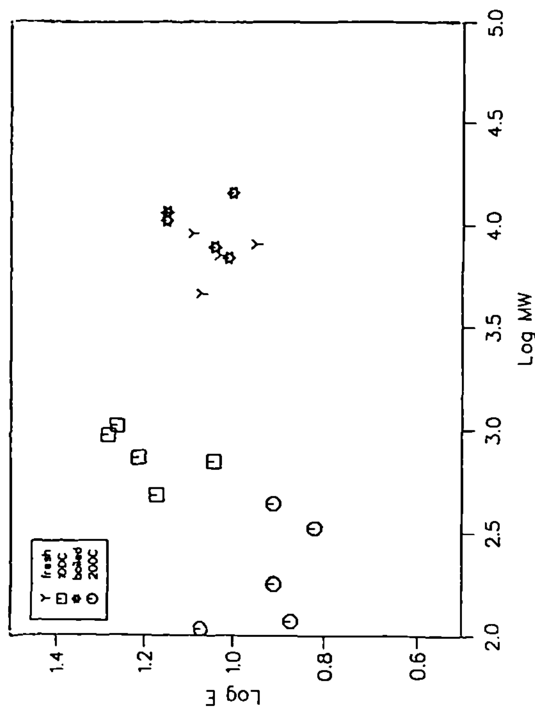


Fig. 4:5 Scatterplots of Log Stiffness (E) against Log Strength (MR), and Stiffness (E) against Temperature.







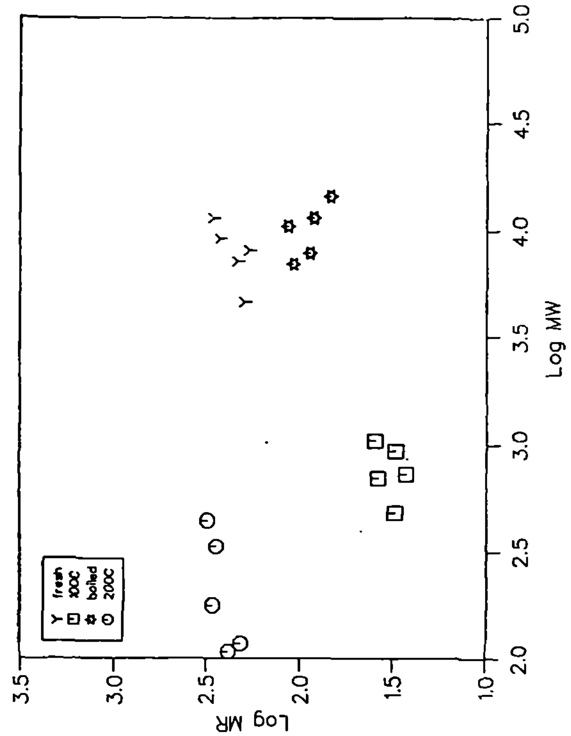


Fig. 4:6 Scatterplots of Log Stiffness (E) against Log Modulus of Work (MW), and Log Strength (MR) against Log Modulus of Work (MW)

4.6.4 Conclusions : Static bending tests

The value of these results for archaeology can be seen in terms of the likelihood for preservation and incorporation of bone into the archaeological record. Bones exposed on the ground surface are liable to be subjected to forces such as trampling, freezing and thawing, abrasion, and collision with other objects, perhaps as a result of wind movement. How well will the bones resist damage? The experiments suggest that bone subjected to temperatures above 200°C become very brittle, and as temperature of burning increases, so the resistance of the bone to withstand forces applied to it decrease. Boiled bone seems to retain more-or-less the same properties as fresh bone. It appears that, all other things being equal, bone heated to high temperatures (i.e. white bone) should *survive less* well than bones heated to lower temperatures, although it seems that bone heated to 900°C and over may survive slightly better than bone heated to 700-800°C. It must be born in mind, however, that bacterial and fungal action will tend to further degrade bone in which some organic material remains, while organic acids will leach the mineral elements.

4.7 Burning: Overall Conclusions

These analyses illustrate that there is information to be gained from a study of burnt bone. It has proved possible:
1. To recognise to what sort of temperature bone has been heated to, for a variety of taxa, for modern material and for archaeological material.
2. To show how burning affects the skeletal assemblage composition.
3. To illustrate the extent to which the resistance of bone to destruction by physical force is altered by heating.

Looking at the surface morphology of bone burned when

fresh should enable an approximate indication of the temperature which the bone reached, and could help to distinguish between burned and unburned bone in cases where colour may be equivocal. The colour and surface morphology of individual bones can not be used to deduce the type of fire used, however, or the temperature which the fire reached. Only by using large assemblages of burnt bone from the same or associated contexts can an assessment of fire temperature be made.

This investigation has also pointed out the limitations of using a single method to interpret apparently burnt bone. Alteration to colour and to crystal structure as a result of weathering or diagenesis is clearly a problem which needs further attention. Consequently interpretations based on single specimens of bone, using a single method of analysis, should be avoided. Where more than one feature indicates burning (e.g. colour and surface morphology) the conclusion is obviously strengthened.

There is clearly scope for a considerable amount of further work. It would be useful, for example, to investigate whether different sorts of fires cause different amounts of fragmentation to bones heated within them. The extent of mottling, and range of colours exhibited by bones burnt in different sorts of fires could also prove diagnostic of the conditions of burning, and again field experiments could be used to investigate. A study of the surface morphology of a range of weathered specimens, both from unheated and heated bone, is also required.

CHAPTER 5. PHYSICAL FORCE: THE EFFECTS OF TUMBLING AND TRAMPLING.

5.1 Introduction

In this chapter the effects of sedimentary abrasion and trampling on animal hard tissues are investigated. Two groups of experiments were conducted, one using an end-over-end tumbling device to investigate abrasion, the other involving trampling skeletal remains into a slightly yielding particulate substrate.

Variables of interest in both sets of experiments include the relative amount of breakage exhibited by different groups of skeletal elements, between the different taxa and between fresh and boiled bones. Additionally, the effect of sedimentary abrasion on the surface appearance of bones was investigated for physical modifications visible to the naked eye, and those illustrated using the scanning electron microscope. Differences in gross appearance between bones subjected to abrasion, trampling, weathering and chewing and/or digestion are discussed further in Chapter 7. No attempt has been made to examine the scratch marks made on bone as a result of tumbling or trampling, to distinguish them from tooth marks and/or butchery marks. These areas have been comprehensively explored by, among others, Myers *et al.* (1980), Bunn (1981), Potts and Shipman (1981), Shipman and Rose (1983), Bromage (1984), Behrensmeyer *et al.* (1986) and Olsen and Shipman (1988).

5.2 Background

Previous work examining the effects of physical force on animal remains include a limited number of experiments into the effects of abrasion, trampling and other forms of crushing, on a variety of materials. Chave (1964) and Driscoll and Weltin (1973) investigated the effects of abrading bivalve and gastropod shells by tumbling in

substrates of sand of varying grain sizes for long periods (of up to two and a half months). The latter paper gives illustrations of the patterns of damage resulting from the tumbling experiments. Mussel shells, *Mytilus edulis* developed holes in the central part of the valve, followed by fragmentation of the valves. Gastropods commonly developed perforations at the apex and spire, but holes were generally absent from the body whorl. The greatest amount of damage was observed on the mussel shells, which were the shells with the greatest surface area:weight ratio. Many shells appeared polished after tumbling. Chave's experiments (*ibid.*) indicated that at the point at which mussel valves began to fragment and were perforated, limpet shells and a gastropod *Tegula* (a turban snail) appeared only worn. Echinoderms and calcareous algae were completely destroyed in the same period of tumbling in silica sand.

Korth (1979) tumbled two small mammal skeletons in a substrate of small quartz grains to investigate disarticulation and fragmentation.

Fiorillo (1984, cited in Olsen and Shipman 1988) examined the effects on large mammal bones of trampling by herds of animals, and Andrews and Cook (1985) observed the damage done to cow bones inferred as resulting from trampling by cattle. Villa and Courtin (1983) examined movement of artifacts including bones, shells, pottery, flints and pebbles after periods of trampling into a sand or mixed sand and rubble substrate on an area frequently passed by humans during an archaeological excavation. They also commented briefly on the amounts of breakage and edge damage observed. Newcomer and Olsen (in prep.) also examined the effects of human trampling on artifacts including bone, in terms of movement of objects and modifications to their surfaces and edges, using a similar experimental design to that implemented by Villa and Courtin. Jones (forthcoming) has examined the results of a human walking on a bag of cod bones for various lengths of

time, and Bron (1987) examined the implications of crushing cod bones using a weighted roller on a hard, flat surface. These last two experiments do not take into account the tendency for some bones to become preferentially buried and so protected from damage. Breakage by a roller, in which pressure is constant is also not closely analogous to the situation likely to have affected skeletal remains in the past.

Many authors have used the frequency or presence/absence of certain skeletal elements to indicate carcass disposal or butchery patterns. Shawcross (1965) used the absence of vertebrae to indicate beheading of fish. Wilkinson (1979) also used discrepancies in the numbers of cod bones to indicate the presence of stockfish in medieval Exeter, as did Jonsson (forthcoming) for a small assemblage of cod bones from Uppsala in Sweden. Similar arguments have been put forward for the importation of butchered carcasses based on the dominance of prime meat-bearing bones on archaeological sites. Breakage of certain bones has been used as evidence of butchery even in the absence of cut marks. Shawcross (1965) suggested that broken snapper skulls indicated butchery for extraction of the brain. The trampling experiments were instigated partly to investigate whether some patterns of damage were distinctive and could be mistaken for butchery and whether some bones or parts of bones were more liable to destruction than others.

The tendency for objects to migrate downwards through sediment has been extensively discussed by, for example, Gifford (1981), Moeyersons (1978), Rowlett and Robbins (1982), Courtin and Villa (1982), Villa and Courtin (1983) and Gifford-Gonzalez *et al.* (1985). The extent to which weight, shape or size influences the movement and resulting distribution of artifacts is unclear, however, and seems to depend on factors such as the force responsible for movement and the positions of the objects prior to (in these cases) the experiments. For a review of the arguments see Gifford-Gonzalez *et al.* (1985).

One of the most important forces responsible for downwards migration is trampling by animals, including humans, and Gifford (1981) looking at modern camp sites in Kenya, noted that trampling caused small bones to become rapidly buried and so less susceptible to damage and weathering. Collection of surface and excavation of sub-surface bone assemblages from the Amboseli Basin, also in Kenya, reported by Behrensmeyer *et al.* (1979) provided different results; they "did not detect any trend indicating that the smaller animals were more commonly buried". From this they concluded that the bones of smaller species were not preferentially buried and that pre-depositional taphonomic factors such as weathering, carnivore and scavenger activity and trampling had led to the greater destruction of the bones of smaller species relative to larger ones.

By investigating the movement of bones through the sediment profile in the trampling experiments described below, the question of whether small bones are rapidly buried and/or whether they are preferentially destroyed on the surface is again addressed.

The effects of cooking on the resistance of bones to destruction by physical or mechanical force is addressed in this study, and has not previously been reported to the knowledge of this author. The susceptibility of different sorts of insect skeletons to mechanical and physical assault has also not previously been investigated in an archaeological context.

5.3 Experiments to Investigate the Effects of Sedimentary Abrasion.

5.3.1 Aim

To examine the effects of sedimentary abrasion, defined as the alteration due to frictional force to the structure and surface morphology of the bones of bird, fish and small

mammals and the integument of insects.

Variables of interest included: a) the effects of different tumbling media (sand and gravel were chosen, followed by a mixture of pebbles and steel ballbearings); b) the effects of boiling the bones prior to the experiment; and c) variation in the rates of attrition between different skeletal elements, different shapes of skeletal element and between different taxa.

5.3.2 Experiment 1

Methods and Materials.

Complete skeletons of four haddock (total lengths 0.36m., 0.39m., 0.39m., 0.38m.), four herring (total lengths 0.28m., 0.27m., 0.295m., 0.285m.), four plaice (total lengths 0.37m., 0.38m., 0.39m., 0.36m.), four frogs, three house mice (two adult one sub-adult), one adult shrew and one dogfish were prepared by partly defleshing the corpse and soaking in tap water with a small amount of commercial biological washing powder for three weeks at room temperature. Additionally four sets of pigeon bones each comprising one cranium, scapula, coracoid, femur, carpometacarpus and five vertebrae were similarly prepared. Any remaining flesh was manually cleaned off the bones. Two sets of each of the fish, frog and mouse skeletons, pigeon bones, and twenty dogfish calcified vertebral centra were boiled in tap water for 1 hour 15 minutes, the other two sets (including the shrew instead of a mouse) were unboiled. Ten salmon and ten haddock middle caudal vertebrae were heated to 700°C for two and a half hours, at which point they were predominantly white, with grey mottles. Additionally, two sets of insects, each comprising twenty adult *Tenebrio* beetles, twenty adult bluebottles (*Calliphora vomitoria*) and twenty bluebottle puparia were dried at room temperature for two weeks prior to the experiment.

Shells were not included in the tumbling experiments because extensive experiments have already been performed using bivalves and gastropods (Chave 1964; Driscoll and Weltin 1973). These experiments indicated that considerable time was required to modify mollusc shell by abrasion. Additionally, the equipment available was not large enough to accommodate many mollusc shells.

The skeletal remains were tumbled using a circular rotating end-over-end shaker of diameter 600 mm., to which eight containers were attached. The substrates used in the initial runs were medium-fine sand and small builder's gravel. The latter comprised a mixture of predominantly quartz and flint angular and subangular chips, with a size range of 3 - 6 mm. maximum dimension, but mainly in the range 3 - 4 mm. The sand grains were mainly in the size groups 250-500 μm, and grains were subangular to subrounded. Each container was filled to 1/3 capacity (27.5 mls.) with either sand or gravel, 200 mls. of tap water was added and the disarticulated skeletons put in. Two of the containers were filled with gravel, two with sand. These conditions were chosen to simulate environments found in areas subjected to incursions by fast flowing rivers or the sea.

One set of boiled and one set of unboiled bones were placed with each substrate, so that one of the gravel-filled containers held one set of unboiled bones (a set comprised one complete skeleton from each fish, one mouse or shrew, one frog and ten dogfish vertebrae), the other gravel-filled container one set of boiled bones, and similarly for the sand-filled containers. The shrew was unboiled and placed in a sand-filled container. One set of insects and ten burnt bones (five from each species) were placed in the gravel-filled container with the unboiled bones, the other set of insects and ten burnt bones in the sand-filled container with the unboiled bones. The containers were attached to the end-over-end shaker at regular intervals around the circumference. Initially

tumbling proceeded for 48 hours at a speed of 30 revolutions per minute, previous trials by the author and by Jones (pers. comm.) having established that little damage occurred during shorter periods or faster speeds. The tumbling barrels therefore travelled at a velocity of 0.942 ms^{-1}, which is near the middle of the range given by Behrensmeyer (1975) for natural stream velocities. The distance travelled and velocity of the objects within the containers will be complex and difficult to establish, however.

Insect remains were recovered by standard paraffin flotation (Kenward *et al.* 1980) using a 300 μm flot sieve, and by dry-sorting through the residues. Bones were recovered by dry-sorting after the residues had been wet-sieved through a 1 mm. mesh, using cold water, to remove adhering sand and fine particles and so facilitate sorting.

The bones were dried at air temperature, then examined using a light microscope at X10, and the assemblages photographed. Bones were examined for cracks, polishing and surface striations resulting from abrasion. Their condition was scored in terms of fragment completeness and fragment position within the whole bone, extent and area of erosion, flaking and any other observed surface modification. These data were stored using D-Base III+. Only fragments easily identified to skeletal element were recorded. Some cranial bones, ribs, rays, spines small hyal, facial and branchial bones of fish were considered unidentifiable on the basis that species identification would be difficult or impossible were the remains recovered archaeologically. For the same reason ribs were ignored for the small mammals. Of the frog head bones, only the maxilla was used. Skulls of small mammals were not included in the skeletal element analyses either, as the skull comprises many individual bones, which will tend to separate at different rates owing to the age of the animal and extent to which the sutures have closed.

The insect remains were photographed, individual sclerites (in the case of *Tenebrio* and *Calliphora* adults) counted and their condition noted as intact, fragmented and/or squashed and whether eroded, using the recording form illustrated in Appendix 2.1.

Once recording was completed the skeletal assemblages were replaced and tumbling recommenced for a further 97 hours. Sand was added as necessary to make up for that lost through the 1 mm. sieve during washing. This longer period of tumbling was determined because of the limited damage observed on the majority of the bones after 48 hours. The remains were removed, photographed and their condition recorded a second time before the experiment was restarted for a further 155 hours. At the end of this period the contents had all been tumbled for a total of 300 hours. The skeletal remains were recovered, photographed and recorded as before.

Finally, to speed up the rate of attrition, in order to examine further the breakdown of different skeletal elements and to compare rates of attrition between the different fish species, three of the experiments were restarted using a substrate of pebbles and ballbearings. The experiment using boiled bones in gravel was not restarted, as a considerable amount of attrition had already taken place. Insect remains were not included at this stage. A total of 130 grams of rounded pebbles, of between 20 mm. and 40 mm. in the maximum dimension, was used in each case, with an additional 85 grams of steel ballbearings comprising 1 of 8 grams, 25 of 3 grams and 10 of 0.2 grams. The speed of rotation was again 30 revolutions per minute. The experiment was run for 24 hours in the first instance and the bones recorded as before. Only one assemblage, that of fresh bones previously tumbled in gravel, was continued for a further 24 hours (total 48 hours) in the substrate of pebbles and ballbearings.

Data Presentation.

Bones.

The bone data were stored and interrogated using "D-Base III+" on a microcomputer and "Minitab" on the Vax mainframe. Statistics were not computed because only one individual from each species was used for each experimental condition.

The data are presented as Figures (histograms), Tables and Plates. In order to compare the extent of bone fragmentation between taxa, the results are displayed in terms of fragment completeness, i.e. the proportion of the whole bone that the fragment represents. The completeness of each fragment was recorded as a percentage of the whole bone, to the nearest estimated 10%. Long bones were classed as complete even when unfused or poorly fused epiphyses had separated from the shaft. The mean fragment completeness score for each of the major skeletal elements was obtained by summing the fragment completeness scores and dividing by the number of bones of the relevant skeletal element originally present, per animal. Where bones had broken into two or more identifiable fragments the mean value for fragment completeness for the individual bone was calculated and this figure used in the calculation of the mean fragment completeness score for the skeletal element group (see Chapter 2, p. 33-34). By recording the area of bone represented by the fragment, pieces originating from the same bone could be identified. Where individual bones were not recovered the fragment completeness score was taken as 0 for the purposes of this analysis. In the case of very small bones, however, such as small mammal metapodials and phalanges and the smaller frog phalanges, there may be an under-representation due to loss through the 1mm. mesh used to wet-sieve the residues or due to retrieval deficiencies when dry-sorting the residues.

The pigeon bones, being considerably larger than the bones of the other taxa, did not exhibit comparable amounts of damage; the bones remained complete throughout most of the experiments. For this reason, and because whole skeletons were not used, discussion of modifications to the pigeon elements is restricted to observations concerning patterns of bone damage.

Tables 5:1-5:5 present the mean fragment completeness scores for the skeletal elements from each taxon, for the recorded stages where the assemblage as a whole showed damage (excluding pigeon and dogfish). Table 5:6 gives the proportions of whole bones per taxon after the final stages of tumbling in each substrate. Histograms illustrate the mean fragment completeness value for all the commonly identified skeletal elements for each species (excluding pigeon and dogfish) after the boiled bones were tumbled in gravel for 300 hours (Fig. 5:1a-e) after which time most assemblages had undergone considerable attrition. Plates 5:1a-l illustrate the condition of the skeletal elements for the various animals after tumbling had caused considerable attrition.

Bones were classified subjectively according to shape as detailed in Chapter 2 (p. 32-33).

Insects.

The extent of disarticulation, fragmentation and erosion are detailed in Appendix 5.1, using the insect recording forms illustrated in Appendix 2.1. Plate 5:2 shows the extent of modification to the insect assemblage visible to the naked eye after 300 hours tumbling in gravel.

Results and Discussion .

Bones

The most useful results were obtained for the boiled bones after tumbling in gravel for 300 hours, and for all other assemblages after tumbling in pebbles and ballbearings. All the fresh bones remained intact and unaltered even after 300 hours of tumbling, in both sand and gravel. The boiled bones in both substrates had begun to fragment and erode after 48 hours tumbling, and many bones appeared polished, especially after tumbling in gravel. The boiled bones tumbled in gravel fragmented much more rapidly than those in sand. Of all the skeletons, the herring and small mammal exhibited the most rapid loss of bones, in all cases. In general terms the haddock bones broke up more rapidly than the similar sized plaice bones (although some plaice bones such as the jaw elements were smaller than the same haddock bones). Frog bone, despite its fragile appearance, resisted erosion as well or better than bone from other taxa, in most cases. Dogfish calcified vertebral centra also survived surprisingly well, given their superficially fragile appearance.

KEY TO EXPERIMENT CODES USED IN THE FOLLOWING TABLES.

1:1 = Boiled bones tumbled in gravel for 48 hours.
1:2 = Boiled bones tumbled in gravel for 145 hours.
1:3 = Boiled bones tumbled in gravel for 300 hours.
2:1 = Boiled bones tumbled in sand for 48 hours.
2:2 = Boiled bones tumbled in sand for 145 hours.
2:3 = Boiled bones tumbled in sand for 300 hours.
3:1 = Fresh bones tumbled in gravel for 48 hours.
3:2 = Fresh bones tumbled in gravel for 145 hours.
3:3 = Fresh bones tumbled in gravel for 300 hours.
4:1 = Fresh bones tumbled in sand for 48 hours.
4:2 = Fresh bones tumbled in sand for 145 hours.
4:3 = Fresh bones tumbled in sand for 300 hours.
5:1 = Fresh bones tumbled in sand for 300 hours followed by 24 hours tumbling with pebbles and ballbearings.
6:1 = Fresh bones tumbled in gravel for 300 hours followed by tumbling with pebbles and ballbearings for 24 hours.
6:2 = Fresh bones tumbled in gravel for 300 hours followed by 48 hours tumbling with pebbles and ballbearings.
7:1 = Boiled bones tumbled in sand for 300 hours and tumbled in pebbles and ballbearings for 24 hours.

Table 5:1.

Mean fragment completeness of skeletal elements of haddock, after tumbling.

Codes 3:1, 3:2, 4:1, 4:2 and 4:3 not included, as little damage was observed)

	SHAPE	No.	CODE 1:1	1:2	1:3	2:1	2:2	2:3	7:1	3:3	6:1	6:2	5:1
Ethmoid	I	1	100	0	0	100	100	100	0	100	100	60	70
Frontal	F	1	40	0	0	90	60	30	0	90	70	60	60
Prefrontal	I	2	80	0	0	70	50	50	0	95	0	0	0
Supraoccipital	I	1	50	30	0	60	50	40	0	90	60	0	40
Prevomer	R	1	90	50	40	100	100	50	0	100	70	70	70
Parasphenoid	I	1	80	50	0	90	80	60	0	90	70	70	80
Basioccipital	S	1	80	60	0	100	100	60	0	100	90	70	80
Premaxilla	R	2	100	100	100	100	100	100	0	100	100	90	90
Maxilla	R	2	100	100	90	100	100	100	0	100	100	80	90
Dentary	R	2	75	60	40	100	100	90	0	100	100	80	85
Articular	R	2	100	100	85	100	100	100	30	100	100	90	100
Quadrate	R	2	80	60	30	100	90	90	35	100	90	70	80
Hyomandibular	I	2	85	55	5	95	85	90	0	100	80	60	80
Symplectic	F	2	40	25	0	100	100	100	0	100	90	100	85
Lacrimal	F	2	70	0	0	90	80	70	0	100	45	0	75
Nasal	I	2	0	0	0	0	0	0	0	0	0	0	0
Preopercular	F	2	80	50	0	95	80	75	0	100	90	80	85
Opercular	F	2	80	20	0	100	100	100	0	100	50	40	100
Subopercular	F	2	0	0	0	100	100	95	0	100	100	90	50
Interopercular	F	2	85	85	60	100	100	90	0	100	100	85	100
Palatine	R	2	100	80	0	100	100	90	0	100	100	80	95
Ectopterygoid	F	2	80	25	0	95	90	90	0	100	90	85	100
Entopterygoid	F	2	0	0	0	100	0	0	0	100	0	0	0
Metapterygoid	F	2	0	0	0	100	0	0	0	100	0	0	0
Epihyal	F	2	90	90	65	100	100	100	0	100	90	0	50
Ceratohyal	F	2	90	65	0	100	85	70	0	90	90	70	90
Hypohyal	R	4	100	100	50	100	100	100	0	100	100	75	50
Infrapharyngeal	I	2	90	90	90	100	100	90	0	100	90	40	90
Suprapharyngeal	I	6	35	10	10	100	100	80	0	100	45	0	50
Urohyal	F	1	0	0	0	100	100	0	0	90	100	90	100
Posttemporal	R	2	90	55	10	100	100	90	0	100	75	65	90
Cleithrum	I	2	50	30	25	100	100	90	0	100	80	45	50
Supracleithrum	R	2	100	80	45	100	100	100	0	100	100	85	90
Postcleithrum	F	2	0	0	0	70	65	65	0	100	100	60	45
Scapula	F	2	75	0	0	100	0	0	0	100	0	0	0
Coracoid	F	2	0	0	0	50	0	0	0	80	35	0	0
Basipterygium	F	2	0	0	0	100	0	0	0	85	35	10	25
First vert.	S	1	90	70	50	100	100	90	0	100	80	80	80
Abdominal vert.	S	18	90	80	50	90	90	90	0	95	90	80	80
Caudal vert.	S	31	90	70	30	90	90	90	0	95	90	40	70
Ultimate vert.	S	1	100	100	0	100	90	90	0	100	100	70	60
Otolith	F	2	100	100	90	100	100	100	50	100	75	65	65
Mean			66	45	23	93	78	69	3	95	73	53	64

Codes as on p.150

No. = Numbers of bones in one fish (=expected value, as n=1)
Shape: R = Robust, I = Irregular, F = Flat, S = Spherical.
Mean fragment completeness was calculated by summing the mean fragment completeness scores for each skeletal element (recorded as the percentage of the whole bone represented by the fragment) and dividing by the expected number of that skeletal element.

Table 5:2.

Mean fragment completeness for plaice bones after tumbling.

(Codes 3:1, 3:2, 4:1, 4:2 and 4:3 not included because little damage observed)

	SHAPE	No	1:1	1:2	1:3	2:1	2:2	2:3	7:1	3:3	6:1	6:2	5:1
							CODE						
Frontal	R	2	90	80	75	100	100	100	0	100	80	45	95
Prefrontal	I	2	100	80	80	100	100	100	0	100	80	25	100
Supraoccipital	I	1	100	80	50	100	100	100	0	100	60	0	100
Prevomer	R	1	100	90	70	100	100	100	0	100	100	90	100
Parasphenoid	I	1	100	70	0	100	100	90	0	100	0	0	100
Basioccipital	S	1	100	100	80	100	100	90	0	100	90	80	100
Premaxilla	R	2	100	100	100	100	100	100	0	100	100	90	100
Maxilla	R	2	100	90	45	100	100	100	0	100	100	85	100
Dentary	R	2	100	100	90	100	100	100	0	100	100	85	100
Articular	R	2	100	95	95	100	100	100	0	100	100	95	100
Quadrate	R	2	100	95	95	100	100	100	20	100	100	90	100
Hyomandibular	F	2	100	85	85	100	100	100	0	100	100	80	100
Symplectic	F	2	100	80	0	100	100	50	0	100	45	40	100
Preopercular	F	2	90	90	80	100	100	85	0	100	90	80	90
Opercular	F	2	90	65	35	90	100	70	0	100	100	90	100
Subopercular	F	2	100	75	0	100	0	0	0	100	100	100	100
Interopercular	F	2	100	100	70	85	70	70	0	100	85	85	100
Palatine	R	2	100	90	45	100	50	45	0	100	90	80	100
Ectopterygoid	F	2	0	0	0	100	0	0	0	100	0	0	100
Entopterygoid	F	2	100	0	0	100	0	0	0	100	90	0	100
Metapterygoid	F	2	100	0	0	100	80	0	0	100	0	0	85
Epihyal	F	2	100	100	85	100	100	0	0	100	100	40	100
Ceratohyal	F	2	90	90	25	100	100	75	0	100	95	60	100
Hypohyal	R	4	100	100	45	100	100	100	0	100	100	80	100
Infrapharyngeal	R	2	100	90	85	100	100	100	0	100	100	90	100
Suprapharyngeal	R	6	100	70	45	100	100	70	0	100	70	20	100
Urohyal	F	1	100	80	60	100	100	100	0	100	100	90	100
Posttemporal	R	2	100	100	75	100	100	100	0	100	95	40	100
Cleithrum	I	2	90	90	30	100	100	60	0	100	90	90	100
Supracleithrum	R	2	100	100	85	100	100	100	0	100	100	90	100
Scapula	R	2	100	100	100	100	100	100	0	100	100	0	100
Coracoid	F	2	50	0	0	100	100	70	0	0	0	0	40
Basipterygium	F	2	95	95	0	100	100	100	0	100	50	50	100
First vert.	S	1	100	100	60	100	100	100	0	90	70	70	100
Abdominal vert.	S	12	90	80	60	90	90	90	0	100	90	80	100
Caudal vert.	S	29	90	80	50	90	90	90	0	95	90	80	90
Ultimate vert.	S	1	100	100	50	100	90	90	0	100	100	100	100
Otolith	F	2	100	100	100	100	100	100	0	100	45	0	0
Anal pteryg.	R	1	100	100	90	100	100	100	80	100	90	80	100
Mean			94	81	55	99	89	78	3	97	79	59	95

No = Numbers of bones in one fish (= expected value as n = 1)

Mean fragment completeness was calculated by summing the mean fragment completeness scores for each skeletal element (recorded as the percentage of the whole bone represented by the fragment) and dividing by the expected number of that skeletal element.

Shape : R = Robust, F = Flat, I = Irregular, S = Spherical.

Codes as on p.150

Table 5:3.

Mean fragment completeness of herring bones after tumbling.

(Codes 3:1, 3:2, 4:1, 4:2 and 4:3 not included as little damage was observed)

	SHAPE	No	CODE 1:1	1:2	1:3	2:1	2:2	2:3	7:1	3:3	6:1	6:2	5:1
Ethmoid	I	1	0	0	0	100	70	0	0	100	0	0	80
Frontal	F	2	0	0	0	75	75	30	0	100	50	0	0
Prevomer	I	1	0	0	0	0	0	0	0	100	60	0	0
Parasphenoid	I	1	40	0	0	0	0	0	0	100	100	60	90
Basioccipital	S	1	70	0	0	100	100	60	0	100	0	0	0
Premaxilla	F	2	0	0	0	100	0	0	0	50	50	0	80
Maxilla	R	2	100	50	50	85	70	70	0	70	20	0	75
Supramaxilla	F	2	70	0	0	80	75	40	0	100	100	100	100
Dentary	F	2	0	0	0	75	30	0	0	60	60	30	70
Articular	F	2	75	20	10	90	90	70	0	90	60	0	80
Quadrate	F	2	20	0	0	80	90	70	20	30	90	0	85
Hyomandibular	F	2	35	35	0	70	50	30	0	70	0	0	90
Preopercular	F	2	25	0	0	45	30	0	0	60	20	0	30
Opercular	F	2	80	0	0	35	0	0	0	50	30	0	75
Subopercular	F	2	0	0	0	50	40	0	0	100	45	0	90
Interopercular	F	2	0	0	0	0	0	0	0	90	0	0	0
Ectopterygoid	F	2	0	0	0	0	0	0	0	0	0	0	0
Metapterygoid	I	2	0	0	0	40	35	20	0	0	0	0	0
Epihyal	F	2	90	50	35	100	100	90	0	0	0	0	100
Ceratohyal	F	2	80	80	25	90	80	80	0	65	35	0	90
Urohyal	F	1	80	0	0	90	90	90	0	90	80	0	0
Posttemporal	F	2	0	0	0	0	0	0	0	0	0	0	0
Cleithrum	I	2	25	20	15	45	30	30	0	20	15	15	90
Supracleithrum	F	2	35	0	0	40	0	0	0	0	0	0	0
Scapula	F	2	0	0	0	0	0	0	0	0	0	0	0
Coracoid	I	2	0	0	0	0	0	0	0	0	0	0	0
Basipterygium	F	2	0	0	0	50	40	0	0	100	0	0	0
First vert.	S	1	90	90	90	90	90	90	0	90	90	90	90
Abdominal vert	S	23	90	90	50	90	90	90	10	90	60	60	75
Caudal vert.	S	32	90	90	70	90	90	80	30	90	70	60	90
Ultimate vert.	S	1	90	90	0	100	100	100	0	100	70	0	100
Otolith	F	2	50	40	0	100	100	0	0	0	0	0	0
Otic bulla	S	2	70	70	0	90	80	0	0	90	80	0	0
Mean			40	22	10	61	50	32	2	61	36	13	48

No = Number of bones in 1 fish (= expected value as n = 1)

Mean fragment completeness was calculated by summing the fragment completeness scores (recorded as the percentage of the whole bone that the fragment represents) for each skeletal element and dividing by the expected number of that skeletal element.

Shape : R = Robust, F = Flat, I = Irregular, S = Spherical

Table 5:4

Mean fragment size of small mammal bones after tumbling

(4:1 and 4:2 not included as little damage observed)

			CODE													
	Shape	No	1:1	1:2	1:3	2:1	2:2	2:3	7:1	3:1	3:2	3:3	6:1	6:2	4:3	5:1
Mandible	F	2	95	95	75	100	100	100	0	100	90	90	0	0	100	30
Scapula	F	2	0	0	0	80	80	80	0	100	80	80	0	0	100	0
Humerus	TU	2	90	90	80	80	70	55	0	100	90	90	0	0	100	0
Radius	TU	2	50	70	0	100	90	70	0	100	100	90	0	0	100	0
Ulna	TU	2	100	90	90	100	100	100	0	100	100	100	30	0	100	50
Pelvis	F	2	60	25	15	80	80	80	0	90	90	80	0	0	100	0
Femur	TU	2	90	80	70	70	70	70	0	100	90	90	0	0	100	0
Tibio-fibula	TU	2	15	10	0	90	90	90	0	100	90	90	45	0	100	70
Sacrum	R	1	100	0	0	100	100	60	0	100	80	80	0	0	100	0
Astragalus	S	2	100	100	0	100	100	100	0	100	100	100	0	0	100	0
Calcaneum	S	2	100	100	0	100	100	100	0	100	100	100	40	0	100	0
Cervical vert.	S	8	15	10	10	100	100	80	0	100	100	75	0	0	100	0
Lumbar/Thoracic v.	S	26	0	0	0	40	20	15	0	40	20	15	0	0	100	0
Caudal vert.	S	21	45	40	30	60	50	50	0	100	100	100	5	0	100	10
Metapodials	TU	20	60	40	40	35	30	25	0	70	30	20	0	0	90	0
Phalanges	SH	56	20	10	10	5	5	5	0	30	10	5	0	0	50	0
Mean			59	·48	26	78	74	68	0	89	79	75	8	0	96	10

Metapodials and phalanges may be under-represented due to retrieval deficiences.

No = Number of bones in one mouse (= expected value as n = 1)

Shape: F = Flat, TU = Tubular, S = Spherical, SH = Short. Codes as on p.

Mean fragment completeness was calculated by summing the fragment completeness scores for each skeletal element (recorded as the percentage of the whole bone that the fragment represents) and dividing by the expected number of that skeletal element.

Table 5:5

Mean fragment completeness of frog bones after tumbling.

(Codes 3:1, 3:2, 4:1, 4:2 and 4:3 not included as little damage was observed).

	SHAPE	No	CODE 1:1	1:2	1:3	2:1	2:2	2:3	7:1	3:3	6:1	6:2	5:1
Maxilla	F	2	100	100	50	100	100	100	0	100	0	0	50
Humerus	TU	2	100	100	100	100	100	100	60	100	100	70	100
Radio-Ulna	TU	2	100	100	100	100	100	100	65	100	100	80	100
Femur	TU	2	100	100	100	100	100	100	65	100	100	100	100
Tibio-fibula	TU	2	100	100	100	100	100	100	85	100	100	80	100
Scapula	F	2	100	100	100	100	100	100	30	100	90	85	100
Ilium	F	2	100	100	95	100	100	100	70	100	100	90	85
Urostyle	I	1	100	100	80	100	100	100	0	100	90	90	0
Vertebrae	S	9	100	100	100	100	100	100	60	100	100	65	100
Lower limb	TU+SH	52	40	30	25	52	52	40	5	45	40	15	45
Mean			94	93	85	95	95	94	44	95	82	68	78

Metapodials and phalanges may be under-represented due to retrieval deficiences. The tiny ultimate phalanges are not included in the expected value, as they would certainly pass through the 1mm mesh used to separate out the sand residue.

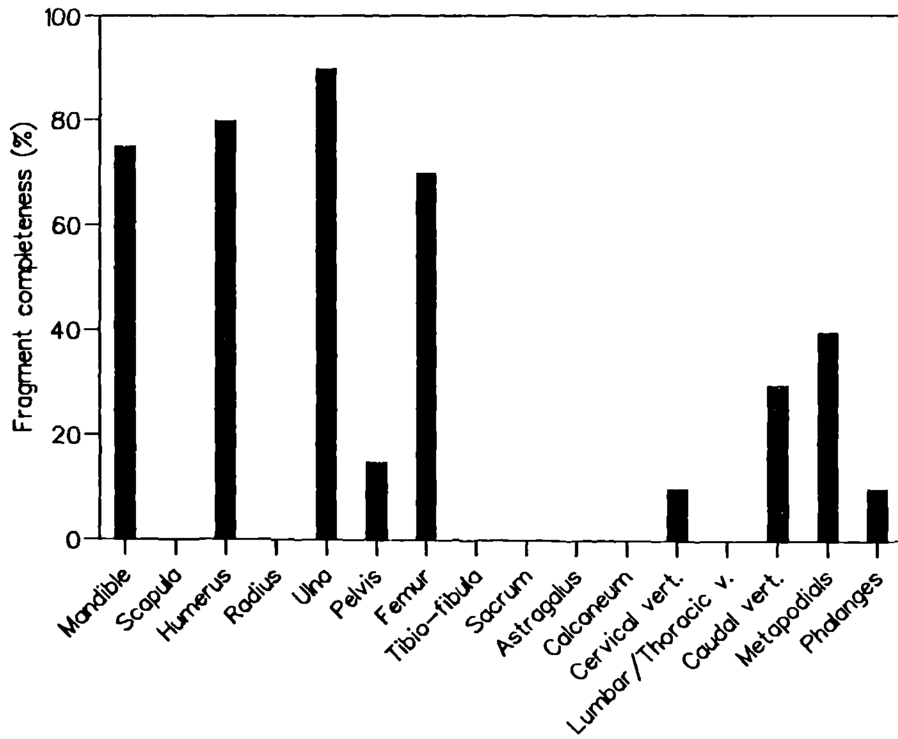
No = Number of bones in one frog (= expected value as n =1)

Shape: F = Flat, TU = Tubular, I = Irregular, S = Spherical, SH = Short.

Mean fragment completeness was calculated by summing the fragment completeness scores for each skeletal element (recorded as the percentage of the whole bone that the fragment represented) and dividing by the expected number of that skeletal element.

Codes as on p.150

a.



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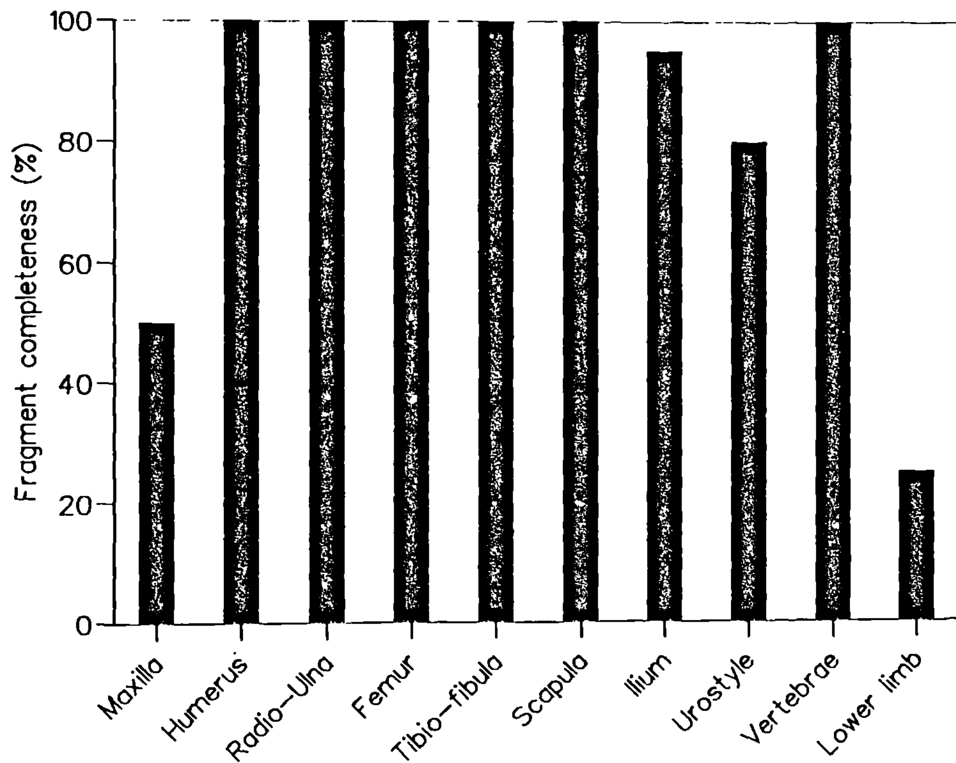
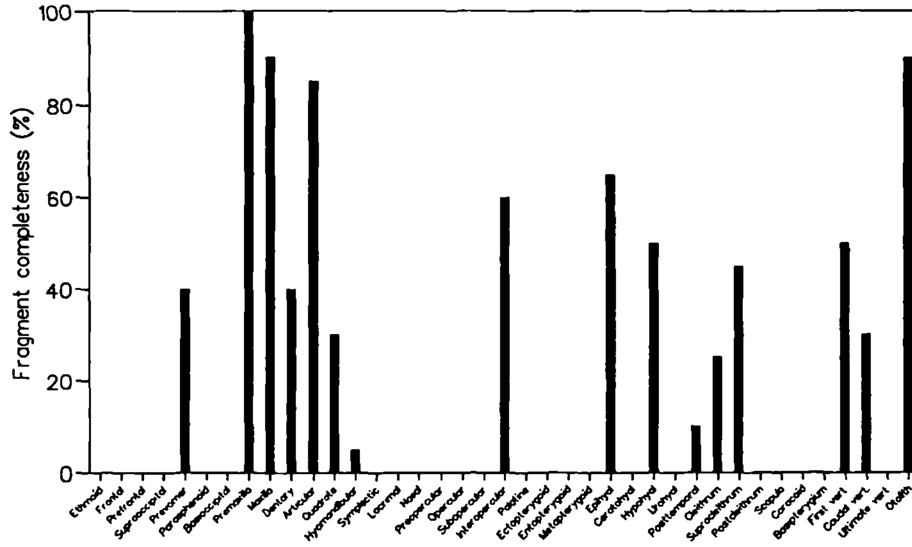
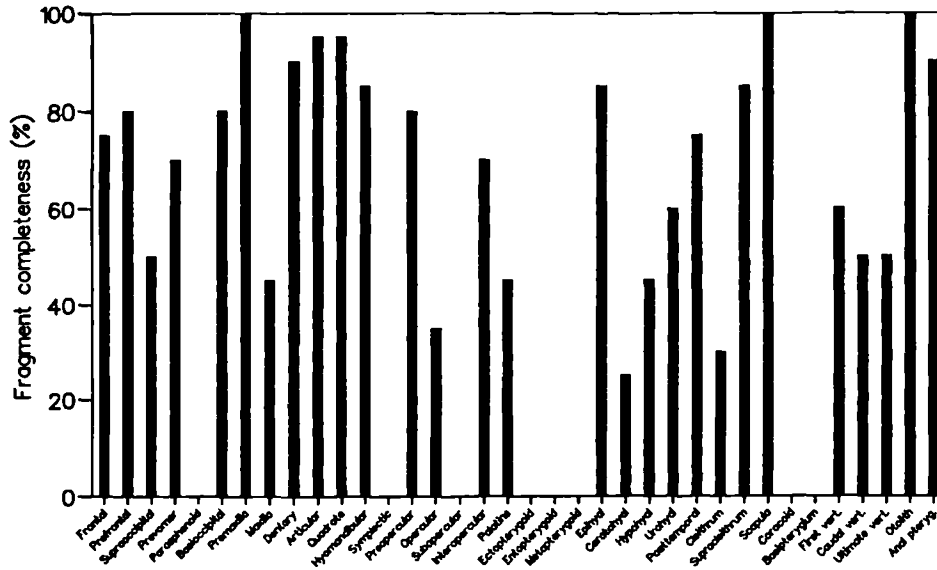


Fig. 5:1 Histograms Showing Relative Completeness of Boiled Bones after Tumbling in Gravel for 300 hours, by Taxon (a-e).

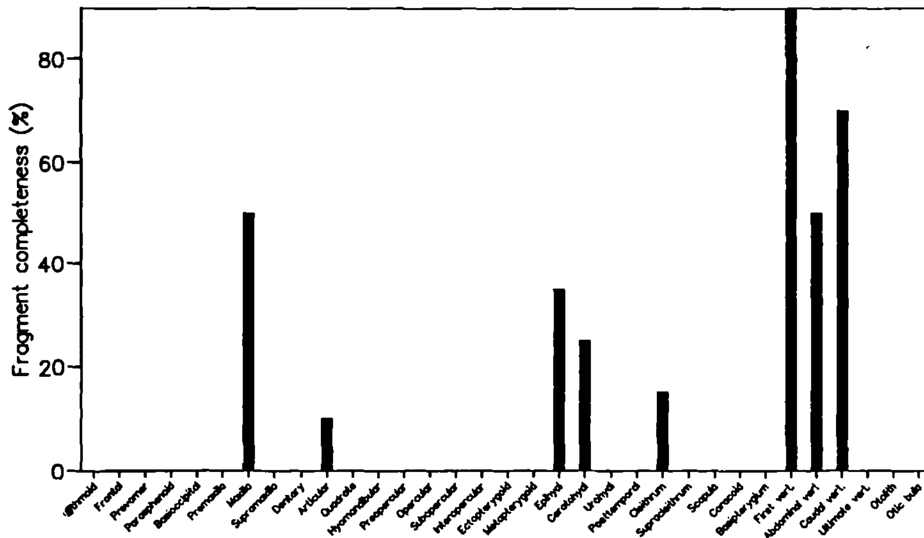
Fragment completeness of boiled haddock bones after 300h. tumbling in gravel

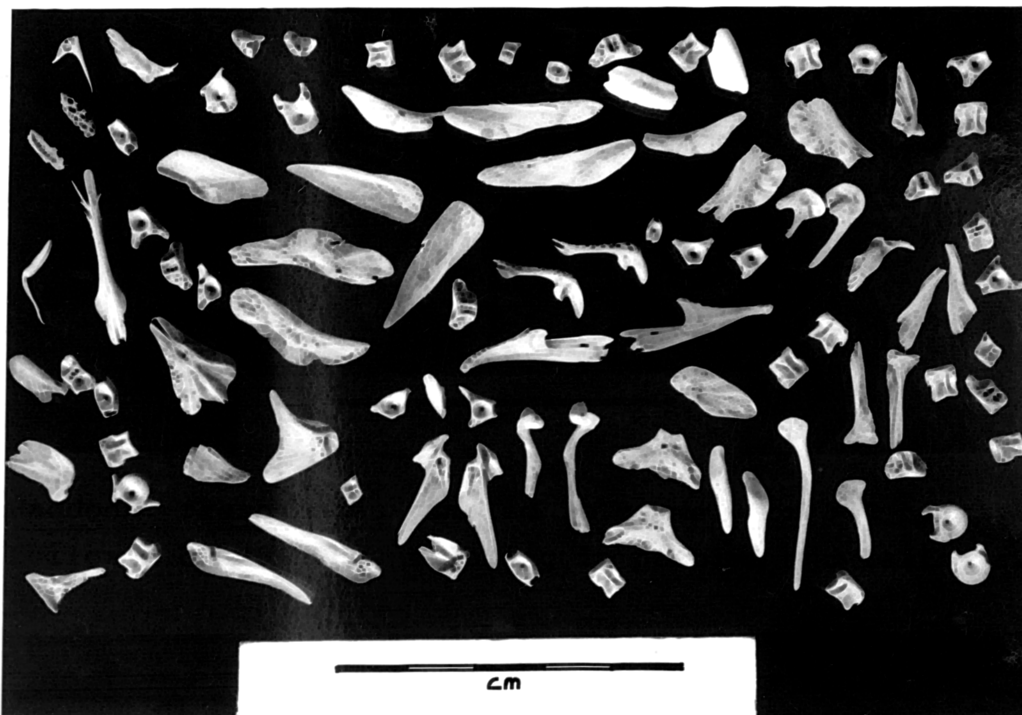


Fragment completeness of boiled plaice bones after 300h. tumbling in gravel

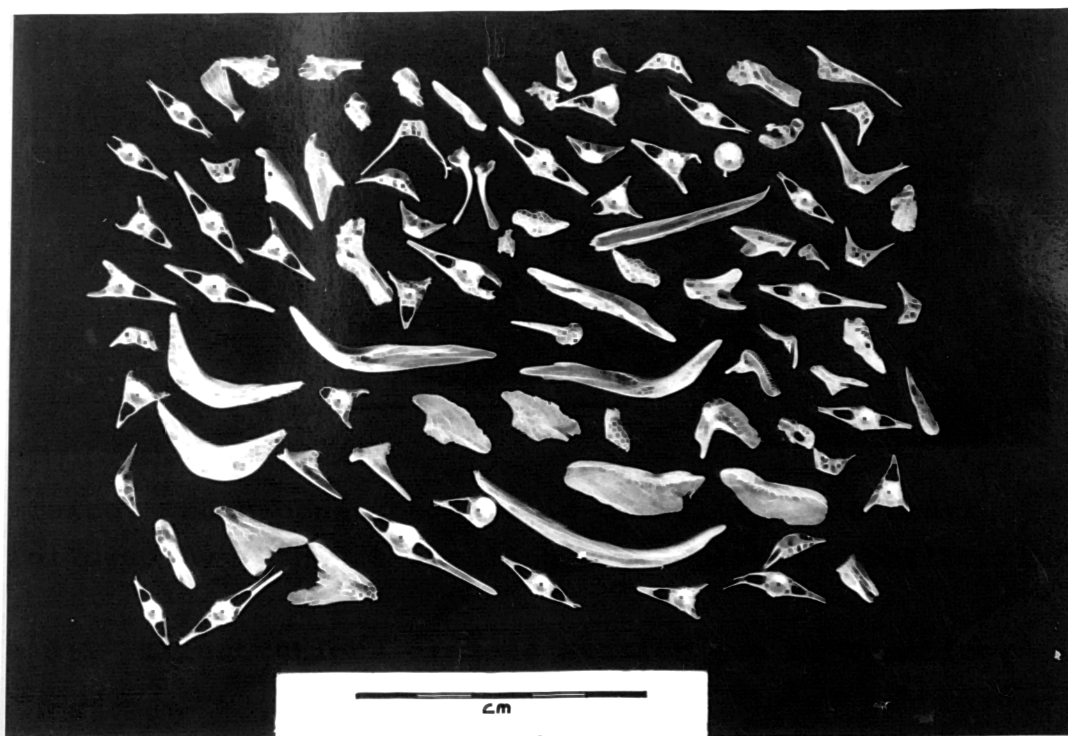


Fragment completeness of boiled herring bones after 300h. tumbling in gravel



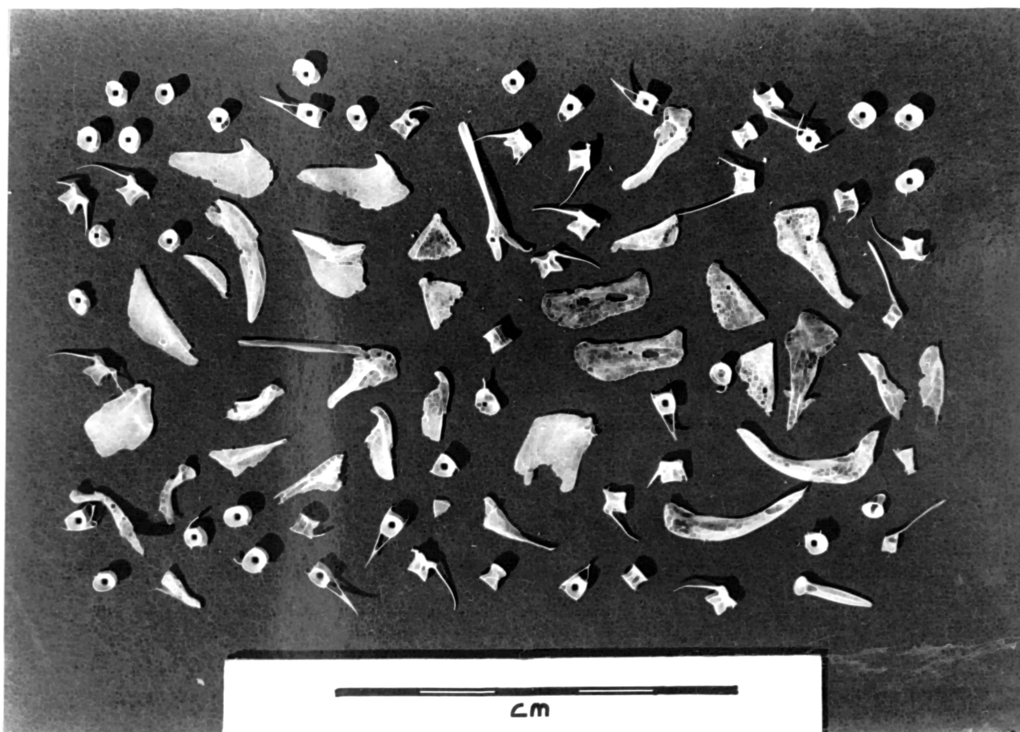


a. Haddock: fresh bones tumbled in gravel for 300 hours, followed by 48 hours tumbling in pebbles and ballbearings.

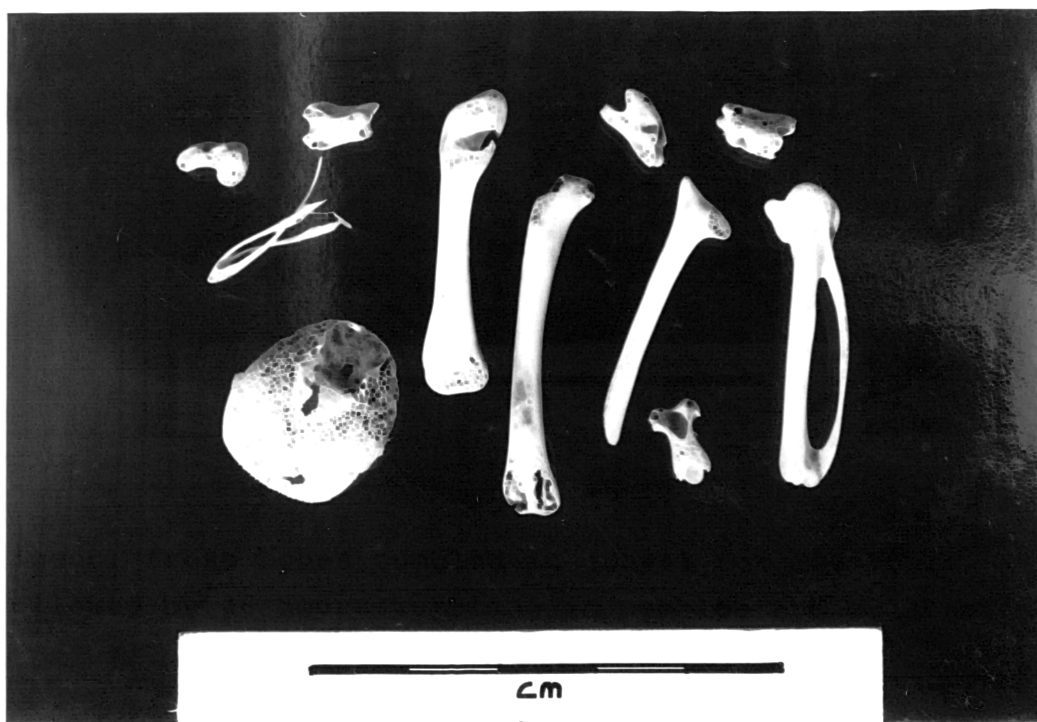


b. Plaice: fresh bones tumbled in gravel for 300 hours, followed by 48 hours tumbling in pebbles and ballbearings.

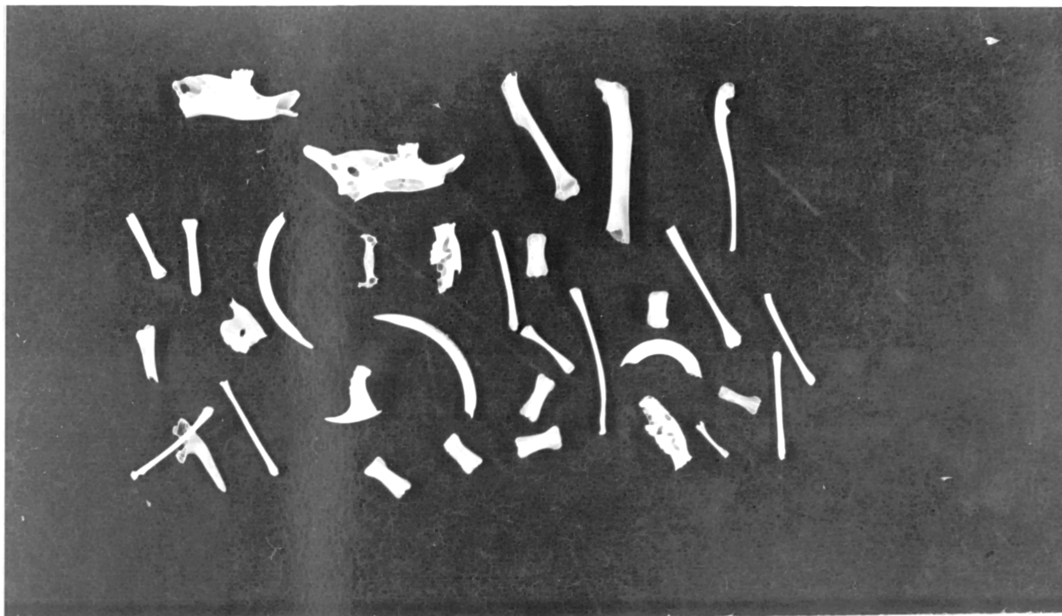
Plate 5:1 Illustrations of Bone Erosion due to Tumbling.



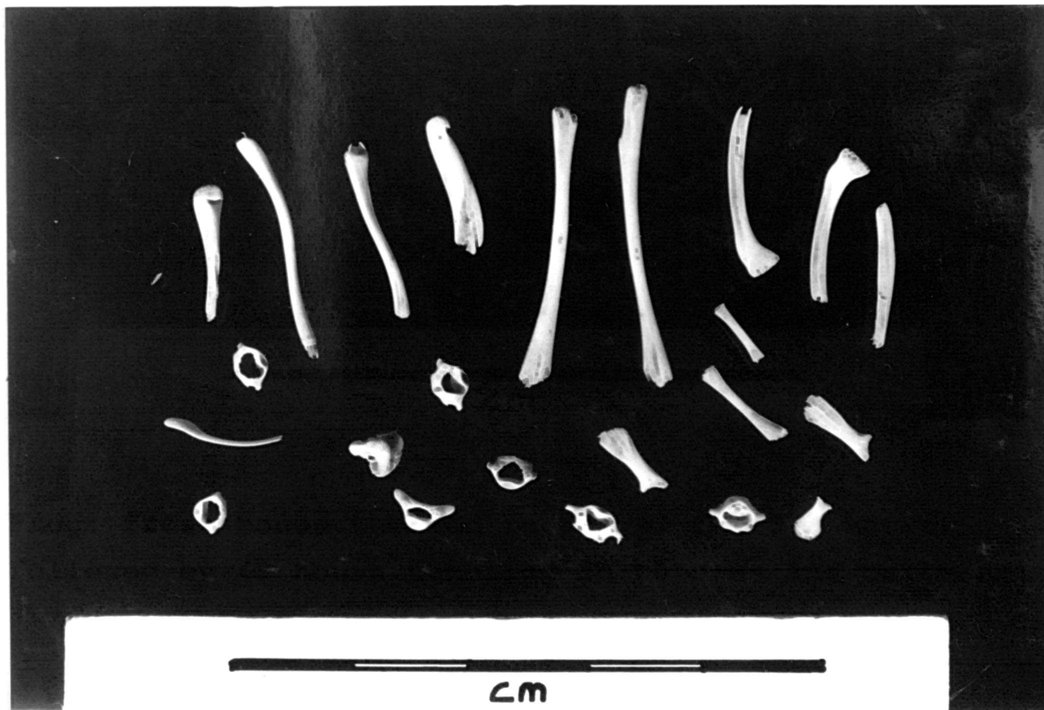
c. **Herring: fresh bones tumbled in sand for 300 hours, followed by 24 hours tumbling in pebbles and ballbearings.**



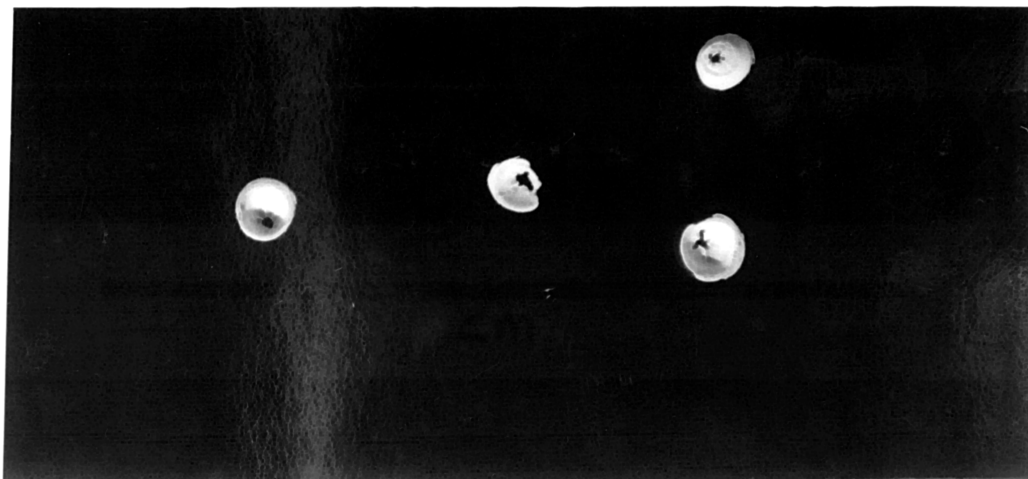
d. **Pigeon: fresh bones tumbled in gravel for 300 hours, followed by 48 hours tumbling in pebbles and ballbearings.**



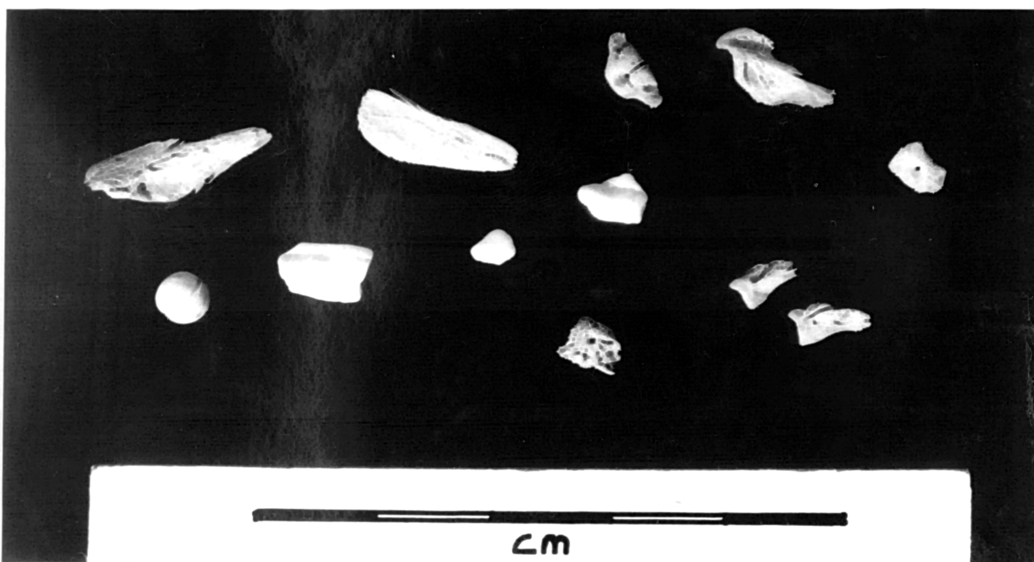
e. Mouse: boiled bones tumbled in gravel for 300 hours.



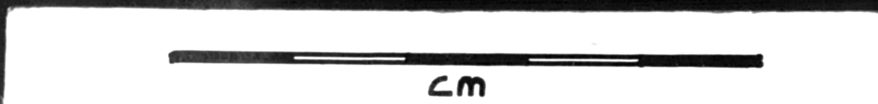
f. Frog: fresh bones tumbled in gravel for 300 hours, followed by 48 hours tumbling in pebbles and ballbearings.

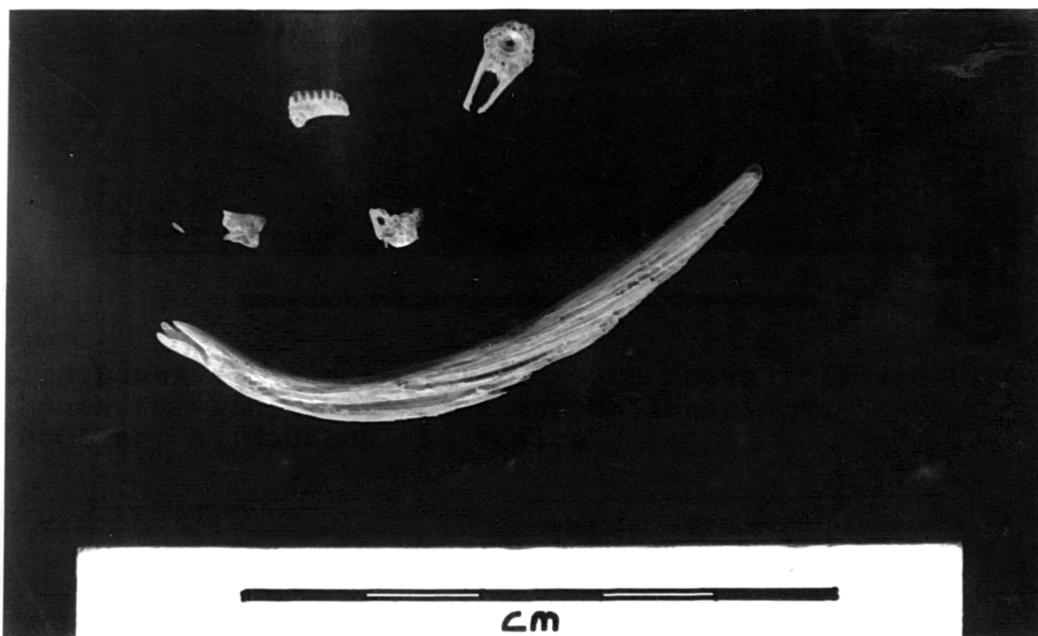


g.



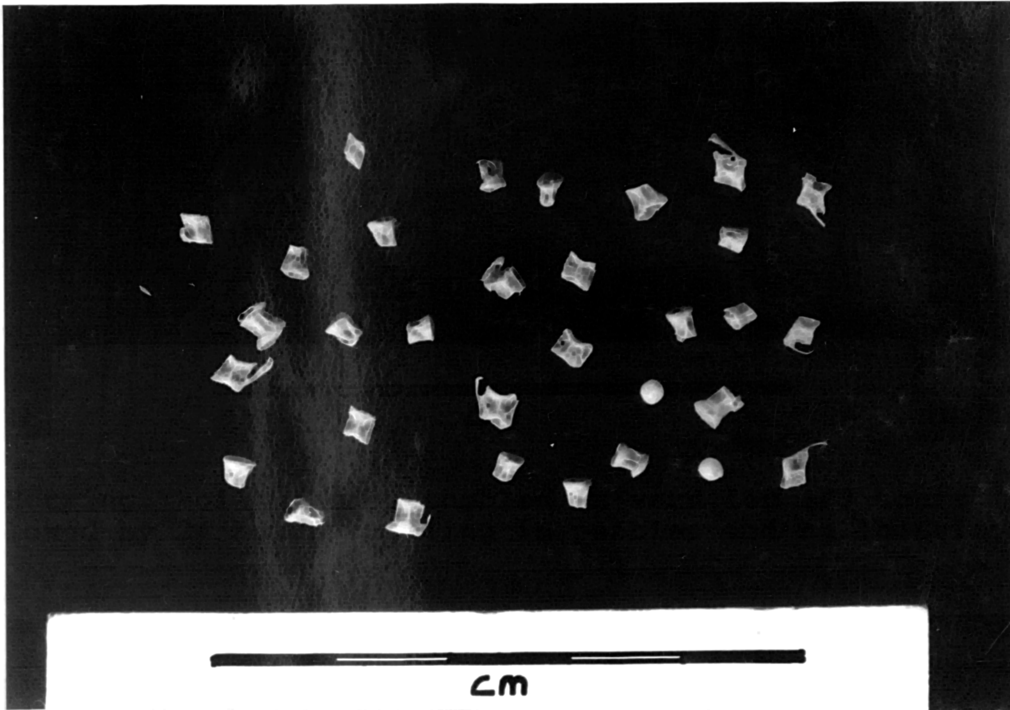
h.



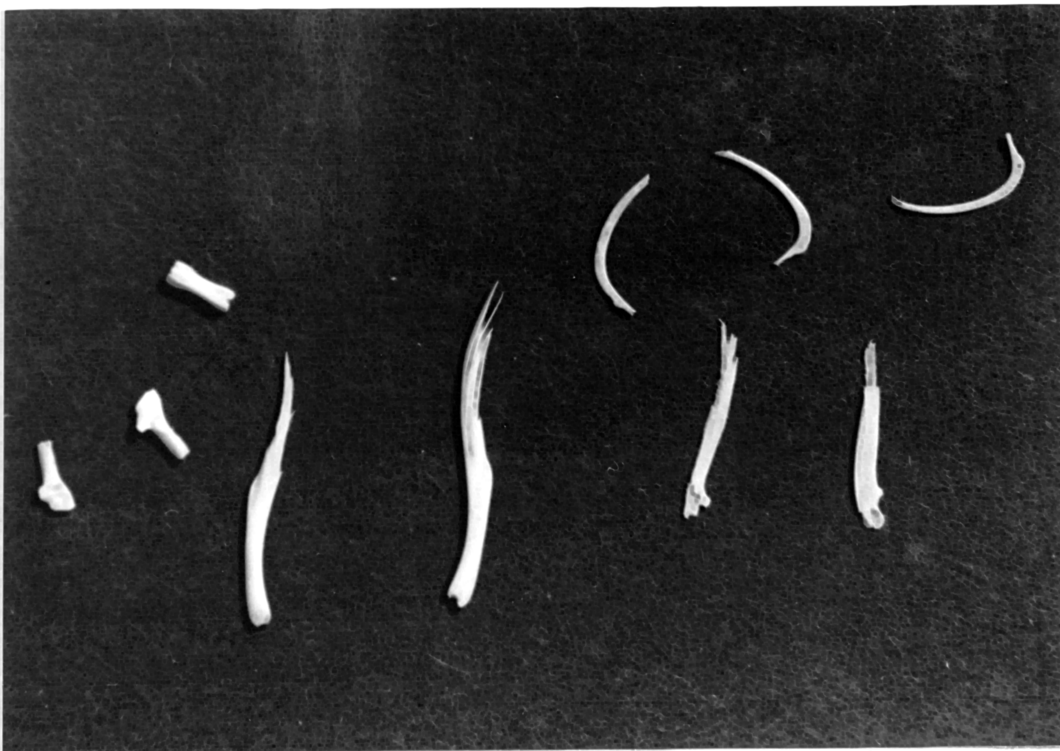


i.

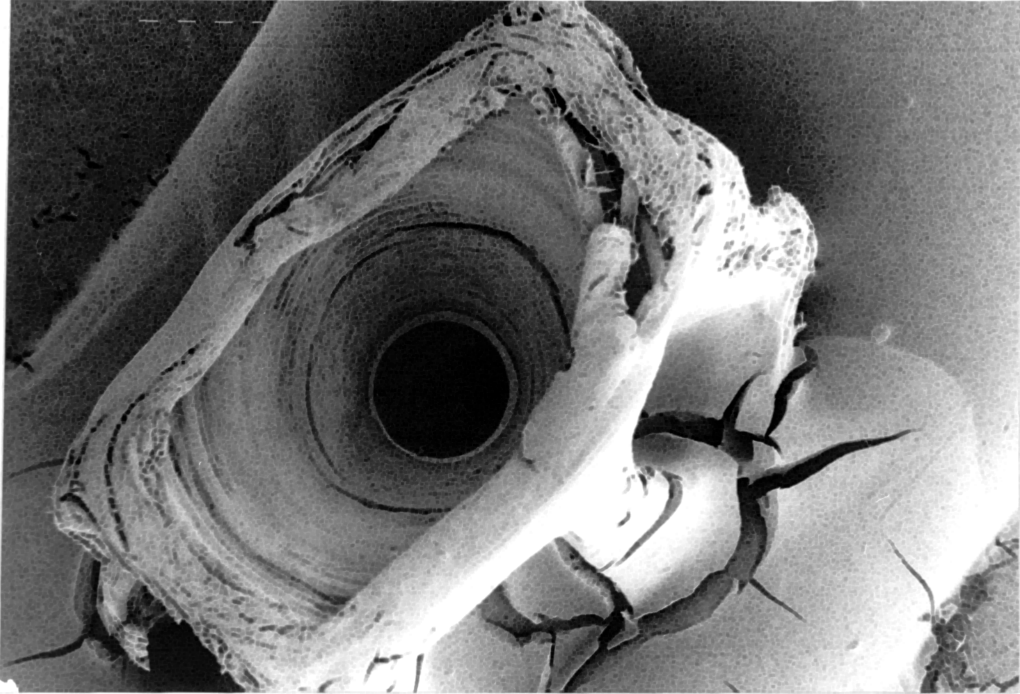
Boiled bones tumbled in sand for 300 hours followed by 24 hours tumbling in pebbles and ballbearings:
g. Dogfish, h. Haddock, i. Plaice



j. Herring: Boiled bones tumbled in sand for 300 hours followed by 24 hours tumbling in pebbles and ballbearings.



k. Mouse: Fresh bones tumbled in sand followed by 24 hours tumbling in pebbles and ballbearings.



1. Detail of a haddock vertebra after 300 hours tumbling in gravel followed by 24 hours in pebbles and ballbearings. (S.E.M.)

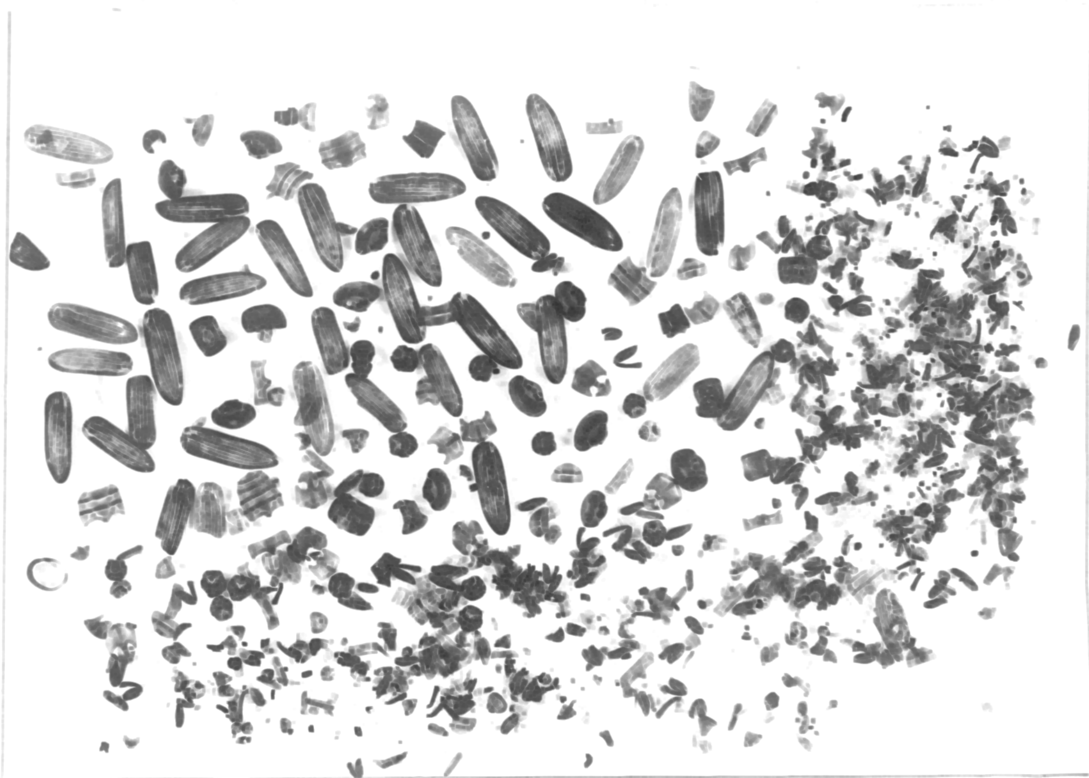


Plate 5:2 Insect remains after 300 hours tumbling in gravel.

Table 5:6 Proportions of whole bones per taxon for the later stages of each tumbling condition (whole bones = 80% or more complete).

	Experiment Code						
	Expected No.	1:3	2:3	7:1	6:1	6:2	5:1
Haddock	122	11	97	0	97	55	75
Plaice	113	32	87	1	98	80	102
Herring	109	12	43	0	51	22	66
Dogfish	10	9	10	0	0	0	0
Mouse/shrew	75	18	34	0	2	0	3
Frog	72	34	44	9	40	23	44
Total	501	116	315	10	288	180	290

KEY TO CODES:

1:3 = Boiled bones tumbled in gravel for 300 hours.
2:3 = Boiled bones tumbled in sand for 300 hours.
7:1 = Boiled bones tumbled in sand for 300 hours followed by 24 hours tumbling in pebbles and ballbearings.
6:1 = Fresh bones tumbled in gravel for 300 hours followed by 24 hours tumbling in pebbles and ballbearings.
6:2 = As 6:1, but 48 hours tumbling in pebbles and ball-bearings.
5:1 = Fresh bones tumbled in sand for 300 hours followed by 24 hours tumbling in pebbles and ballbearings.

How does boiling and burning affect the break-up of bone?

In all cases (except for dogfish calcified vertebral centra tumbled in gravel and sand, see below) boiled bone fragmented more rapidly than fresh bone. As a general rule the loss of bone experienced after 145 hours tumbling boiled bones in gravel was not experienced by the fresh bone assemblages until they had been tumbled in gravel for 300 hours followed by 48 hours tumbling in pebbles and ballbearings. With the exception of pigeon and frog, most or all of the boiled bones had disintegrated completely after tumbling in gravel for 300 hours followed by 24 hours tumbling with pebbles and ballbearings (see Table 5:6). A higher proportion of frog bones survived this process than any of the other taxa (except the larger pigeon) and boiling seems, from the results of tumbling boiled bones in gravel compared with fresh bones in gravel, to have less of an impact on the rates of attrition of mouse and frog bone than fish bone. After 145 hours tumbling in gravel there was very little damage to either the unboiled or the boiled frog bone assemblage. The amount of attrition exhibited by the frog bone assemblage after boiled bones had been tumbled for 300 hours in gravel was similar to that experienced by the unboiled fish bones after 300 hours tumbling in gravel followed by 24 hours in pebbles and ballbearings.

Some of the boiled bones of haddock and plaice in particular exhibited areas of exfoliation and/or erosion on the surface of the bones after just 48 hours tumbling in gravel and 145 hours in sand. Where present, split lines developed along the "grain" of the boiled bones, causing areas such as the ventral portion of the haddock dentary to break away. Tooth rows were particularly susceptible to erosion when bones had been boiled. The fresh bones, however, appeared only polished after 300 hours tumbling in both gravel and in sand, and modifications other than polishing were generally not evident until the bones had been tumbled with pebbles and ballbearings.

Many of the burned vertebrae tumbled in gravel and sand were broken into two or more pieces by 48 hours of tumbling. Those that were complete (in sand all the salmon and two haddock, in gravel two salmon) had areas of the centrum worn away. After 300 hours tumbling in gravel all of the burned bones had broken into at least two pieces and only one of the haddock centra was recognisable. The bones tumbled in sand showed little change, even after tumbling for 300 hours. All bones were completely destroyed by 24 hours tumbling in pebbles and ballbearings.

How do the different animals compare in rate of break-up? Do certain skeletal elements fragment more than others and if so, is it shape determined? (See Tables 5:1-5:5)

Of the complete skeletons used in this experiment, frog and plaice were consistently the least affected by tumbling irrespective of boiling and/or substrate. Of the fish, herring bones suffered more rapid attrition overall than the bones of the other taxa but the herring vertebrae proved to be more resistant than the larger vertebrae of haddock and plaice, and several survived even tumbling in gravel followed by 48 hours with pebbles and ballbearings. Small mammal bones were considerably more fragmented by tumbling than the bones from all other taxa when fresh, but boiling seemed to weaken the fish bones to a greater extent.

Dogfish

The dogfish centra, comprising calcified cartilage rather than true bone, might be expected to crumble more easily than true bone when subjected to a tumbling environment. This was not the case, however. When tumbled in sand or gravel the only significant damage observed to the boiled and fresh centra was fragmentation into two halves along the middle of the centra, laterally, thus separating the

two articulating facets. After tumbling in pebbles and ballbearings for 24 hours no further damage was observed to most of the fresh bones, although a small proportion of the centra facets had disintegrated. After 48 hours tumbling the fresh bones in pebbles and ballbearings 60% of the centra articulating facets survived, but most were extremely eroded and fragile. Only 25% of the boiled centra facets survived after tumbling in pebbles and ballbearings for 24 hours, and all were extremely eroded and fragile. Given the low numbers of haddock and plaice bones to survive this process dogfish centra do not seem to be eroded preferentially to other similar sized fish bones.

Although in the early stages of this experiment the dogfish centra appeared to survive better when boiled than when fresh (Table 5:6), this may have been due to differences in the robustness of the vertebrae prior to the commencement of the experiment rather than a result of differences caused by boiling. The trend was reversed after tumbling in pebbles and ballbearings, so despite the initial apparent strength the boiled centra finally proved to be weaker.

Haddock

The skeletal elements most consistently rapidly eroded or fragmented to the point of non-recognition were the scapula, coracoid, basipterygium, cleithrum, entopterygoid, metapterygoid, and nasal; followed by the prefrontal, frontal, post-cleithrum and suprapharangeal. Of these, all are classified as "flat" or "irregular" in shape. Most of the bones classified prior to the experiment as "robust", for example: the prevomer, premaxilla, articular, maxilla, quadrate, palatine, supracleithrum and hypohyal survived relatively well, as did the spherical bones (vertebrae and basioccipital) and some of the flat bones (the interopercular and epihyal in particular). The dentaries commonly lost the proximal part of the bone after tumbling in gravel or pebbles and ballbearings (boiled bones only)

and further damage included separation of the distal portion with the ventral portion of the bone, isolating an area of tooth row which rapidly became reduced. Tooth rows were particularly susceptible to erosion when bones had been boiled. The cleithra rapidly broke dorso-ventrally across the thinnest area, leaving a proximal and a distal section. In the case of the boiled bones, this happened within 48 hours of tumbling in both substrates. The distal portion is often the most commonly surviving haddock bone in archaeological deposits.

Many vertebrae displayed squared or angled edges to the centrum facets as a result of abrasion by the pebbles and ballbearings. Other vertebrae appeared worn, with areas of exfoliation or erosion.

The otoliths remained intact throughout the period of tumbling in both sand and gravel. Apart from some polishing they appeared almost unchanged even after 300 hours tumbling in gravel. After tumbling in pebbles and ballbearings all otoliths broke into several or many pieces, however, and all edges appeared rounded. This process destroyed the plaice otoliths and rendered the haddock otoliths identifiable as "Gadidae" at best.

One fragment of articular, quadrate and otolith were all that survived after boiled bones had been tumbled in gravel followed by 24 hours in pebbles and ballbearings.

Plaice

Plaice bones in general survived better than the similar sized haddock bones. The consistently best surviving skeletal elements included the frontal, prefrontal, prevomer, basioccipital, premaxilla, maxilla, dentary, articular, quadrate, hyomandibular, preopercular, interopercular, epihyal, hypohyal, infrapharyngeal, supracleithrum, post-temporal, scapula, vertebrae and first anal pterygiophore. These bones included most of those

previously classified as "robust", all of those classified as "spherical" and some classified as "flat" and one "irregular" (the prefrontal - possibly better classified as "robust"). Bones consistently rendered unidentifiable include the ectopterygoid, entopterygoid and coracoid, all classified as flat, and all difficult to identify when broken. The edges of the vertebral centrum facets seldom appeared compressed, but the caudal vertebrae did show angled or squared edges after tumbling in pebbles and ballbearings. Areas of erosion and/or exfoliation were frequently observed around the edges of the centra, however.

Only one fragment of quadrate and the anal pterygiophore survived after 300 hours tumbling in gravel followed by 24 hours in pebbles and ballbearings.

Herring

Herring head bones proved less resistant to tumbling than the bones of plaice and haddock, as a result of their papery-thin construction and the lack of diagnostic zones on many of the bones, making the identification of fragments difficult. Some of the edges of the head bones chipped at an early stage in all the experiments except for the fresh bones tumbled in sand. Consistently resistant bones included the proximal maxilla, the articular, epihyal, ceratohyal and vertebrae. The vertebrae in particular proved to be resilient to all but the most severe conditions of tumbling, and a larger proportion of them remained intact than did the plaice and haddock vertebrae after boiled bones were tumbled in gravel for 300 hours.

After boiled bones were tumbled in gravel for 300 hours followed by 24 hours tumbling in pebbles and ballbearings, one fragment of quadrate and several compressed vertebrae remained.

Although all the small mammal bones are discussed together it is probable that the shrew bones, being smaller, were more susceptible to damage and destruction than the mouse bones.

Through all the experimental situations the mandible, long bones (particularly the ulna), astragalus and calcaneum were the most commonly intact bones. The pelvis, scapula and sacrum tended to break easily, but the fragments remained identifiable through the experiments, while damage to smaller bones, such as metapodials, calcaneum and astragalus would render them unidentifiable owing to their small size (this small size probably also lead to under-representation due to poor recovery). Of the vertebrae the lumbar/thoracic group were the most readily abraded, whereas, surprisingly, the superficially fragile-looking cervical vertebrae had a similar survival rate to the caudal vertebrae in most circumstances. No bones survived after 300 hours tumbling in gravel followed by 24 hours in pebbles and ballbearings.

The small mammal crania were the first elements to fragment, with abrasion first causing breaks at the tympanic bullae and occipital as well as at the nasal and zygomatic arches. The cranial bones then tended to break or separate at the sutures, and edges of these fragments were rapidly rounded and chipped. The most resistant areas of the skull were the maxillae, which retained most of the molars until the bone was worn away around them after tumbling in pebbles and ballbearings. Mandibles lost the incisors at an early stage, but retained at least one molar until tumbled in pebbles and ballbearings. The first areas of the mandible to show abrasion were the processes and the bone around the root of the incisor. Later the ventral margin of the mandible, beneath the molars, became reduced, but not until the ascending ramus had almost been eliminated. One separated from the bone, the ends of the

incisors and roots of the molars were rounded. Teeth survived after all bone had been destroyed or rendered unidentifiable.

Pelves were eroded and broken at an early stage in the tumbling. The end of the iliac blade and the pubic ramus were the first areas to suffer; the pubic ramus was missing by 48 hours tumbling (fresh bone in gravel) and the entire ischium and pubis soon broke away. Scapulae initially lost the dorsal spine and dorsal edge of the blade, followed by the coracoid process. The sacrum suffered reduction across all of the surfaces, but the arboral end in particular was rapidly worn away.

Of the limb bones, the first to be modified were the tibia-fibulae, which lost the fibulae at an early stage, and one boiled mouse femur broke after tumbling in gravel for less than 48 hours. The ends of the other long bones became rounded, and areas of cancellous bone were exposed, followed by the wearing of holes around previous ridges such as on the anterior epicondyles of the femora, around the patellar facet. The femora trochanters and heads were also worn away, and eventually (after tumbling in pebbles and ballbearings) both ends broke away. Ulnae lost their distal ends first, followed by a reduction of the proximal area. The *final stage exhibited by the long bones after* tumbling with pebbles and ballbearings was of a laterally compressed area of shaft with fibrous or torn edges (Plate 5:1k).

There was no clear relationship between the rates of survival and the bone classification into shape (Table 5:4).

These results are similar to those documented by Korth (1979) for tumbling two small mammal skeletons (from *Microtus* and *Peromyscus*) with small quartz grains and water.

Frog

Frog bones survived better than the bones of all the other taxa. The only frog bones to show erosion or fragmentation in all but the most extreme tumbling stages was the maxilla, a very fragile-looking flat bone, and possibly the metapodials and phalanges, although these results may have been biased by poor recovery. After boiled bones were tumbled for 300 hours followed by 24 hours in pebbles and ballbearings all bones except the urostyle, maxilla and most of the tarsals, metapodials and phalanges were recognisable if rather squashed and abraded. The ends of most of the limb bones were rounded or appeared torn or "feathery".

Pigeon

Pigeon bones, probably in part at least due to their relatively large size, survived through all the tumbling conditions. Boiling caused more rapid erosion of the ends of the long bones and the surface of the cranium, and tumbling in pebbles and ballbearings caused considerable attrition and rounding of all edges, with holes appearing in the cranium and on both anterior aspects of the femur epicondyles.

The only elements to break were the cranium and the scapula, after tumbling for 48 hours in pebbles and ballbearings. The former was reduced to unidentifiable fragments, the latter lost the distal end and the remaining blade was extensively cracked. The carpometacarpus also eventually lost the metacarpal III, by gradual wearing away rather than breakage. The coracoid remained intact throughout all the tumbling regimes, with only rounding of the angles of the distal end and wear on the bicipital tuberosity to evidence abrasion.

What are the effects of tumbling in different substrates?

The rate of attrition of all remains increased with the enlargement in grain size of the tumbling media. All bones eroded more rapidly in a substrate of gravel than sand, and pebbles and ballbearings caused much more rapid attrition of all assemblages. While there was very little fragmentation caused by tumbling in sand or gravel, bone loss being mainly by erosion, when tumbled in pebbles and ballbearings some elements, notably small mammal limb bones and fish otoliths, broke. The bones of all the taxa appeared polished after tumbling in all the substrates. Fragmentation was only observed on fresh bones after tumbling in pebbles and ballbearings, but many of the boiled bones of haddock, herring and mouse had become substantially eroded or broken by 48 hours of tumbling in gravel and a few after 48 hours tumbling in sand. Angular edges to vertebral centra were only seen after tumbling in pebbles and ballbearings, but further tumbling in gravel would be needed to ascertain whether the same pattern would emerge given enough time. No other differences were observed macroscopically to distinguish bones tumbled in the various substrates.

The lack of erosion or distinctive surface modifications exhibited by bones tumbled in sand, even after many hours of tumbling at a velocity similar to that of a moderately fast flowing stream or river, indicates that it may not always be easy to determine whether skeletal remains have been transported or re-worked by their surface condition. This conclusion was also reached by Eaton *et al.* (1989) for occurrences of shark and dinosaur teeth from Paleocene deposits. Light polishing may not always be distinguishable on excavated material. Examination of the depositional environment, by analysis of sediment grain size as well as careful recording of the orientation of skeletal fragments, may help to refine the possibilities.

Can tumbled bone be distinguished from trampled and digested bone. What characterises a tumbled assemblage?

In contrast to trampled bone, tumbled bone exhibited an overall polished appearance, with all edges appearing rounded. Ends of long bones, in particular, were rounded and areas of cancellous bone were frequently exposed on the epiphyses. With the exception of the small mammal limb bones, edges of flat bones and haddock cleithra (which broke into a proximal and distal section) the bones did not break up. Rather entire surfaces appeared thinned, and ridges and upstanding areas, such as the trochanter of small mammal femora, were reduced. Frog and small mammal limb bones *exhibited a torn or "feathery"* appear*ance after* the epiphyses had worn away (Plate 5:1k). This form was not observed on any bones subjected to other processes. Where broken, rough edges were rapidly smoothed.

The edges of the articulating facets of the fish vertebrae were rounded after tumbling in gravel or sand, but after tumbling in pebbles and ballbearings the facet edges often appeared rectangular, square or octagonal due to the sides being worn flat. Some vertebrae (particularly haddock and herring) were laterally compressed (Plate 5:1l), a form also seen on digested and trampled vertebrae. The squared edges of the centra articulating facets were not seen on trampled specimens, but were observed on some bones from gull pellets (see Plate 7:1a, p.341). Occasionally this lateral crushing caused the outer edge of the centrum facet to become separated, a form seen on digested and trampled material. No other evidence of crushing was observed, however.

Insects (see Appendix 5.1)

The insect remains showed similar patterns of disarticulation but less damage after tumbling in sand than after tumbling in gravel, but both processes were more rapid in gravel. Most of the damage observed for beetle

exoskeletal elements was only observed after tumbling in gravel. The insect remains were not tumbled in pebbles and ballbearings.

One of the general trends of significance to the interpretation of archaeological assemblages of insects was that all remains of flies were lost by only 48 hours tumbling in gravel. After 48 hours tumbling in sand most heads were disarticulated from the thoraces, and many abdominal sclerites were completely fragmented. By 145 hours tumbling in sand all the abdomens had disintegrated into individual sclerites and pieces of sclerite, and most thoraces were fragmented. The prothorax was the most commonly surviving part of the thorax. Most heads were complete. Apart from 14 heads (some torn) all the fly remains had disintegrated after 300 hours tumbling in sand. This fragility would render the corpses of flies liable to rapid destruction under most circumstances.

The fly puparia had mostly broken into two or more recognisable portions after 48 hours tumbling in gravel, and by 145 hours very few recognisable fragments remained. Most fly puparia were broken into at least two pieces after 145 hours tumbling in sand. After 300 hours tumbling in gravel the mealworms were represented by 11 head capsules and a few articulated segments only. No colour changes were observed for either of these groups.

Beetles proved to be the most resistant of the insect groups used in this study. The disarticulation sequence was similar to that recorded from other experiments with the elytra, heads and prothoraces disarticulating first, followed by groups of abdominal sternites, the meso- and metathorax, the meso- and metanota and episterna. Wings of both flies and beetles disintegrated rapidly. Beetle elytra commonly showed paler or transparent areas after tumbling, these were commonly spots on the more convex base of the elytra, but further tumbling caused pale stripes (Plate 5:2). This pattern of erosion may be visible on ancient

material, but is more likely to be of paleoecological significance as insect remains in archaeology are usually only recovered from deposits subject to minimal disturbance. No other colour changes were observed.

The most fragile portions of the beetle exoskeleton, apart from the filamentous wings, tergites and metanotum, proved to be the abdominal sternites and anal tergite (pygideum). The prothorax tended to split in half from front to back, but the portions remained identifiable. Elytra became broken or torn during later stages of tumbling in a gravel substrate.

5.3.3 Experiment 2

To examine the relative rates of destruction by erosion of mammal, bird and fish bone. This experiment is very crude, but was intended to provide qualitative rather than quantitative results, to provide a simple comparison of the relative rates of destruction.

Methods and Materials.

Small samples of sheep bone, taken from the midshaft of metapodials from adult sheep (modern breed, but exact breed unknown) were prepared from fresh bone by cutting matchstick-shaped pieces of bone, using a bandsaw, with the long axis of each sample aligned to the long axis of the shaft. Twenty samples were prepared, and each sanded down to a standard size of approximately 17 mm. x 5 mm. x 2.25 mm. (see Tables 5:7-5:9 for exact measurements) using glasspaper. Samples of fish bone were prepared from the distal ends of haddock cleithra (from fish of 400-490 mm. total length). These bones were the only ones available to the author which were dense enough to allow the preparation of matchstick-sized samples of similar size to those taken from the sheep bone. Eighteen samples (this number dictated by the number of available cleithra of sufficient size which withstood the preparation procedure) were prepared by

sanding the distal ends of the cleithra into a rectangular solid of roughly the same dimensions as those taken from the sheep (Table 5:7). The irregular shape and size of the cleithra dictated that the long axis of the samples was orientated along the long axis of the bone, and that not all samples were perfectly rectangular.

Unfortunately the thin walls and convex nature of most bird bone meant that standard rectangular solids could not be obtained. Six tubes of bone from a night heron (*Nycticorax* sp.) were therefore used. These were removed by bandsaw and the cut edges sanded down. Six samples were similarly taken from rabbit femora. Sample sizes are given in Table 5:7). The animals were frozen prior to dissection, but after defrosting the bones were cleaned, air-dried and not further treated.

Table 5:7. Mean, Median and Standard Deviation for measurements of sheep, haddock, rabbit and night heron bones prior to tumbling (weight in grams, other measurements in mm)

FRESH BONES:

		Length			Width			Depth			Weight		
	No.	Mean	Median	St.dev	Mean	Median	St.dev	Mean	Median	St.dev	Mean	Median	St.dev
Sheep	10	19.78	19.40	1.66	5.09	5.05	0.24	2.77	2.80	0.14	0.44	0.44	0.029
Haddock	10	19.32	19.05	1.84	4.97	4.90	0.37	2.65	2.70	0.24	0.19	0.19	0.048
Rabbit	6	20.40	20.85	2.01	6.22	6.10	0.71	1.37	1.40	0.24	0.54	0.50	0.119
Night heron	6	18.08	18.75	1.87	5.90	5.80	0.55	0.83	0.80	0.17	0.38	0.39	0.059

Depth measurements for rabbit and night heron bones = wall thickness, taken at the thickest point of the wall exposed at the ends of the cylinder. Width of the rabbit and night-heron cylinders of bone was measured across the middle of the cylinder and is the equivalent of the medio-lateral breadth.

BOILED BONES:

		Length			Width			Depth			Weight		
	No.	Mean	Median	St.dev	Mean	Median	St.dev	Mean	Median	St.dev	Mean	Median	St.dev
Sheep	10	17.91	18.60	1.36	4.77	4.75	0.19	2.44	2.40	0.17	0.35	0.36	0.035
Haddock	8	16.01	15.70	1.19	4.79	4.70	0.24	2.18	2.25	0.33	0.15	0.16	0.031

The equipment used in this experiment was identical to that used in the previously described tumbling experiment. The containers were filled to about one third with 215 grams of ballbearings and pebbles as before, but 200 mls. of tap water was added to each container, both to simulate a fluvial environment and to reduce the amount of dust which accumulated from erosion of the pebbles. The

ballbearings were added to provide greater weight without substantially increasing the volume of substrate.

All samples of bone were measured and weighed prior to commencement of tumbling. Each of the bones was marked with a sample number using indelible ink. Initially ten of the sheep bone samples, ten haddock, six night heron and six rabbit bone samples were placed in one of the containers. All were in the fresh state. The container was rotated at 30 revs/minute for 25 hours (checks before this time indicated little damage had been inflicted) after which time the specimens were recovered, air-dried, re-weighed, re-marked (as the ink had become rather worn) and the experiment continued. Tumbling continued for a further 30 hours, the bones being dried and weighed after a total of 40 hours and 55 hours tumbling.

The cylinders of night heron bone tended to chip at the edges and crack along the long axis, leading to fragmentation, whereas the thicker-walled rabbit bones did not. Because of this it was felt that the value of the results for bird bone when compared with mammal bone was very limited and further experiments were not conducted. As the samples from night heron and rabbit bone were of completely different shape, with much larger surface areas than the samples of sheep and haddock bone, the results are not comparable.

The experiment was repeated using boiled sheep and haddock bones. Ten specimens of sheep and eight of haddock bone were boiled in water for one hour. Tumbling proceeded as before, but the specimens were removed and weighed after 6, 12, 24 and 48 hours. Many of the haddock specimens had disintegrated after 6 hours tumbling, and all had disintegrated by the 24 hour point.

Results and Discussion.

The results of the experiments are given in Tables 5:8

and 5:9 (individual parameters) and 5:10 (combined statistics). The median values for weight loss for the fresh sheep and haddock bones and the boiled sheep and haddock bones are presented in Fig. 5:2. Median values were chosen rather than mean weight loss values because the low number of replicates, and chips from the edges of several bones caused the haddock results in particular to show non-normal distributions. The median value was therefore felt to be a more representative value. Where bones had disintegrated, and therefore could not be weighed, the median value was calculated from the weighed fragments.

Table 5:8

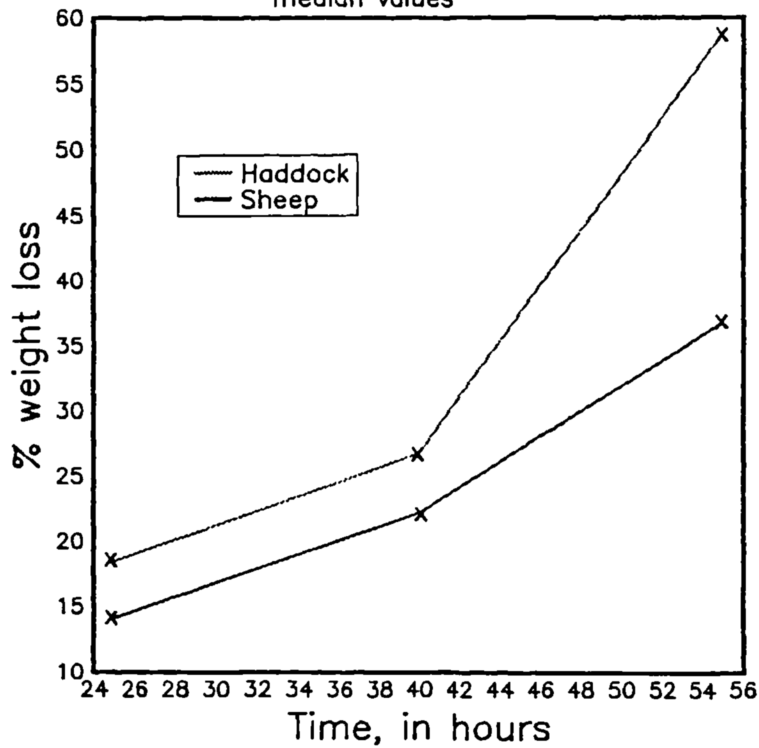
Weight loss of sheep, haddock, rabbit and night heron bone after tumbling. Substrate = pebbles and ballbearings, total wt 215g. Unboiled bones. (Dimensions measured in millimetres, weight in grams)

Species	Length	Width	Depth	Orig.wt.	25h	%wtloss	40h	%wtloss	55h	%wt loss
sheep	18.0	4.9	2.8	.444	.394	11.27	.345	22.30	.237	46.62
	18.4	5.4	2.9	.441	.369	16.33	.342	22.45	.194	56.01
	19.7	4.9	2.6	.410	.359	12.44	.333	18.79	.282	31.22
	19.5	5.0	2.5	.385	.342	11.17	.335	12.99	.184	52.21
	18.5	4.8	2.8	.401	.364	9.23	.359	10.48	.315	21.45
	19.4	5.6	3.0	.479	.455	5.02	.435	9.19	.360	24.84
sheep2	19.4	5.1	2.8	.464	.391	15.73	.362	21.98	.314	32.33
	19.4	5.0	2.8	.431	.348	19.26	.321	25.52	.320	25.75
	22.6	5.1	2.7	.441	.367	16.79	.311	29.48	.261	40.82
	22.9	5.1	2.8	.453	.364	19.65	.310	31.57	.265	41.50
haddock	20.8	4.9	2.7	.229	.187	18.34	.166	27.52	.062	72.93
	17.9	5.3	3.0	.213	.171	19.72	.158	25.83	-	-
	18.7	4.7	2.4	.130	.123	5.38	.105	19.24	-	-
	22.0	4.6	2.7	.178	.145	18.54	.140	21.35	-	-
	21.0	5.5	2.6	.237	.179	24.48	.162	31.65	.066	72.15
	19.4	4.4	2.3	.122	.112	8.20	.101	17.22	-	-
haddock2	18.3	5.5	2.7	.211	.160	24.18	.120	45.70	.108	51.13
	17.7	4.9	2.7	.150	.134	10.67	.120	20.00	.080	46.67
	16.3	4.8	2.4	.139	.119	14.39	.072	48.20	.047	66.19
	21.1	5.1	3.0	.249	.178	28.52	.146	41.37	.133	46.59
Rabbit	21.0	6.8	1.6	.710	.560	21.13	.493	30.56		
	22.3	6.5	1.6	.656	.502	23.48	.438	33.23		
	19.6	5.7	1.5	.505	.389	22.79	.349	30.89		
	16.8	7.2	1.3	.487	.369	24.23	.325	33.26		
	22.0	5.5	1.2	.445	.319	28.31	.278	37.53		
	20.7	5.6	1.0	.415	.302	27.23	.264	36.39		
n.heron	17.3	6.8	1.0	.388	.268	30.93	.232	40.21		
	19.4	6.0	0.8	.424	.262	38.21	.268	36.79		
	18.2	6.2	1.1	.386	.234	39.38	.232	39.90		
	19.6	5.6	0.6	.422	.310	26.54	.199	52.84		
	14.7	5.4	0.7	.264	.172	34.85	.155	41.29		
	19.3	5.4	0.8	.386	.235	39.12	.173	55.18		

Table 5:9
Weight loss for boiled sheep and haddock bones after tumbling in 215 grams pebbles and ballbearings. (Dimensions measured in millimetres, weight in grams).

	Length	Width	Depth	Weight	6h	%wtloss	12h	%wtloss	24h	%wtloss	48h	
sheep	17.2	4.6	2.2	.295	.282	4.41	.269	8.81	.227	23.05	.183	37.97
	19.3	4.9	2.3	.364	.345	5.22	.324	10.99	.319	12.36	.265	31.52
	17.0	4.9	2.7	.387	.368	4.91	.342	11.63	.340	12.14	.275	24.45
	18.7	5.1	2.4	.368	.344	6.52	.318	13.59	.251	31.79	.189	51.04
	18.8	4.7	2.4	.344	.325	5.52	.304	11.63	.246	28.49	.218	36.63
	18.7	4.8	2.3	.346	.325	6.07	.295	14.74	.267	22.83	.230	33.53
	18.5	4.7	2.4	.339	.318	6.19	.306	9.73	.300	11.50	.248	32.97
	17.0	4.7	2.6	.367	.344	6.27	.338	7.90	.318	13.35	.259	29.43
	19.0	4.9	2.4	.370	.345	6.76	.342	7.57	.283	23.51	.152	48.47*
	14.9	4.4	2.7	.275	.270	1.82	.250	9.10	.239	11.49	.197	28.36
haddock	15.4	4.6	2.5	.149	.116	22.15	000	000				
	15.7	4.6	1.9	.119	.098	17.05	000	000				
	14.7	4.7	1.8	.114	.081	28.95	000	000				
	16.1	4.7	2.5	.181	.129	28.71	000	000				
	18.7	5.1	2.5	.189	.173	8.47	.126	33.33				
	16.3	5.0	2.3	.171	.129	24.56	.114	37.02				
	15.5	4.5	1.7	.113	.072	36.28	000	000				
	15.7	5.1	2.2	.164	.114	30.49	000	000				

*=broken



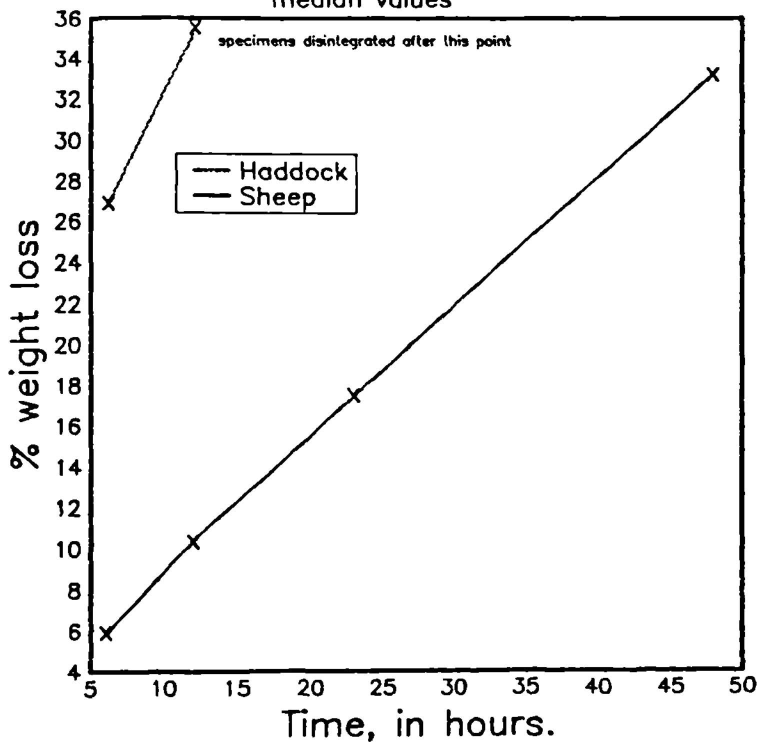


Fig. 5:2 Percentage Weight Loss for fresh (above) and boiled (below) Bone from Sheep and Haddock after Mechanical Abrasion (Tumbling).

Table 5:10. Mean, Median and standard deviation of weight loss values for sheep, haddock, rabbit and night heron bones after tumbling.

FRESH BONES:

% WEIGHT LOSS VALUES	no.	25 hours Mean	Median	St.dev	40 hours Mean	Median	St.dev	55 hours Mean	Median	St.dev
Sheep	10	13.69	14.09	4.67	20.48	22.14	7.64	37.28	36.58	11.98
Haddock	10	17.24	18.44	7.53	29.81	26.68	11.48	*47.12	58.66	
Rabbit	6	24.53	23.85	2.73	33.64	33.24	2.83	experiment discontinued		
N. heron	6	34.84	36.53	5.19	44.37	40.75	7.65	"		"

* = values calculated from only those samples which survived, n = 6

BOILED BONES.

% WEIGHT LOSS VALUES	no.	6 hours Mean	Median	St.dev	12 hours Mean	Median	St.dev	24 hours Mean	Median	St.dev	48 hours Mean	Median	St.dev
Sheep	10	5.37	5.80	1.45	10.57	10.36	2.38	19.05	18.09	7.75	35.4	33.25	8.52
Haddock	8	24.58	26.64	8.70	35.17	35.17		bones disintegrated					

* = values calculated from only those samples which survived (n=2).

As Fig. 5:2 illustrates, in all cases the sheep bones proved more resistant to erosion than the haddock bones, and this trend was even more apparent from the boiled samples. While both mammal and fish bone were weakened by boiling, the sheep bone samples retained their integrity while the majority of haddock bones disintegrated after between six to twelve hours tumbling. As the samples from haddock cleithra probably represent the densest, most robust area of the gadid skeleton (they are frequently the most common, or only, part of the haddock skeleton which survives archaeologically) the implications for the relative loss of fish bone compared with mammal bone are obvious. Fish bone which had been boiled, in particular, will be susceptible to rapid disintegration given a mobile environment such as may be encountered in shell middens subject to incursions by a water body, aeolian movement of surface deposits or bioturbation, for example.

The relatively high variation in rates of weight loss exhibited by the sheep bones may be due, at least in part, to the side of the metapodial from which the bone samples

were taken. Work by Currey has shown that samples of bone from the anterior and posterior sides of large mammal long bones exhibit different tolerances to applied force (Brear pers. comm.)

The susceptibility of bird bone to fragmentation when compared with similar sized and shaped mammal bone is interesting, but may be of limited relevance to the effects of erosion on intact bones without free edges. In this context the results obtained by Mahon (1990) are interesting. She compared the strength and stiffness of samples taken from wing and leg bones of the Sarus crane (*Grus antigone*) and mute swan (*Cygnus olor*) using an Instron 1122 testing machine and similar methods to those described in Chapter 3 of this report. The results obtained indicated that the bending strengths obtained from the crane were on average 262.8 Mpa and for swan 222.4 Mpa. These bending strengths are of a similar magnitude to those obtained for femoral cortical bone from a range of small and large mammals (Lanyon and Rubin 1985). Another undergraduate project (Chasler 1972, quoted in Wheeler and Jones 1989, 63) demonstrated that fish bone was weaker in bending than mammal bone, but unfortunately the report was not available for my perusal.

5.3.4 Experiment 3.

To examine the effects of tumbling fish otoliths, to compare with the effects of digestion upon otoliths.

The otoliths which had been included as part of the fish skeletons used in Experiment 1 had shown little or no erosion after tumbling in sand or gravel, even after 300 hours tumbling. After tumbling in pebbles and ballbearings they appeared eroded, and polished, however. This experiment was undertaken to examine whether the effects of tumbling otoliths could be distinguished from the effects of digestion on otoliths, which also results in reduced otoliths. Archaeologically recovered otoliths may appear

characteristically eroded (Jones pers. comm. and personal observation) and this has been interpreted as evidence that carnivores (probably dogs) have been fed fish (Jones pers. comm.). As the archaeological site from which the otoliths upon which Jones' observations are based is situated in dune sand, the question of whether these bones could have been eroded by wind or wave action arises.

Methods and materials

Ten fresh haddock and five fresh whiting otoliths were measured and weighed (Table 5:11) and tumbled for fifteen hours in 215 grams of pebbles and ballbearings and 200 grams of water, as described above.

Table 5:11 Measurements of ten haddock and five whiting otoliths prior to tumbling in 215 grams pebbles and steel ballbearings and 200 mls. water (measurements are maximum and measured in millimetres and grams).

	Length	Width	Weight
Haddock	22.0	7.4	0.597
	17.1	5.6	0.300
	21.9	7.5	0.690
	17.2	6.1	0.335
	17.5	6.5	0.345
	15.3	5.8	0.270
	17.6	5.8	0.310
	14.5	5.5	0.211
	15.2	5.5	0.236
	14.9	5.8	0.228
Whiting	17.2	4.8	0.158
	22.4	6.0	0.267
	6.7	5.0	0.195
	13.6	4.6	0.110
	19.9	6.4	0.259

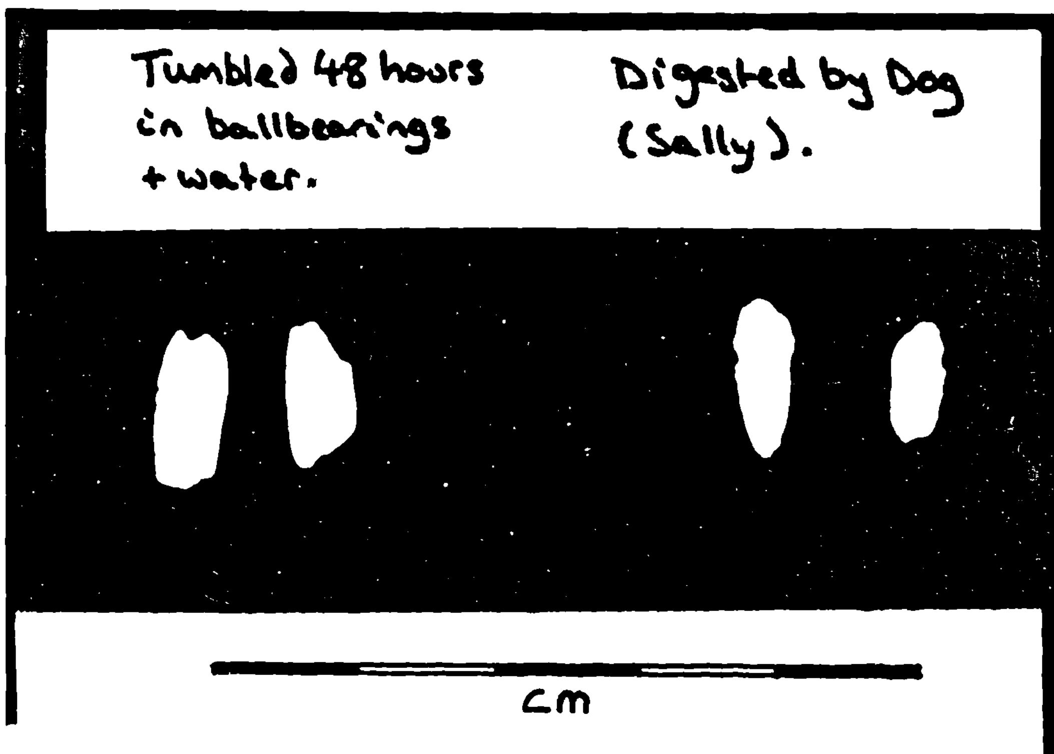
after 15 hours tumbling all otoliths had fragmented into several pieces, and all pieces appeared eroded over the entire surface area.

Results and discussion.

After 15 hours tumbling all the otoliths had broken into several pieces, which made calculations of weight and area loss impossible. Each piece was eroded, with characteristically rounded edges and reduced surface

sculpturing. The fragments were eroded regularly, however, and most pieces appeared rounder than the original otolith. None of the otoliths showed the edge sculpturing which was characteristic of otoliths eroded by digestion in experiments conducted by Jones (1986). The otoliths in Jones' experiments also appeared thinner than fresh otoliths in the interior-exterior aspect, a state not encountered in the experimentally tumbled assemblage. Erosion on the tumbled otoliths was noticeable on the edges, giving the rounded appearance. Plate 5:3 illustrates a tumbled otolith and an otolith after passage through the gut of a dog (the latter from experiments by Jones (1986). Further comparisons between abraded and digested otoliths are given in Chapter 7.

Plate 5:3 Comparison of a Tumbled and a Dog-Digested Otolith (exterior views).



5.4 Experiments to Investigate the Effects of Trampling on Skeletal Tissues.

5.4.1 Aims.

To investigate the effects of trampling by humans on skeletal remains of small mammals, birds, fish, amphibian, molluscs and insects.

a. To examine whether some bones and fragment more easily than others and whether some, by virtue of their size and/or shape, are buried more readily than others and so protected from the effects of trampling.
b. To investigate whether the bones of some taxa or groups of animals fragment more easily than others and to what extent shape affects fragmentation.
c. To determine whether it is possible to predict to what extent assemblages have been subject to physical attrition prior to burial by an examination of the relative frequency of skeletal elements in a recovered assemblage.
d. To investigate whether there is a relationship between bone density (as described in Chapter 2) and fragmentation.
e. To examine the effects of boiling on the survival of bones subjected to trampling.
f. To investigate vertical movement of objects within a profile as a result of trampling.

Of these questions, a-d are investigated in the first trampling experiment and e-f by the second trampling experiment.

5.4.2 Materials.

Two experiments were carried out, using the same basic equipment and following the same methods, one using fresh bones and mollusc shells, the other using selected boiled bones, complete fresh insects and a selection of fresh bones as detailed below. These are respectively referred to

as trampling experiment 1t and 2t. The experiments took place consecutively, and each was run for two months over which time 3500 traverses were made (as described below). For these reasons both are described and discussed together.

Experiment 1t.

Complete animal skeletons were used in this experiment. The skeletons were prepared by burying complete or partially defleshed, previously fly-blown bodies and removing only when all the flesh had been removed (between four and eight weeks later). The animals used in this experiment included: 3 cod (total lengths 580, 560 and 560 mm.); 7 haddock (total lengths from 360 to 395 mm.); six plaice (total lengths from 340 to 380 mm.); seven herrings (total lengths from 280 to 350 mm.); 2 salmon (total lengths 860 and 830 mm.); 4 mice (3 adult, 1 subadult), 1 adult and 2 sub-adult brown rats, 2 adult pigeons, 3 complete adult frogs and 3 headless frogs. Additionally selected skeletal elements, representing a selection of "robust" "flat" and "irregular" bones from haddock and plaice of similar sizes to the complete animals used in this experiment, were included. These bones comprised: 14 haddock dentaries, articulars, premaxillas, quadrates, maxillas, 9 anal pterygiophores (robust), ceratohyals, epihyals, operculars, preoperculars (flat) hyomandibulars and 13 cleithra (irregular); 12 plaice dentaries, articulars, quadrates, 11 maxillae, premaxillae (robust), 12 ceratohyals, epihyals, operculars, preoperculars (flat), 10 hyomandibulars and 12 cleithra (irregular).

Mollusc shells used in the experiment comprised 30 limpets (*Patella cf. vulgata*), 30 periwinkles (*Littorina littorea*), 30 mussel valves (*Mytilus edulis*) and 30 garden snails (*Helix aspersa*).

Experiment 2t

A selection of skeletal elements from cod, haddock, plaice, herring, salmon, pigeon, rat and frog, as detailed in Table 5:12 (by the the expected numbers of bones) was utilised. The skeletal elements chosen comprised a range of shapes. Additionally one hundred dogfish calcified vertebral centra, one complete house mouse and two complete bank voles were included in the experiment. All the bones were taken from skeletons prepared by defleshing with the aid of maggots and burying, as described in Chapter 2 and by C. Nicholson (in prep.).

With the exception of fifty of the dogfish centra, which were stained blue to differentiate them from the other fifty (boiled) centra, all the bones were boiled for one hour fifteen minutes in tap water, after which they were dried at 30°C for 24 hours.

To examine the vertical movement of bones within the limits of the sediment profile used in this experiment, one hundred fresh haddock and one hundred fresh plaice vertebrae were prepared. Fifty of each were marked with a spot of orange paint, fifty of each with a spot of yellow paint. The orange painted bones were placed in a line on the top of the sand and gravel substrate, with the boiled bones. The yellow painted bones were placed in a row half way down the substrate, at 60 mm. depth. The degree to which these bones had moved down and up the profile by the end of the experiment was examined.

A nylon mesh bag, of mesh size about 0.3 mm., containing thirty *Tenebrio* adult beetles, thirty bluebottles *Calliphora vomitoria*, thirty bluebottle puparia and thirty *Tenebrio* mealworms, was placed centrally on the trampling surface of Experiment 2t. All the insects had been dried at room temperature for two weeks prior to the experiment.

5.4.3 Methods

A rectangular box of dimensions 1200 x 450 x 210 mm. was filled with an equal volume of medium builders gravel (comprising mainly angular and subangular stones) and silver sand to a depth of 150 mm. for Experiment 1t (fresh bones) and 120 mm. for Experiment 2t (boiled bones). The box was placed outdoors and the experiments conducted during the months of May to October 1990. The summer of 1990 proved to be particularly hot and dry, but occasional rain was experienced, more notably in September and October, during the second experiment.

All bones (excluding the painted haddock and plaice vertebrae in Experiment 2t, see above) were placed in a large bag and shaken to mix them up. The contents were then spread in an even line across the length of the wooden box, on the surface of the mixed sand and gravel. The surface was covered with a length of cotton cloth to prevent loss due to animal movement and wind and to obscure the bones from view to prevent some bones being selectively trampled on. A number of adults wearing shoes traversed the box over a period of 2 months, to a total of 3500 traverses. One traverse comprised however many steps (usually two or three) were used to cross the box once. An attempt was made to tread over all parts of the surface, and the build-up of sediment at the edges was prevented as far as possible by treading next to the edges at regular intervals. The cloth cover was removed at intervals to observe the movement and break-up of skeletal remains, and photographs were taken of the trampled surface after 2500 and 3000 traverses. The surface was photographed again after 3500 traverses and the contents of the box removed by trowel in units of 20, 20, 40 and 40 mm. (the last only for Experiment 1t where there was a greater depth of sediment). The larger units from the lower levels of sediment reflected the sparser numbers of bones and the coarser nature of the substrate (the gravel had tended to travel downwards, leading to a greater proportion at the bottom of the box). Smaller excavation

units were impractical because long bones, in particular, could occupy several vertical centimetres if oriented vertically with respect to their long axis.

The excavated sediment was sieved through a bank of sieves of 10mm., 4mm., 2mm. and 1mm. mesh size. Sand which passed through the 1mm. mesh was discarded. It should be noted that tiny bones, such as mouse and frog lower limb bones, may have been lost through the 1mm. mesh. It was not practical to sort through the entire sand residue to check for these tiny bones. Examination of a small sample (0.5 litre) of the sand residue failed to recover any identifiable bones, but the possibility of loss exists.

Bones were recovered by dry-sorting the residues caught in the sieves, and assemblages were bagged according to the spit from which they were recovered and the mesh-size that they were caught in. As a result, a study could be made of the relationship between the size of bones and the distance from the surface which they travelled. The bones were also classified subjectively according to shape, as for the tumbling experiments (see above). Four categories of shape were used to describe the fish bones, these were the same as those used consistently throughout this project (see Chapter 2).

The aim of classifying the bones into shape-groups was to examine the effect of shape upon fragmentation and movement down the profile.

5.4.4 Data analysis and Presentation.

Bones

Each bone was recorded in terms of skeletal element type, species, shape category, completeness of the fragment (see below), area of the fragment in relation to the whole bone (i.e. proximal, distal, dorsal etc.), surface modifications (erosion, flaking, scuffing of the edges), depth from which

it was recovered and size of bone (in terms of sieve mesh size through which the bones failed to pass). This last category, size, is to a certain extent dependent on the orientation of the bone. Tubular bones, for example, will pass through a mesh when oriented with their long axis perpendicular to the mesh, but not with their long axis parallel to it. The sieves were shaken for a considerable time, until no more bones passed through.

The bone data were stored using "D-Base III+" on a microcomputer, but analysed using the statistical package for the social services (SPSSX) and the statistical package "Minitab" on the Vax mainframe computer.

The data are presented as Figures (histograms), Tables and Plates. In order to compare the extent of bone fragmentation between taxa, the results are displayed in terms of fragment completeness, i.e. the proportion of the whole bone that the fragment represents. The completeness of each fragment was recorded as a percentage of the whole bone, to the nearest estimated 10%. Figures 5:3a-i illustrate the mean fragment completeness scores (described above, experiment 1t) of skeletal elements, by taxon. The actual scores are given in Tables 5:12-5:17, located in Appendix 5.2. Tables 5:18-5:19, also located in Appendix 5.2, give the numbers and proportions of whole bones (here classed as bones 80% complete or more) with the numbers of identified bones and the expected numbers, based on the number of skeletons used in the experiment. Long bones were classed as intact when unfused or poorly fused epiphyses had separated from the shaft. Where individual bones were not recovered the fragment completeness of that bone was taken as 0 for the purposes of this analysis (i.e. the mean fragment completeness value was calculated by totalling the recovered bone sizes and dividing by the expected). In the case of very small bones, however, such as small mammal and frog metapodials and phalanges, there may be an under-representation due to retrieval deficiencies. Where doubt exists about the efficiency of retrieval, the average

fragment completeness score based on the recovered fragments only is given (in Tables 5:16, 5:17, 5:19 and 5:20 (Appendix 5.2, either in the Table or in the footnotes) in addition to the scores based on the expected numbers of bones which are routinely used in the Tables and Figures.

Tables 5:21-5:24 and Fig. 5:4 show the distribution of shape-classes, taxa, fragment completeness values, and bone sizes (the relative sizes of the bones described by the mesh size through which the bone did not pass) by depth within the substrate after the experiment. The results from profile depths 80-120 mm. and 120-150 mm. in Experiment 1t were combined as few bones were recovered from these low levels.

The bone sizes were obtained to enable an investigation of the extent to which size-sorting takes place as a result of trampling, and as a result the extent to which certain sizes of bones might be protected from fragmentation and erosion by rapid burial.

Fragment completeness values were grouped into five classes, representing fragments of 30% or less of the original bone, 40-50%, 60-70%, 70-90% and whole bones (greater than 90% intact) for the purpose of examining the amount of fragmentation with relation to: a) depth within the substrate after trampling, b) shape of bone and c) taxon.

The mean fragment completeness scores for the skeletal elements of cod, haddock, plaice, rat, small mammal and pigeon were compared with the density measurements (M1) obtained for these taxa and described in Chapter 3. Spearman's Rank Correlations were obtained (Tables 5:25-5:28).

Tables 5:29 and 5:30 concern the extent of damage other than fragmentation to bones by shape and depth, and Table 5:31 summarizes the amount of fragmentation by taxon. Table

5:32, located in Appendix 5.2, summarises the numbers of bones assigned to each shape class by taxon.

Insects

The disarticulation and fragmentation of the insects was recorded using the standard form given in Appendix 2.1. Photographs were also taken. The results are given in Appendix 5.3.

5.4.5 Questions

The questions of interest were, from experiment 1t:

a. Are items at the surface more likely to be broken than items which become buried?
b. Do the skeletal remains of different taxa fragment at significantly different rates?
c. Is there a relationship between the shape of the skeletal elements and the extent of fragmentation?
d. Is there a relationship between bone shape and susceptibility to burial?
e. Is there a relationship between bone density and extent of fragmentation?

and from experiment 2t:

f. To what extent does boiling affect the rate and patterns of fragmentation and disintegration of bones?
g. To what extent do bones travel up and down a sediment profile as a result of trampling?
h. How do insect remains break up as a result of trampling? Which remains are the most vulnerable?

5.4.6 Limitations.

The limitations encountered in the analysis of the results of this experiment concern the crudeness of the measurements (especially shape) and the inter-related

nature of the variables of interest. Most obviously, shape and size are inter-related; short bones and spherical bones tend to be smaller than tubular bones and flat bones. The different design of the bones of different taxa are also important; herring bones tend to be extremely thin and papery, most are flat and very few areas, (e.g. the proximal maxilla) are considered robust). Flat bones from cod, haddock and plaice, however, are much thicker and resistant to warping, tearing and bending. Additionally, once a bone breaks its shape may change. Fish bones in particular have many bones which contain a flat portion with a more robust articulation. The whole bone may therefore be classified as "flat", but once broken the section with articulation should possibly properly be classed as "robust".

Given these limitations it should not be surprising if patterns of bone distribution and fragmentation were rather difficult to interpret. To classify all the bones under study in a more objective manner, taking into account the complexities noted above, would be a enormous project, and is beyond the scope of this research. In all the discussions which follow the problems of classification and discrimination noted above should be born in mind.

5.4.7 Results and Discussion

Trampling Experiment 1t.

The following pages present the results of this experiment, in Figures and Tables followed by discussion. Further Tables are located in Appendix 5.2.

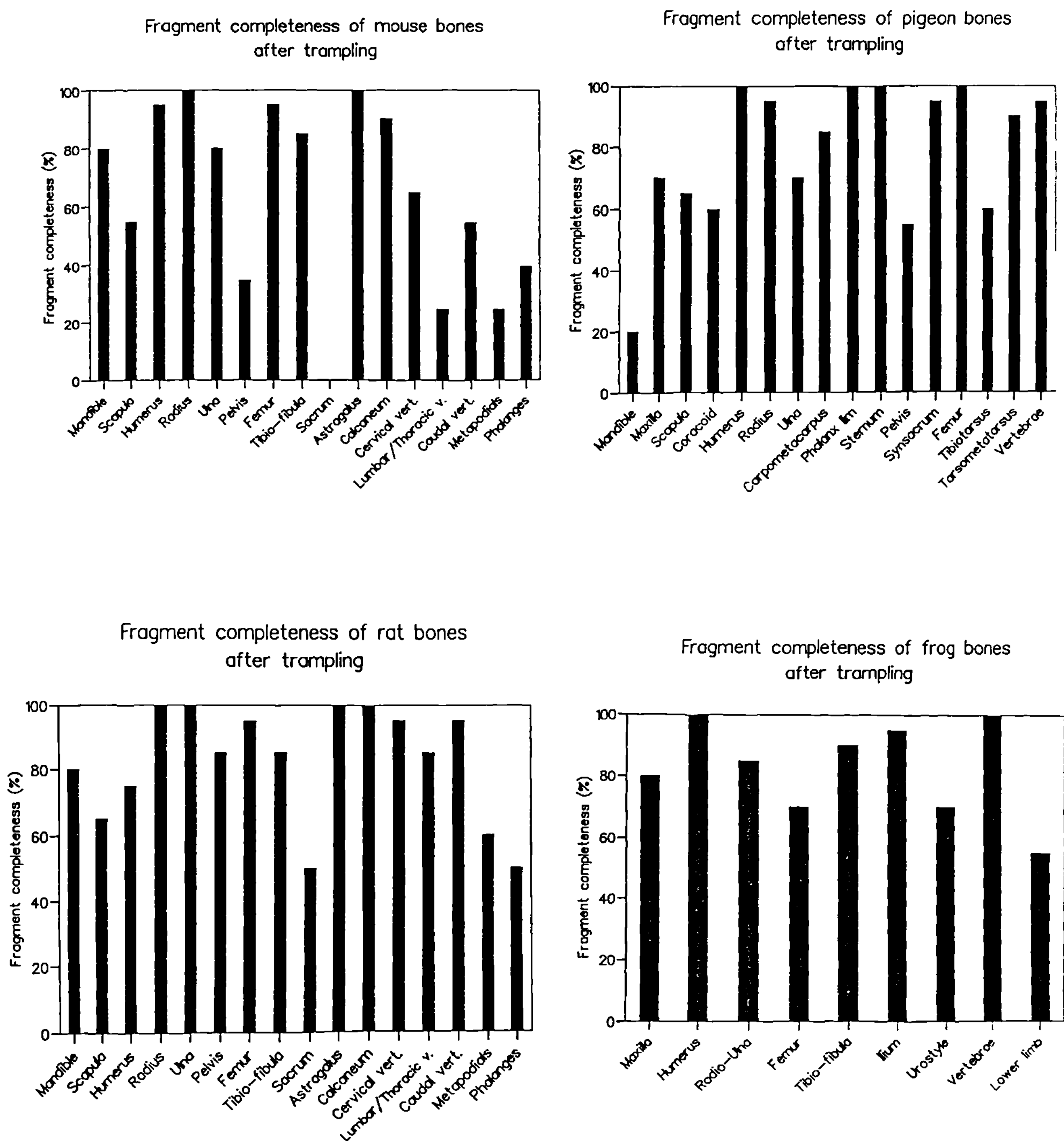
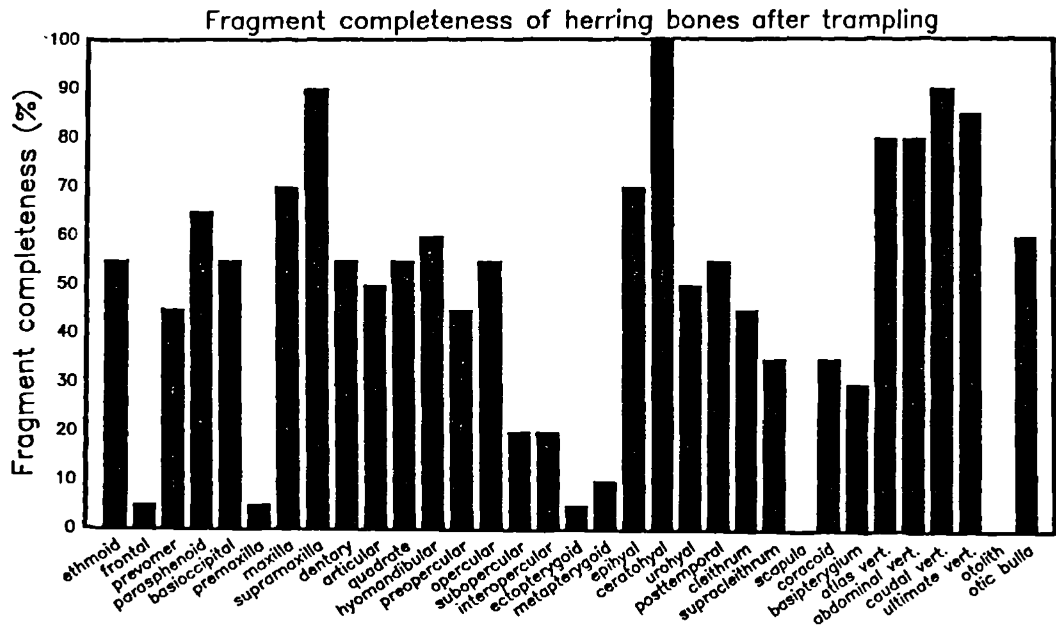


Fig. 5:3 Histograms showing the Mean Fragment Completeness Scores for Fresh Bones after Trampling, by Taxon.

Fragment completeness of cod bones after trampling

Fragment completeness of haddock bones after trampling

Fragment completeness of plaice bones after trampling


Fragment completeness of herring bones after trampling
Fragment completeness (%)
100
90
80
70
60
50
40
30
20
10
0
ethmoid
frontal
prevomer
parasphenoid
basioccipital
premaxilla
maxilla
supramaxilla
dentary
articular
quadrate
hyomandibular
preopercular
opercular
subopercular
interopercular
ectopterygoid
metapterygoid
epihyal
ceratohyal
urohyal
posttemporal
cleithrum
supracleithrum
scapula
coracoid
basipterygium
atlas vert.
abdominal vert.
caudal vert.
ultimate vert.
otolith
otic bulla

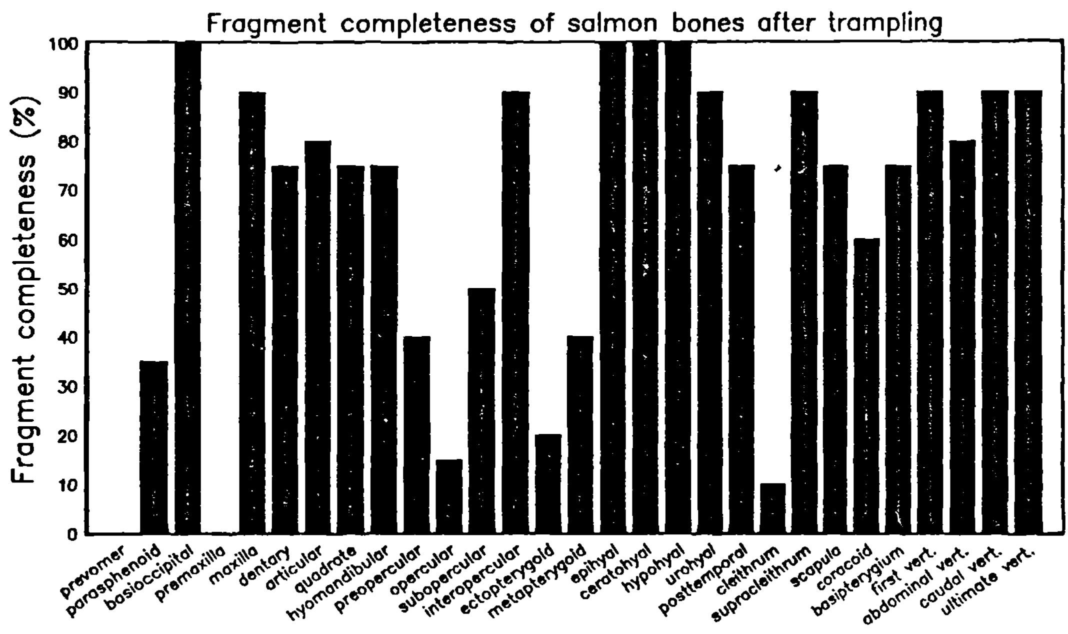

Fragment completeness of salmon bones after trampling
Fragment completeness (%)
100
90
80
70
60
50
40
30
20
10
0
prevomer
parasphenoid
basioccipital
premaxilla
maxilla
dentary
articular
quadrate
hyomandibular
preopercular
opercular
subopercular
interopercular
ectopterygoid
metapterygoid
epihyal
ceratohyal
hypohyal
urohyal
posttemporal
cleithrum
supracleithrum
scapula
coracoid
basipterygium
first vert.
abdominal vert.
caudal vert.
ultimate vert.

Table 5:21

Bone shape by depth within the substrate after trampling. All taxa. Fresh bones.

SHAPE	Count / Row % / Column % / Total %	DEPTH (mm) 0-20	20-40	40-80	80-150	Row Total
Flat	Count	250	235	193	8	686
	Row %	36.4	34.3	28.1	1.2	18.4
	Column %	22.7	17.5	15.4	22.9	
	Total %	6.7	6.3	5.2	.2	
Irregular	Count	102	97	55	3	257
	Row %	39.7	37.7	21.4	1.2	6.9
	Column %	9.3	7.2	4.4	8.6	
	Total %	2.7	2.6	1.5	.1	
Robust	Count	178	204	159	4	545
	Row %	32.7	37.4	29.2	.7	14.6
	Column %	16.2	15.2	12.6	11.4	
	Total %	4.8	5.5	4.3	.1	
Spherical	Count	459	646	529	9	1643
	Row %	27.9	39.3	32.2	.5	44.0
	Column %	41.8	48.0	42.1	25.7	
	Total %	12.3	17.3	14.2	.2	
Short	Count	55	89	192	4	340
	Row %	16.2	26.2	56.5	1.2	9.1
	Column %	5.0	6.6	15.3	11.4	
	Total %	1.5	2.4	5.1	.1	
Tubular	Count	55	74	129	7	265
	Row %	20.8	27.9	48.7	2.6	7.1
	Column %	5.0	5.5	10.3	20.0	
	Total %	1.5	2.0	3.5	.2	
Column Total		1099	1345	1257	35	3736
		29.4	36.0	33.6	.9	100.0

Chi-Square	Value	DF	Significance
Pearson's	175.18	15	<0.001

3 cells with exp. value <5.

reject the null hypothesis of no difference.

Combining depths 40-80 and 80-150 chi-square = 166.05, 10 degrees of freedom, significance <0.001

Table 5:22. Size of fragments (by size of mesh which they failed to pass through) by depth within the substrate, after trampling. All taxa, fresh bones.

SIEVE SIZE (mm)	Count / Row % / Column % / Total %	DEPTH (mm) 0-20	20-40	40-80	80-120	120-150	Row Total
1	Count	51	142	272	2	2	469
	Row %	10.9	30.3	58.0	.4	.4	12.0
	Column %	4.4	10.1	20.5	6.3	33.3	
	Total %	1.3	3.6	6.9	.1	.1	
2	Count	293	356	404	10		1063
	Row %	27.5	33.5	38.1	.9		27.2
	Column %	25.5	25.4	30.6	31.3		
	Total %	7.5	9.1	10.3	.3		
4	Count	673	780	570	16	4	2043
	Row %	32.9	38.2	27.9	.8	.2	52.2
	Column %	58.5	55.6	43.0	50.0	66.7	
	Total %	17.2	19.9	14.6	.4	.1	
10	Count	133	124	78	4		339
	Row %	39.2	36.6	23.0	1.2		8.7
	Column %	11.6	8.8	5.9	12.5		
	Total %	3.4	3.2	2.0	.1		
Column Total		1150	1402	1324	32	6	3914
		29.4	35.8	33.8	.8	.2	100.0

combining depths 80-120 and 120-150:

Chi-Square	Value	DF	Significance
Pearson's	204.59	12	<.001

Minimum Expected Frequency - 3.29

2 cells with exp. frequency <5.

reject the null hypothesis of no difference.

Table 5:23. Shape by fragmentation (percent of the whole bone represented by the fragment) per species, after trampling. Fresh bones.

SPECIES = Cod

SHAPE	Count / Row % / Column %	Fragment Completeness (%) 10-30	40-50	60-70	80-90	100	Row Total
Flat	Count	3	4	2	20	34	63
	Row %	4.8	6.3	3.2	31.7	54.0	22.3
	Column %	50.0	40.0	22.2	17.7	23.4	
Irregular	Count	1	2	4	6	22	35
	Row %	2.9	5.7	11.4	17.1	62.9	12.4
	Column %	16.7	20.0	44.4	5.3	15.2	
Robust	Count	1	4	3	9	44	61
	Row %	1.6	6.6	4.9	14.8	72.1	21.6
	Column %	16.7	40.0	33.3	8.0	30.3	
Spherical	Count	1			78	45	124
	Row %	.8			62.9	36.3	43.8
	Column %	16.7			69.0	31.0	
Column Total		6	10	9	113	145	283
		2.1	3.5	3.2	39.9	51.2	100.0

*excludes otoliths

SPECIES = Frog

SHAPE	Count / Row % / Column %	Fragment Completeness (%) 10-30	40-50	60-70	80-90	100	Row Total
Flat	Count		2	3	7	20	32
	Row %		6.3	9.4	21.9	62.5	10.4
	Column %		40.0	50.0	3.3	23.8	
Irregular	Count	1	1	2		2	6
	Row %	16.7	16.7	33.3		33.3	2.0
	Column %	50.0	20.0	33.3		2.4	
Spherical	Count		1		6	47	54
	Row %		1.9		11.1	87.0	17.6
	Column %		20.0		2.9	56.0	
Short	Count				116		116
	Row %				100.0		37.8
	Column %				55.2		
Tubular	Count	1	1	1	81	15	99
	Row %	1.0	1.0	1.0	81.8	15.2	32.2
	Column %	50.0	20.0	16.7	38.6	17.9	
Column Total		2	5	6	210	84	307
		.7	1.6	2.0	68.4	27.4	100.0

SPECIES = Herring

SHAPE (Count / Row % / Column %)	Fragment Completeness (%) 10-30	40-50	60-70	80-90	100	Row Total
Flat	4	6	17	35	64	126
	3.2	4.8	13.5	27.8	50.8	21.2
	50.0	40.0	54.8	12.2	25.5	
Irregular	1	4	7	4	14	30
	3.3	13.3	23.3	13.3	46.7	5.1
	12.5	26.7	22.6	1.4	5.6	
Robust		2	3	3	3	11
		18.2	27.3	27.3	27.3	1.9
		13.3	9.7	1.0	1.2	
Spherical	3	3	4	246	170	426
	.7	.7	.9	57.7	39.9	71.8
	37.5	20.0	12.9	85.4	67.7	
Column Total	8	15	31	288	251	593
	1.3	2.5	5.2	48.6	42.3	100.0

SPECIES = Haddock

SHAPE (Count / Row % / Column %)	Fragment Completeness (%) 10-30	40-50	60-70	80-90	100	Row Total
Flat	9	19	22	50	76	176
	5.1	10.8	12.5	28.4	43.2	20.1
	19.1	29.2	25.6	14.5	23.0	
Irregular	31	23	22	27	34	137
	22.6	16.8	16.1	19.7	24.8	15.7
	66.0	35.4	25.6	7.8	10.3	
Robust	7	20	40	60	98	225
	3.1	8.9	17.8	26.7	43.6	25.7
	14.9	30.8	46.5	17.3	29.7	
Spherical		3	2	209	122	336
		.9	.6	62.2	36.3	38.4
		4.6	2.3	60.4	37.0	
Column Total	47	65	86	346	330	874
	5.4	7.4	9.8	39.6	37.8	100.0

*excludes otoliths

SPECIES = Mouse

Fragment Completeness (%) — cells show Count / Row % / Column %

SHAPE		10-30	40-50	60-70	80-90	100	Row Total
Flat	Count	3	2	6	7	3	21
	Row %	14.3	9.5	28.6	33.3	14.3	7.2
	Column %	50.0	40.0	60.0	20.6	1.3	
Spherical	Count		2	1	25	87	115
	Row %		1.7	.9	21.7	75.7	39.5
	Column %		40.0	10.0	73.5	36.9	
Short	Count					93	93
	Row %					100.0	32.0
	Column %					39.4	
Tubular	Count	3	1	3	2	53	62
	Row %	4.8	1.6	4.8	3.2	85.5	21.3
	Column %	50.0	20.0	30.0	5.9	22.5	
Column Total		6	5	10	34	236	291
		2.1	1.7	3.4	11.7	81.1	100.0

SPECIES = Pigeon

Fragment Completeness (%) — cells show Count / Row % / Column %

SHAPE		10-30	40-50	60-70	80-90	100	Row Total
Flat	Count	3	2	1	2	9	17
	Row %	17.6	11.8	5.9	11.8	52.9	12.1
	Column %	18.8	20.0	50.0	22.2	8.7	
Irregular	Count	6			1	1	8
	Row %	75.0			12.5	12.5	5.7
	Column %	37.5			11.1	1.0	
Robust	Count				1	1	2
	Row %				50.0	50.0	1.4
	Column %				11.1	1.0	
Spherical	Count				4	34	38
	Row %				10.5	89.5	27.0
	Column %				44.4	32.7	
Short	Count					40	40
	Row %					100.0	28.4
	Column %					38.5	
Tubular	Count	7	8	1	1	19	36
	Row %	19.4	22.2	2.8	2.8	52.8	25.5
	Column %	43.8	80.0	50.0	11.1	18.3	
Column Total		16	10	2	9	104	141
		11.3	7.1	1.4	6.4	73.8	100.0

SPECIES = Plaice

SHAPE	Count / Row % / Column %	10-30	40-50	60-70	80-90	100	Row Total
		Fragment Completeness (%)					
Flat	Count	2	4	16	39	82	143
	Row %	1.4	2.8	11.2	27.3	57.3	21.8
	Column %	33.3	25.0	61.5	20.0	19.9	
Irregular	Count	2	6	2	11	12	33
	Row %	6.1	18.2	6.1	33.3	36.4	5.0
	Column %	33.3	37.5	7.7	5.6	2.9	
Robust	Count	2	5	8	24	181	220
	Row %	.9	2.3	3.6	10.9	82.3	33.5
	Column %	33.3	31.3	30.8	12.3	43.8	
Spherical	Count		1		121	138	260
	Row %		.4		46.5	53.1	39.6
	Column %		6.3		62.1	33.4	
Column Total		6	16	26	195	413	656
		.9	2.4	4.0	29.7	63.0	100.0

* excludes otoliths

SPECIES = Rat

SHAPE	Count / Row % / Column %	10-30	40-50	60-70	80-90	100	Row Total
		Fragment Completeness (%)					
Flat	Count	1	3	5	6	4	19
	Row %	5.3	15.8	26.3	31.6	21.1	5.3
	Column %	25.0	30.0	71.4	9.0	1.5	
Robust	Count		3				3
	Row %		100.0				.8
	Column %		30.0				
Spherical	Count		3	1	55	116	175
	Row %		1.7	.6	31.4	66.3	49.2
	Column %		30.0	14.3	82.1	43.3	
Short	Count				1	90	91
	Row %				1.1	98.9	25.6
	Column %				1.5	33.6	
Tubular	Count	3	1	1	5	58	68
	Row %	4.4	1.5	1.5	7.4	85.3	19.1
	Column %	75.0	10.0	14.3	7.5	21.6	
Column Total		4	10	7	67	268	356
		1.1	2.8	2.0	18.8	75.3	100.0

SPECIES - Salmon

SHAPE (Count / Row % / Column %)	Fragment Completeness (%) 40-50	60-70	80-90	100	Row Total
Flat	3	2	15	19	39
	7.7	5.1	38.5	48.7	21.4
	75.0	28.6	14.0	29.7	
Irregular	1	1	2	4	8
	12.5	12.5	25.0	50.0	4.4
	25.0	14.3	1.9	6.3	
Robust		4	7	12	23
		17.4	30.4	52.2	12.6
		57.1	6.5	18.8	
Spherical			83	29	112
			74.1	25.9	61.5
			77.6	45.3	
Column Total	4	7	107	64	182
	2.2	3.8	58.8	35.2	100.0

Table 5:24.

Fragment completeness (by percentage of the whole bone that the fragment represents) by depth within the substrate after trampling. All species. Fresh bones.

DEPTH (mm)

FRAGMENT COMPLETENESS (%)	Count / Row % / Column % / Tot Pct	0-20	20-40	40-80	80-150	Row Total
10-30	Count	38	51	28		117
	Row %	32.5	43.6	23.9		3.1
	Column %	3.5	3.8	2.2		
	Tot Pct	1.0	1.4	.7		
40-50	Count	74	42	30	2	148
	Row %	50.0	28.4	20.3	1.4	4.0
	Column %	6.7	3.1	2.4	5.7	
	Tot Pct	2.0	1.1	.8	.1	
60-70	Count	75	61	47	2	185
	Row %	40.5	33.0	25.4	1.1	5.0
	Column %	6.8	4.5	3.7	5.7	
	Tot Pct	2.0	1.6	1.3	.1	
80-90	Count	439	481	449	10	1379
	Row %	31.8	34.9	32.6	.7	36.9
	Column %	39.9	35.8	35.7	28.6	
	Tot Pct	11.7	12.9	12.0	.3	
100	Count	473	710	703	21	1907
	Row %	24.8	37.2	36.9	1.1	51.1
	Column %	43.0	52.8	56.0	60.0	
	Tot Pct	12.7	19.0	18.8	.6	
Column Total		1099	1345	1257	35	3736
		29.4	36.0	33.7	.9	100.0

Chi-Square	Value	DF	Significance
Pearson's	75.88	12	<.001

Minimum Expected Frequency - 1.10

3 cells with exp. value <5

reject the null hypothesis of no difference

Table 5:25

Correlations of mean fragment completeness (%) of trampled cod and haddock bones with mean density measurement m1 for cod bones and for haddock cleithra.

	Cod	Rank	m1	Rank	Haddock	Rank	m1	Rank
Ethmoid	100	35.0	0.88	5.0	95	35.0	0.88	5.0
Frontal	55	8.5	0.71	1.0	45	8.0	0.71	1.0
Prefrontal	50	6.5	0.84	3.0	45	8.0	0.84	3.0
Supraoccipital	80	22.0	0.86	4.0	60	13.5	0.86	4.0
Prevomer	75	18.0	1.20	23.0	45	8.0	1.20	23.0
Parasphenoid	65	13.0	0.99	10.0	45	8.0	0.99	10.0
Basioccipital	90	27.0	0.89	6.0	70	19.0	0.89	6.0
Premaxilla	100	35.0	1.44	29.0	90	30.0	1.44	30.0
Maxilla	95	30.5	1.42	27.5	75	22.5	1.42	28.5
Dentary	90	27.0	1.42	27.5	70	19.0	1.42	28.5
Articular	75	18.0	1.39	26.0	80	25.0	1.39	27.0
Quadrate	90	27.0	0.93	7.5	90	30.0	0.93	7.5
Hyomandibular	60	10.5	0.74	2.0	65	15.5	0.74	2.0
Symplectic	100	35.0	1.06	14.0	80	25.0	1.06	14.0
Lacrimal	30	3.0	1.07	15.0	30	3.5	1.07	15.0
Preopercular	70	15.0	0.95	9.0	70	19.0	0.95	9.0
Opercular	75	18.0	0.93	7.5	70	19.0	0.93	7.5
Subopercular	60	10.5	1.56	31.0	50	11.5	1.56	32.0
Interopercular	75	18.0	1.37	25.0	60	13.5	1.37	26.0
Palatine	80	22.0	1.13	18.0	95	35.0	1.13	18.0
Ectopterygoid	65	13.0	1.47	30.0	65	15.5	1.47	31.0
Epihyal	100	35.0	1.10	17.0	95	35.0	1.10	17.0
Ceratohyal	90	27.0	1.14	19.0	85	27.0	1.14	19.0
Hypohyal	75	18.0	1.57	32.5	95	35.0	1.57	33.0
Infrapharyngeal	50	6.5	1.02	11.5	75	22.5	1.02	11.5
Suprapharyngeal	30	3.0	1.16	22.0	40	5.0	1.16	22.0
Urohyal	90	27.0	1.63	36.0	70	19.0	1.63	36.0
Posttemporal	100	35.0	1.15	20.5	90	30.0	1.15	20.5
Cleithrum	95	30.5	1.57	32.5	45	8.0	1.35	25.0
Supracleithrum	100	35.0	1.09	16.0	100	38.0	1.09	16.0
Postcleithrum	55	8.5	1.25	24.0	50	11.5	1.25	24.0
Scapula	0	1.0	1.58	34.0	80	25.0	1.58	34.0
Coracoid	30	3.0	1.02	11.5	10	1.5	1.02	11.5
Basipterygium	65	13.0	1.60	35.0	10	1.5	1.60	35.0
Abdominal vert.	85	24.0	1.05	13.0	95	35.0	1.05	13.0
Caudal vert.	80	22.0	1.15	20.5	90	30.0	1.15	20.5

Spearman's Rank Correlations, at 34 degrees of freedom:

Cod and density m1 = 0.062, not significant
Haddock and density m1= 0.005, not significant
Cod and haddock= 0.651, significant at 99%.

Table 5:26

Correlations of mean fragment completeness (%) of trampled plaice bones compared with density (ml).

	Mean %	Rank	ml	Rank
Frontal	40	8.0	0.60	5.0
Prefrontal	30	5.5	0.59	2.0
Supraoccipital	30	5.5	0.76	13.0
Prevomer	65	13.5	0.48	1.0
Parasphenoid	60	12.0	1.72	36.0
Basioccipital	95	31.5	0.60	5.0
Premaxilla	90	26.5	1.00	21.0
Maxilla	95	31.5	1.25	31.0
Dentary	80	20.5	0.79	14.5
Articular	95	31.5	1.15	27.0
Quadrate	70	16.0	0.79	14.5
Hyomandibular	90	26.5	1.08	22.0
Symplectic	20	4.0	0.80	16.5
Preopercular	80	20.5	1.62	34.0
Opercular	70	16.0	1.24	30.0
Subopercular	40	8.0	1.20	29.0
Interopercular	80	20.5	1.14	25.5
Palatine	65	13.5	0.75	12.0
Ectopterygoid	40	8.0	0.90	18.0
Entopterygoid	15	3.0	0.60	5.0
Metapterygoid	5	1.0	0.70	10.0
Epihyal	100	35.0	0.60	5.0
Ceratohyal	90	26.5	0.60	5.0
Hypohyal	50	11.0	0.70	10.0
Infrapharyngeal	100	35.0	0.65	8.0
Suprapharyngeal	45	10.0	0.96	19.0
Urohyal	80	20.5	0.98	20.0
Posttemporal	90	26.5	1.17	28.5
Cleithrum	75	18.0	1.14	25.5
Supracleithrum	100	35.0	1.13	24.0
Scapula	90	26.5	0.70	10.0
Coracoid	10	2.0	0.80	16.5
Basipterygium	70	16.0	1.40	33.0
Abdominal vert	85	23.0	1.27	32.0
Caudal vert.	95	31.5	1.71	35.0
Anal pteryg.	90	26.5	1.10	23.0

Spearman's Rank Correlation Coefficient between Fragment Completeness and Density = 0.218, not significant at 34 degrees of freedom.

Table 5:27

Correlations of mean fragment completeness (%) of rat and mouse bones after trampling with density measurement ml.

		Rat (n=3)						Mouse (n=4)					
		No	Exp.	Mean %	Rank	Density	Rank	No	Exp.	Mean%	Rank	Density	Rank
Mandible	F	7	6	80	4.0	1.20	6.0	12	8	80	5.5	1.20	6.0
Scapula	F	6	6	65	2.0	1.43	7.0	6	8	55	4.0	1.43	7.0
Humerus	TU	5	6	75	3.0	1.15	4.0	8	8	95	8.5	1.15	4.0
Radius	TU	6	6	100	9.5	1.75	10.0	8	8	100	10.0	1.75	10.0
Ulna	TU	6	6	100	9.5	1.53	5.5	8	8	80	5.5	1.53	8.0
Pelvis	F	6	6	85	5.5	1.56	2.0	3	8	35	2.0	1.56	9.0
Femur	TU	6	6	95	8.0	1.16	8.5	8	8	95	8.5	1.16	5.0
Tibio-fibula	TU	7	6	85	5.5	1.13	7.0	9	8	85	7.0	1.13	2.5
Sacrum	R	3	3	50	1.0	1.13	1.0	0	4	0	1.0	1.13	2.5
Vertebrae	S	162	165	90	7.0	1.09	3.0	100	220	50	3.0	1.09	1.0

Spearman's Rank Correlation between Fragment Completness and Density at 8 degrees of freedom:

Rat : 0.382, not significant

Mouse : 0.245, not significant

* average density measurement for vertebrae

Table 5:28.

Correlation of mean fragment completeness (%) of pigeon bones after trampling, with density measurement ml.

	Mean %	Rank	ml	Rank
Scapula	65	4.0	1.62	14.0
Coracoid	60	2.5	0.70	5.0
Humerus	100	12.5	0.54	3.0
Radius	95	9.0	0.97	10.5
Ulna	70	5.0	0.71	6.0
Carpometacarpus	85	6.0	0.74	7.0
Phalanx I manii	100	12.5	1.20	13.0
Sternum	100	12.5	0.45	1.0
Pelvis	55	1.0	0.90	9.0
Synsacrum	95	9.0	0.69	4.0
Femur	100	12.5	0.81	8.0
Tibiotarsus	60	2.5	0.97	10.5
Tarsometatarsus	90	7.0	1.10	12.0
Vertebrae	95	9.0	0.53	2.0

Spearman's Rank Correlation between Fragment Completeness and Density: rho = -0.30, not significant at 12 degrees of freedom.

Table 5:29

Numbers and proportions of damaged fragments by depth within the substrate after trampling. All taxa, fresh bones.
Damage = erosion, scuffing, bending etc. but not fragmentation.

DEPTH	Count / Row % / Column % / Total %	Damage? No	Damage? Yes	Row Total
top 20mm	Count	1015	135	1150
	Row %	88.3	11.7	29.4
	Column %	27.9	49.5	
	Total %	25.9	3.4	
20-40mm	Count	1295	107	1402
	Row %	92.4	7.6	35.8
	Column %	35.6	39.2	
	Total %	33.1	2.7	
40-80mm	Count	1296	29	1325
	Row %	97.8	2.2	33.8
	Column %	35.6	10.6	
	Total %	33.1	.7	
80-150mm	Count	36	2	38
	Row %	94.7	5.3	1.0
	Column %	1.0	.7	
	Total %	.9	.1	
Column Total		3642	273	3915
		93.0	7.0	100.0

Chi-Square	Value	DF	Significance
Pearson's	88.13	3	<.001

Minimum Expected Frequency - 2.650
Cells with Expected Frequency < 5 - 1 OF 8 (12.5%)

reject the null hypothesis of no difference

Table 5:30.

Numbers and proportions of damaged bones by shape of bone.
Damage = erosion, scuffing, bending etc. but not fragmentation.
All taxa, fresh bones.

SHAPE	Count / Row % / Column %	Damage? No	Damage? Yes	Row Total
*Flat	Count	599	37	636
	Row %	94.2	5.8	17.3
	Column %	17.5	14.1	
Irregular	Count	221	36	257
	Row %	86.0	14.0	7.0
	Column %	6.5	13.7	
Robust	Count	524	21	545
	Row %	96.1	3.9	14.8
	Column %	15.3	8.0	
Spherical	Count	1483	160	1643
	Row %	90.3	9.7	44.6
	Column %	43.3	60.8	
Short	Count	340		340
	Row %	100.0		9.2
	Column %	9.9		
Tubular	Count	256	9	265
	Row %	96.6	3.4	7.2
	Column %	7.5	3.4	
Column Total		3423	263	3686
		92.9	7.1	100.0

*excludes otoliths

Chi-Square	Value	DF	Significance
Pearson's	77.37	5	<.001

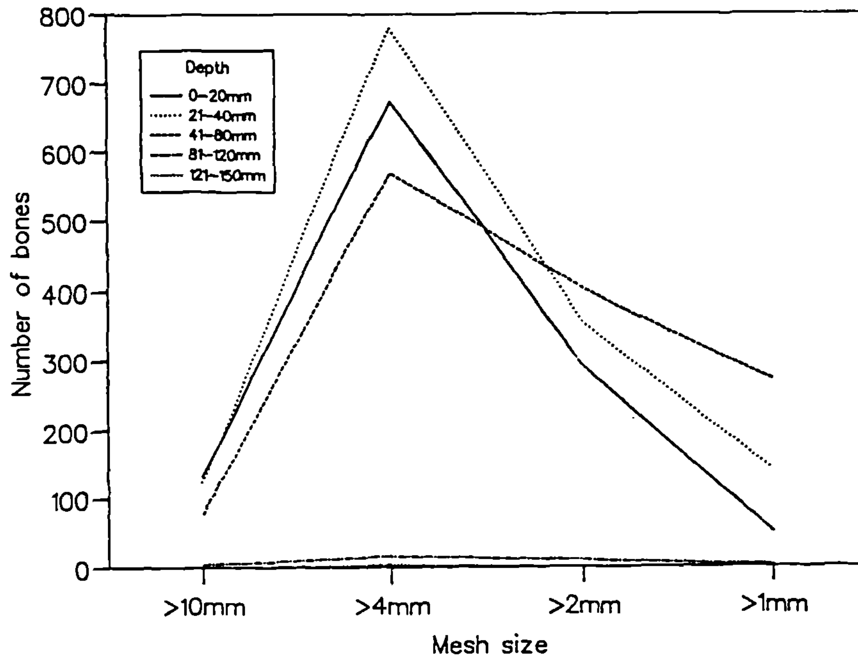
Minimum Expected Frequency - 18.337

reject the null hypothesis of no difference

FRAGMENT COMPLETENESS (%)	Count / Row % / Column %	COD	FISH nfi.	FROG	GADID nfi.	HERRING	HADDOCK	MOUSE	PIGEON	PLAICE	RAT	SALMON	Row Total
10-30	Count	11	1	2	2	8	61	6	16	6	4		117
	Row %	9.4	.9	1.7	1.7	6.8	52.1	5.1	13.7	5.1	3.4		3.1
	Column %	3.8	100.0	.7	100.0	1.3	6.8	2.1	11.3	.9	1.1		
40-50	Count	13		5		15	68	5	10	18	10	4	148
	Row %	8.8		3.4		10.1	45.9	3.4	6.8	12.2	6.8	2.7	4.0
	Column %	4.4		1.6		2.5	7.5	1.7	7.1	2.7	2.8	2.2	
60-70	Count	9		6		31	87	10	2	26	7	7	185
	Row %	4.9		3.2		16.8	47.0	5.4	1.1	14.1	3.8	3.8	5.0
	Column %	3.1		2.0		5.2	9.6	3.4	1.4	3.9	2.0	3.8	
80-90	Count	113		210		288	353	34	9	198	67	107	1379
	Row %	8.2		15.2		20.9	25.6	2.5	.7	14.4	4.9	7.8	36.9
	Column %	38.6		68.4		48.6	39.1	11.7	6.4	29.6	18.8	58.8	
100	Count	147		84		251	333	236	104	420	268	64	1907
	Row %	7.7		4.4		13.2	17.5	12.4	5.5	22.0	14.1	3.4	51.0
	Column %	50.2		27.4		42.3	36.9	81.1	73.8	62.9	75.3	35.2	
Column Total		293	1	307	2	593	902	291	141	668	356	182	3736
		7.8	.0	8.2	.1	15.9	24.1	7.8	3.8	17.9	9.5	4.9	100.0

FISH = FISH BONES NOT IDENTIFIED TO SPECIES; GADID = COD OR HADDOCK - BONES ONLY IDENTIFIED TO FAMILY

Table 5:31 Fragment Completeness (%) by taxon, after trampling. Fresh Bones.



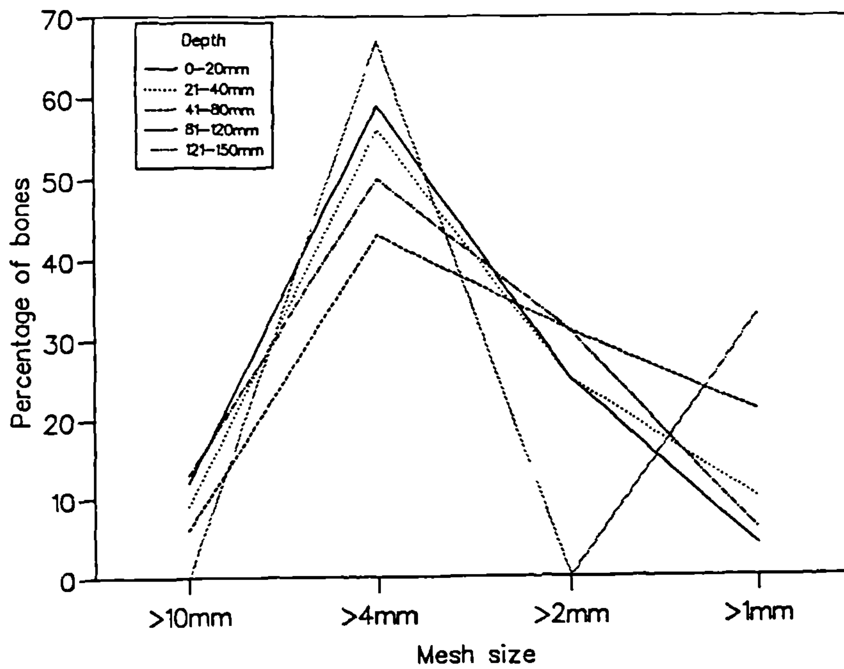
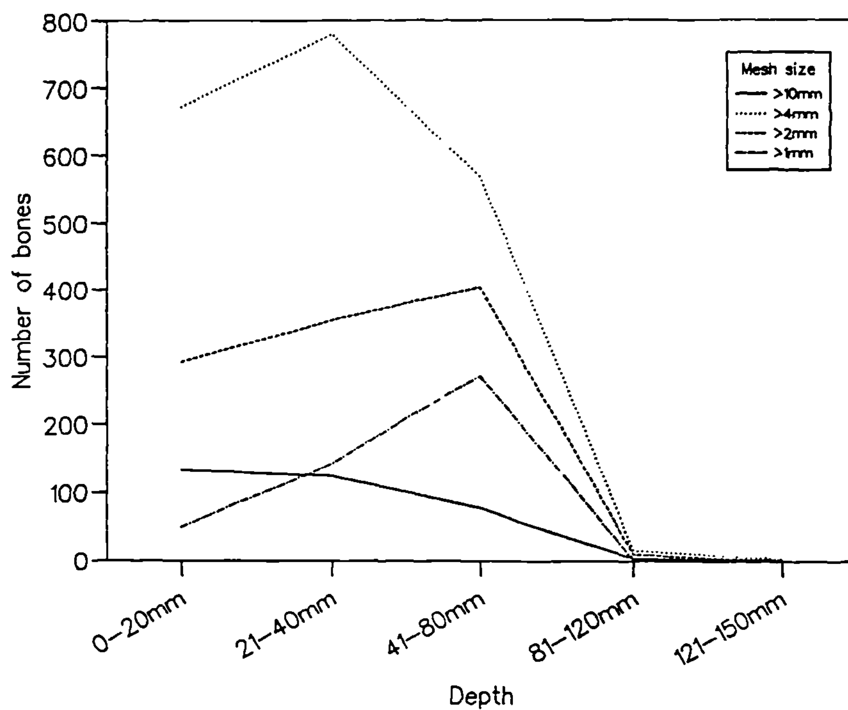
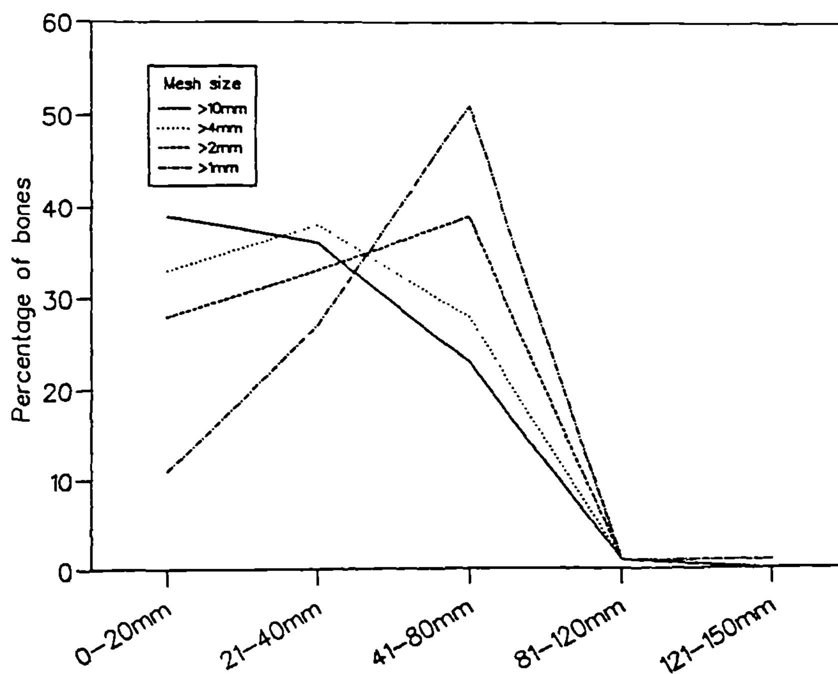


Fig. 5:4 Distribution of Fresh Bones by Size and Depth after Trampling.

Number of fresh bones by depth and size, after trampling



Proportions of fresh bones by depth and size, after trampling



Distribution of bones.

Despite the limitations of the classificatory system noted above, some patterning of bones was evident through the trampled substrate.

That bones were unevenly distributed with regard to depth within the profile, both in terms of shape and size is illustrated by Tables 5:21, and 5:22 and supported by chi-squared tests, both of which were significant at the 99% significance level, indicating non-random effects. The distributions of bones by depth and by size is illustrated in Fig. 5:4.

Short and spherical bones were more commonly found in the lower levels than all the other categories of bones, as were small bones (here defined as those fragments which pass through the 4mm. mesh). These groups comprise a large proportion of the mouse, frog and herring bones in particular (see Table 5:23). As a result the small bones were more often complete than the larger bones, and short and spherical bones were less fragmented than those classified as flat and tubular in particular. This trend was apparent for all species. Bones which remained on the surface were more fragmented than bones lower down the profile. This is illustrated in Fig 5:4 and Table 5:24 by the greater proportion of fragmented bones (less than 80% complete) than whole bones (80% or more complete) located in the upper 20 mm.

Density compared with mean fragment completeness of skeletal elements

As illustrated by Tables 5:25-5:28, there were no significant correlations between the rankings obtained for density measurement m1 and the mean fragment completeness values for cod, haddock, plaice, small mammal or pigeon bones. This indicates that the property defined as density does not significantly affect the extent to which complete

bones will break up under stress. This point is further developed in Chapter 8 (p.414).

Bone damage

Although proportionately few bones exhibited damage other than breakage, most of those that did were located in the top 20 mm. of the substrate at the end of the period of trampling (Table 5:29). Proportionately more "irregular" and "spherical" bones were damaged than the other shape-classes (Table 5:30). No "short" bones were damaged. Much of the damage to "spherical" bones was in the form of scuffed or squashed edges to the vertebrae of fish.

Fragmentation by taxon (Tables 5:31-5:32).

Probably due to the greater chance of small bones being buried, the bones of mouse, and frog survived relatively well (7.5% and 4.3% of fragments representing less than 80% of the original bone). Most of the loss of identified bones was probably due to retrieval deficiencies as far as the small metapodials and phalanges of mouse and frog are concerned. Loss of the soft ends to the long bones accounted for the high number of tubular bones classified as 80-90% complete for frog. Rat bones also survived well, with a very small proportion (5.9% of fragments representing 80% or less of the whole bone). Pigeon fared worse, with 19.8% of fragments of less than 80% of the whole bone, but the sample size was small (141 bones) compared with the other taxa.

In general fish bones fragmented to a greater extent, although there was considerable inter-species variation. Cod fared relatively well: only 8.8% of fragments represented under 80% of the whole bone. Haddock, however, fared worst with 22.6% of fragments representing under 80% of the complete bone. For plaice the figure was only 7.3%, herring 9.0% and salmon 6.0%.

Although these figures illustrate that even after 3500 traverses (an estimated 2 hours continuous trampling) most bones exhibited relatively little damage, the trends are interesting, especially in that the amount of destruction was not clearly related to the size of the animal concerned. Despite the small, obviously fragile nature of the bones of mouse, frog and herring, they fared well when the amount of fragmentation was compared with the apparently more robust bones of larger animals. Among the fish, while the larger skeletal elements of cod and salmon proved fairly resistant to fragmentation, the smaller, but superficially robust-looking bones of haddock proved to be more liable to fragmentation than the bones of any other taxa, including similar sized bones from similar sized plaice. Despite, or perhaps because of, the flat, papery nature of the herring head bones, many survived intact and undamaged.

Skeletal element representation, by species

As Tables 5:13-5:21 and Figs. 5:3a-i illustrate, fragmentation was not uniform: certain elements were more prone to destruction than others. It should be noted, however, that the figures for mean fragment completeness and proportion of whole bones, by skeletal element, refer to the identified fragments. Destruction, in this context, means failure to identify the bone. Some bones are easier to identify from fragments than others, so that while the cod parasphenoid, for example, may be identified to skeletal element and species from relatively small fragments, other bones, such as the nasal, have very little by way of diagnostic features to facilitate the identification of fragments. The use of diagnostic areas, to enable a mean fragment completeness value for each bone to be established, prevents the problem of some bones being over-represented due to their breaking up into a number of identifiable fragments. It does not prevent some bones appearing to be under-represented because fragments are not recognised, however. The patterns of fragmentation examined

from this experiment are therefore a product not only of the susceptibility of different bones to fragmentation but also to recognition. This is true for material recovered archaeologically, however, so the problem of differentiating between loss due to breakage and loss due to failure to recognise the fragments should not be seen as detrimental to this study.

Fish bones.

The skeletal elements used in this study have been confined to those bones which can be consistently recognised by myself for a number of fish taxa. Differences in skeletal design between taxa, and differences in the overall size of the fish used, mean that it is difficult to compare directly the extent of fragmentation between species, and not all skeletal elements could be recognised for all the fish used in the study. As the skeletons of cod and haddock are very similar in design, these two species are considered together, and most differences in fragmentation are probably attributable to the size of the fish used. The plaice used in the experiment were similar sizes to the haddock, and the herring only slightly smaller. While these species are considered separately, most of the differences in breakage between the bones of plaice, herring and haddock are probably due to variability in the density, overall shape and composition of the bones. The bones of salmon are considered separately, as the bones are larger than the bones of the other species considered here. Being cellular, the salmon bones are more akin to herring bones than to plaice, cod or haddock (which are acellular). However this difference is unlikely to be of great significance in determining the physical characteristics of the bone. Of more significance, perhaps, is the fact that salmon, herring and plaice bones both appear to contain more organic material than gadid bones. This has been determined by weight loss on ashing (see Chapter 3) and, more subjectively, can be observed when dealing with fresh, defleshed bones: salmon, herring and

plaice bones rapidly begin to exude oil and turn orange while gadid bones remain white and dry.

Cod and Haddock.

Although the haddock bones were generally more fragmented than cod, some general trends were apparent for both species. The least well-represented bones were the lacrimal, nasal, entopterygoid, metapterygoid, coracoid and ultimate vertebra (the last probably misidentified as a caudal vertebra when damaged, in some cases). With the exeption of the ultimate vertebra (classified as spherical, but including the flat hypural plates) and the nasal (classified as "irregular" owing to its' corrugated appearance) all these bones were classified as flat.

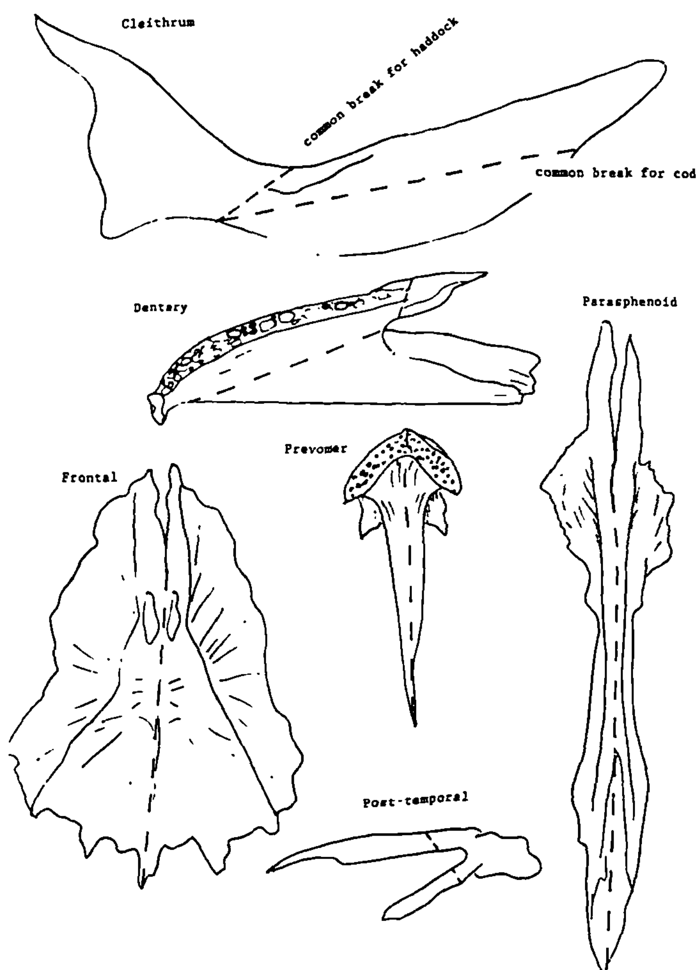


Fig. 5:5 Some of the Commonly Observed Breaks on Gadid Bones.

Bones which survived well included the ethmoid, basioccipital, premaxilla, maxilla, dentary, quadrate, articular, symplectic, palatine, ceratohyal, epihyal, hypohyal, urohyal, supracleithrum and vertebrae. These bones were classified as "robust", "flat" or "spherical". "Irregular" bones and some of the flat bones were the most easily fragmented. Those flat bones which survived well were the thicker, more compact bones such as the ceratohyal, epihyal and symplectic. The more plate-like bones of the opercular series, and the laminated frontal (perhaps in retrospect better classified as irregular) were more susceptible to fragmentation. The frontal tended to break characteristically along the mid line in the anterior-posterior plane, a fracture pattern commonly observed in archaeological material. The haddock cleithra were far more susceptible to breakage than the cod cleithra, generally breaking along the middle of the bone, dorso-ventrally, leaving a small proximal fragment and a larger, rather spherical and robust distal end. This portion of haddock cleithra is commonly found in archaeological deposits in the absence of other haddock bones, suggesting that it survives preferentially. Cod cleithra often exhibited breakage to the ventral margin, but not sufficient to divide the bone. Haddock dentaries also broke in a characteristic manner, with the tooth row and anterior symphysis surviving while the ventral portion broke away. Again this is commonly observed in archaeological material. Fig. 5:5 illustrates some of these common breaks.

The only other results available to me at the time of writing, of trampling experiments in which the relative survival of skeletal elements is discussed, were from the trampling of cod bones by Jones (forthcoming). Jones monitored the identifiability of all cod bones after 25, 75, 175 and 375 paces on a hard floor. All the bones of one large cod were placed in a mesh bag and trampled on. By examining the point at which bones were no longer identifiable, Jones constructed an "Index of Robustness",

with elements scoring from 1 to 5. Those bones which proved most durable, or identifiable the longest, were the parasphenoid, prevomer, dentary, premaxilla, maxilla and first vertebra. Slightly less durable were the last few caudal and first few abdominal vertebrae, post-temporal, opercular, quadrate and otolith. With the exception of some flat bones, in particular the ceratohyal, epihyal, symplectic and urohyal, as well as the palatine and hypohyal, which survived well in my experiments but poorly in Jones's, the sets of results are similar. Further trampling on a soft substrate and/or more replication for trampling on a hard substrate (which has the advantage of more rapid fragmentation, but is a less realistic situation) could further refine the ranking of skeletal element survival, or "Index of Robustness".

Plaice

Plaice bones survived well, and a large proportion remained whole. The least well represented bones included the prefrontal, supraoccipital, symplectic, entopterygoid, metapterygoid and coracoid. Of these the prefrontal and supraoccipital were classified as "irregular" and the other bones as "flat". All lack easily recognisable zones when fragmented. The basioccipital, premaxilla, maxilla, dentary, articular, hyomandibular, ceratohyal, epihyal, infrapharyngeal, urohyal, post-temporal, supracleithrum, scapula, vertebrae and first anal pterygiophore were the most intact bones. These include elements classified as robust, spherical and flat. Again, those bones classified as "flat" which survived well were relatively thick and compact when compared to the flat bones which survived less well. The smaller, more fragile-looking plaice otoliths survived better than the thicker and larger gadid otoliths (mean fragment size 85% for plaice, 50% for cod and 50% for haddock).

Herring

Herring was the least well represented of all the fish species, however many herring bones were surprisingly little altered by trampling given their apparently fragile state. The low average size of many of the bones is an indication in most cases of failure to recognise the broken fragments of bone, as many herring bones are difficult to identify when damaged. Most bones which were identified were complete, or nearly so. Of the least well surviving elements the frontal, premaxilla, preopercular, subopercular, interopercular, ectopterygoid, metapterygoid, prevomer, cleithrum, supracleithrum, scapula, coracoid and basipterygium were represented by a mean fragment completeness score of less than 50%. These bones were all classified as "flat" or "irregular". The best represented bones were the ceratohyal, supramaxilla and vertebrae; the last spherical, the other two flat.

Salmon.

Not surprisingly, given their size, many salmon bones remained intact. The vertebrae in particular are very resistant to physical pressure. The other best surviving bones include the ceratohyal, epihyal, maxilla, articular, interopercular, urohyal and supracleithrum. The poorest survivors were the preopercular, opercular, ectopterygoid, metapterygoid and cleithrum. In both the best surviving and worst surviving groups are bones classified as "flat" and "irregular". Those bones classified as "robust" all survived reasonably well. The flat bones which survived well were either relatively thick (e.g. ceratohyal, epihyal) or of uniform thickness (e.g. interopercular, supracleithrum). The flat bones which were fragmented were generally of large surface area, with flaking edges before the experiment began (e.g. opercular, preopercular). The cleithrum (classed as irregular) has relatively thin bone and a large surface area, but is irregularly shaped, so concentrating force on certain upstanding areas of bone.

Small Mammals.

The rat and mouse bones are treated together as the form of the bones is very similar; only the size of animal differs. The skull was not considered, as the patterns of fragmentation are complex and rely to a certain extent on the state of fusion of the sutures. Phalanges and metapodials, particularly of mouse, may be under-represented due to retrieval deficiencies. Despite the different sizes, the fragmentation patterns observed for rat and mouse showed a number of similarities although the mouse bones were more fragmented than the rat bones. In both cases the sacrum was poorly represented, and the scapula blade was generally broken. The long bones were variously fragmented, with the radius, ulna and femur being the most well represented of the rat long bones while the humerus, radius and femur were the most complete mouse long bones. All the recovered calcanea and astragali were intact (one mouse calcaneum was not recovered). The rat pelves survived better than those of mouse; the mouse pelvis was one of the most fragmented bones. Both rat and mouse mandibles remained relatively complete, with only some teeth lost and the ends of the processes broken in some cases. The vertebrae of the rats survived better than those of the mice. Possibly some of this was due to poor recovery of the mice bones, but many of the mice vertebrae appeared rather abraded. Of the vertebrae the caudal and cervical were better represented than the lumbar and thoracic group in both rats and mice, though the difference was more marked for mice.

Pigeon

The pigeon bones in general survived well, with the exception of the mandible, a rather thin, bone which snaps easily when oriented with its long axis at an angle to the horizontal. The pelvis too, classified as a flat bone, but possessing a curved surface, was susceptible to fragmentation. More surprisingly the apparently robust,

although flat, coracoid and rather thinner scapula also fragmented in a number of cases, although never into more than two pieces. Of the tubular long bones only the tibiotarsus and the ulna were broken in several cases. Both these bones have a relatively small diameter in relation to their length when compared with the other long bones. The skulls both broke into many pieces. The figures for mean fragment completeness could not easily be calculated because of the problems of identifying the areas of the skull from which the fragments originated.

Frog.

Of all the animals used in this experiment, the frog proved to have the most consistently robust skeleton. The maxilla and parietofrontal were the only head bones identified to skeletal element and considered in this analysis. Virtually all the bones recovered were intact, apart in most cases for the soft ends of the bones. The under-representation of the metapodials and phalanges is probably due to insufficient recovery rather than fragmentation. No broken metapodials or phalanges were recovered. The resistance of the frog bones is surprising; frog bones are extremely thin-walled and the limb bones are hollow. Presumably early burial protected the majority of the bones from destruction. Further work on the relative strength of frog bone compared with other forms of bone would be interesting but is beyond the scope of this work.

Mollusc shell

Of the molluscs, the garden snails all broke up into many pieces fairly rapidly, and by the end of the trampling period no identifiable fragments remained. During the experiment the apices of the garden snails were observed to be often the last pieces of the shell to remain. Mussel valves also fragmented in many cases. Of the thirty valves only seven remained intact, and these were among the

smallest of the valves. Additionally seven valves were 50% complete or more, all including the hinge portion. Four other mussel hinge portions were identified, but all other fragments were small (maximum size about 15 x 10 mm.). Even small pieces of mussel shell are usually identifiable, however, due to their blue colour which persists in archaeological material. No surface erosion was observed, and the nacreous layer did not separate from the exterior shell layer.

Only three of the periwinkle shells were broken, and in each of these cases only a small portion of the rim was missing. Twenty five of the limpet shells were complete and uneroded. Of the remaining five, all had portions or entire circumferences of the rim missing. Additionally, one shell had a hole worn near the apex. A few of the other limpet shells had worn, thinned patches on the apex which were not seen before the experiment.

Most shells were recovered from depths of between 20 mm and 80 mm. Only one limpet and a few fragments of mussel remained in the top 20 mm. (see Table 5:33).

Trampling experiment 2t.

The results are presented in Tables and Figures in the following pages, as numbers of recovered bones by taxon (Table 5:34), shape (Table 5:35), condition (Table 5:36), erosion (Table 5:37), fragment completeness (Table 5:38) and depth at which they were recovered (Fig. 5:6a-d).

Boiled Bones

Boiling had very different effects on the survival rates of fish, mammal, amphibian and bird bone (see Table 5.34). Due to the extremely small numbers of recovered fish bones, it should be noted that the mean fragment completeness values have been calculated from the recovered rather than the expected numbers of bones.

Table 5.33
Dry weights of fresh and of boiled bone and dry weight of shell, by size (sieve size through which the bones failed to pass) and depth, after trampling.

Depth (mm.)	Sieve size (mm.)	Weight of fresh bone (g.)	Weight of boiled bone (g.)
0-20	10	81.2	16.3
	4	99.1	13.2
	2	15.7	4.0
	1	3.3	0.3
	total	199.3	33.8
21-40	10	72.1	29.1
	4	103.2	22.9
	2	20.0	7.0
	1	6.9	0.5
	total	202.2	59.5
41-80	10	44.4	5.3
	4	64.8	9.5
	2	17.4	2.2
	1	10.0	0.4
	total	136.6	17.4
81-120	10	2.0	0.0
	4	0.8	0.5
	2	0.2	0.6
	1	0.01	0.0
	total	3.01	1.1
121-150	10	0	
	4	0.2	
	2	0.01	
	1	0.01	
	total	0.22	

Dry weight of shell by depth, after trampling.

Depth (mm.)	Weight (g.)
0-20	20.2
21-40	103.1
41-80	186.4
81-120	7.5
121-150	0
Total	317.2

Table 5:34

Recovered number, expected number and mean recovered fragment size of boiled bones identifiable after trampling (to nearest 5%).

	Cod				Haddock		
	Shape	No	Exp.	Mean %	No	Exp	Mean%
Parasphenoid	I	0	5	0	0	10	0
Maxilla	R	0	10	0	0	12	0
Dentary	R	0	10	0	0	12	0
Articular	R	0	10	0	2	12	20
Quadrate	R	0	10	0	0	12	0
Hyomandibular	I	0	10	0	0	12	0
Preopercular	F	0	10	0	0	12	0
Opercular	F	0	10	0	0	12	0
Interopercular	F	0	10	0	0	12	0
Palatine	R	0	10	0	0	12	0
Cleithrum	I	0	10	0	2	4	30
Posttemporal	R	0	10	0	0	12	0
Vertebrae	S	0	100	0	3	100	65
Otolith	-	4	4	75	6	6	80
Total		4	219		13	240	

	Plaice				Herring			
	Shape	No	Exp	Mean %	Shape	No	Exp	Mean %
Parasphenoid	I	0	8	0	I	0	8	0
Maxilla	R	0	12	0	R	3	12	40
Dentary	R	0	12	0	F	0	12	0
Articular	R	0	12	0	F	1	9	80
Quadrate	R	1	12	0	F	0	12	0
Hyomandibular	F	0	12	0	F	4	9	70
Preopercular	F	0	12	0	F	0	12	0
Opercular	F	1	12	50	F	0	12	0
Interopercular	F	1	12	60	F	0	12	0
Palatine	R	0	12	0				
Cleithrum	I	0	12	0	I	0	12	0
Posttemporal	R	0	12	0	F	0	12	0
Vertebrae	S	13	100	75	S	90	100	80 (70% if exp. value used)
Anal Pterygiophore	R	3	8	35				
Total		19	248			98	222	

	Salmon			
	Shape	No	Exp	Mean %
Parasphenoid	I	0	3	0
Maxilla	R	0	6	0
Dentary	R	0	6	0
Articular	R	3	6	30
Quadrate	R	0	6	0
Hyomandibular	F	1	6	70
Preopercular	F	0	6	0
Opercular	F	0	6	0
Interopercular	F	0	6	0
Cleithrum	I	0	4	0
Posttemporal	F	0	4	0
Vertebrae	S	16	100	35
Total		20	159	

	Dogfish			
	Shape	No	Exp	Mean %
Vertebrae	S	49	50	70

	Fish n.f.i			
	Shape	No	Exp	Mean %
Vertebrae	S	70	-	40

Table 5:34 cont'd...

	Shape	Rat No	Rat Exp	Rat Mean %	Small mammal No	Small mammal Exp	Small mammal Mean %
Mandible	F	4	4	80	5	6	55
Scapula	F	3	4	65	3	6	80
Humerus	TU	4	4	85	5	6	90
Radius	TU	4	4	90	6	6	100
Ulna	TU	4	4	100	4	6	100
Pelvis	F	4	4	75	5	6	75
Femur	TU	4	4	90	6	6	100
Tibia-fibula	TU	4	4	80	6	6	85
Sacrum	I	-	-	-	0	3	0
Astragalus	S	-	-	-	2	6	100
Calcaneum	S	-	-	-	2	6	100
Cervical vert.	S	10	10	100	10	24	95
Lumbar/Thoracic v.	S	10	10	95	9	78	90
Caudal vert.	S	10	10	100	3	50	100
Metapodials	TU	-	-	-	9	60	100
Total		61	62		75	277	

Pigeon

	Shape	No	Exp	Mean %
Scapula	F	8	8	100
Coracoid	F	8	8	100
Humerus	TU	8	8	100
Radius	TU	8	8	100
Ulna	TU	8	8	100
Carpometacarpus	TU	5	5	100
Femur	TU	8	8	90
Tibiotarsus	TU	8	8	100
Sternum	I	6	6	60
Pelvis	F	4	6	80
Vertebrae	S	23	30	90
Total		94	103	

Frog

	Shape	No	Exp	Mean %
Humerus	TU	9	10	90
Radius/Ulna	F	10	10	100
Femur	TU	9	10	90
Tibia-fibula	TU	10	10	90
Pelvis	F	10	10	85
Urostyal	I	5	5	95
Vertebrae	S	39	40	100
Metapodials	TU	20	20	90
Total		112	115	

Table 5:35 Shape by fragment completeness for boiled bones after trampling (all vertebrates).

Shape	Count / Row % / Column %	Fragment Completeness (%) 10-30	40-50	60-70	80-90	100	Row Total
Flat	Count	3	13	20	14	37	87
	Row %	3.4	14.9	23.0	16.1	42.5	13.4
	Column %	7.5	10.5	33.3	8.3	14.3	
Robust	Count	6	7	1			14
	Row %	42.9	50.0	7.1			2.2
	Column %	15.0	5.6	1.7			
Spherical	Count	30	101	34	103	121	389
	Row %	7.7	26.0	8.7	26.5	31.1	59.8
	Column %	75.0	81.5	56.7	61.3	46.7	
Short	Count					8	8
	Row %					100.0	1.2
	Column %					3.1	
Tubular	Count	1	3	5	51	93	153
	Row %	.7	2.0	3.3	33.3	60.8	23.5
	Column %	2.5	2.4	8.3	30.4	35.9	
	Column Total	40	124	60	168	259	651
		6.1	19.0	9.2	25.8	39.8	100.0

Chi-Square	Value	DF	Significance
Pearson	158.16	16	<.001

Minimum Expected Frequency - .492

Cells with Expected Frequency < 5 - 9 OF 25 (36.0%)

Reject the null hypothesis of no difference.

Table 5:36. Condition by Taxon for Boiled Bones after Trampling (includes * cod and haddock otoliths).

Condition (Count / Row % / Column %)	Cod	Dog-fish	Fish indet.	Frog	Herr-ing	Hadd-ock	Pigeon	Plaice	Rat	Salmon	Small mammal	Row Total
0	*5	71	3	114	54	*7	72		46		78	450
	1.1	15.8	.7	25.3	12.0	1.6	16.0		10.2		17.3	66.1
	100.0	94.7	4.3	97.4	55.1	41.2	74.2		68.7		82.1	
1.0		2		3	20	2	21	2	16	1	7	74
		2.7		4.1	27.0	2.7	28.4	2.7	21.6	1.4	9.5	10.9
		2.7		2.6	20.4	11.8	21.6	10.0	23.9	5.0	7.4	
2.0		2			9		3	4	5	1	10	34
		5.9			26.5		8.8	11.8	14.7	2.9	29.4	5.0
		2.7			9.2		3.1	20.0	7.5	5.0	10.5	
3.0					11		1					12
					91.7		8.3					1.8
					11.2		1.0					
4.0					3	2		2		2		9
					33.3	22.2		22.2		22.2		1.3
					3.1	11.8		10.0		10.0		
5.0			14		1	4		5				24
			58.3		4.2	16.7		20.8				3.5
			20.0		1.0	23.5		25.0				
6.0 and over			53			2		7		16		78
			67.9			2.6		9.0		20.5		11.5
			75.7			11.8		35.0		80.0		
Column Total	5	75	70	117	98	17	97	20	67	20	95	681
	.7	11.0	10.3	17.2	14.4	2.5	14.2	2.9	9.8	2.9	14.0	100.0

Table 5:37. Erosion by Taxon for Boiled Bones after Trampling (includes * cod and haddock otoliths).

Erosion	Count / Row % / Column %	Cod	Dog-fish	Fish indet.	Frog	Herr-ing	Hadd-ock	Pigeon	Plaice	Rat	Salmon	Small mammal	Row Total
0	Count	*5	71	3	116	62	*7	89	2	50	1	79	485
	Row %	1.0	14.6	.6	23.9	12.8	1.4	18.4	.4	10.3	.2	16.3	71.2
	Column %	100.0	94.7	4.3	99.1	63.3	41.2	91.8	10.0	74.6	5.0	83.2	
1.0	Count		2		1	30	2	5	3	12		7	62
	Row %		3.2		1.6	48.4	3.2	8.1	4.8	19.4		11.3	9.1
	Column %		2.7		.9	30.6	11.8	5.2	15.0	17.9		7.4	
2.0	Count		2			2		2	2	5	2	9	24
	Row %		8.3			8.3		8.3	8.3	20.8	8.3	37.5	3.5
	Column %		2.7			2.0		2.1	10.0	7.5	10.0	9.5	
3.0	Count			1		4		1	4		1		11
	Row %			9.1		36.4		9.1	36.4		9.1		1.6
	Column %			1.4		4.1		1.0	20.0		5.0		
4.0	Count						2		3		1		6
	Row %						33.3		50.0		16.7		.9
	Column %						11.8		15.0		5.0		
5.0	Count			66			6		6		15		93
	Row %			71.0			6.5		6.5		16.1		13.7
	Column %			94.3			35.3		30.0		75.0		
Column Total		5	75	70	117	98	17	97	20	67	20	95	681
		.7	11.0	10.3	17.2	14.4	2.5	14.2	2.9	9.8	2.9	14.0	100.0

Table 5:38. Fragment Completeness (%) of Boiled Bones by Taxon, after Trampling (including * cod and haddock otoliths, excluding two small mammal cranial fragments).

Fragment Completeness (%)	Count / Row % / Column %	Cod	Dog-fish	Fish indet.	Frog	Herr-ing	Hadd-ock	Pigeon	Plaice	Rat	Salmon	Small mammal	Row Total
10-30	Count	*2		23		1	(*1) 7	1	1		9	2	46
	Row %	4.3		50.0		2.2	15.2	2.2	2.2		19.6	4.3	6.8
	Column %	40.0		32.9		1.0	41.2	1.0	5.0		45.0	2.2	
40-50	Count		51	47	1	3	1	8	5	6	5	4	131
	Row %		38.9	35.9	.8	2.3	.8	6.1	3.8	4.6	3.8	3.1	19.3
	Column %		68.0	67.1	.9	3.1	5.9	8.2	25.0	9.0	25.0	4.3	
60-70	Count		1		4	18	(*1) 3	4	11	7	4	9	61
	Row %		1.6		6.6	29.5	4.9	6.6	18.0	11.5	6.6	14.8	9.0
	Column %		1.3		3.4	18.4	17.6	4.1	55.0	10.4	20.0	9.7	
80-90	Count	*1	11		48	75	(*1) 2	8	1	12	2	12	172
	Row %	.6	6.4		27.9	43.6	1.2	4.7	.6	7.0	1.2	7.0	25.3
	Column %	20.0	14.7		41.0	76.5	11.8	8.2	5.0	17.9	10.0	12.9	
100	Count	*2	12		64	1	*4	76	2	42		66	269
	Row %	.7	4.5		23.8	.4	1.5	28.3	.7	15.6		24.5	39.6
	Column %	40.0	16.0		54.7	1.0	23.5	78.4	10.0	62.7		71.0	
Column Total		5	75	70	117	98	17	97	20	67	20	93	679
		.7	11.0	10.3	17.2	14.4	2.5	14.3	2.9	9.9	2.9	13.7	100.0

(*) indicates that of the total, the number following the * are otoliths.

Table 5:39 Fragment completeness by major shape categories for boiled bones, after trampling (excluding otoliths).

DOGFISH

Shape	Count / Row % / Column %	Fragment completeness (%) 40-50	60-70	80-90	100	Row Total
Spherical	Count	44	1	10	11	66
	Row %	66.7	1.5	15.2	16.7	100.0
	Column %	100.0	100.0	100.0	100.0	
Column Total		44	1	10	11	66
		66.7	1.5	15.2	16.7	100.0

FISH (not further identified)

Shape	Count / Row % / Column %	Fragment completeness (%) 10-30	40-50	Row Total
Spherical	Count	23	47	70
	Row %	32.9	67.1	100.0
	Column %	100.0	100.0	
Column Total		23	47	70
		32.9	67.1	100.0

FROG

Shape	Count / Row % / Column %	Fragment completeness (%) 40-50	60-70	80-90	100	Row Total
Flat	Count		4	3	18	25
	Row %		16.0	12.0	72.0	20.8
	Column %		100.0	5.9	28.1	
Spherical	Count	1		3	36	40
	Row %	2.5		7.5	90.0	33.3
	Column %	100.0		5.9	56.3	
Short	Count			4		4
	Row %			100.0		3.3
	Column %			7.8		
Tubular	Count			41	10	51
	Row %			80.4	19.6	42.5
	Column %			80.4	15.6	
Column Total		1	4	51	64	120
		.8	3.3	42.5	53.3	100.0

HERRING

Count / Row % / Column % — Fragment compleţness (%)

Shape	10-30	40-50	60-70	80-90	100	Row Total
Flat	1		1	3		5
	20.0		20.0	60.0		5.1
	100.0		5.6	4.0		
Robust		3				3
		100.0				3.1
		100.0				
Spherical			17	72	1	90
			18.9	80.0	1.1	91.8
			94.4	96.0	100.0	
Column Total	1	3	18	75	1	98
	1.0	3.1	18.4	76.5	1.0	100.0

HADDOCK

Count / Row % / Column % — Fragment compleţness (%)

Shape	10-30	40-50	60-70	Row Total
Robust	4	1		5
	80.0	20.0		62.5
	100.0	100.0		
Spherical			3	3
			100.0	37.5
			100.0	
Column Total	4	1	3	8
	50.0	12.5	37.5	100.0

RAT

Count / Row % / Column % — Fragment compleţness (%)

Shape	40-50	60-70	80-90	100	Row Total
Flat	3	4	2	2	11
	27.3	36.4	18.2	18.2	15.9
	50.0	57.1	16.7	4.5	
Spherical	1		6	28	35
	2.9		17.1	80.0	50.7
	16.7		50.0	63.6	
Tubular	2	3	4	11	20
	10.0	15.0	20.0	55.0	29.0
	33.3	42.9	33.3	25.0	
Column Total	6	7	12	41	66
	9.1	10.6	18.2	62.1	100.0

PIGEON

Shape	Count / Row % / Column %	Fragment completeness (%) 10-30	40-50	60-70	80-90	100	Row Total
Flat	Count		6	3	4	15	28
	Row %		21.4	10.7	14.3	53.6	28.9
	Column %		75.0	75.0	50.0	19.7	
Spherical	Count		2	1	4	16	23
	Row %		8.7	4.3	17.4	69.6	23.7
	Column %		25.0	25.0	50.0	21.1	
Tubular	Count	1				45	46
	Row %	2.2				97.8	47.4
	Column %	100.0				59.2	
Column Total		1	8	4	8	76	97
		1.0	8.2	4.1	8.2	78.4	100.0

PLAICE

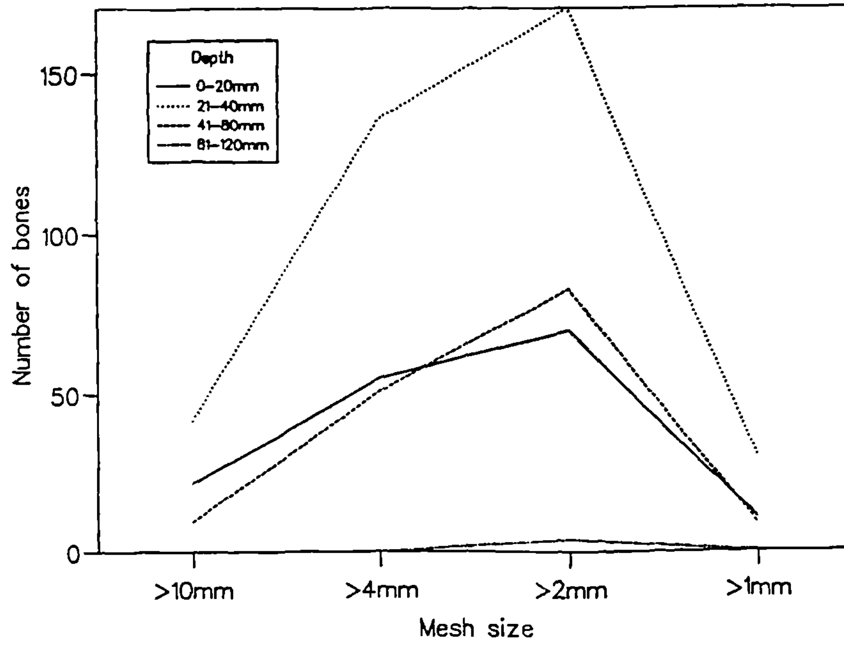
Shape	Count / Row % / Column %	Fragment completeness (%) 10-30	40-50	60-70	80-90	100	Row Total
Flat	Count		1	1			2
	Row %		50.0	50.0			10.0
	Column %		20.0	9.1			
Robust	Count	1	3	1			5
	Row %	20.0	60.0	20.0			25.0
	Column %	100.0	60.0	9.1			
Spherical	Count		1	9	1	2	13
	Row %		7.7	69.2	7.7	15.4	65.0
	Column %		20.0	81.8	100.0	100.0	
Column Total		1	5	11	1	2	20
		5.0	25.0	55.0	5.0	10.0	100.0

SALMON

Shape	Count / Row % / Column %	Fragment completeness (%) 10-30	40-50	60-70	80-90	Row Total
Flat	Count	1	1	1		3
	Row %	33.3	33.3	33.3		15.0
	Column %	11.1	20.0	25.0		
Robust	Count	1				1
	Row %	100.0				5.0
	Column %	11.1				
Spherical	Count	7	4	3	2	16
	Row %	43.8	25.0	18.8	12.5	80.0
	Column %	77.8	80.0	75.0	100.0	
Column Total		9	5	4	2	20
		45.0	25.0	20.0	10.0	100.0

SMALL MAMMAL

Shape	Count / Row % / Column %	Fragment completeness (%) 10-30	40-50	60-70	80-90	100	Row Total
Flat	Count	1	2	6	2	2	13
	Row %	7.7	15.4	46.2	15.4	15.4	14.6
	Column %	100.0	50.0	75.0	16.7	3.1	
Spherical	Count		1		5	27	33
	Row %		3.0		15.2	81.8	37.1
	Column %		25.0		41.7	42.2	
Short	Count					8	8
	Row %					100.0	9.0
	Column %					12.5	
Tubular	Count		1	2	5	27	35
	Row %		2.9	5.7	14.3	77.1	39.3
	Column %		25.0	25.0	41.7	42.2	
Column Total		1	4	8	12	64	89
		1.1	4.5	9.0	13.5	71.9	100.0



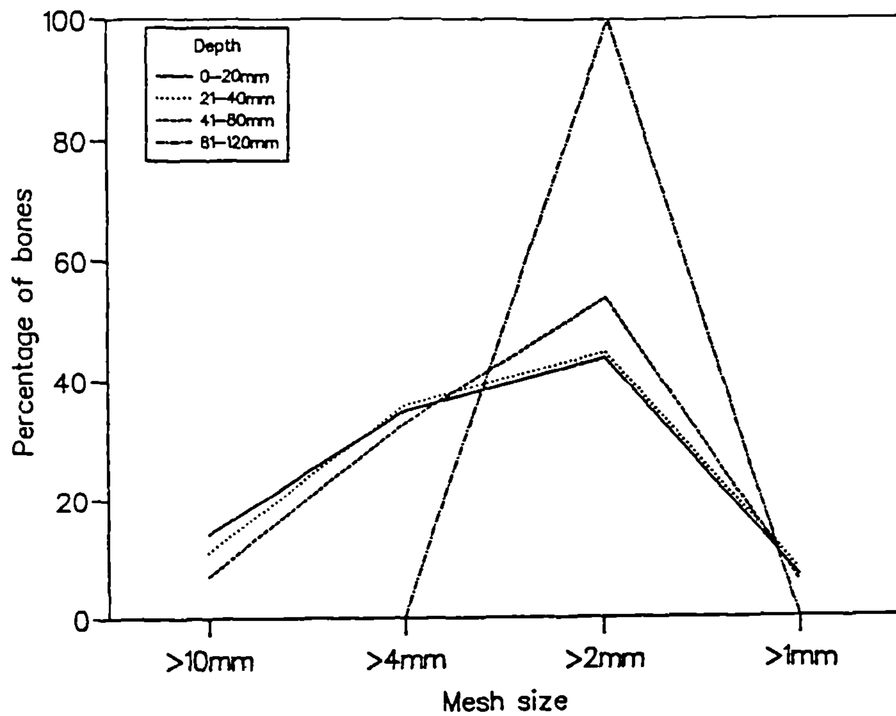
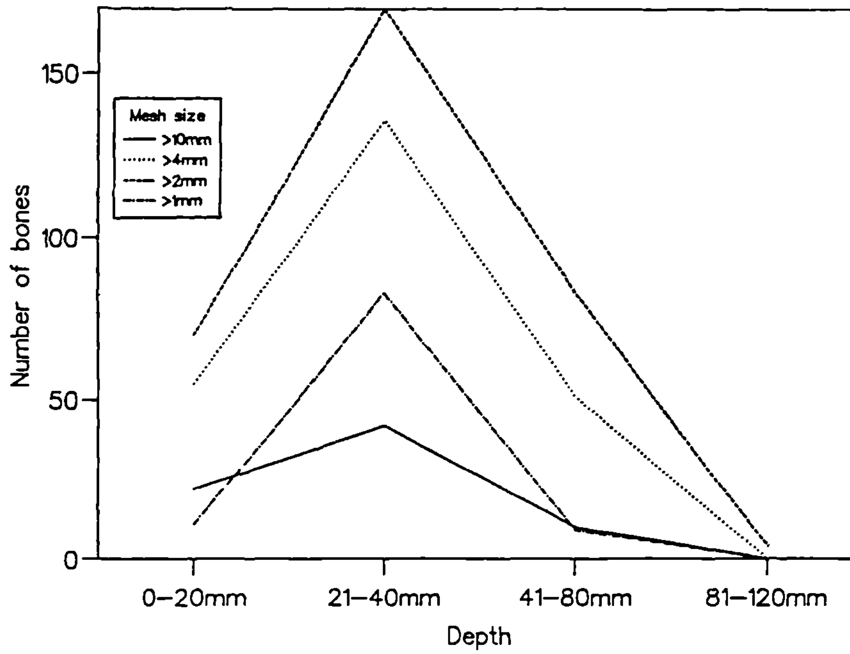
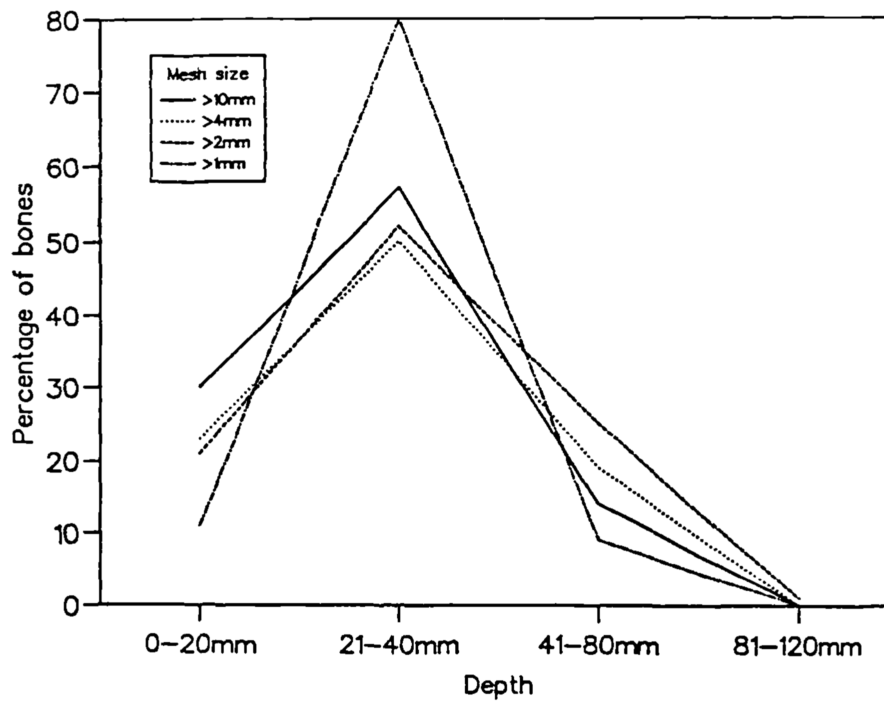


Fig. 5:6 Distribution of Boiled Bones by Size and Depth after Trampling.

Number of boiled bones by depth and size, after trampling



Proportions of boiled bones by depth and size, after trampling



Fish

Fish bones were generally extremely poorly preserved, and very few survived to an identifiable state at all. Even the larger salmon bones were easily fragmented. The salmon vertebrae, when recognisable, were generally broken into several pieces by the end of 3500 traverses. Very few of the cod and haddock bones remained identifiable: only the otoliths from cod, and two articulars, two cleithra, three vertebrae and all the otoliths remained identifiable from the haddock. Of the plaice, only one quadrate, one opercular, one interopercular, three anal pterygiophores and thirteen vertebral fragments were identified. Additionally seventy unidentifiable, extremely abraded and friable vertebrae were recovered, which must have been from cod, haddock and plaice.

Remarkably, 90% of the herring vertebrae were identified, compared with 13% or less for the other fish species. Also four herring hyomandibulars, three maxillae and one articular were recognised. Most of the herring bones were recovered from below 20 mm. depth, but so were most of the other fish remains.

Dogfish calcified centra also survived very well: 49 out of the original 50 were recovered, of which 23 were complete or lacking only the thin layer of tissue surrounding the body of the centrum. Of the remaining centra, most were only broken into the two articulating facets, although a small number had abraded edges to the centrum articulating facets.

Due to the very low rate of fish bone survival, no assessment could be made of the effect of shape on fish bone preservation.

Small Mammal, Pigeon and Frog

Mammal and pigeon bones survived better than fish bone,

and all or most bones were recovered and identified. Preservation was not dissimilar from that observed for the fresh bones, with most elements being intact or nearly so. Not surprisingly given the respective sizes, more mouse than rat bones were lost. The elements to suffer most were the scapula, sacrum, astragalus, calcaneum, vertebrae and phalanges. These are also the smallest bones, so some loss due to retrieval deficiences must be considered. Of the pigeon bones, the pelvis and vertebrae were the only elements for which all bones were not recovered. Sterna tended to be laterally flattened and often cracked, broken or bent. One femur was broken, but otherwise little damage was observed on the bones. Frog bones again survived extremely well, and loss of bone was minimal. About half of the recovered bones from all of these taxa were recovered from the top 20 mm. of the substrate.

Fresh Dogfish Centra

Of the fresh dogfish calcified centra, 38 out of the original 50 remained complete and undamaged. The remaining 12 were broken in half, and a small percentage of the centrum faces appeared abraded at the edges. Eleven complete centra and sixteen half centra remained on the surface.

Insects (see Appendix 5.2)

All assemblages were extremely fragmented, even though the small bag of insects was unlikely to have received 3500 steps, as assistants were unlikely to have trodden on the bag each time they traversed the box.

No remains of the *Calliphora* adults or puparia were identifiable, and only three pieces of *Tenebrio* larva, including two head capsules) survived.

The beetle remains were generally completely disarticulated and many sclerites were squashed one inside

another. These squashed remains had to be dissagregated before the individual components could be recognised and counted. Heads were the most frequently intact elements, followed by leg elements, coxae, episternae and the mesonotum (scutellum). About 50% of elytra and 50% of pronota were broken. The abdominal sternites were frequently articulated, but usually flattened and often torn. The concave surface of the sternites acted as a receptacle for many of the other elements which became squashed inside them. No colour changes were observed.

5.4.8 Movement of bones.

The extent to which the coloured vertebrae moved up and down through the profile is illustrated in Fig. 5:7. Of the 100 vertebrae originally placed on the surface, only four remained in the top 20 mm. after 3500 traverses. All but four travelled to a depth of 40-80 mm., the remaining four were recovered near the bottom of the profile, at 80-120 mm. Of the bones placed at a depth of 60 mm., two had migrated to the top 20 mm., while thirty two had moved down into the lowest excavated level (80-120 mm.). This illustrates that even with a relatively short period of trampling, objects can move both up and down a sediment profile, causing mixing of sequentially deposited horizons. The most common direction of movement was downwards but the fact that two (2%) vertebrae moved upwards by at least 40 mm. is important. Lateral movement was not examined, but would probably be significant, as demonstrated by Gifford-Gonzalez *et al.* (1985). The implications for interpreting archaeological deposits are obvious. This experiment utilised only one substrate: it would also be interesting to see what happens at the interfaces between sediments, analogous to archaeological contexts.

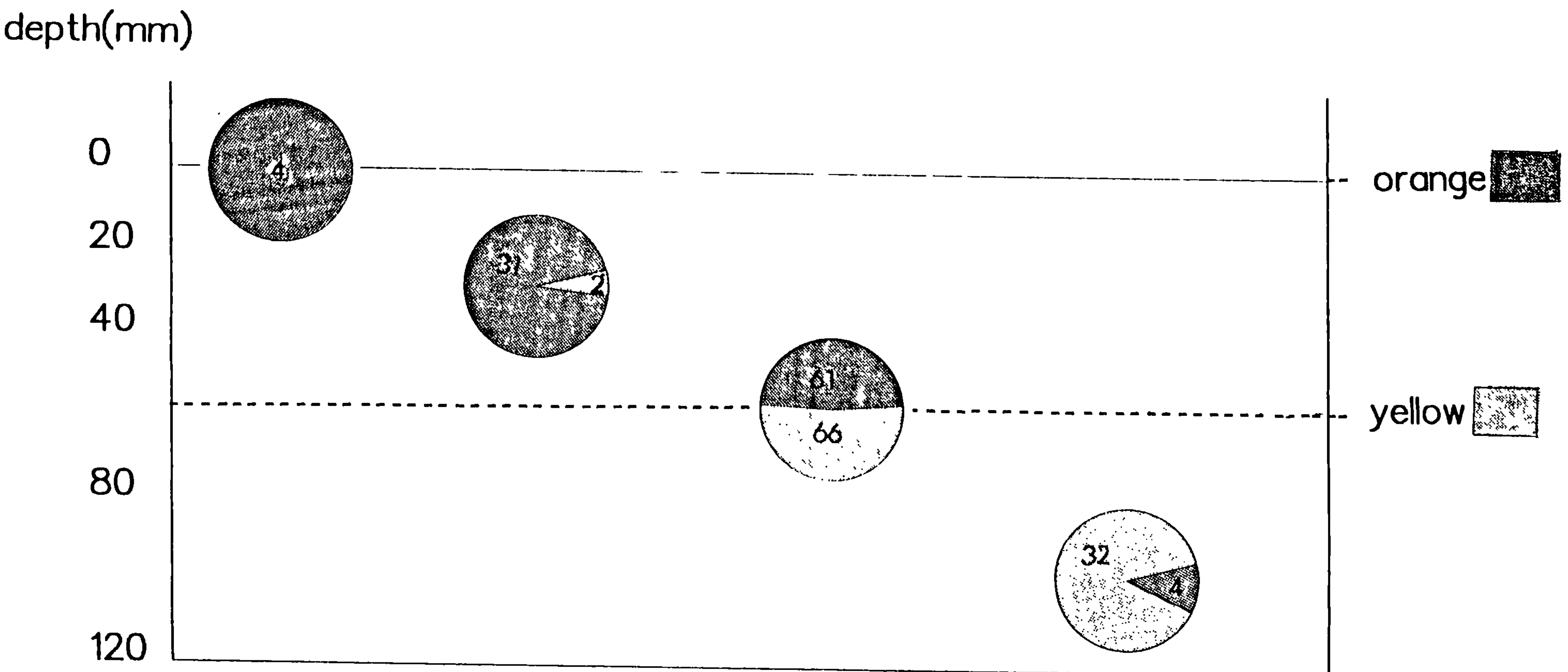


Fig. 5:7 Proportions of coloured bones by depth, after trampling

(the numbers on the pie-charts are the actual numbers of bones)

The movement of bone fragments downwards in this experiment is also illustrated in Figs. 5:6a-d, showing the distribution of the recovered boiled bones by the size of sieve mesh through which they failed to pass (mesh sizes as above). As illustrated, all sizes of bones showed an approximately normal distribution with depth, most fragments being recovered at a depth of between 20-40 mm. from the upper surface. This distribution was also observed by Gifford-Gonzalez *et al.* (1985). Proportionately more of the large bones (over 10 mm.) were located on the surface after trampling than the smaller bones, as illustrated in Figs. 5:4c and d.

While observations based on surface collections of bones and excavation of the underlying sediment at Amboseli in Kenya by Behrensmeyer *et al.* (1979) indicated to the authors that small bones were not preferentially buried, the experiments described above indicate that this observation may not always be replicated. Behrensmeyer *et al.* only excavated to 50 mm. beneath the ground surface. Even using the limited depth available in the experimental situation described in this chapter, it is clear that bones, especially small ones, may travel much further down a profile given a relatively small amount of trampling. Obviously the type of substrate will influence the extent to which bones will travel. Using two different substrates: light sandy silt with organic matter, and medium-fine sand, Gifford-Gonzalez *et al.* (1985) found that movement both horizontally and vertically varied with the type of substrate. Further experiments in the field using other types of sediments such as clay and a mixed waterlogged organic substrate, for example, are clearly required.

Movement down a sediment profile may also be induced by wetting and drying (as demonstrated by Cahen and Moeyersons (1977) and, assuming a fairly light substrate, burrowing animals (Armour-Chelu 1989, for example). Frost, too may open up cracks within the soil down which bones and shells, especially small ones, can fall.

5.5 Conclusions and Archaeological Implications from the Experiments into the Effects of Tumbling and Trampling.

Referring back to the questions posed in the introduction to this chapter and to the experiments, the results of the tumbling and trampling experiments have furnished interesting conclusions in several areas:

1. Under all the conditions of testing, fish bone proved to be weaker than mammal bone and appeared also to be weaker than bird and amphibian bone.

2. Within fish bone, the bone of gadids appears to be less resistant to erosion and fragmentation than similar sized plaice bone, and herring vertebrae are surprisingly resistant given their small size. Dogfish calcified centra also withstand abrasive force and more direct force from trampling better than might be expected given their fragile appearance. It is possible that the microstructure of calcified cartilage inhibits the propagation of cracks.

3. Considering the small size of the tested skeletal elements, and the hollow, fragile appearance of many of the bones, frog bone proved to be remarkably resistant to erosion and fragmentation when subjected to the kinds of forces applied in these experiments. Frog bones remained identifiable after all small mammal bones and almost all fish bones had disintegrated after extensive tumbling. Amphibian bone could therefore be expected to survive in some conditions where comparable sized mammal and fish bones do not.

4. Boiled bone is destroyed much faster than fresh bone under abrasive regimes and by trampling. Fish bone is particularly weakened by boiling. Boiled fish bone is therefore likely to disintegrate rapidly under most circumstances and so is unlikely to be recovered in archaeology. The physical properties of mammal, bird and amphibian bone appear to be less dramatically altered by

boiling, but quantitative methods of analysing changes in the physical properties are required.

5. Burnt bone survives very poorly when subjected to physical force, as is also demonstrated by the tests of the mechanical properties of burnt and fresh bone discussed in Chapter 4.

6. Bones which have been abraded can be recognised by their rounded appearance and smooth edges to breaks. No pitting was observed on any of the tumbled bones. When crushed, tumbled fish vertebrae can be recognised by the rolled or eroded edges to the centra, and abraded centrum faces often develop characteristically "squared" edges. Extensive periods of trampling may cause surface polishing to bones and to the edges of breaks (e.g. Gifford -Gonzalez *et al.* 1985) which can mimic the effects of sedimentary abrasion in a fluvial environment. A severely abraded assemblage should be distinguishable by the even rounding and polishing of most bones on all the bone surfaces, but lightly abraded assemblages, including those that have been reworked, may not be recognisable. Trampling did not cause distinctive and diagnostic striations on the bones such as have been reported by Behrensmeyer *et al.* (1986) and Fiorillo (1988) for experimentally trampled large mammal bones.

7. Otoliths which have been mechanically abraded can be distinguished from digested or acid-eroded otoliths by their rounded shape and reduced surface sculpturing. Depending on the digesting animal, acid-eroded otoliths commonly exhibit overall thinning of surfaces and some may show sculpting at the edges (see also Chapter 7).

8. Density *per se* does not appear to be the principal determinant of the extent to which bones will fragment. Shape, size and structure of the bone appear to be more important.

Currey has demonstrated (Currey 1969; 1984, 114) that increased mineralisation and corresponding density confers increased stiffness, and bending strength is also increased. Toughness, or the modulus of work (a measure of the work needed to break the bone) increases with mineralisation up to ash values of 65.5-67% (Currey 1969). The degreased sheep bone, with 67% ash, had the highest mineral component of any of the bone used in this study (see Chapter 3). Younger, less well mineralised bone is stronger on impact than heavily mineralised bone (Currey 1984, 94). Impact strength may be more important than bending or compressive strength when trampling is considered.

Although the lower ash component of fish bone when compared to mammal bone may account, in part at least, for its reduced resistance to physical and mechanical force in the context of the experiments under discussion, this view is undoubtedly overly simplistic. Low ash values for degreased frog bone (57%) and dogfish calcified cartilage (37%) suggest that their relatively high survival rates in both the trampling and tumbling experiments must be due to some other factor than the extent of bone mineralisation. The bone microstructure may be crucial by determining how cracks will spread. Gadid bones, which have high ash values when compared with the other fish species used, fragmented and eroded to a greater extent than some of the less well mineralised fish bones. Easom (1988) also found that caudal vertebrae from salmon were stronger and stiffer in compression than caudal vertebrae from similar sized saithe (*Pollachius virens*). Further investigations into the physical and mechanical properties of non-mammal bone are clearly required.

It is probable that, as well as the size and shape of bones, the organisation of the mineral and organic fraction is important in determining the susceptibility of bones to fragmentation and erosion when out of the body. Susceptibility to erosion as a result of abrasion, in

particular, is not necessarily related to the mechanical properties of strength, stiffness or toughness. This aspect of the investigation of bone is beyond the scope of the present study, however, and is better left to persons more qualified to discuss the mechanical properties and organisation of bone tissue.

9. Certain skeletal elements fragment in predictable ways. The breaks commonly exhibited are shown in Fig 5:5. Those fragments most likely to be misinterpreted, from the taxa used in this study, were from fish bones. The haddock cleithra frequently broke across the narrowest portion, leaving a small proximal and larger distal portion in virtually every case after both tumbling and trampling. The proximal end of the tooth row of gadid dentaries also broke away from the rest of the dentary in many cases, followed by fragmentation of the lower (ventral) margin. Gadid vomers were commonly split in half longitudinally. Gadid frontals also tended to break into two halves, longitudinally in a manner that could suggest splitting for extraction of the brain. The edges of flat bones of all the taxa tended to crack and break. These patterns of breakage are commonly observed on archaeological material (personal observations) and should not be used to indicate butchery. Some of the other common breaks to the cod bones, such as to the processes of the post-temporals were also observed by Jones (forthcoming).

Extensive amounts of fragmentation including these "signature" breaks may indicate assemblages of bones which have been subjected to trampling and/or, where combined with rounding of all edges and facets, abrasion before burial. This in turn would imply that skeletons were not rapidly buried, and loss of bone could therefore also have occurred by weathering (which should be visible on surviving bones, see Chapter 7) or scavenging, for example.

The results from the trampling experiments are most closely analogous to the effects that could be expected on

a path or unmetalled road surface, where constant trampling and pressure from, in more recent times, wheeled vehicles, could be expected to cause greater movement and breakage of objects given a longer time span than that possible in the limited experimental situation.

Whether trampling or some other process had affected the distribution of bones in an archaeological situation could be tested by examining the distribution of bones down the profile, looking for the effects of size-sorting (in the absence of evidence for other sorting mechanisms such as worm action). The successful implementation of this investigation would require that all soil be sieved to one or two millimetres, however, otherwise many small bones or fragments could be lost. Breakage of bones in the absence of surface erosion or exfoliation is also an indicator of a trampled assemblage, assuming no butchery marks are present.

As a final point, it is clear that the physical properties of bone alter as a result of the changes within the bone due to the effects of weathering and attack by bacteria and fungi. Dry bone has different physical properties to wet bone (Evans 1973). Once dry, bone becomes more porous and brittle, and these properties increases with the weathering process (Johnson 1985; 160). The variables affecting the potential of bone to fragment in a natural situation are therefore more complex than this simple experiment has suggested. It would be interesting to examine the effects of trampling weathered bone, as it is probable that bone depleted in organic matter would break in a different manner to fresh bone. Fiorillo (1988) suggests that weathered bone will tend to break longitudinally and transversely, whereas spiral fracturing is only caused when bone is fresh (the latter point has been extensively debated by several authors with relation to Dart's interpretation of bone tools, e.g. Myers *et al.* 1980). It is possible that, as with boiled bone, severely weathered fish bone may crumble rather than break.

CHAPTER 6. WEATHERING: THE EFFECTS OF CLIMATE AND SURFACE ENVIRONMENT.

This chapter examines the effects of climate on the potential for preservation of faunal remains. The processes examined here have been termed "weathering" by various authors (e.g. Brain 1967; Behrensmeyer 1978; Gifford 1981) who have investigated the effects of environmental variables on large terrestrial mammal bones. The experiments detailed here include a field experiment into subaerial weathering; laboratory experiments into the effects of freezing and thawing, and wetting and drying; and an experiment to try to isolate the effect of exposure on surfaces of variable pH.

6.1 Introduction

Weathering has been described by Shipman (1981, 115) as:

"the damage to body parts produced by exposure to the elements prior to deposition"

and by Behrensmeyer (1978, 153) as:

"the processes by which original microscopic organic and inorganic components of a bone are separated from each other and destroyed by physical or chemical agents operating in situ, either on the surface or within the soil zone".

It is confusion in the definition and use of the term "weathering" which has led some authors to maintain that weathering slows down or virtually stops after burial (e.g. Behrensmeyer 1978; Shipman 1981; Todd and Frison 1986). Yet if chemical deterioration is included in the definition of weathering, as is usually the case (explicitly so in Behrensmeyer's definition), the process must always continue after burial in aerobic sediments - otherwise all undisturbed skeletons would survive intact, which is not the

case. The definition given by Shipman is therefore the one which will be implicit when the term "weathering" is used in this text, so that it is the physical characteristics resulting from physical and chemical changes within the skeletal tissue after exposure to the climatic elements which are considered, in other words the effects of subaerial exposure.

The most obvious effect of exposure to the climatic elements in bone is dehydration, followed by cracking, flaking and warping. During weathering bones develop "split lines" along lines of structural weakness, as described by Tappen (1969; 1976) and Tappen and Peske (1970). These lines of weakness form between collagen bundles on the cortical surface of mammal bone, parallel to the long axis of the bone, as a result of desiccation (Ruangwit 1967). They can be described as lying along the "grain" of the bone, by analogy with wood. After the development of split lines the outer bone surface exfoliates, or flakes. This delamination forms along the longitudinal axis, following the split lines. Delamination thus causes the exposure of the inner bone surfaces, which may be of spongey bone, in which case weathering then causes erosion or dissolution of the bone.

A bone's resistance to physical forces is modified by weathering. As weathering proceeds the strength and hardness of bone are progressively reduced. In the presence of water and oxygen the organic component of bone is broken down and subsequently removed by leaching, which causes breakdown of the microstructure and consequent weakening of the tissue (Hare 1980). Weathering also causes some expansion of the mineral crystals, either through preferential leaching of the smaller calcite crystallites or recrystallisation of the smaller crystallites to form enlarged apatite crystals (Tuross *et al.* 1989a). Of these, the latter explanation is the more likely (A.M. Pollard pers. comm.). The expansion was found to be around 20% of the crystal length and 10% of the width, using

results obtained from adult wildebeest ribs exposed for 10 years in Kenya (Tuross *et al* 1989a). This growth was also observed in fossil specimens of human bone, indicating diagenetic alteration (Tuross , *et al.* 1989b). Expansion and contraction during freezing, thawing, wetting and drying are all likely to contribute towards the propagation of split lines and eventual disintegration of bone. This mode of physical disintegration could therefore be expected to arise more rapidly in some sorts of bone (e.g. fibrolamellar) than in others (e.g. compact haversian). Ground-water pH also affects the rate of weathering. Depending on the acidity or alkalinity of the soil, leaching of mineral and/or collagen will occur. Once collagen is removed, bone becomes chalky and easily crushed. Similarly leaching weakens calcareous shells rendering them chalky.

Insect cuticle is also subject to modification as a result of chemical and physical processes taking place above and below the soil. This is illustrated by the colour changes exhibited by cuticle in various acid and alkaline conditions (see Appendix 2.2) and by the changes in rigidity of the cuticle, which may become brittle or flexible in archaeological deposits (Kenward pers. comm.). Literature concerning the breakdown of insect cuticle is limited, however, and while a brief resumé of the composition of insect cuticle is given in Appendix 2.2, detailed discussion of the biochemistry of the breakdown of the various proteins and chitin within insect cuticle is beyond the scope of this work.

6.2 Background

Behrensmeyer (1978) described six weathering stages which she successfully correlated with known time since death, these are given in Table 6:1. From this she argued that the weathering stage exhibited by bones within an assemblage could be used to infer the length of time that the bone had been exposed prior to burial, and that allochthonous and

autochthonous deposits of bones could be distinguished by the range of weathering states exhibited.

Table 6:1.

Definitions of Behrensmeyer's weathering stages (1978).

Stage	Description
0	No flaking or cracking; greasy; soft tissue present.
1	Cracking parallel to fibre structure.
2	Flaking of outer surface, usually associated with cracks; flakes are long and thin with one edge attached to the bone; crack edge angular; exfoliation started.
3	Bone surface rough, fibrous texture; weathering only 1-1.5 mm. deep; crack edges rounded.
4	Bone surface coarse, rough and fibrous; large and small splinters loosely attached; weathering penetrates to inner cavities; cracks open.
5	Bone mechanically falling apart into pieces, very fragile.

Lyman and Fox (1989) have comprehensively discussed the problems associated with inferring the length of time for which a bone has been exposed prior to burial, using Behrensmeyer's weathering stages. It is clear that climate, species of animal and age of animal all contribute to the rate at which a bone will decompose (Lyman and Fox 1989; Gifford 1977; 1981). Hare (1980) has shown that weathering states correlate with progressive amino acid racemisation, and the rate at which this takes place is related to local conditions such as pH, humidity, light and temperature. Neighbouring bones or areas on the same bone may weather at different rates depending on the microclimates to which they are exposed. Brain (1967) observed that bones in the shade weather substantially less in a given period than bones exposed to full sunshine. Furthermore, different skeletal elements may weather at different rates dependent upon their size and structure. It is therefore not possible to infer the length of time a bone may have been exposed prior to burial unless very detailed information about the climate and microclimate to which it was exposed are known, which is extremely unlikely

for archaeologically recovered material.

Miller (1975) examined the bones of large mammals which had been exposed for various lengths of time, from less than one year to over a hundred years in a desert environment. He also conducted experiments into the propagation of cracks on large mammal limb bones as a result of wetting and drying, and freezing and thawing. He concluded that cracks were a result of drying out rather than freezing and thawing.

The decomposition of a piglet was studied by Payne (1965) who observed the activities of insects on the carcass and established six stages of decomposition/disarticulation. Voorhies (1969) looked at the decomposition and disarticulation of a calf, coyote, rabbit, badger, and raccoon in a semi-arid environment. These studies confirmed that both processes are strongly temperature-dependent. No weathering stages were described for the bones of these animals.

In Britain, Andrews and Cook (1985) studied the disarticulation, dispersal, weathering and other surface modifications to the skeleton of a cow in Somerset. After seven and a half years very little weathering was observed. Stallibrass (1986) considered the effects of weathering on sheep and deer bones, some from complete carcasses others isolated elements, exposed for a number of years, although the exact timespan was not always known.

Dodson (1973) investigated the decomposition of a mouse in water, while Korth (1979) observed the disarticulation of several small mammals placed outdoors, beneath a screen. Dodson found that the mouse took 77 days to decompose, completely whereas Korth's mammals were completely disarticulated in five to six days; another three to nine days were required for complete disarticulation. Neither of these experiments included investigations of bone weathering, but Voorhies (1969) observed that small mammal

bones were soft and starting to disintegrate in advance of large mammal bones, after one year of subaerial exposure. Korth (1979) suggested that the bones of small mammals must be buried rapidly after disarticulation if they are to survive.

The only study touching on the effects of climatically induced weathering on the bones of non-mammals is that of Gifford (1977) who examined some bones of fish and reptiles which had been deposited with other bones during occupation of human campsites in Kenya. She suggested that the bones of these non-mammals disintegrate more rapidly than those of mammals, but had only a few observations on which to base this suggestion. Dodson (1973) investigated the disarticulation sequence of frog skeletons in water. This paucity of experimental work aimed at elucidating the effects of weathering on non-mammal bone caused Gifford (1981, 417) to point out that "detailed work on the weathering of non-mammalian bone is required". It is likely that the patterns of weathering on non-mammal bone may vary from that experienced by mammal bone due to differences in basic bone structure and skeletal design.

6.3 Aims

When archaeozoologists examine a collection of excavated animal remains one of the most important questions pertaining to the value of the assemblage is whether the remains are representative of what was originally deposited. Answering this question requires an understanding of the predepositional processes which have affected the assemblage, in particular whether the remains were buried rapidly or were left on the ground surface for extensive periods of time prior to burial. If the latter is the case, then considerable dispersal and destruction of the remains could be expected, which would reduce the chances of the recovered assemblage being a representative sample of that originally deposited. Even more critically, if the remains were buried and then re-exposed, becoming

reburied with remains of animals deposited at a later period, the archaeologically recovered assemblage could give a completely erroneous picture. Its detailed study would then yield invalid conclusions, and waste both specialists' time and financial resources (unless other forms of evidence demonstrated a residual component).

Investigating the deterioration of skeletal remains resulting from exposure to the climatic elements therefore has an important practical application. If assemblages of bone which have been exposed prior to burial can be distinguished, then research priorities can be constructed or modified based on an appreciation of the limitations of the evidence which can be obtained *from the recovered* remains. A study of weathering states may also enable the archaeozoologist to recognise assemblages of mixed origin and likewise modify the research strategy accordingly.

The overall aim of the investigation described in this chapter was to examine and compare the weathering of skeletal remains from a range of animals, including fish, bird, small mammal, large mammal, amphibian, molluscs and insects. It was intended not only to examine the results of the weathering process on different skeletal materials, but also to determine to what extent the rates of, and the physical consequences of, weathering varied between different materials and as a result of cooking. Specifically, the aims were to:

a. Examine the rates and patterns of decay of a wide range of different skeletons.
b. Investigate the rates and patterns of decay of skeletal elements within an animal.
c. Explore the effects of cooking on the rates and patterns of decay.
d. Assess the effects of cycles of wetting and drying and freezing and thawing on skeletal material.
e. Examine the consequences for the survival of calcareous materials of placing skeletal tissues on surfaces

saturated with solutions of varying pH.

By understanding the processes of physical breakdown in animal tissues as a result of weathering and the variability which may result, it may be possible to distinguish:

1. When an assemblage has been subaerially weathered.
2. The sorts of modifications to the skeletons which may have obtained as a result of prolonged weathering.
3. When an assemblage has originated from more than one source.

Three series of experiments are described in this chapter, the first examining the effects of subaerial weathering in the field (to answer questions a-c) the second looking at the effects of repeated cycles of freezing and thawing and of wetting and drying in the laboratory (question d) and the third investigating the effects of different surface pH solutions (question e). The methods and results of each experimental series are described separately, but the discussion combines all three.

I recognise that *much of what is presented in* this chapter is superficial in its nature. This is a consequence of the potential breadth of the subject area, not all permutations of which could be investigated in the time available. In the same vein as for the thesis as a whole, the experiments detailed in this chapter and discussion following from them do not aspire to be all-embracing exploration of the processes subsumed under the term "weathering". Instead, the intention was to have a relatively rapid look at the variability in rates and patterns of decay between different taxa, treatments and within a skeleton.

6.4 An Experiment into the Effects of Subaerial Exposure

When initially planning this project my aim had been to compare the effects of burial within different soil environments on a range of animal remains, the "control" for which would be the examination of subaerial weathering by placing a similar range of faunal remains away from the soil, but exposed to the climatic elements. For logistical reasons, while twenty sets of organic remains were buried in a selection of soil environments these have not yet been excavated and the results do not form part of this research programme. Brief details of the buried assemblages are given in Appendix 6.1, and it is intended to excavate and study these groups of material at a later date. The "control" experiment was set up as described below and has been monitored on a regular basis as a study of the effects of subaerial weathering on mammal, bird, fish and amphibian bone, mollusc shell and insect cuticle. The consequences of boiling and baking on the survival of bone were also investigated.

6.4.1 Materials and methods

A selection of animal remains were placed in a metal mesh cage, of dimensions 1 $m.^3$, which contained a shelf, also constructed of metal mesh, which divided the cage into an equal-sized upper and a lower section. The cage was constructed of 10 mm. wire mesh, and all surfaces were initially covered with a finer (approximately 5 mm.) plastic mesh. This outer layer was added to prevent the loss of bones by aeolian action, but the overall design of the cage allowed light, rain and wind to penetrate. The insect remains were placed together in a fine mesh nylon bag (mesh size less than 1 mm.) for the same reason. The cage was placed on a rooftop, over a surface of free-draining coarse gravel (Plate 6:1).

The assemblage of animal remains, as originally conceived, comprised similar assemblages for each of the

burial locations and for the group exposed to subaerial weathering. This group included mammal, bird and fish bones (both fresh and cooked) insects and molluscs. All the animal remains had been frozen for up to one year prior to the experiment. Details of the animal remains used are given below, Table 6:2. All of animals were partially skeletonised by defleshing before placing in the cage, with the object of obtaining some useful results on bone weathering within the limited time available for research. Complete animals were added at a later stage to examine the early stages of decomposition and disarticulation (see below). The animal remains were placed in the cage, initially with uncooked remains on the floor and the cooked remains on the shelf. This organisation was changed with each monitoring, to even out the effects of shade which was greater for the remains on the floor of the cage. All articulated animal remains were placed loose in the cage, but once the skeletons had begun to disarticulate into small units the bones were progressively placed in nylon mesh bags to prevent loss. Placing bones in mesh bags was a compromise between preventing loss of bones by wind action and exposing them to the climatic elements. Rain penetration was particularly important, as the passage of water through the skeletal tissue causes amino acid racemisation and leaching of protein and mineral from bones (Hare 1980, 212). Sunlight also bleaches the bones; bones in the shade degrease and weather at a much slower rate (Brain 1967).

Monitoring of the condition of the bones was undertaken approximately every four months for the first twenty months and finally after another six months.

Table 6:2
The Assemblage of Animals Placed in the Cage in June 1988.

Large Mammal: Fresh, defleshed bones from the lower limb (metapodial and below) of cow; two sets of sheep lower limb bones, one set fresh but defleshed, and the other set roasted in the flesh for one hour at 200°C and subsequently defleshed.

Small Mammal: One brown rat: skinned and partially defleshed.

Bird: One pigeon: plucked and partially defleshed.

Fish: Two cod: one fresh, filleted (total length 0.44 m) and one boiled for 60 minutes (total length 0.425 m).
Two plaice: one fresh, filleted (total length 0.35 m) and one baked in the oven at 200 °C for fifteen minutes (total length 0.32m).
Two herrings: one fresh (total length 0.29 m) and one baked in the oven at 200 °C for fifteen minutes (total length 0.265 m).
One whiting: filleted (total length 0.33 m).

All the cooked fish were defleshed.

Molluscs: Six periwinkles *Littorina littorea*, six cockles *Cerastoderma edule* (empty shells).

Insects: Ten adult bluebottles, ten adult *Tenebrio* beetles, ten puparia of *Calliphora vomitoria* .

Burnt bones: One sheep metapodial, one sheep first or second phalanx, one one cod first vertebra and one cod otolith: each set heated to one of 200°C, 400°C and 900°C.

Further skeletons were added to the cage at later dates to extend the range being studied. These included:

Small mammal: A complete brown rat.

Fish: A complete haddock and a complete herring.

These were added in November 1988 in order to assess the process of decay and disarticulation on complete specimens. Other remains added were, in February 1989:

Molluscs: Six limpets *Patella vulgata*, six garden snails *Helix aspersa*, six mussel valves *Mytilus edulis* and six horse mussel valves *Modiolus modiolus* (Empty shells).

In March 1989:

Mammal: Limb bones, scapulae, mandibles and vertebrae from rabbit, boiled for one hour.

Fish: One plaice (total length 0.35 m) and one herring (total length 0.27 m) boiled for one hour, and defleshed.

In August 1989:

Fish: Selected head bones and vertebrae from salmon.

Bird: One pigeon, boiled for one hour followed by partial defleshing.

Amphibian: One frog.

Obviously the time available for this work has been relatively short in terms of the time required for bone decay, particularly in the absence of ground-water and soil-borne bacteria and fungi. For those skeletal remains added late to the experiment the exposure time has been particularly short, and the effects are accordingly limited. The results should therefore be viewed more as an interim report on a continuing experiment rather than a completed investigation.

The weather during the two years duration of the experiment was atypical for Britain, typified by mild, fairly dry, winters with very little frost, and hot, dry summers.

6.4.2 Recording.

At each monitoring stage the cage was removed from the roof and the contents photographed, described and, when completely disarticulated and showing evidence of bone breakdown, each bone was recorded for texture, extent of erosion, flaking, cracking and size and area represented by the bone fragment. Observations were made in the laboratory using a 60 watt desk lamp, or, where small bones were involved, a X10 microscope was utilised. The categories of texture, erosion and flaking, each scored in the range 0-5, were summed to provide a condition category with a potential range of 1 - 15. These scores may be grouped into larger divisions, which can be translated into weathering groups. All the scores, species information and treatments were stored in D-Base III+ and interrogated using the statistical package SPSSX.

Based on actual observations of the insect remains in this experiment a set of stages has been described for the insect remains. No other published accounts of the weathering of insect cuticle are available. These stages correspond to those given in Appendix 2.3. It had

originally been intended to relate the changes in insect cuticle to stages observed and documented from the chemical alterations visible in insect cuticle after cumulative periods of time in various chemical solutions. The results of these latter experiments are presented in Appendix 2.2. In practice, however, there was very little visible alteration to the appearance of the insect cuticle, although the processes of disarticulation and fragmentation are worthy of notice.

6.4.3 Results

Bones

Disarticulation.

The complete haddock, herring and rat which were placed in the cage in November 1988 decomposed slowly. Details of the stages of decomposition observed are given below (Table 6:3), as are details of the disarticulation of the fresh, but partially defleshed, animals (Table 6:4). The disarticulation stages observed in the cooked specimens are not given, as many of the bones were disarticulated as a result of cooking prior to the experiment so the results would be of minimal value. Where little change was recorded between observations the average disarticulation stage is described and all the relevant observation dates appended.

Table 6:3. Disarticulation stages observed for the complete animals.
(Times, in weeks, refer to the periods of observation, starting when the animal in question was introduced into the cage).

Haddock.

1. 6 weeks. Stomach area split. Body dry and the soft tissue shrunken and dehydrated.
2. 32 weeks. Some abdominal vertebrae exposed, but still greasy. The body was still complete and the head dried out but intact. Some of the bones of the opercular series appeared dry and slightly flaky on the exposed (left) side of the fish. The scales were warped and flaky.

3. 48 and 62 weeks. Abdominal vertebrae exposed, stained brown by contact with the decomposing flesh. Some of the upper abdominal vertebrae were disarticulated but still lay in position on the decomposing body. Some of the head bones were separated from the main corpse and lay in groups of articulated elements; for example the jaws and jaw support bones were articulated with the left preopercular, interopercular and hyal series. Completely disarticulated elements included the cleithra (which separated first), coracoids, one scapula, opercular, hyomandibular, symplectic and two infrapharyngeals. The cranium remained intact and articulated with the remaining elements of the spine.
4. 90 weeks. Flesh almost completely decomposed, only the caudal region was covered in flesh, but even here most of the vertebrae were exposed to a degree. Most abdominal vertebrae were completely disarticulated and jumbled; the lowest three abdominal and first few caudal vertebrae rested *in situ* on decomposing flesh. The cranium, including the parasphenoid, basioccipital, lacrimals, premaxillae, left maxilla and cranial bones, was articulated, but defleshed and slightly dry. The rest of the head and pectoral bones were disarticulated, although a few bones (e.g. a group comprising the dentaries and articulars, right hyomandibular and preopercular, ceratohyals and epihyals) were articulated together. The bones were slightly greasy, and uncracked.

Herring.

1. 6 and 32 weeks. Body dry and flesh shrunken and dehydrated.
2. 48 and 62 weeks. Stomach area split, but the body was dry and the soft tissue shrunken.
3. 90 weeks. Body substantially decomposed, but still intact. The head was dry and split from the base of the gill cover through the throat to articulation of the dentaries, exposing the gills and base of the cranium. Where vertebrae could be discerned in the mass of rotting flesh, they were intact and stained brown. All bones were greasy and uncracked.

Rat.

1. 6 weeks. Body largely intact, but substantial decomposition of the flesh had occurred. Some cervical vertebrae were displaced and the head was attached only by matted fur and skin. The mandible, ribs, pelvis, femur and tibia of the upper (right) side were exposed, but were still greasy.
2. 32 weeks. Most bones were exposed in a cocoon of matted fur. The mandibles were disassociating from the skull, and further displacement of the vertebrae had occurred.
3. 48 and 62 weeks. Body held together only by matted fur. Scapulae, mandibles, cervical and some thoracic vertebrae were disarticulated, and the ribs, femur, tibia, pelvis and mandible on the upper (right) side were exposed and dry, although no cracking or flaking was observed.
4. 90 weeks. Body completely disarticulated except for the

caudal vertebrae, which were still held together within the tough skin of the tail. All bones were white and dry, and the tympanic areas of the skull were broken (this may be due to a blow on the head when the rat was killed). No cracking or flaking was observable to the naked eye.

Table 6:4 Disarticulation stages observed for the fresh, partially defleshed animals. (Times, in weeks, refer to periods of observation, starting when the animal in question was introduced into the cage).

Fish

1 Herring 16 weeks. Body completely articulated, bones greasy .
2. Herring 32, 52 and 64 weeks. Body completely articulated except for the cleithra.
3. Cod, whiting and plaice, 16 weeks; plaice 32, 52 and 64 weeks; herring 89 and 109 weeks. Majority of the body was articulated, but areas of the jaw and cheeks had separated as groups of associated elements. The cleithra had disarticulated completely. Some groups of vertebrae may be disarticulated from the majority of the corpse.
4. Cod, 32, 52 and 64 weeks; plaice 89 weeks. Majority of the head disarticulated, but the cranium and associated bones (i.e. prevomer, parasphenoid, basioccipital) remained articulated together, as were groups of associated facial and jaw/jaw support elements. The viscera and gills adhered with the bones of the branchial and hyal series. The spine was disarticulated from the cranium, but large groups of vertebrae were articulated together.
5. Whiting 32 and 52 weeks; cod 89 weeks; plaice 109 weeks. Most of the skeleton was disarticulated, except for the cranium and associated bones (including the parasphenoid, basioccipital and prevomer). Groups of conjoining vertebrae remained. Pairs or groups of articulating bones included the ceratohyals with epihyals and hypohyals, the post-temporals with supracleithra, and combinations of bones of the opercular series and groups of jaw elements. The bones were mainly degreased.
6. Whiting 64, 89 and 109 weeks, cod 109 weeks. The corpse was completely disarticulated except for the cranium (including the parasphenoid, prevomer and basioccipital). Other articulated bones included the ceratohyal with the epihyal and groups of 2-4 vertebrae. Bones were dry but little flaking or cracking was observed.

Rat.

1. 16 weeks. Body completely articulated except for mandibles.
2. 32 and 52 weeks. Body mainly articulated, but all legs, both mandibles, and one scapula had disarticulated from the main body. Bones greasy.

3. 64, 89 and 109 weeks. Pelvis disarticulated and the upper three cervical vertebrae and the atlas were completely separate, disconnecting the head from the body cavity. Some bones appeared dry.

Pigeon.

1. 16 weeks. Body completely articulated, mandible loosely attached.
2. 32 and 52 weeks. Legs, wings, mandible and sternum disarticulated, as were the cervical vertebrae, in groups of 4-6, separating the head from the main body. The leg and wing elements were articulated as limb units. All bones were greasy.
3. 64 and 89 weeks. Femora had separated from the tibiotarsi and these in turn had separated from the lower legs. Both humeri were completely unattached. Both radii and ulnae had separated from the rest of the wing but were articulated together. The left scapula and coracoid had disarticulated from the main body as a pair, the other scapula and coracoid were joined as a unit with the furcula. The cervical vertebrae were articulated in groups of 2-6.
4. 109 weeks. As above, but the right foot had begun to detach. Most bones were still greasy; the skull and the sternum being the exception.

Weathering.

Although relating to large mammal remains in an arid environment, Behrensmeyer's stages (Table 6:1) are useful as a means of providing standard descriptions for the conditions of skeletal remains subject to the process of physical breakdown as a result of exposure. For this reason observations on the states of the bone assemblages in the present study have been compared with Behrensmeyer's weathering states, and, where relevant, the terminology used to describe the weathering stages observed is similar. Where she has described six stages, only five have been defined in this study (Table 6:5). Stages 3 and 4 in this analysis (bones brittle to crumbly, extensive exfoliation) conflate Behrensmeyer's stages 3, 4 and 5, as the subtle differences between her later stages could not be distinguished on the more rapidly disintegrating fish bone. These stages have been assigned to each skeletal group at each observational period, and are given in Table 6:6. This Table illustrates the speed of breakdown of the skeletons

from the different animals and between different treatments for the same species.

Table 6:5 Definitions of the Weathering Stages used in this Study, with the Condition Categories which Describe them.

Stage	Description	Condition Category
0	Bone greasy, no cracks.	1
1	Bone dry, no cracks or only few, very superficial cracks.	2-3
2	Bones dry and brittle or chalky, some flaking of outer surface, usually associated with superficial cracks mostly parallel to the fibre structure. Flakes long and thin with one edge at least still attached to the bone.	4-5
3	Bones dry and brittle to crumbly; surface rough with extensive exfoliation and eroded areas.	6-8
4.	Bones extremely crumbly and fall apart easily. Deep cracks and fissures penetrate the whole bone.	9-15

Table 6:6 Average Weathering States of Bones after Sub-aerial Exposure in the Absence of Soil.

	TIME (WEEKS)						
	10-16	26-32	44-48	55-71	82	109	
Cow Foot	0	0	0	0	0	0	
Sheep Foot	0	0	0	0	0	0	
Sheep Foot, Boiled	0	0	1	1	1	1	
Whiting	0	1	1	1	1	1	
Cod	0	0	1	1	1	1	(Cranium 2)
Cod, Boiled	1	2	2	3/4	4	4	
Plaice	0	0	0	0	1	1	
Plaice, Baked	0	1	1	1	1	1	(Cranium 2)
Plaice, Boiled	1	1	2	3	-	-	
Herring	0	0	1	0	1	1	
Herring, Baked	0	1	1	1	2	2	(Vert. 1)
Herring, Boiled	0	1	2	2	-	-	
Rat	0	0	0	1	1	1	
Pigeon	0	0	0	0	1	1	
Pigeon, Boiled	0	0	0	1	-	-	
Rabbit Bones, Boiled	0	1	1	1	-	-	
Frog	0	0	0	1	-	-	
Salmon Bones	0	0	0	0/1	-	-	

\- = NOT RECORDED. As some remains were placed in the cage after the start of the experiment their states were recorded after different lengths of time to the rest of the experimental assemblage.

All skeletons were complete but partially defleshed, except where otherwise stated.

One clear trend emerged from the experiment: cooking, particularly boiling, dramatically decreased the resistance of the fish bones to weathering. Boiled bones in particular disintegrated rapidly; the boiled cod bones were extremely crumbly, fragmented, eroded and cracked by the last observation of the experiment (after 26.5 calendar months). The same rapid decay was observed in the boiled plaice and herring skeletons, which had been exposed for 16 calendar months by the final observational period. The boiled sheep, pigeon and rabbit bones, although dry, had not weathered to any real extent during the period of exposure, however. The baked plaice and herring were degreased more rapidly than the fresh bones. They exhibited superficial split lines on a proportion of the bones, particularly the vertebrae, but had not otherwise weathered by the end of the period of exposure.

There was no evidence from this experiment to indicate that the bones of oily fish, such as herring, disintegrate due to the autolysis of the bones by fatty acids in aerobic conditions. This explanation has been used by Lepiksaar and Heinrich (1977, 75, 113-4, 116) to explain the lack of herring bones on archaeological sites, a fact more likely attributable to poor recovery and lack of sieving.

Of all the animals used in the experiment, the fish of the Gadidae weathered more rapidly than the other animals subjected to the same treatment; the uncooked whiting and cod weathered more rapidly than the other uncooked skeletons, and the boiled cod weathered faster than any other skeleton. Plates 6:2a-c illustrate the distinctive characteristics of weathering observed on the vertebrae of whiting (fresh), herring (boiled) and cod (boiled) by the end of the period of exposure. These Plates show early and late stages of weathering. In the early stages radial cracks were observed which penetrated the outer layers of bone, causing peeling and flaking of the surface. At this

Plate 6:1 Subaerial Exposure: The Cage *in situ*.

Plate 6:2a Weathered Whiting Vertebra, fresh bone exposed sub-aerially for 109 weeks (S.E.M., right-hand scale bar = 100 μm).

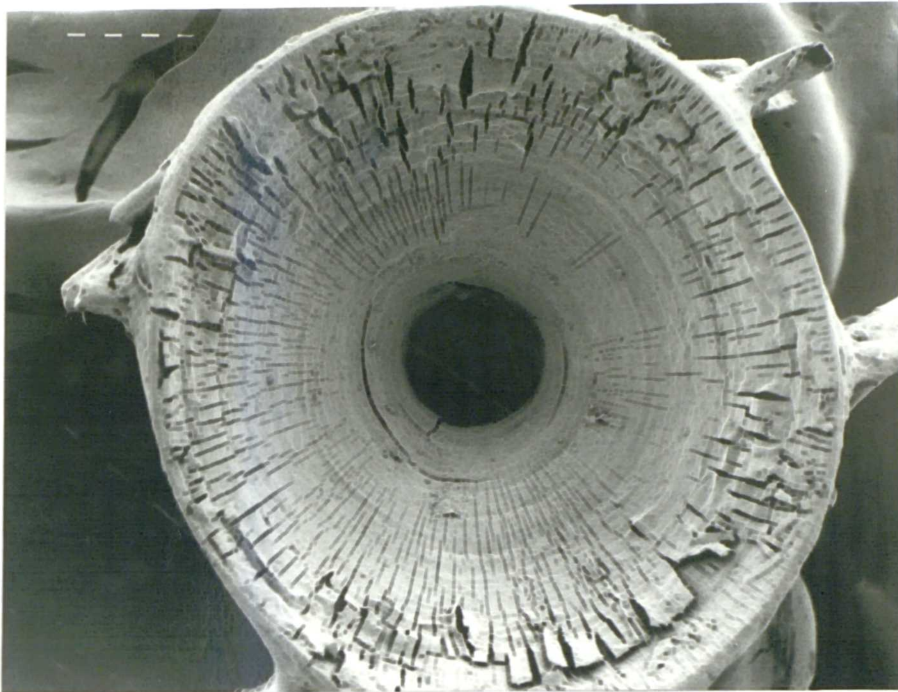


Plate 6:2b. Weathered Herring Vertebra: boiled bone, exposed sub-aerially for 71 weeks (S.E.M., right-hand scale bar = 100 μm).

Plate 6:2c Weathered Cod Vertebra: boiled bone, exposed sub-aerially for 109 weeks (S.E.M., right-hand scale bar = 100 μm)

stage spines commonly broke away. Subsequently deep circumferential cracks developed which penetrated many millimetres into the vertebra (Plate 6:2c). As a result of circumferential cracks the outer rim of the articulating facet frequently separated from the body of the vertebra, revealing a rough surface along the edge (Plate 6:2c). Radial cracks deepened and thicker layers exfoliated from the articulating facet. By removing the outer rim of the vertebrae, weathering removes those areas vital for attempts to use the growth rings visible in fish vertebrae for seasonal dating. On the head bones, flaking and cracking was predominantly longitudinal, along the "grain" of the bone. Edges of flat bones cracked and subsequently warped. Feathery edges, for example on the cod parasphenoid and frontal, were reduced by flaking. Tooth rows were eventually eroded (Plate 6:3). Severe erosion and flaking were accompanied by a crumbly, biscuity texture and the propagation of cracks opened up the interior of the bones to the weathering process.

The database records of condition and fragment completeness have been utilised in order to provide objectivity in the assignment of weathering stages, and mean condition values for each weathering stage are given in Table 6:6. The mean, maximum, minimum and standard deviation values for the condition, erosion, flaking and fragment size categories for the boiled cod, baked plaice and baked herring skeletons (the only skeletons to disarticulate completely and to illustrate a full range of weathering states) are given in Appendix 6.2.

As the boiled cod was the only specimen to show extreme weathering, resulting in substantial loss of bone, this skeleton is the only one used to illustrate the relative breakdown of the various parts of the skeleton, as illustrated in Fig. 6:1. Table 6:7 presents the mean fragment completeness and condition scores for each bone type. The condition of the skeleton after 109 weeks exposure is shown by Plate 6:4. As illustrated, the most

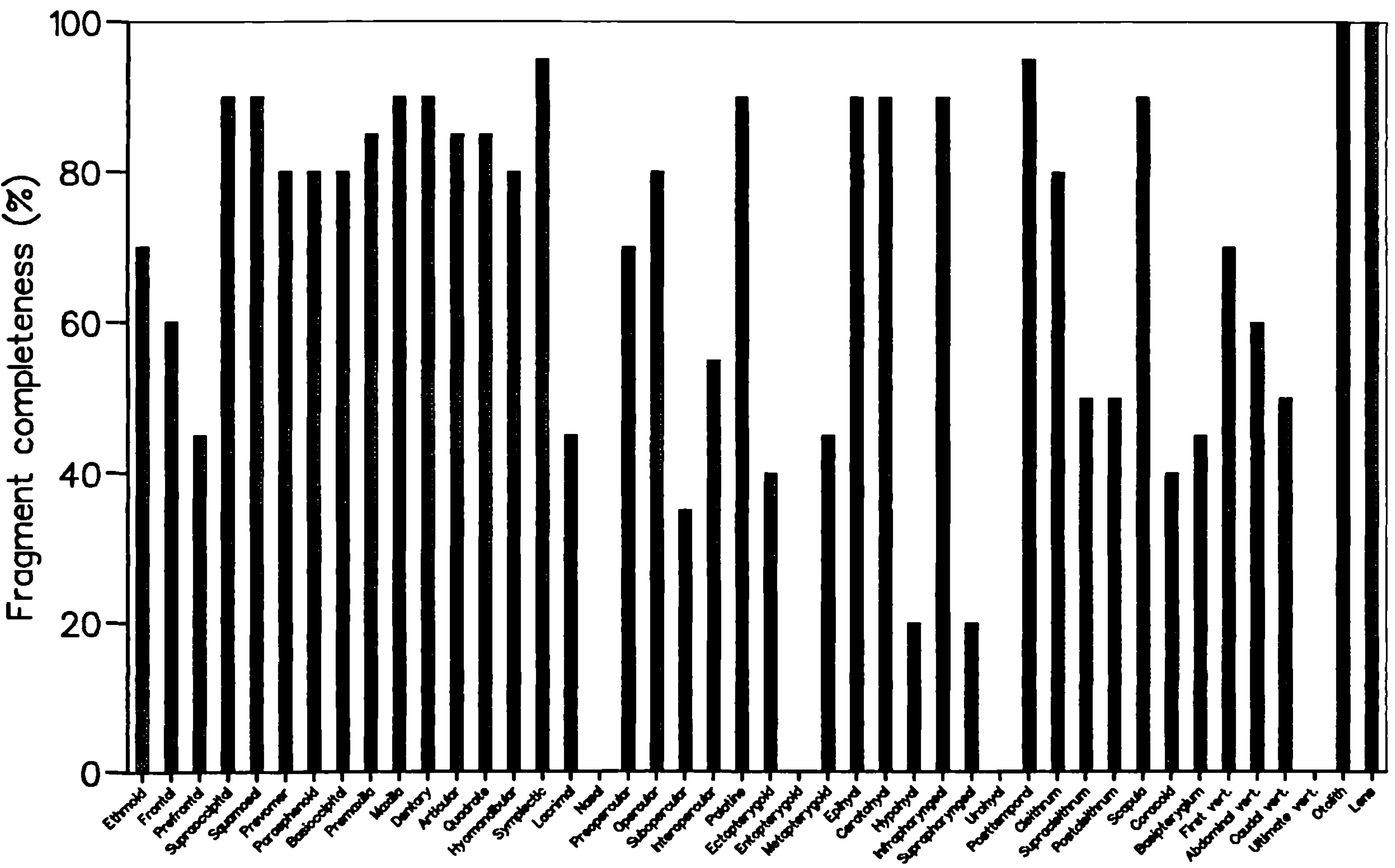


Fig. 6:1 Mean Fragment Completeness of Skeletal Elements of a Boiled Cod after 109 Weeks Sub-aerial Exposure.

Table 6:7

Mean condition and fragment completeness of boiled cod bones after subaerial exposure for 109 weeks.

Bone	Shape	No. Exp.	No. Recovered	Condition	Fragment Completeness (%)
Ethmoid	I	1	1	10	70
Frontal	F	1	1	10	60
Prefrontal	I	2	1	9	45
Supraoccipital	I	1	1	7	90
Squamosal	I	2	2	9	90
Prevomer	R	1	1	13	80
Parasphenoid	I	1	1	9	80
Basioccipital	S	1	1	10	80
Premaxilla	R	2	2	11.5	85
Maxilla	R	2	2	11	90
Dentary	R	2	2	12	90
Articular	R	2	2	11	85
Quadrate	R	2	2	10	85
Hyomandibular	I	2	2	8	80
Symplectic	F	2	2	6.5	95
Lacrimal	F	2	1	5	45
Nasal	I	2	0	-	0
Preopercular	F	2	2	9	70
Opercular	F	2	2	9	80
Subopercular	F	2	1	9	35
Interopercular	F	2	2	10.5	55
Palatine	R	2	2	8.5	90
Ectopterygoid	F	2	1	6	40
Entopterygoid	F	2	0	-	0
Metapterygoid	F	2	1	9	45
Epihyal	F	2	2	10	90
Ceratohyal	F	2	2	10	90
Hypohyal	R	4	1	5	20
Infrapharyngeal	I	2	2	8.5	90
Suprapharyngeal	I	6	1	10	20
Urohyal	F	1	0	-	0
Posttemporal	R	2	2	8	95
Cleithrum	I	2	2	9	80
Supracleithrum	R	2	1	7	50
Postcleithrum	F	2	1	5	50
Scapula	F	2	2	7	90
Coracoid	F	2	1	5	40
Basipterygium	F	2	1	5	45
First vert.	S	1	1	13	70
Abdominal vert.	S	18	16	13	60
Caudal vert.	S	28	25	13	50
Ultimate vert.	S	1	0	-	0
Otolith	F	2	2	2	100
Lens	S	2	2	3	100

Shape : R = Robust, F = Flat, I = Irregular, S = Spherical.
Exp. = Number of bones expected.
Mean condition = sum of the condition scores for each element, divided by the recovered number(s) of that element.
Mean % = Mean of all the fragment completeness scores for each skeletal element, calculated by summing the fragment completeness scores for each skeletal element (recorded as percentages of the total bone represented by the fragment) and dividing by the expected number of that skeletal element.

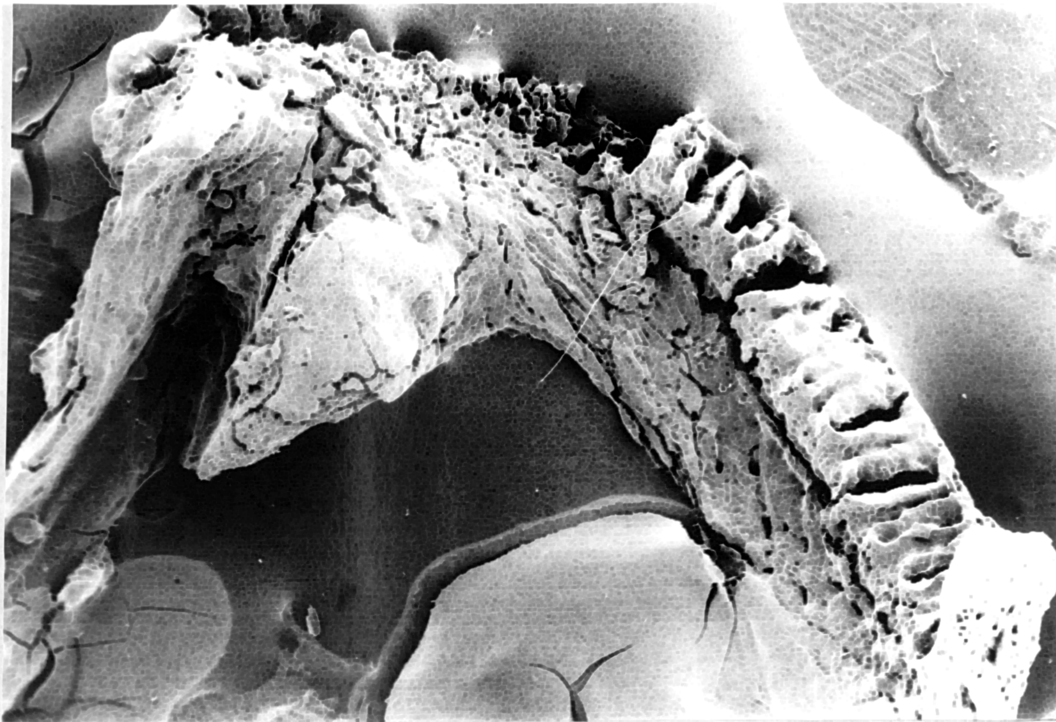


Plate 6:3 Weathered Tooth Row on a Boiled Plaice Premaxilla, after 71 weeks sub-aerial exposure (S.E.M, X10).

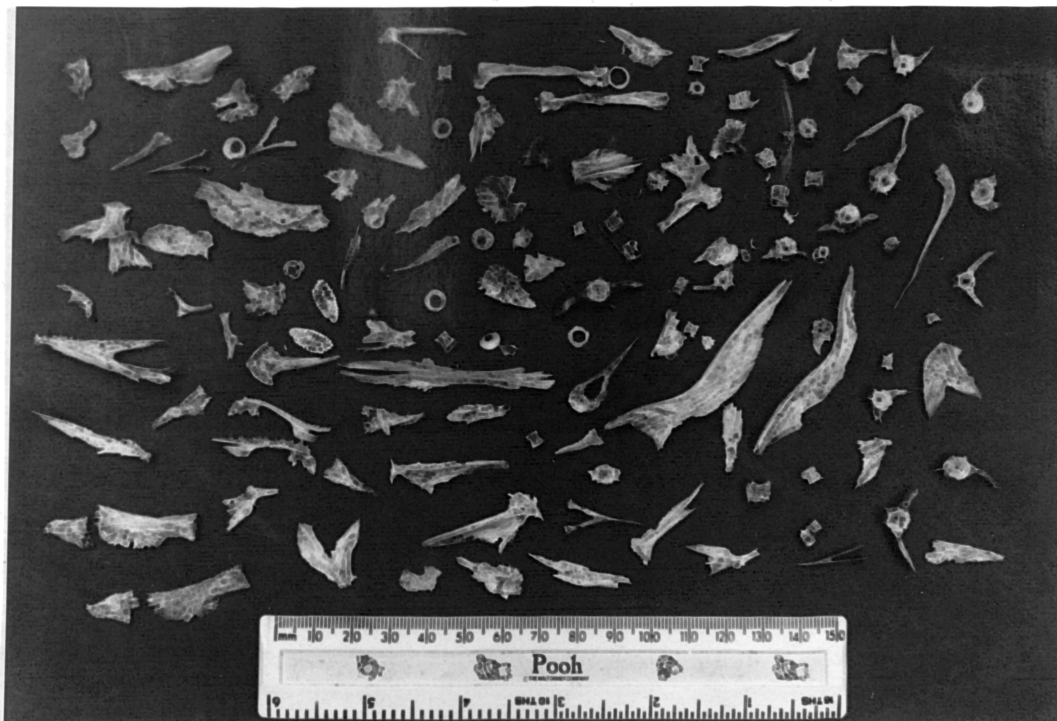


Plate 6:4 Boiled Cod Bones after 109 Weeks Sub-Aerial Exposure.

resilient elements were the otoliths and eye lenses; the former were unchanged after 109 weeks exposure, the latter were dry and slighty cracked. Vertebrae were among the least well preserved bones, several were completely lost, while most others were extensively cracked and eroded. Most had completely lost their neural and haemal processes and/or spines and many centra were reduced by erosion to all surfaces. Other poorly surviving bones included the pterygoid series, the pectoral bones (coracoid and basipterygium) lacrimal, nasal, the smaller operculum bones (subopercular and interopercular), the hypohyals and suprapharyngeals. While in most cases right and left side elements weathered to a similar extent, this was not always true; one supracleithrum and one postcleithrum (from the upper, exposed side of the fish) were lost while the partner elements were relatively well preserved.

An easily visible difference between the animals, observed after only a few weeks of exposure, was variation in the amount of mould present on the bones. No attempt was made to identify the moulds, but the dominant one was probably an Ascomycete (T. O'Connor, pers. comm.). While the mammal, pigeon, plaice and herring bones were covered in a dense coating of black mould for most of the experimental period, the cod and whiting bones had only a light covering. As other bones became degreased the mould also decreased. It seems likely that the extent of the black mould reflected the amount of grease in the bones, and that the cod and whiting bones had less than the other skeletons.

Boiling also appeared to reduce the amount of grease in the bones, while baking did not. Those bones which had been boiled, and therefore had lost some grease during the process, were less mouldy than their fresh equivalents at any given time. The bones heated to 400°C, 600°C and 800°C never appeared to have been colonised by mould, but some mould was observed on the epiphyses of the sheep bones heated to 200°C, presumably because organic matter remained

in the latter. Although crude, this interpretation of the amounts of grease within bones of different species, as reflected by the amount of mould on the bones after exposure, is supported by the findings of Chapter 2 into the amount of weight loss on degreasing. As the bones which weathered most rapidly were those which were the least mouldy at any given time, it seems possible that the proportion of lipid within a bone may be important in determining the rate at which it will weather. It is possible that the lipid and the associated mould acts as a protective coat, protecting the bone from weathering. Other important factors may be the extent of mineralisation and the microstructural organisation of the bone. The presence of fungi on the bone will eventually cause bone disintegration as the fungi and other microorganisms attack collagen and secrete organic acids which dissolve the bone mineral and so alter the histological structure (Sillen 1989; Garland 1987).

One other consequence of the organic component of bone was the tendency, in the herring and plaice in particular, for the skeleton to become jumbled and compacted with bones adhering together, as a result of proteinaceous glues exuding from the bones. Other than in cod this was particularly noticeable in the boiled specimens; the skeletons exfoliated, cracked and fragmented as a concreted mass rather than as individual disarticulated elements. The main area of adhesion in all cases was around the head, with cranial elements and jaw elements sticking to the cheeks and gills, which had the effect of protecting the innermost bones at the expense of those bones on the outside of the mass. Some of the vertebrae also adhered.

Burned bones. (Plate 6:5)

Little change was observed in the bones heated to 400°C (grey and black) and 900°C (white). All specimens were cracked as a result of heating, and some further fragmentation occurred by elongation of the original

cracks. Breaks and cracks were longitudinal, transverse and curved (parabolic). By the end of the experiment the sheep metapodials had broken into six pieces (400°C) and seven pieces (900°C). Of these most of the proximal and distal end fragments were identifiable to sheep/goat, and several shaft fragments also remained identifiable. The phalanges remained intact in both cases and, apart from a little erosion on the ends of the sheep phalanx which had been heated to 900°C, no changes were observed. The cod vertebra heated to 900°C broke in two and lost its neural spine and haemal processes early in the experiment, but the two centrum portions remained unchanged from then on. The vertebra which had been heated to 400°C lost its spine and processes only.

The sheep metapodial heated to 200°C showed much greater destruction due to weathering. No cracks were observed on heating, but after several months of exposure the metapodial began to crack longitudinally, and surface exfoliation was observed. Cracking proceeded rapidly until by the end of the experiment only two portions of the distal epiphysis remained. These portions together comprised less than 20% of the original bone. The remaining part of the bone was represented by tiny needle-shaped splinters. The sheep phalanx and cod first vertebra which had been heated to 200°C remained intact, however. Of the otoliths, the one heated to 200°C survived at least superficially unchanged throughout the experiment.

Both other otoliths disintegrated: the one heated to 900°C was extremely fragile after heating, and crumbled almost immediately. The otolith heated to 400°C cracked during heating, and broke into several pieces after less than three months. These pieces survived for almost two years, but would have been easily destroyed in a less protected environment.

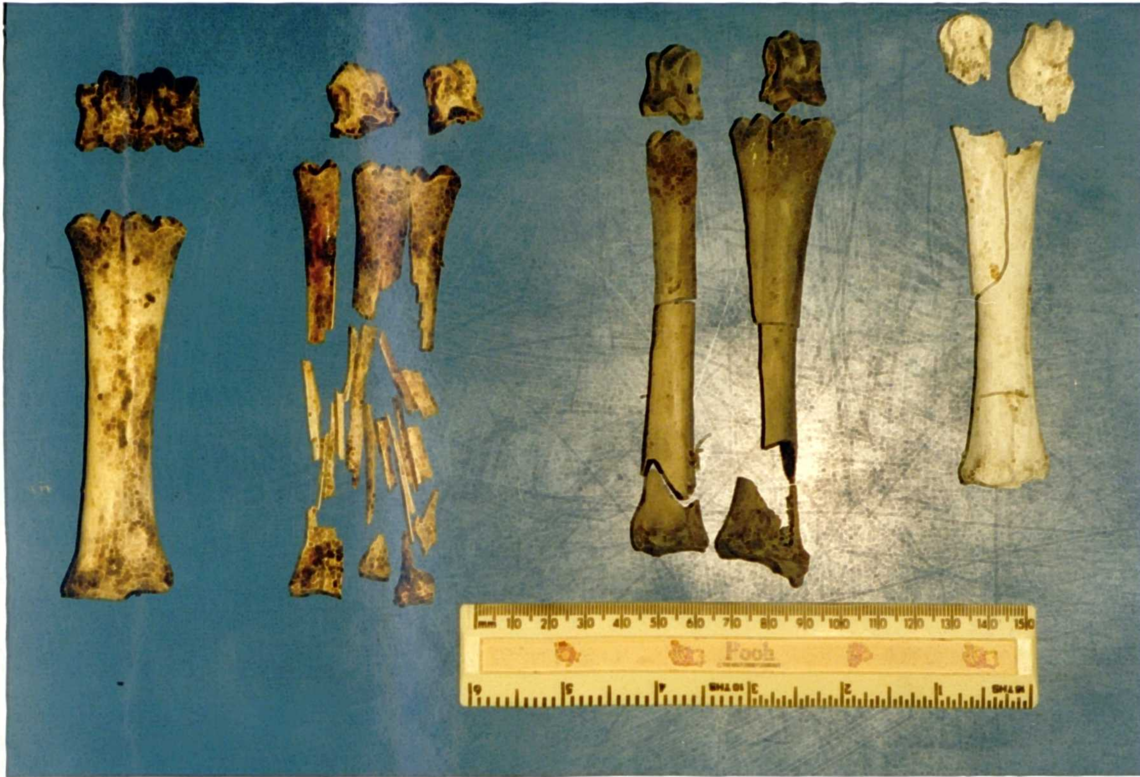


Plate 6:5 Fresh and Burnt Sheep Lower Limb Bones, After 109 Weeks Sub-Aerial Exposure (a = fresh, b = heated to 200 °C, c = 400°C, d = 900°C)

Molluscs

Apart from some bleaching of the *Helix aspersa* shells in particular, and a slight roughening of the surface of some of the periwinkles and cockles, no obvious changes to the mollusc shells were observed. No fragmentation occurred. The mechanical properties were not tested, but might be expected to have shown some weakening as a consequence of weathering.

Insects

The stages of disarticulation observed for the insect assemblages are given below (Tables 6:8-6:9). These stages relate to the descriptions of insect disarticulation stages given in Appendix 2.3, which were designated as a result of the observations made during this experiment and the wet/dry and freeze/thaw experiments (discussed below). It should be noticed that, because the *Calliphora vomitoria* fragmented much more rapidly than the *Tenebrio* sp., only six stages are given for the disintegration of the blowflies whereas seven are described for the *Tenebrio* in Appendix 2.3. Of these, only those observed during the period of subaerial exposure are described in Table 6:8. These stages refer primarily to disarticulation, as no significant amount of fragmentation occurred during the twenty six months of observation. As most puparia remained little changed, only two stages are described (stages 1 and 2 of those described in Appendix 2.3). It should be noted that correspondingly numbered stages do not relate to comparable amounts of disarticulation and fragmentation between the three groups of insect remains used in this experiment.

Despite protection in the mesh bag, after 89 weeks of exposure very few bluebottle sclerites were recovered. The bluebottle puparia, by contrast, remained in good condition, although many were darker than when fresh, and more brittle, presumably as a result of desiccation and

leaching. The sclerites of the *Tenebrio* adults had more-or-less completely disarticulated by 89 weeks, and some reddening or lightening of some sclerites, particularly the elytra, was observed. The colours observed after exposure for 109 weeks was similar to stage 2 of chemical erosion obtained experimentally (see Appendix 2.2). After only 32 weeks many of the elytra had separated from the abdomen, and most heads were either separate or articulated only with the prothorax. Several elytra showed chewing marks around the edges, caused by the larvae of small flies, identified from the numerous puparia as *Calliphora vicina* Desvoidy, by Professor John Phipps.

Table 6:8. Insect disarticulation and erosion from observations after subaerial exposure.

***Tenebrio* adults.**

0. Beetles intact, no disarticulation.
1. Head is separate from the rest of the body.
2. Head and prothorax are disarticulated, also some elytra and legs are separate.
3. Most elytra are disarticulated, most legs separate from the body at the junction of the coxa with the trochanter. In many cases the abdominal sclerites have disarticulated as a unit. Some meso- and metathoraces separate, usually as a pair.
4. Abdominal sclerites break up into individual sternites and tergites, meso- and metathorax disarticulate, meso- and metanota and episterna disarticulate. Trochanter separates from the rest of the leg. Some fragmentation and paling or reddening in colour of some sclerites at this point. Many sclerites seem brittle.
5. Body is completely disarticulated, except for the femora and tibiae, and some coxae which are still articulated with the prothorax. Internal struts liberated and fragmenting. Increased reddening/paling of sclerites, and increased fragmentation of abdominal sclerites, elytra and prothoraces (ca. 25% are cracked or broken).

***Calliphora vomitoria*, adults**

0. Body complete
1. Heads disarticulate from body
2. Thorax and abdomen and most legs and wings separate.
3. Abdominal sclerites separate, and fragment. Eyes frequently cracked or missing. Legs elements separate.
4. Thorax and heads crack and break up. Few identifiable fragments of legs and abdomen remain.

***Calliphora vomitoria* puparia**

0. Puparia complete
1. Puparia brittle, darkened in colour. A proportion are squashed, others are cracked or broken (<50% are damaged).

Table 6:9
Disarticulation and fragmentation stages exhibited by insect remains after exposure in the absence of soil.

Time (in weeks)	16	32	52	64	89	109
Tenebrio sp.	2	3	3/4	4/5	5	5
Calliphora vomitoria	1	2	3	3	4	4
Calliphora vomitoria puparia	0	1	1	1	1	1

6.4.4 Discussion

Given the relatively short time available for this experiment, it is to be expected that many of the skeletal remains should show little physical decay. Even so, the results proved interesting, particularly regarding the fish assemblages and the comparison of the rates of weathering between cooked and uncooked bones. Ideally, similar experiments should be run for many more years, however.

Once bone and shell have weathered they will not only be structurally weaker, leading to rapid fragmentation if trampled, but will also be more porous, rendering them susceptible to preferential transport by water and wind when dry, and to waterlogging when wet. Those remains which weather most rapidly may therefore be lost from the archaeological record before they would have disintegrated

completely when influenced only by variables connected with exposure.

Those areas of the skeleton exposed first by decay of the fleshy covering will be subject to a greater period of exposure than those areas shielded by flesh for longer. Patterns of disarticulation and decay of fleshy parts of mammals when free of predators, and when attacked by predators, have been studied in detail by many authors, including Andrews and Cook (1985), Brain (1980), Toots (1965), Müller (1951) and are to a large extent predictable. Disarticulation of small mammals and anura (frogs and toads) in water has been studied by Dodson (1973). The disarticulation of fish skeletons in natural environments has not been examined until now, to my knowledge, and further work in this area would be desirable. Cultural preparation of carcasses will affect the order in which body parts are exposed, however, so that assumptions based on disarticulation sequences should only be used when man's intervention is not suspected.

The length of time that a body takes to decay will depend on many things, including temperature, humidity and local fauna (from micro-organisms and fungi to insects and carnivorous mammals). These factors will determine the difference in time between exposure of the first and last parts of the skeleton. Local climate and microclimates will then influence the rate of breakdown of the skeletal tissue, as will the structure of the tissue. Predicting the rates of decay of different parts of the skeleton is thus subject to many restrictions, only some of which will be identifiable on archaeological material. Care must therefore be exercised when interpreting the origins of an assemblage of skeletal remains showing very mixed weathering states. In particular, the weathering states displayed by the bones of different groups of animals should not be compared uncritically. It has been shown here that different sorts of bone weather at different rates, and this applies to different taxa in the case of fishes.

Changes in bone as a result of cooking clearly facilitate the process of weathering. These points are expanded as a result of the other experiments included in this chapter, below.

6.5 Experiments into Repeated Freezing and Thawing, Wetting and Drying.

While many archaeozoologists have mentioned freezing and thawing and wetting and drying as important causes of bone destruction (e.g. Chaplin 1971; Gifford 1981) only one, Miller (1975) attempted to study the effects of these processes on bone under laboratory controlled conditions. Miller used cow limb bones and observed longitudinal cracking, associated with a loud pop, after previously frozen and wet bones had been allowed to dry out.

6.5.1 Methods and Materials

To investigate the effects of continuous freeze/thaw and wet/dry cycles on bone, mollusc shells and insect cuticle, a series of laboratory-based experiments was conducted.

Similar sets of animal remains were used in each experiment. The vertebrate assemblages comprised bones of selected shapes (i.e. long bones, flat bones, spherical bones, irregular bones and robust bones) from mammal, bird, amphibian and fish. The vertebrates used included rabbit or stoat (either, not both used per experiment), pigeon, cod, haddock, herring, plaice and salmon, and, additionally, frog limb bones and dogfish calcified vertebral centra. Molluscs included mussel valves, cockles, periwinkles, limpets and garden snails. Insects included *Tenebrio* adult beetles, adult bluebottles, bluebottle puparia and *Tenebrio* larvae. Further details of the skeletal elements used in each experiment are given in Table 6:10. All vertebrate remains were dissected from fresh corpses and cleaned by hand using only water and a scalpel.

Table 6:10. Skeletal Elements Used in the Freeze/Thaw and Wet/Dry Experiments.

Experiment Code.

ANIMAL	Freeze/Thaw 1 and 2	Freeze/Thaw 3-6	Wet/Dry 1	Wet/Dry 2	Wet/Dry 3
Sheep	Metapodial	Metapodial	Metapodial	10 1st Phalanges	Metapodial
	3rd Phalanx	2nd Phalanx	2nd Phalanx		2nd Phalanx
	3rd Phalanx	3rd Phalanx	2nd Phalanx		3rd Phalanx
Stoat	Mandible				
	Femur				
	Humerus				
	3 Vertebrae				
Rabbit		Ulna/Radius		8 Metatarsals	Ulna/Radius
		Femur	Femur	2 Tibia	Femur
		Mandible	Mandible		Mandible
		3 Vertebrae	3 Vertebrae		3 Vertebrae
Pigeon	Ulna	Ulna	Ulna		Tibia
		Coracoid	Coracoid		Carpometacarpus
	1st Phalanx Manii	1st Phalanx Manii	1st Phalanx Manii		3 Vertebrae
	Carpometacarpus	Carpometacarpus	Carpometacarpus		
	3 Vertebrae	3 Vertebrae	3 Vertebrae		
Frog	Humerus	Humerus	Humerus	10 Tibio-fibulae	Humerus
	Tibio-fibula	Femur	Tibio-fibula		Femur
	Carpometacarpus	Carpometacarpus	Carpo-metacarpus		Carpometacarpus
Cod	Premaxilla	Premaxilla	Premaxilla	8 Dentaries	Premaxilla
	Cleithrum	Cleithrum	Cleithrum	10 Subopercular	Cleithrum
	Post-temporal	Post-temporal	Post-temporal	10 Caudal Vertebrae	Post-temporal
	Preopercular	Preopercular	Preopercular	10 Precaudal Vertebrae	Preopercular
	3 Vertebrae	3 Vertebrae	3 Vertebrae		3 Vertebrae
	Otolith	Otolith (FT 4-6)			
Salmon	Maxilla	Maxilla	Maxilla	10 Dentaries (2 male)	Maxilla
	Cleithrum	Cleithrum	Cleithrum	10 Entopterygoids	Cleithrum
	Post-temporal	Post-temporal	Post-temporal	10 Caudal Vertebrae	Post-temporal
	Preopercular	Preopercular	Preopercular	10 Precaudal Vertebrae	Preopercular
	3 Vertebrae	3 Vertebrae	3 Vertebrae		3 Vertebrae
Haddock	Premaxilla	Premaxilla	Premaxilla		Premaxilla
	Cleithrum	Cleithrum	Cleithrum		Cleithrum
	Post-temporal	Post-temporal	Post-temporal		Post-temporal
	Preopercular	Preopercular	Preopercular		Preopercular
	3 Vertebrae	3 Vertebrae	3 Vertebrae		3 Vertebrae
		Otolith (FT 3-4)	Otolith	5 Otoliths	Otolith
Plaice	Premaxilla	Premaxilla	Premaxilla		Premaxilla
	Cleithrum	Cleithrum	Cleithrum		Cleithrum
	Post-temporal	Post-temporal	Post-temporal		Post-temporal
	Preopercular	Preopercular	Preopercular		Preopercular
	3 Vertebrae	3 Vertebrae	3 Vertebrae		3 Vertebrae
Herring	Maxilla	Maxilla	Maxilla		Maxilla
	Cleithrum	Cleithrum	Cleithrum		Cleithrum
	Post-temporal	Post-temporal	Post-temporal		Post-temporal
	Preopercular	Preopercular	Preopercular		Preopercular
	3 Vertebrae	3 Vertebrae	3 Vertebrae		3 Vertebrae
Dogfish	4 Vertebrae	4 Vertebrae	4 Vertebrae		4 Otoliths
Whiting				5 Otoliths	

KEY TO EXPERIMENT CODES:

FT1 = Freeze/Thaw Dry Bones; FT2 = Freeze/Thaw Fresh Bones in Water; FT3 = Freeze/Thaw Dry Bones in Water; FT4 = Freeze/Thaw Fresh Bones (Damp); FT5 = Freeze/Thaw Boiled Bones (Damp); FT6 = Freeze/Thaw, Wet/Dry Bones; WD1 = Wet/Dry, Fresh Bones; WD2 = Wet/Dry, Replicates; WD3 = Wet/Dry Boiled Bones.

Separate sets of similar animal remains were subjected to one of a specific regime of wetting and drying and/or freezing and thawing. In addition to fresh bones, boiled bones were also tested, after boiling the cleaned skeletal elements for one hour. The animal remains were tested both in the "fresh", i.e. damp, state and after drying at 40°C for 12 hours, and with and without submersion in water, such that the contents and conditions of testing for each experimental set were:

1. Dry remains frozen overnight and thawed for 8 hours.
2. Dry remains frozen in water overnight and thawed for 8 hours.
3. Fresh remains frozen overnight and thawed for 8 hours.
4. Fresh remains frozen in water overnight and thawed for 8 hours.
5. Boiled remains, frozen when damp overnight and thawed for 8 hours (not insects).
6. Dry remains frozen in water overnight, thawed and left to stand in water for 8 hours and then dried at 40°C overnight.
7. Fresh remains wetted for 8 hours and dried overnight at 40°C.
8. Boiled remains wetted for 8 hours and dried at 40°C overnight (not insects).

9. In addition, to examine further the effects of alternate wetting and drying, using replicates, groups of 8 - 10 cod and salmon dentaries, cod and salmon abdominal and caudal vertebrae, cod suboperculars, salmon entopterygoids, sheep first phalanges, rabbit metatarsals, pigeon metatarsals and frog tibio-fibulae were alternately wetted and dried on a 24 hour cycle.

It should be noted that while these experiment timings were adhered to for the most of the experiment, during a one week holiday and some weekends the remains were left for extended periods either frozen (for all the experiments involving freezing) or dry (for the wet/dry experiments).

Additionally, while drying was intended to take place at 40°C on one occasion all the experimental sets were subjected to a temperature of nearly 80°C, due to human interference. This temperature affected all the sets equally, and would have had the effect of deforming the collagen fibrils irreversibly, and so would be expected to speed up the weathering process. All sets were frozen at -15°C.

To investigate the effects of freezing and thawing on burnt bone a selection of cod bones and sheep phalanges (details in Table 6:10) were heated in a muffle furnace for two hours, two sets to 350°C and two sets to 900°C. One set of bones heated to each temperature were included in experiment set 1 and frozen and thawed dry, and the other set was frozen and thawed in water (set 2). These experiments indicated that when heated in an oven, both when completely calcined and incompletely calcined, bones crumble when frozen and thawed in water, but do not fragment when frozen and thawed dry. Following the results of these experiments thirty sheep phalanges (first or second) were heated in the muffle furnace; ten at 200°C, ten at 350°C, and ten at 900°C, again for two hours. Ten phalanges were left unheated. Five phalanges from each heating condition were frozen and thawed in water, the rest were placed in a covering of water, but were not frozen.

6.5.2 Recording

Recording of sets 1-5 took place after 75 cycles, and after 150 cycles. The freeze/thaw, wet/dry set (6) was examined after every 15 cycles up to 75 cycles and then after 100 and 150 cycles, and wet/dry sets (7, 8, 9) every 15 cycles to a total of 75, owing to the more rapid disintegration of these assemblages. At each recording stage the skeletal remains were examined by eye and under a dissecting (X10) microscope and variations from the fresh state registered. The vertebrate remains were scored as detailed in Chapter 2 for categories of texture, erosion,

flaking, cracking (extent and direction) and completeness of the bone. A condition category was added as the sum of texture, erosion and flaking. These data were stored using the database package D-Base III+, later transferred onto the University of York Vax cluster mainframe computer and interrogated using SPSSX.

As fragmentation and surface erosion were the only modifications visible on the molluscan remains, recording was by sketches and descriptive.

The state of disarticulation, fragmentation and colour change was recorded for the insect remains using the standard form given in Appendix 2.1. Changes in colour were compared with stages of chemical erosion obtained by immersing insect cuticle in a range of acidic and alkaline solutions for various times, as detailed in Appendix 2.2.

6.5.3 Results

Rates of decay for the vertebrate assemblages are given in Tables 6:11 and 6:12 in terms of mean condition per taxon (potential range from 1 to 15) for sets 1-8 and per taxon and skeletal element for set 9, with time. In all cases the patterns of disintegration were similar, but the rate of decay varied according to the experimental situations. The mean condition scores for those experiments showing substantial modifications to the assemblage with time (i.e. after wetting and drying fresh and boiled bones, sets 7 and 8, and freezing and thawing followed by wetting and drying, set 6) are illustrated for each taxon used, in Fig. 6:2. While many of the taxa showed relatively little alteration, and so cluster at the lower ends of the condition scale, the most significant information, illustrated by the graphs, is in the comparison between the rate of decomposition of fish bone (especially cod and haddock) when compared with the bone of all the other animals.

Table 6:11

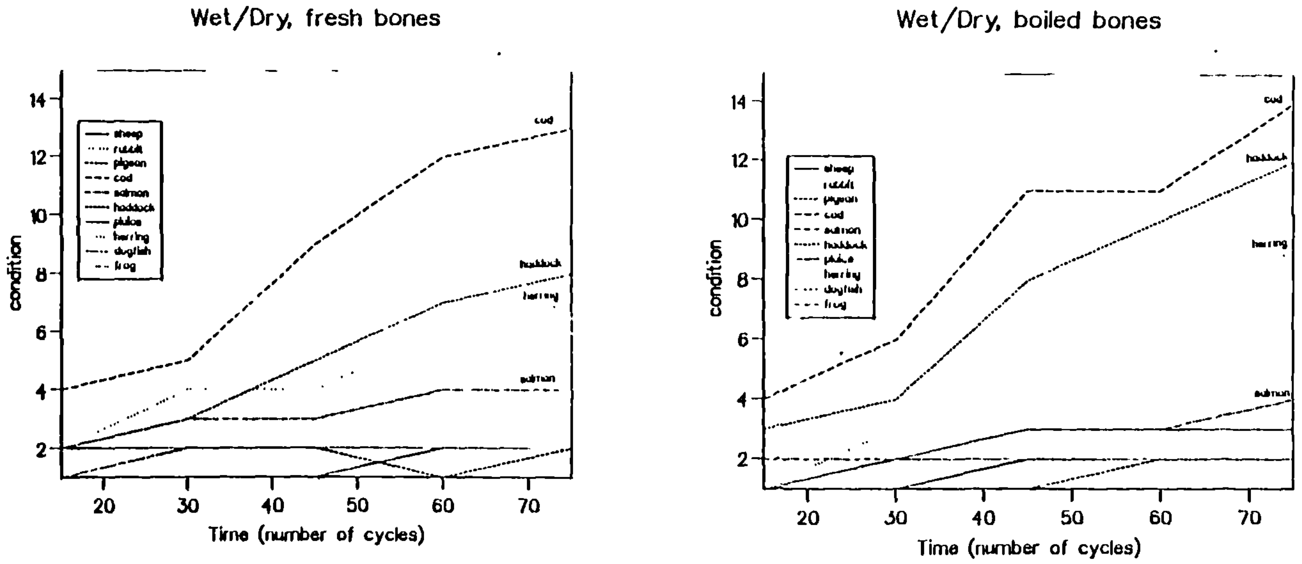
Mean Condition Scores for Vertebrate Remains after Freezing and Thawing, and Wetting and Drying.

Set No.	Time (cycles)	Sheep	Rabbit	Pigeon	Cod	Salmon	Haddock	Plaice	Herr-ing	Dog-fish	Frog
1	75	1	1	1	1	1	1	1	1	1	1
1	150	1	1	1	1	1	1	1	1	1	1
2	75	1	1	1	1	1	1	1	1	1	1
2	150	1	1	1	2	1	2	1	1	1	1
3	75	1	1	1	1	1	1	1	1	1	1
3	150	2	2	1	5	2	2	3	5	2	2
4	75	1	1	1	1	1	1	1	1	1	1
4	150	2	2	2	2	2	2	2	2	2	2
5	75	2	2	1	11	4	8	3	3	1	1
5	150	2	2	2	15	4	9	4	5	2	2
6	15	1	1	1	1	1	1	1	1	1	1
6	30	1	1	1	2	1	1	1	1	1	1
6	45	1	1	1	3	1	2	1	1	1	1
6	60	1	1	1	5	1	3	1	2	1	1
6	75	1	1	1	7	2	5	1	5	2	2
6	100	2	2	2	9	2	5	2	7	2	2
6	150	2	2	2	13	4	12	4	11	6	3
7	15	1	1	1	4	2	2	2	2	1	1
7	30	1	2	2	5	3	3	2	4	1	2
7	45	1	2	2	9	3	5	2	4	1	2
7	60	2	2	1	12	4	7	2	6	2	2
7	75	2	2	2	13	4	8	2	7	2	2
8	15	1	1	1	4	2	3	1	1	1	1
8	30	1	2	1	6	2	4	2	3	2	2
8	45	2	2	1	11	3	8	3	5	2	2
8	60	2	2	2	11	3	10	3	7	2	2
8	75	2	2	2	14	4	12	3	9	2	2

Table 6:12
Mean Condition of Vertebrate Remains after Repeated Wetting and Drying (experiment set 9).

Time (cyc-les)	Sheep P	CodD D	CodV V	Cod SOP	Salmon D	Salmon V	Salmon ENT	Rabbit MP	Pigeon TB	Frog TB	Gadid OT
15	1	2	2	2	3	1	2	1	1	1	1
30	1	3	2	2	3	1	2	1	1	1	1
45	1	5	3	2	5	2	3	1	1	2	1
60	2	7	3	6	5	2	3	1	1	2	1
75	2	7	4	7	5	2	3	1	1	2	2

P = Phalanges, D = Dentary, V = Vertebrae, SOP = Subopercular, ENT = Entopterygoid, MP = Metapodial, TB = Tibiotarsus/Tibio-fibula OT = Otolith.



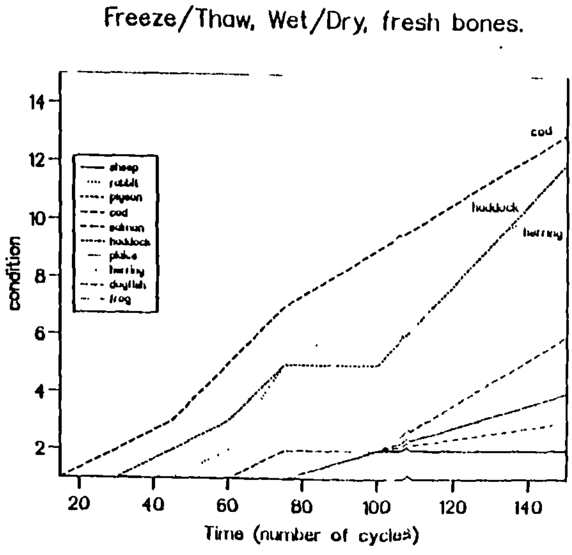


Fig. 6:2 Condition of Bones, by Taxon, after Cycles of Freezing and Thawing, and Wetting and Drying.

Despite the disparate testing conditions, the patterns of decomposition were similar for all the experiments where positive results were obtained (i.e. in which decay took place). It was just the rate at which the modifications occurred which differed. No changes were observed in the skeletal tissues which were frozen and thawed in the dry state (set 1) after even 150 cycles. Otherwise, one obvious characteristic which emerged from the experiments were that very little modification to the bones transpired until they appeared to have become degreased. The rate at which degreasing took place was therefore crucial in determining the relative rates of decomposition. The conditions which promoted the most rapid decay were continually damp freeze/thaw and wet/dry, in which the assemblages were left wet for many hours. It was also clear that the boiled bones degraded much more rapidly than fresh bones.

Most of the cracking observed on the bones occurred after drying, rather than freezing. The most extensive cracking occurred in those experiments which included wetting and drying. Freezing in fact seemed to slow down the bone decay, and all bones were degraded much faster after wetting and drying (sets 7 and 8) than after freezing and thawing in water (sets 2, 4 and 5). Damp conditions appeared to encourage the breakdown of bone tissue, a picture which was reversed for the molluscs, which possess very little organic material in their shells.

The first sign of bone decay was the development of fine cracks along the direction of the collagen fibres. Following this, the texture of the bone progressed from "dry" to increasingly "crumbly". At its most extreme the bone had the texture of biscuit and surface layers of bone were lost when the bone was touched. This extreme form was only reached for the bones of cod and haddock. Salmon and herring bones never became crumbly, but after degreasing the thin head bones became papery and either developed multiple cracks along the "grain" of the bone, followed by extensive exfoliation (Plate 6:6), or they tore. The fish

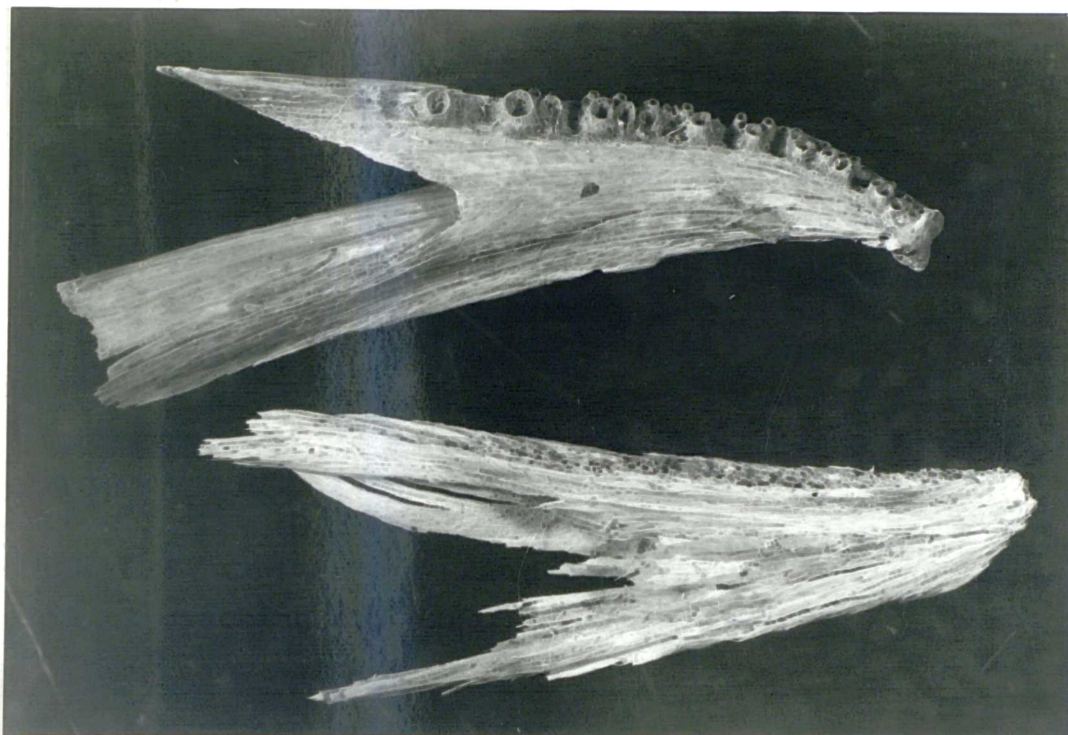


Plate 6:6 Cod (above) and Salmon (below) Dentaries: detail of cracking and exfoliation (x 1.5)

bone, particularly the cod and haddock bones, decomposed before the bones of the mammals, pigeon and frog. The deterioration of the mammal, pigeon and frog bones, in fact, never progressed further than my weathering stage 2 (i.e. dry with several longitudinal cracks).

Mammal, Bird and Amphibian bone.

While the sheep phalanges showed no modifications apart from appearing dry and degreased, the sheep metapodials, rabbit metatarsals and pigeon ulna developed longitudinal hairline cracks in those experiments which involved continual wetting and drying with or without freezing. These cracks are analagous to the "split lines" described by Tappen (1969) for fossil bone and Miller (1975) for fresh cow bones after freezing and thawing. These cracks were present on all aspects, and were sometimes slightly oblique. They form as a result of dehydration of the bone, and some extended into the marrow cavity. Several rabbit mandibles developed hairline cracks below the diastema, and in most cases the teeth fell out and fragmented soon after the development of longitudinal and transverse cracks. Despite the cracking, which was observed on many of the bones after as few as 45 cycles, all bones were complete at the end of all the experiments. No vertebrae developed cracks or were otherwise eroded.

Frog limb bones too survived all the experiments intact apart from the early loss of cartilaginous epiphyses, one consequence of which was to separate the two tarsals (calcaneum and astragalus).

Fish

The most noticeable alterations were to the fish bones, in particular the cod and haddock bones which in all cases disintegrated or showed signs of degeneration before the bones of other species. This is clearly shown by Fig. 6:2, and by Table 6:12 which deals with experiment set 9. Of the

cod bones used in set 9, the dentaries and suboperculars decayed more rapidly than the vertebrae. As the experiments progressed the flat bones of cod and haddock developed cracks around the edges, followed by extensive cracking along the "grain" of the bone which eventually induced disintegration. Vertebrae developed circumferential cracks to the centrum articular surfaces, followed by exfoliation and loss of spines and processes. Finally radial cracks penetrated the centrum and disintegration followed. At the same time as the cracks became apparent the bone became crumbly and surfaces eroded easily. These modifications are similar to those observed following subaerial exposure (see above).

The fresh cod otolith had broken into two pieces after freezing and thawing in water for 30 cycles but these portions were not further fragmented. The boiled otolith remained intact through 150 freeze/thaw cycles. Wetting and drying had no appreciable effect on most otoliths, although several became slightly chalky after 75 cycles.

Salmon and herring head bones tended to warp and crack at the edges rather than exfoliate or erode; bones of these species were more resistant to decay than the gadid bones, despite their superficially thin and fragile appearance. The flat herring head bones (i.e. post-temporal, preopercular, cleithrum and maxilla) eventually fragmented, due to the propagation of cracks, but the vertebrae remained intact and seemingly unchanged to the end of the experiment. Salmon bones with large surface areas, including preoperculars, cleithra, post-temporals, and entopterygoids also developed cracks at the edges, and when torn, the edges warped. Flaking occurred on all of the salmon bones once the bone had become degreased, as indicated in Tables 6:11 and 6:12 by a condition of 2 or above. The salmon dentaries which were used for the second wet/dry experiment (9) included two from male salmon. These two bones started to exfoliate and split much sooner than the eight dentaries from female salmon of comparable size,

and by the end of the experiment were almost unrecognisable. It is the preferential disintegration of these two dentaries which caused the relatively high score given in Table 6:11. Probably these two bones were depleted in calcium as a result of the fish having recently spawned. Plate 6:6 illustrates this exfoliation.

The most resilient fish bones of those used in these experiments were from plaice, none of which were visibly altered by any of the experiments. None of the plaice bones became completely degreased (as indicated by whitening) by the end of the experiments. Dogfish calcified vertebral centra were also resistant to decay, although most split transversely during the experiment, separating the two articular surfaces. However, these centrum fragments did not further disintegrate.

Burnt bones

Turning to the burnt bones, the results from all the experiments indicated that freezing and thawing of completely calcined bone (heated to 900°C) rapidly results in the complete disintegration of the bone when the bone is soaked in water. After 75 freeze/thaw cycles all the fish and mammal bones tested in set 2 had disintegrated to powder. The same phenomenon was apparent in all but one of the sheep phalanges heated to 900°C and frozen and thawed in water after 50 cycles; the bones had fragmented into several pieces after as few as ten freeze/thaw cycles. Bones heated to 350°C were somewhat more resilient; although several (including all the fish bones) had fragmented after 50-75 cycles, further freezing and thawing up to the temporal limits of these experiments did not reduce the bones to powder. Heating to 200°C did not result in fragmentation. No change was observed to the unheated sheep phalanges, or to any of the sets not subjected to a freeze/thaw regime.

Molluscs

Very little deterioration was observed in all but those shells subjected to freezing and thawing in water. Although several of the *Helix aspersa* shells and mussel valves cracked during the freeze/thaw, wet/dry regime (experiment 6), it was only after freezing and thawing in water that extensive amounts of fragmentation occurred. All species were affected. The limpets and periwinkles commonly lost the apex. Cockle shells cracked both parallel to the outer edge and transversely causing surface layers of shell to peel away. Mussel valves tended to crack from the edge towards the hinge and the nacreous layer usually flaked, separating sheets of nacre from the outer prismatic material. The *Helix* shells broke into several or many fragments, this started from cracks which developed around the aperture and along the body whorls. As the organic component of mollusc shell is very small, the main cause of degradation may have been mechanical, which would explain why extensive fragmentation was only observed after freezing and thawing in water, and not after wetting and drying, which would favour microbial attack and chemical breakdown. Expansion and shrinkage consequent upon wetting and drying would also affect proteinaceous material to a much greater extent than calcitic or aragonitic material.

Insects.

Similarly to the results obtained from the freezing and thawing, and wetting and drying of bone, the patterns of disintegration of insect remains were comparable for all the conditions tested, but more rapid under the wet/dry regimes. Freezing seemed to retard decomposition and subsequent fragmentation. Cycles of repeated wetting and drying had the effect of speeding up disarticulation. In all cases the flies broke up rapidly into head, thorax and groups of associated abdominal sclerites, the latter soon separating and fragmenting. Further fragmentation of the head, legs and thorax followed and wings disintegrated. The

fly puparia remained intact for much longer, although repeated drying had the effect of making the puparia brittle and darkened in appearance. Some became "squashed" or flattened. Fragmentation resulted in several identifiable pieces. Disarticulation of the *Tenebrio* adults proceeded in predictable ways, similar to that seen in the beetles exposed to subaerial weathering. The stages of disarticulation are given in Table 6:13, based on the stages given in Appendix 2.3. Although chemical erosion, as indicated by paling and thinning of cuticle, was not apparent, the cuticle did become noticeably brittle and darker than when fresh as a result of continual wetting and drying. Water covering the decomposing animals repeatedly took on a dark brown hue, even when all the body parts had disappeared and the water had subsequently been changed. This colouration may have originated as a product of the hydrolysis of some of the phenols in the cuticle. The *Tenebrio* larvae showed little change in the experiments in which they were kept wet, but when allowed to dry out the cuticle rapidly shrivelled and became papery, and segments broke up readily. The head capsule usually survived intact.

Disarticulation and, where exhibited, fragmentation, was in all cases more rapid in those experiments where the animal remains were covered in water.

Table 6:13.

Disarticulation and fragmentation stages exhibited by insect remains after freezing/thawing, and wetting/drying.

(stages correlate with those documented in Appendix 2.3 note that the same stages do not refer to a corresponding extent of disarticulation/fragmentation between the groups of insect remains)

Time (in number of cycles)	15	30	45	60	75	100
Experiment 1						
Tenebrio adults	-	-	-	-	0	-
Calliphora vomitoria	-	-	-	-	0	-
C. vomitoria puparia	-	-	-	-	0	-
Tenebrio larvae	-	-	-	-	0	-

Experiment 2						
Tenebrio adults	-	-	-	-	1	-
Calliphora vomitoria	-	-	-	-	1	-
C. vomitoria puparia	-	-	-	-	0/1	-
Tenebrio larvae	-	-	-	-	1	-
Experiment 3						
Tenebrio adults	-	-	-	-	1	-
Calliphora vomitoria	-	-	-	-	1	-
C. vomitoria puparia	-	-	-	-	0	-
Tenebrio larvae	-	-	-	-	0	-
Experiment 4						
Tenebrio adults	-	-	-	-	0/1	-
Calliphora vomitoria	-	-	-	-	0/1	-
C. vomitoria puparia	-	-	-	-	0	-
Tenebrio larvae	-	-	-	-	0	-
Experiment 6						
Tenebrio adults	1	1	1	2	2/3	-
Calliphora vomitoria	1	2	3	4	4	-
C. vomitoria puparia	0/1	1	2	3	3/4	-
Tenebrio larvae	0	1	2	3	4	-
Experiment 7						
Tenebrio adults	2	3	4	4/5	5	6
Calliphora vomitoria	2	3	4	4	5	5
C. vomitoria puparia	1	1	2	3	3	4
Tenebrio larvae	2	3	3	4	4	5

6.5.5 Discussion.

It is commonly assumed that freezing and thawing is directly responsible for bone fragmentation, for example Gejvall (1963, 381) states:

"it is obviously to be expected that in areas with a high water content in regions where winters are cold, further fragmentation will take place as a result of repeated frosts"

The results obtained for this experiment did not support this concept, however. Despite the different conditions of freezing and thawing, the stages of bone disintegration were similar in all the experimental sets, it was just the rate of break-up which varied. It did not appear to be freezing and thawing but drying which caused the bones to break up. The only assemblage to show no change throughout 150 freeze/thaw cycles was the dry assemblage (1).

Clearly the presence of water is crucial in the decay process, but damp bones, and bones periodically dried and wetted, disintegrated more rapidly than bones frozen and thawed in water. At the temperatures used, it appears that mechanical force due to the expansion and contraction of water as a result of freezing and thawing is not a significant factor in causing bone fragmentation or decay, whereas dehydration does cause cracking (as also argued by Miller 1975). The most obvious characteristic, however, was that very little degradation took place until the bones appeared to have become degreased. The rate at which degreasing took place was therefore crucial in determining the relative rates of decomposition, and bones which were more obviously greasy when fresh (e.g. salmon, plaice and some pigeon and mammal bones) survived better than apparently less greasy bones (e.g. cod and haddock). Calcium depletion in two male salmon dentaries appeared to cause rapid degeneration. Reduction in the mineral portion of bone will leave the organic component much more vulnerable to attack by micro-organisms.

Boiled bone, in which the organic fraction has been leached to a certain extent and the collagen fibrils denatured (Richter 1986; Rottländer 1976) degraded at a much faster rate than fresh bone, under all conditions of testing. Given this, it seems possible that the amount and condition of organic matter present in bones is an important factor in determining which bones will survive for the longest time, and so which bones stand the greatest chance of being recovered archaeologically, all other things being equal. The conditions which promoted the most rapid decomposition were continually damp freeze/thaw and wet/dry (sets 3,5,7,8,9). Damp conditions promote bacterial and fungal activity, and as a result the organic matrix of the bone is attacked. Boiling denatures the collagen fibrils (Richter 1986) and thus weakens the protein/mineral framework, rendering the bone susceptible to invasive attack by micro-organisms and to leaching of the

constituent protein and mineral parts. Heating reduces the resistance of bone to the mechanical forces exerted when water expands and contracts within it. The greater the degree of calcination the less able is the bone to withstand these forces, resulting in the complete disintegration of calcined bone.

6.6 Experiments into the Effects of Surface pH.

6.6.1 Aim

To investigate the effects of different surface pH on the preservation of animal remains. To observe whether acid surface environments caused skeletal remains to disintegrate, and if so whether the lower portion of the element (in contact with the sediment surface) would display more rapid attrition than the upper bone or shell surface.

6.6.2 Methods and materials

Six trays of dimensions 450 mm X 300 mm were filled with silver sand to a depth of 20 mm. On each tray were placed: one sheep metapodial and second phalanx; one rabbit femur or ulna, scapula and vertebra; one pigeon femur and radius; one mouse scapula and femur; one frog femur; one haddock otolith; lacrimal and maxilla; one plaice subopercular and maxilla, one salmon hyomandibular; one herring subopercular and hyomandibular; and two vertebrae each from cod, haddock, salmon, plaice and herring. There were also two vertebrae (one salmon and one haddock) which had been heated to 900°C for two hours, and similarly two vertebrae heated to 300°C for two hours. Additionally two mussel valves and two periwinkles were included. Insect remains were excluded as experiments immersing cuticle in solutions of acid and alkali had already been carried out (Appendix 2:3 and below). All the bones and shells were dried at 40°C for 48 hours and weighed prior to the experiment.

The sand in each tank was saturated by the addition of a buffered solution at one of pH 2.5, 5.0, 7.0, 9.0 and 11.0. The same buffer solution was used for each experiment, based on the universal mixture described by Prideaux and Ward (1924) with HCL and NaOH added to bring the solutions to the desired pH. This mixture includes phosphoric acid, phenylacetic acid and boric acid. Single distilled water at pH 6.5 was used for the sixth tray. The pH range approximates to that found in soil environments, although acidic environments of less than about pH 3.5 and greater than 10.0 are unusual. The sand was kept wet by the regular addition of the respective solution. All the trays were maintained at room temperature (approximately 20°C), but evaporation was increased by the necessary use of a ventilated cabinet.

After ten days some of the bones in the tray at pH 2.5 were observed to have a fine covering of white crystals, probably of calcium chloride (from the reaction of hydrochloric acid with the bone mineral). Over several days this efflorescence was observed to extend over some of the sand and more bones, so the sand was changed and re-saturated, the bones replaced as before, and the experiment continued. This change of sand was also performed for all of the other trays, and before the experiment was completed six changes of sand had taken place in each tray. In all trays except for that with solution pH 2.5, the solution turned a brown colour after contact with the sand and the bones for several days. The reasons for this are unclear.

After sixty days the bones and shells were removed and examined. Even after exposure to pH 2.5 many bones and all shells were very little changed. The experiment was modified at this stage to try to accelerate the processes of decay and to simulate the breakdown of skeletal tissues by microbial attack. After removal each bone and shell was washed in distilled water, placed on clean sand and the sand saturated with a solution of the enzyme pepsin, made up as one gram of pepsin (in powder form) to one litre of

single distilled water at room temperature. Pepsin was used to mimic the effects of proteases secreted by soil micro-organisms. The bones were placed with the same surface next to the sand as before and the sand was kept wet with solution added as necessary. This procedure was continued for 14 days, after which time the bone and shells were removed for observation, dried for 24 hours at 40°C and weighed.

6.6.3 Results

The weights before and after the experiment are given in Appendix 6.3. The most dramatic weight changes were for the bones in the pH 2.5 environment, many of which were completely, or partly, dissolved. Fig. 6:3 depicts the mean weight loss experienced by the skeletal remains of each taxon (excluding the otolith and burned bones) for each pH condition, after both stages of the experiment. Plate 6:7 illustrates the appearance of the otoliths after exposure to the pH solutions (after stage 1).

Stage 1.

During the first stage of the experiment, before the addition of pepsin, the most clear modifications were to the burnt vertebrae and to the smaller bones on the pH 2.5 surface.

After ten days on a substrate kept at pH 2.5 the undersides of the vertebrae heated to 900°C were crumbly, and by the second change of sand (18 days) these bones crumbled to powder on touch. Some of the smaller bones, including the mouse and frog bones rapidly became flexible after immersion in pH 2.5 solution; the smaller bones were completely covered when the sand was saturated, larger bones had only their undersides in direct contact. After one month the bones burnt to 300°C were extremely crumbly, and areas of the underside had dissolved, leaving a black flexible scum on the surface of the sand. Some of the

larger bones, including the pigeon femur, sheep metapodial, rabbit femur and rabbit scapula appeared polished and slightly pitted on the underside. The otolith too appeared polished on the underside after exposure to pH 2.5. After 60 days exposed to pH 2.5 the flat fish bones, including lacrimals, suboperculars and hyomandibulars were flexible and warped. All other fish bones were rubbery. The mouse scapula had completely disappeared, and the frog and mouse femora were thinned. The shells, particularly the periwinkles, appeared roughened and slightly pitted on the lower surfaces.

On the pH 5.0, pH 7.0, 9.0 and distilled water saturated surfaces, all the burnt bones were crumbly after 60 days. In the first case, the undersides of the calcined bones had partially dissolved. In the pH 11.0 tray the bones heated to 300°C were soft and extremely friable after one month and had disintegrated after 60 days, while the calcined bones remained unchanged (although the haddock vertebra broke into two pieces). Otherwise no changes were observed to the bones in these trays, except for a rather rubbery texture to the small bones in pH 5.0 and a chalky feel to the haddock otolith.

Stage 2.

After washing and the addition of pepsin solution for 14 days, the differences between the assemblages which had been exposed to the various pH solutions were more obvious. The rates of dissolution are illustrated by Fig 6:3, and by Appendix 6.3.

Many of the smaller or flat bones which had been exposed to pH 2.5 had completely disappeared after 14 days in pepsin. These included all the mouse bones, as well as the herring subopercular and hyomandibular, the haddock lacrimal and vertebrae and the cod caudal vertebra and lacrimal. All other fish bones from the pH 2.5 tray were floppy when wet and, when dry, crumbly and in the case of

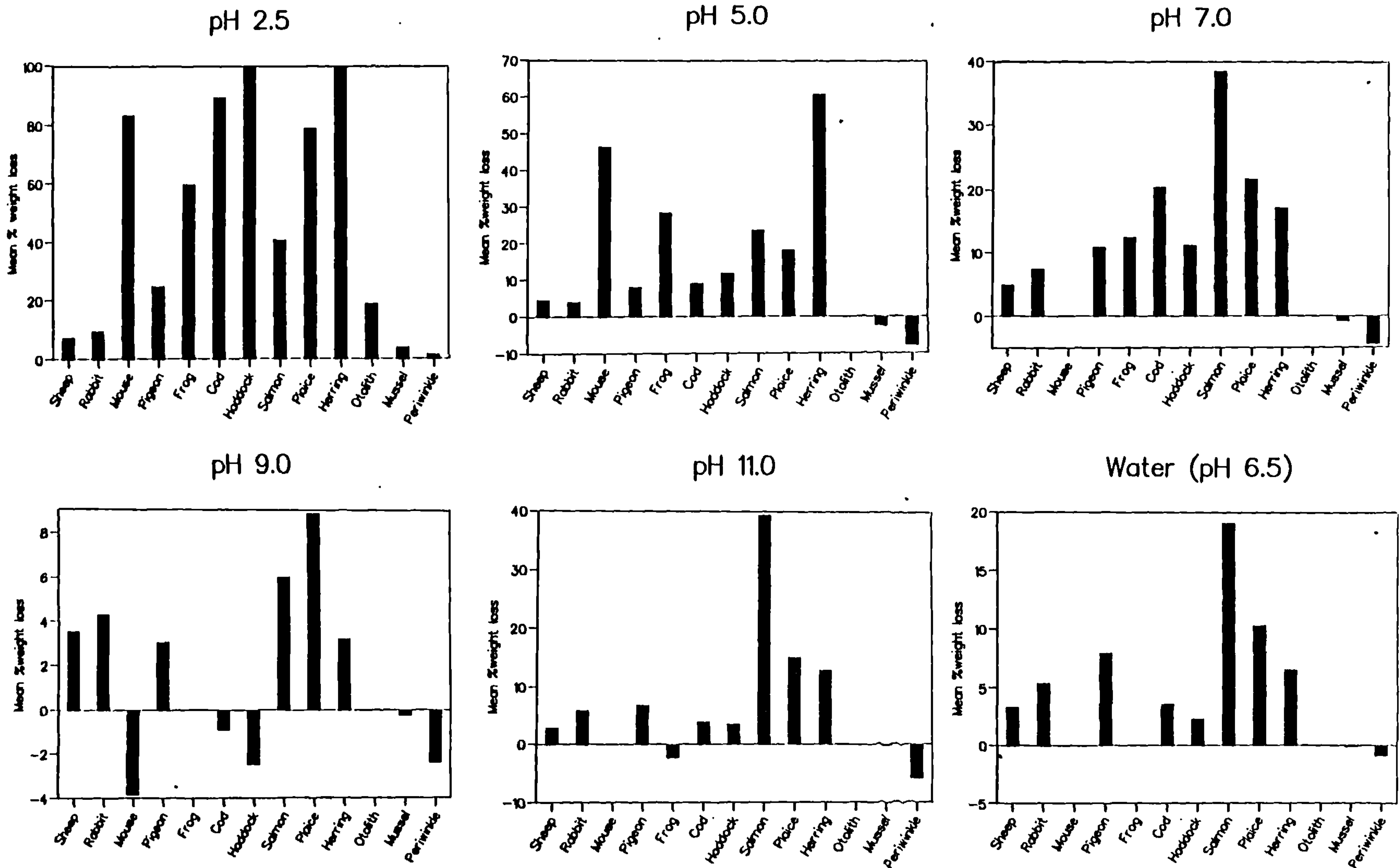


Fig. 6:3 Mean Percentage Weight Loss for Bone and Shell after Surface Contact with a Range of pH Solutions and Pepsin, by Taxon.

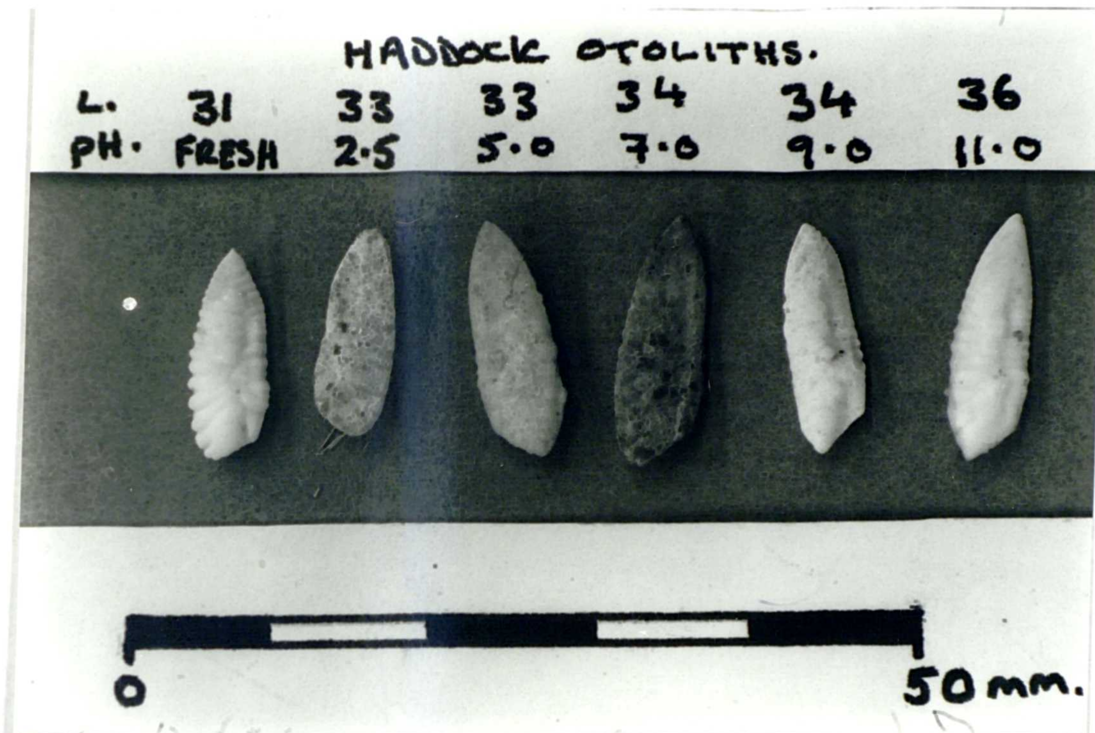


Plate 6:7 Condition of Haddock Otoliths after Surface Contact with a Range of pH Solutions (views of the exterior surfaces, which were face down on the saturated substrate).

L. = total length of fish (cm)

the cod maxilla, flaky. The rabbit and pigeon limb bones and sheep metapodial were markedly pitted on the lower surfaces and these surfaces also appeared flaky and eroded when dry. The frog femur was extremely thin and eroded. All edges of the shells which rested on or in the sand were crumbly. The lower surface of the otolith was chalky and surface sculpturing was reduced. No part of the burned bones survived.

Apart from the bones heated to 300°C, which crumbled completely after exposure to pH 11.0 followed by contact with a solution of pepsin, no further surface modifications were observed for the bones or shells in the other trays. The patterns of weight loss show that rates of dissolution were generally greater after exposure to pH 5.0 than after contact with higher pH solutions. Even at high pH some bones lost considerable amounts of weight, however, particularly the salmon bones. This weight loss was accompanied by the loss of the orange colouration which had typified all the salmon bones prior to the experiment, and could be attributable to the organic portion of the bone. Evidently the poor mineralisation of the salmon bones, particularly the head bones (here represented by the hyomandibular) enabled more rapid breakdown and leaching of the organic component. This leaching could also have been responsible for the brown colour assimilated by the solutions of pH greater than 2.5, noted above.

Some bones and particularly shells seemed to gain small amounts of weight between weighings. It is possible that small differences in moisture content and/or imperfect washing away of sand grains accounts for some of these cases. The mouse bones on the pH 9.0 substrate appear anomalous in gaining weight, for example. It is also possible that the tissues have absorbed some part of the buffer solution, however, which would explain the weight gain consistently recorded for the mollusc shells.

6.6.4 Further experiments into the effects of pH on skeletal tissue

To investigate further the effect of different pH solutions on otoliths, as a comparison with the results of tumbling otoliths (Chapter 5) and the effects of digestion (Chapter 7) otoliths were submerged in eleven different solutions ranging from pH 1.0 - pH 10.0. These solutions were made up using Universal Buffer Solution as before, with HCl and NaOH added as necessary. Distilled water was used as a control. To each beaker filled with 500 mls. of solution was added two whiting otoliths (from whiting of length 350-450 mm.). The experiments were conducted at 5°C to minimise evaporation, and the solutions changed every other day. The contents of the beakers were examined regularly for one week.

Similar solutions were made up and five adult *Tenebrio* beetles, five adult *Calliphora vomitoria* and five *Calliphora* puparia added to each. These were also left for one week at 5°C.

After 12 hours the whiting otolith had dissolved entirely in the pH 1.0 solution. At pH 2.0 after 12 hours the edges of the otolith appeared reduced, and the surface slightly polished. After 48 hours the otolith edges were clearly rounded, and the surface sculpting was less evident than when fresh. The solutions were renewed every two days, as the acid solutions at pH 1.0 and 2.0 (outside the buffering capacity) had become less acidic as a result of the dissolution of the calcareous material. At the end of the week the otoliths at pH 2.0 and 3.0 had rounded edges and were thinned over the entire surface, with reduction of the surface sculpting. The general thinning was also seen on digested otoliths (Plate 7:5a, p. 378) but no edge sculpturing was observable on the undigested specimens. At pH 4.0-6.0 the surfaces of the otoliths felt rather chalky but no size reduction was obvious. No other modifications were evident. Unlike tumbled otoliths, the general shape of

the otolith was thinned, rather than rounded, after submersion in acidic solutions.

The insect remains showed little change over the week, a result not surprising given their general resilience in extremely acid and alkaline solutions (as discussed in Appendix 2.2). The only observable change was a reddening of the fly puparia in the pH 1.0 solution, corresponding to chemical erosion stage 2 (Appendix 2.2).

6.6.5 Discussion of the results from the pH experiments

The loss of weight exhibited most strikingly by the bones which had been in contact with the pH 2.5 buffer solution, is an indication of the extent of mineral loss as a result of chemical breakdown of the crystalline structure and leaching of the solute. The rubbery nature of the bones subjected to this pH environment indicates that mineral had been removed, however some collagen may also have been hydrolysed by the acidic surroundings and removed in solution (Sillen 1989). Once the mineral has been removed the organic matter is exposed and open to attack by protein-digesting enzymes such as the pepsin used in this experiment. Not surprisingly, the smaller bones were the first to be lost, owing to their larger surface area:volume.

The loss of completely calcined bones at low pH has obvious archaeological consequences on sites where the substrate is very acidic. On sites where the ground water pH is only mildly acidic the solution effects on bone mineral may be less rapid than the loss of organic matter resulting from attack by micro-organisms, however. This could explain why, in aerated acid soils, calcined bone is often the only bone to survive (e.g. Castell Henllys, Gilchrist and Mytum 1986). Incompletely calcined bones, where organic material remained but collagen had been denatured by heat, may be preferentially lost owing to the activity of microbes. Knight (1990) examined the effects

of an acidic pH solution on burned bone and found that incompletely calcined bone dissolved faster than either completely calcined bone or fresh bone. The publication of these results will be interesting and useful for elucidating the diagenesis of burned bone.

It is clear from these experiments that in very acid environments otoliths will be reduced and finally lost. As with calcined bone, in mildly acidic conditions in aerated soils it might be expected that otoliths could survive as long or longer than fresh bone, however. This seems not to be the case, as otoliths are usually only associated archaeologically with excavations on calcareous soils. It is possible that their small size is responsible for their preferential loss, yet on some sites some small fish bones survive but no otoliths are found (e.g. excavations at Pool, Sanday, Orkney, Nicholson forthcoming a.). More work is clearly required, but as it concerns processes acting after burial, further investigation is beyond the scope of this research. Reduction of the otoliths by surface dissolution in acidic ground water may appear similar to the reduction seen after otoliths have been ingested. While it is possible that the edge and surface sculpting which can be seen on otoliths digested by a dog (from an experiment by Andrew Jones, here illustrated in Chapter 5, Plate 5:3 p.185) and on some otoliths after ingestion by a seal (this report, Chapter 7, Plate 7:2b, p. 351) would not be seen on those eroded by groundwater, this needs further testing. Care must be exercised when interpreting thinned otoliths in the absence of other evidence for the presence of material which has passed through the gut, however. It should be noted that not all otoliths which have passed through the mammalian gut will possess characterisic sculpting (see Chapter 7).

From the investigations discussed in this section, it may be suggested that fish bone is dissolved more rapidly than mammal and bird bone of similar size. The rates of dissolution appear to be shape dependent to a certain

extent, not surprisingly flat bones with large surface areas frequently lost more weight under acid conditions than thicker bones. As the skeletal elements used were of varying shapes and sizes, and were not totally submerged in the pH solution (the extent of submersion depending on the shape and size of the element) any conclusions about relative rates of dissolution must be tentative, however.

In the future it would be useful to examine the effects of different pH solutions on similar sized bones of different animal types, as differences in bone size clearly make comparisions of rate of bone loss between species impossible. Comparisons between rates of breakdown between mammal, bird, fish, reptile and amphibian bone would be of enormous value to investigations into the diagenesis of bone and to archaeozoologists. It would be also be interesting to examine the effects of different sorts of acid environments on skeletal dissolution, as different acids will reduce tissues in distinct ways (Cleminson 1979). Additionally, it would be useful to contrast the effects of low ambient pH in conditions of free drainage to compare with that of impeded drainage, to see what happens when the products of acid leaching are quickly/not quickly removed.

6.7 Discussion and Conclusions from the Weathering Experiments

Taking the general trends apparent from all of the experiments into weathering discussed in this chapter, several interesting points emerge. That different sorts of skeletal tissue, including different types of bone, weather at different rates is clear. In all the experimental situations fish bone decayed more rapidly than any other type of bone. This has important implications for interpreting archaeozoological remains. If estimations of the various dietary components are made on the basis of meat-weight estimates taken from bone counts, then fish may be drastically under-represented. This may explain why

examination of osteological samples from prehistoric human skeletons from Denmark and Greenland, by analysis of the proportions of the carbon isotopes ^{12}C and ^{13}C (Tauber 1986) indicated a higher intake of marine resources compared to terrestrial resources in the diet than was suggested by the analysis of bone and shell from contemporary midden deposits (such as those Danish midden sites excavated by Clarke 1975). Establishing the subsistence or economic strategies of past human societies may also be affected by the preferential loss of fish bone. In some cases, where reliance on marine resources was seasonal, with terrestrial resources being exploited at other times of the year, then the interpretation of the archaeological site as a seasonal or a permanent habitation could be confused. Absence of evidence in this case may not indicate original absence.

The chemical processes which operate to reduce bone above ground operate similarly below ground, and a varied suite of micro-organisms will attack bone in the soil. Physical processes such as freezing and thawing will penetrate the subsurface layers on occasion, at depths relating to the climatic regime. If fish bone is lost preferentially above ground, then it is likely that the same trend will operate during diagenesis.

The more rapid decay of gadid bones compared with the bones of other fish taxa which is indicated by these experiments also has important archaeological repercussions. Fish of the gadid family frequently out-number the bones from all other families of fish in terms of numbers of bones and estimated minimum numbers of individuals. It has often been argued that this trend resulted in part at least from the preferential preservation of the "robust" gadid skeleton. The increased importance of gadids in the fish catch and therefore in the economy cannot be ignored for some sites, such as Norse sites in Scotland and on Orkney (e.g. Jones 1991, Nicholson forthcoming a and b). For less clear-cut cases of fishing

specialisation, the conclusions drawn about the relative chance of survival of gadid bones compared to the bones of other species is of paramount importance to the interpretation of the fishing strategy.

Bird bone survived virtually unchanged through most of the experiments, even when similar sized mammal bone (from rabbit and rat) showed signs of desiccation and cracking. Although further experiments are required, of longer duration than that possible here, the results are at least worthy of note and correspond to my intuitive feeling from looking at archaeological material, that when bird and mammal bone occur together the bird bone is frequently better preserved both in terms of extent of fragmentation and in texture. Unfortunately there has been very little published on the preservation of bird bone, but it is interesting that Tappen and Peske (1970) have also noted that more collagen was preserved in bird bone than in mammal bone recovered archaeologically from the same deposits. Research by Jackson at the University of London Institute of Archaeology, with results unavailable to me at the time of writing, may provide useful information.

Assessing the rates of weathering within the skeleton proved more difficult, as few skeletons showed much change during the three years of exposure, and between taxa variations were more obvious than differences within skeletons in all the experiments. The trends exhibited by the boiled cod skeleton were for early disintegration of the smaller flat bones first, followed by the larger flat bones and vertebrae.

Cooking clearly had a great effect on the rate at which bone weathers. Heating denatures the collagen fibrils, and these fibrils are then preferentially further broken down by proteolytic enzymes (Snowden and Weidman 1976). Heating to 80°C left some fibrils intact, but after 30 minutes boiling in distilled water, fish bone collagen was completely denatured and the fibrils were unrecognisable

(Richter 1986). As collagen fibrils are denatured, so the organic-mineral bond is broken, thereby destroying the bone microstructure. Clearly this weakens the bone and renders it open to microbiological attack. Within the limits imposed by the exposure experiment it seems that boiling has a greater effect on the rate of bone weathering than heating in an oven (baking or roasting), although the differences could not be quantified from this experiment. Further work in this area would be very valuable.

Mounteney (1981) examined the mammal bones from a chalk site at Thwing, North Humberside, and interpreted the remains from different areas of the site by reference to the extent of attrition. He interpreted the attrition observed as the result of weathering, which he divided into "physical" and "chemical" weathering. Physical weathering is defined as the development from *"solid well-preserved bone via superficial flaking and hairline cracking to profuse fracturing"* and chemical weathering as *"resulting from the removal of osseous material in solution...extreme attrition resulted in the bone structure crumbling away"*. Chemical attrition is interpreted as primarily caused by soil acids and roots, whereas physical weathering is interpreted as the result of exposure to the elements. This interpretation lead Mounteney to conclude that bones from one area of the site had been exposed for a long period prior to deep burial, and so exhibited physical weathering, while bones from another area had been buried in shallow contexts and were subject to chemical weathering from percolating ground-water and root penetration.

While this division of weathering proved useful in this case, in fact all weathering results from chemical changes within the bone. Leaching of mineral and collagen takes place above ground as well as below. Cracking and erosion may occur after burial if the substrate is subject to periodic wetting and drying. As cooking affects the susceptibility of bone to physical and chemical breakdown, so an assemblage displaying disparate weathering states may

reflect not different lengths of exposure, as Behrensmeyer (1978) suggests, but unequal susceptibilities of the various bone types or bones subjected to different treatments.

In and on the soil environment bacteria such as *Clostridium histolyticum* are active in breaking down protein in bone (Rottländer 1976) given suitable temperatures and moisture. White and Hannus (1983) concluded that in the environment acids form as a result of microbial decay of collagen, which in turn cause diagenesis of the hydroxyapatite in bone by the replacement of calcium with other metals. As the collagen is removed the weathering and recrystallisation of hydroxyapatite continues in a moist acidic environment. Hydroxyapatite is soluble at pH 6.5 and below, in more basic soils weathering slows down or stops as calcium levels are stabilised (Price 1989). More porous bone is more susceptible to penetration by micro-organisms and water; therefore diagenesis proceeds more rapidly in porous areas of bone, as demonstrated by Cleminson (1979) who examined the dissolution of bones of pig, sheep and cow in various acid and alkaline solutions.

Recrystallisation of hydroxyapatite causes the mean crystal size to increase (Tuross *et al.* 1989). The increase in the length of the crystallites, as indicated by X-Ray diffraction (changes in the reciprocal breadth of the 002 diffraction peak of the apatite mineral phase) is of the order of 20% in weathered wildebeest bone. This size increase is similar to that indicated by Bonnucci and Graziani (1975) and Shipman *et al.* (1984) for bone heated to between about 300 and 650°C. Consequently it seemed possible that this crystal growth due to weathering may produce areas of bone which, when viewed under the scanning electron microscope appear similar to bone which has been heated. For this reason a selection of the extensively weathered boiled cod and plaice vertebrae articulating facets were examined through the scanning electron microscope, after brushing with alcohol and acetone, and

viewed at magnifications similar to those used for burnt bone (Chapter 3). Out of ten specimens examined, only one showed areas of increased crystal growth. The crystal structure, comprising areas of large spherical-polygonal plates, was similar to that observed on calcined salmon bone (see Plates 4:3M and 4:4J, p. 116 and 119) and was also similar to that illustrated by Shipman *et al.* (1984) for calcined sheep subchondral bone. This illustrates one problem with the use of crystal structure as an indicator of heated bone, although the weathered bone showed only one such area, and the rest of the bone appeared similar to fresh bone in crystal structure. The calcined bones showed characteristic patterns of crystal growth over the whole, or great majority of the surfaces examined. For this reason it is unlikely that calcined and weathered bone would be confused, however as heavily weathered bone can be recognised by extensive cracking and exfoliation, even when burned (see Chapter 4).

The experiments described in this chapter have, in keeping with the aims of the project as a whole, dealt only with processes affecting skeletal tissues before permanent burial. To what extent the physical properties of skeletal tissues may be altered after burial is poorly understood, however, yet this is clearly of vital importance if the effects of subaerial weathering are to be distinguished from diagenetic effects. The assemblages of animal remains I buried in 1987 in soils including dune sand, acidic peat, alkaline peat, organic detritus, silty clay, acidic woodland soil, agricultural soil and acidic sand, should yield useful information in this area (see Appendix 6.1 for brief details). Currently the decomposition of organic remains after burial in an experimental earthwork in a calcareous soil is being studied at Wareham and Overton Down, where cooked and fresh sheep bones were buried to be excavated and studied at regular intervals. One result from this experiment has been to show that when buried under turf in a calcareous environment dissolution of sheep femora was greater on the upper than the lower surface, due

to percolating water (Evans and Limbrey 1974). This effect could be confused with bones which have dissolved preferentially on the lower surface caused by weathering on an acidic substrate, however the depositional environment may indicate which process is the more likely.

Given the scope of this study, it was not possible to do more than "scratch the surface" of the potential research area. Further experiments and replication would refine the conclusions derived from this study. It would be interesting, for example, to discover how far different surface environments affect the rates of weathering. Probably on a damp surface skeletal tissues would weather much more rapidly than was the case in the free-draining environment of the exposure experiment on the roof. This suggestion is supported by the speed at which the bones decayed which were repeatedly wetted and dried. That different surface environments affect the rate and pattern of bone weathering is also supported by the surface pH experiments described above, but field experiments would clearly be useful in order to observe and quantify the differences in a natural environment.

This study has not dealt with the variations in rates of weathering and exposure on bones from animals of different ages, although this would also be an area worthy of investigation.

CHAPTER 7. THE EFFECTS OF DIGESTION ON ANIMAL HARD TISSUES.

7.1 Introduction

This chapter concerns the study of contemporary bird pellets, otter spraints, seal droppings, fox scats and human faeces in terms of their component skeletal assemblages. Comparisons are drawn with archaeological material in several cases. An experiment was also conducted to compare the relative rates of destruction of different bone tissues by a protein-digesting enzyme (pepsin), as a crude approximation to conditions within the gut.

7.2 Background

Contemporary assemblages of vertebrate remains modified by the feeding activities of other animals have been the subject of a number of studies in recent decades. Generally the modifications involved are produced by jaw action (i.e. chewing and tearing) and by the action of acids and enzymes in the gut during digestion.

In Africa several scholars have examined natural accumulations of bones attributable to animal activity, including Brain (1981) who looked at bones from porcupine lairs, and Shipman and Walker (1980) who examined accumulations of small bones by harvester ants.

Haynes (1982; 1983), Binford (1981), Brain (1981) and Todd and Rapson (1988) among others, recorded carnivore damage to bones of prey animals from the remains found at kill sites. These authors concluded that specific predators and scavengers produce recognisable patterns of tooth marks and scratches on bone and destroy bones in predictable and definable ways. Assuming some knowledge of the local fauna, an indication of the species responsible may be possible from a study of the punctures, grooves and edge modification to the bones. Some of the fragments produced could be misidentified as former tools (e.g. Kitching

1963).

In Britain, Sue Stallibrass documented the types of damage inflicted by foxes (as an analogy for dogs on domestic sites) on the bones of sheep and deer (1986). She also found that bone elements and assemblages were predictably modified, and that these patterns could be recognised in archaeological material. More recently she has gathered empirical data on bone destruction by a dog (Stallibrass 1990). Rodents gnaw bones, and a study of the gnawing patterns produced has been published by Andrews (1990). Humans, as carnivores and users of animal products, also modify bone assemblages and the identification of butchery marks has been the object of many reports.

Other animals also modify and accumulate the remains of other creatures. The study of bones from raptor pellets, as well as accumulations of bones deposited around nesting and roosting sites, is not new. Several detailed studies have been undertaken, some by ecologists, others by paleoecologists, paleontologists and archaeozoologists, and there is a reasonable literature on the subject, for example Glue (1970), Mayhew (1977), Dodson and Wexlar (1979), Denys (1985) and most recently, Andrews (1990). The approaches taken include both the study of pellets produced by known raptor species and, in some cases, the results of feeding small mammals to raptors (e.g. Duke *et al.* 1974; Raczynski and Ruprecht 1974; Dodson and Wexlar 1979; Yalden and Yalden 1985). Andrews (1990) investigated the effects of trampling on small mammal bones within pellets, as well as the disintegration of pellets and damage of the bone assemblage resulting from weathering. These studies include documentation of both assemblage composition and bone fragment modification.

Many other birds regurgitate parts of their food, sometimes in pellet form. Gulls, for example, commonly regurgitate fish bones and mollusc shells, as well as assorted pieces of scavenged rubbish, as a number of

studies by students of Biology at the University of York have shown (unpublished information). Magpies, skuas, herons and, though not in Britain, vultures and condors also produce pellets which may contain bone (Andrews 1990, 5). Interestingly, herons appear to digest fish and amphibian bone completely, while ejecting some small mammal bones in the pellets (Hibbert-Ware 1940).

In a number of cases comparisons have been drawn between the appearance of water-abraded small mammal bones and the bones recovered from raptor pellets (e.g. Korth 1979; Denys 1985). Some studies have successfully related the modern observations to archaeological material, for example Denys *et al.* (1987), Klippel and Snyder *(1987)*, *Andrews (1983*, 1990). Sarah Colley (1983) compared the species and size of fish found in modern otter spraint in order to interpret archaeologically recovered assemblages of small fish bones, but she did not look at the extent of bone loss or the types of damage to the bones. Wilson (1987) examined fossil coprolites of unknown origin with the aim of elucidating whether they were formed by birds (i.e. were regurgitated pellets) or whether they could have been produced by fish. Wilson concludes that the former is more likely because intact bones were recovered. Wilson notes that fish bones are usually completely digested within the first third of the gut beyond the stomach, in salmonids, and there is no evidence for the regurgitation of stomach contents by fish. Gutting fish may, of course, leave the bones of prey species displaying various states of digestion. Bones from fish guts may be represented in archaeological material.

Ethnographic examples of bone destruction by domesticated animals include observations by Brain (1981) on the damage inflicted on goat bones by Hottentot dogs, and by Lyon (1970) of the destruction of small mammals, birds and fish by dogs in Peru. Lyon concluded that all bones may be lost if scavenged by dogs. Casteel (1971) argued that not all bones would be lost, but clearly the archaeozoological record may be modified by dogs. I have observed the

destruction of fish bones by several domestic dogs in Salango, Ecuador. In this case four dogs were fed daily almost exclusively on boiled fish carcasses, after soup preparation. Most fish were large (over 1 m. total length) and from many species. Although no quantification was attempted, it was clear that many bones survived completely, in particular the jaw elements such as the dentary, premaxilla and articular, as well as the cleithrum. Crania were usually broken into many fragments. Most bones showed gnawing damage, and many were removed from the feeding site by distances of many metres. When smaller fish were fed to the dogs they were consumed entirely. The dogs were also observed to scavenge fish beached on the nearby shore, or rejected by the local fishermen, a process which also caused the movement of whole fish or parts of fish from the shore to areas of human habitation. This has obvious implications for the mixing of "natural" with "cultural" refuse. On most urban sites and archaeological sites in temperate latitudes, scavenging by domestic animals will be more important as a source of bone loss or modification than will be the activities of wild carnivores.

Even herbivorous animals may chew bones: Brothwell (1976) records damage to bones inflicted by sheep, and Sutcliffe (1973) points out that a wide range of ungulates may chew bones. Smaller scavengers include rats, which may have been abundant within domestic settlements in the past. That rats can dispose of bones completely has been observed by Brothwell (1976) and Jones (1986). Domestic cats will also gnaw bones, and produce tooth punctures and scratches quite different from those produced by canids (O'Connor pers. comm.). Bones chewed by cats have tentatively been identified from York (O'Connor 1991). Presumably cats were more wont to chew bones in the past, before the advent of tinned cat food.

Perhaps because of the unpleasantness involved, there have been relatively few pieces of work looking at the

damage inflicted to bones by passage through the mammalian gut. On most archaeological sites, it is likely that more bones will have been modified by mammals than by raptors; humans and domestic animals are the most likely consumers of meat and depositor of bones in faeces. Mellett (1974), Andrews and Nesbit-Evans (1983), Stallibrass (1990) and Andrews (1990) have examined bones found in recent carnivore scats and compared them with fossil assemblages. Bones which have passed through the guts of large carnivorous mammals may be characteristically etched and pitted. Fragments similarly eroded have been recognised at Creswell crags in Derbyshire (Kitching 1963).

Studies of an experimental nature are few. Steenstrup (1862) fed bones to dogs and collected bones from contemporary Eskimo middens, to compare with those recovered from Mesolithic Danish midden sites. He concluded that dogs were probably responsible for the loss of the weaker bones. Payne and Munson (1985) fed the heads and feet of 37 squirrels (*Sciurus niger*), as well as the limb bones from 15 of them, to a domestic dog and examined the bones passed in faeces and those rejected. In subsequent experiments goat bones (*Capra*) and cottontail (*Sylvilagus floridanus*) were fed to dogs (*ibid.*). These experiments showed that considerable amounts of bone were lost due to complete digestion. Of the squirrels, only 14 were recovered (minimum number of individuals based on the second phalanx). Those bones which were digested were extremely corroded, and no tooth marks remained. Some of the vomited bones also were corroded. Rejected bones often showed no damage, although some showed clear evidence of gnawing. Similarly Jones (1984; 1986) examined the loss of bone after passage through the digestive tracts of dog, pig, rat and man, and documented the types of damage seen on the very few fragments which survived the process. His studies relied on very few (usually one) experiment, however. All these experiments also documented the assemblage composition from the recovered bones.

The survival of organic remains through the human digestive tract was investigated experimentally by Calder (1977). Among the organic materials tested were scales of flounder (*Rhombosolea* sp.) and sole (*Peltorhamphus novaezeelandiae*), shark dermal denticles (unknown species), limpet (Calyptroeidae) radulae and periwinkle (Littorinidae) opercula. Of these, the scales were completely digested, while almost all of the mollusc parts and shark denticles were recovered intact.

Occasionally coprolites and pellets are recovered intact from archaeological excavations, usually from dry sites but sometimes in desiccated or mineralised form (e.g. the human coprolite from the site of 6-8 Pavement, York (Jones 1983)). Many of these appear to have been dog coprolites (e.g. Dimbleby 1968; Paap 1976; Jones 1990). Other archaeological studies of intact ancient human coprolites containing bones include coprolites containing numerous fish remains, from Lovelock Cave, Churchill County, Nevada (Follett 1967, 1970). Intact human as well as dog coprolites have also been recovered from Lake Cahuilla, Coachella Valley, California (Wilke 1978). Bird pellets have been identified from bone remains from Neolithic Orkney (Armour-Chelu 1988), from a late Roman site at Kingscote, *Gloucestershire (O'Connor 1987) and from the* Roman town of Caerleon, Gwent (O'Connor 1983; 1986) for example. It is fairly unusual for whole droppings or pellets to be identified in archaeology. More often the matrix will disintegrate, making their contents less easy to recognise. It is for this reason that investigations into criteria by which digested remains may be identified are useful.

Many mammals and birds feed on insects, and accumulations of insect body parts are frequently recovered in scats, pellets and droppings. Hedgehogs, for example, are now common even in towns, and may commonly be responsible for accumulations of insect body parts from their droppings. Although accumulations of insect remains on archaeological

sites may frequently have resulted from their inclusion in pellets, droppings or scats, to date little attention has been paid to this source of information. Kenward (1975) noted the probability of birds importing insects onto urban sites, and Girling (1977) identified insect-rich pellets, probably from crows, in Bronze age deposits on the Somerset Levels. Contemporary raptor pellets and scats examined by Andrews (1990) often contained insect remains, but details are not given. Bat droppings usually contain tiny insect remains, such as moth wings and Coleoptera fragments (M.Thompson pers. comm.). Some insects and other arthropods are also responsible for chewing the remains of other insects (see Chapter 6, p.278) and bones, a particular problem for museum curators. The results of destruction of reference skeletons by cockroaches have been observed by this author.

Mollusc shells may be damaged by other invertebrates, for example the dog whelk *Nucella lapillus*, also the gastropod *Natica catena* and starfish (Asteroidea) bore holes into shells. Sponges may tunnel into oyster shells (Lawrence 1971). Sea birds commonly feed on invertebrates, breaking their shells into often tiny pieces in the process. Invertebrates and birds may also erode or break land snail shells (Carter 1990). Molluscs may also damage bones: Bickart (1984) suggests that land snails may have been reponsible for boring holes into bird bone.

7.3 Aims

The aims of the observations and experiments detailed in this chapter were threefold. Firstly, to assess the extent to which different predators modify bone assemblages during ingestion. Secondly, to assess the potential for recognising in archaeozoological assemblages bones which have passed through the digestive tract, and for establishing the animal involved. Thirdly, to compare the rates of decomposition of bone from different animal groups. More specifically, the aims were:

1. To examine the extent to which skeletons are modified by ingestion by predators.
2. To investigate whether different predators can be recognised by the composition of the bone assemblage recovered from their faeces/regurgitated pellets.
3. To assess whether digested bone can be distinguished from bone subjected to other attritional processes.
4. To investigate the extent to which archaeologically recovered assemblages can be compared with modern assemblages known to have been ingested.
5. To compare rates of digestion by a protease (pepsin) of bone from mammal, bird, fish (several taxa) and amphibian.

7.4 Analysis of Modern Bird Pellets and Mammal Scats, and a Comparison with Archaeologically Recovered Material.

7.4.1 Materials and methods.

Modern material.

The choice of predator species was partly determined by availability. In the case of otter and seal, however, the droppings were studied as a means of investigating possible sources of small fish bones in coastal archaeological sites.

Regurgitated pellets from kestrel *Falco tinnunculus* L., barn owl *Tyto alba* (Scopoli), tawny owl *Strix aluco* (L.), buzzard *Buteo buteo* (L.), hen harrier *Circus cyaneus* (L.) and little owl *Athene noctua* (Scopoli), as well as several otter (*Lutra lutra* (L.)) spraints, all collected from a number of inland sites in England and Wales, were donated by Peter Andrews of the Department of Paleontology, British Museum, Natural History. They had been stored in a dry state for a number of years.

Raptor pellets typically consist of a tightly packed ball of fur or feathers in the core of which are bones. This

packing prevents the sharp bone fragments from perforating the gullet during regurgitation (Glue 1977). Details of the diets and pellet characteristics of these and other birds are given by Andrews (1990, 178-201) and will not be repeated here. It should be noted that the little owl is a recent introduction into Britain, so its pellets are not likely to be recognised archaeologically.

The contents of twenty two grey seal (*Halichoerus grypus* Fabricius) droppings collected from Orkney were obtained from Graham Pierce, University of Aberdeen, and had been stored in alcohol prior to study. Otter spraints were obtained from Andrew Jones who collected them from Freswick, Caithness. Some of these spraints were disaggregated and sorted for bones by Colin Nicholson. Otter spraints from Shetland were obtained from Jim Conroy at the Institute of Terrestrial Ecology in Banchory. These were obtained complete but frozen.

Otter spraints typically comprise a collection of small bones bound together by mucus, and sometimes with blades of grass included. The mucus coat is frequently black, and some bones may be stained by it. Further details of the characteristics of otter spraints are given by Chanin (1987) and seal scats are described by Prime and Hammond (1987). Gull pellets were collected by staff and students of the Department of Biology, University of York during two field courses on the island of Great Cumbrae in the Firth of Clyde. These were morphologically very diverse, as described below.

The amount of material available from each predator species varied, and very little bone was recovered from the buzzard pellets (although they were full of beetle remains). The pellets were stored dry, and many had partly or completely disintegrated during the years of storage. Care was taken to try to use complete individual pellets or whole scat assemblages for the study. The pellets assemblages were weighed, disaggregated manually in the

laboratory, and all bones removed with care, using fine forceps and a low power binocular microscope (x10 magnification). Some pellets, particularly those of the hen harrier, comprised mainly compact hair and fur. These were broken up using commercially available hair remover, as discussed by Dodson and Wexlar (1979).

The otter spraints were disaggregated under a gentle stream of warm water.

Information on provenance, species, bone, anatomical side and position of the fragment was recorded as a database using D-Base III+. As the main forms of modification were by breaking, crushing or chewing and acid dissolution, the categories of texture, erosion and flaking were not very useful descriptives. To allow better description of the assemblage composition, a category for acid erosion, as characterised by a combination of polishing, thinning, pitting and sculpting of bones was added to the standard record. Evidence of crushing or chewing was also scored.

Only those bones potentially identifiable to at least family level were recorded (see below) thus ribs, small skull fragments and carpal bones were not recorded, for example, nor were fish skull fragments, hyal bones, branchials, ribs, rays, spines and small bones of the pelvic, orbital and facial region.

Archaeological material.

Fish bones from one Iron Age context (PL 0431/0487) from excavations at Pool, Sanday, Orkney comprised one part of a larger assemblage of fish bones from the site as a whole (Nicholson forthcoming a.). The excavations were conducted by a team led by John Hunter of the University of Bradford. The bones from PL 0431/0487 had been recovered by wet-sieving though a 1 mm. mesh. The entire context, comprising a lens of tiny fish bones, was recovered, but a small sub-sample of 76 grams was obtained by use of a standard sample

dividing box, and this sub-sample formed the basis for the study.

Similarly, a layer of small fish bones formed part of an assemblage of fish from the prehistoric site at Tofts Ness, Sanday, Orkney (Nicholson forthcoming b.) The excavations were led by Steve Dockrill of the University of Bradford. The layer, (TN 0619) also of Iron Age date, comprised 654.3 grams of fish bone. A sample of 23.5 grams was obtained using a sample divider, and forms the basis for this analysis.

All bones were examined using a dissecting microscope. Only skeletal elements potentially identifiable to at least family level were recorded. Identifications were made with reference to the comparative collection of fish remains held in the Environmental Archaeology Unit, University of York. Where useful for illustrative purposes, some bones were examined and photographed under the scanning electron microscope.

7.4.2 Data presentation

The results are displayed as Tables (7:1-7:21) and Figures (7:1-7:7) illustrating the proportional representation of skeletal elements, proportion of whole bones, completeness of fragments and areas of bone surviving. Photographs illustrating some of the more common forms of damage are also presented (Plates 7:1-7:6).

The Tables and Figures have been constructed for assemblages as a whole, without regard for species (as not all bones could be readily identified to species). Different species of small mammal and fish have different numbers of vertebrae, so expected values have been estimated as approximating to an average figure, in the case of fish. The estimated expected vertebrae numbers used are 45 for fish and 50 for small mammals (the latter following Dodson and Wexlar 1979, whose figures were based

on mice). No attempt has been made to divide vertebrae into anatomical areas along the spine, as this would complicate the estimates even more, for example because voles and shrews have far fewer caudal vertebrae than mice. Consequently the expected numbers of vertebrae will be higher for a mixture of mice, shrews and voles than for mice alone. Also the expected figure assumes total recovery of the small vertebrae, whereas in practise some tiny caudal vertebrae could have been missed.

Only bones readily identifiable by the author to skeletal element were used in the statistical analyses. Small mammal carpals, tarsals (except calcaneum and astragalus), sesamoids, metapodials, phalanges, clavicle and ribs were not included owing to their small size or problems of identification. Small mammal skulls fragments (classified as cranium less than 50% complete) were not included in the analysis of proportional representation. Only those fish bones which I could easily assign to skeletal element for a wide range of species were used in the statistical analyses and graphical representations. Otoliths and eye lenses were excluded because it was felt that they might be lost in preference to bones in some soils.

The proportional representation of skeletal elements has been calculated using the method given by Dodson and Wexlar (1979, Table 1) and is based on the numbers of bones surviving compared with the expected number:

$$PRO = \frac{FO}{(FT \times MNI)} X100$$

where FO = the number of each element recovered in an assemblage

MNI = the minimum number of individuals, by the most frequent bone

FT = The expected number of the bone element in one individual.

The expected number is obtained by multiplying the number of bones in one prey animal by the minimum number of that animal represented in the pellet assemblage. The minimum

number of individuals (MNI) is calculated from the most common side (left or right) of the most commonly represented bone in the pellet or spraint assemblage. It should be noted that this figure is a minimum; the most commonly represented bone will probably have suffered some loss too. Because, for simplicity, the MNI is calculated using paired bones only, it is possible that some other bones, e.g. vertebrae, may be better represented and so score over 100% for proportional representation. The figures should not be taken as indicating the actual numbers originally present of any of the bones, so that a score of 100% does not mean that no loss has occurred, it is the relative proportions which are important.

The Tables detailing proportional representation include pooled figures for all the pellet/spraint assemblages. The minimum number of individuals has been obtained from the entire assemblage rather than by summing the individual MNI's for each pellet/ spraint. This will inevitably grossly under-estimate the true MNI but has been adopted to equate with the methods used for archaeological assemblages, where individual spraints or pellets cannot be distinguished. As pointed out by Grayson (1984), proportions based on the minimum numbers of individuals will be affected by sample size. Thus only the ranks are used for statistical comparison, rather than the proportional representation scores.

To test the hypothesis that the archaeological material from Pool and Tofts Ness originated as otter spraint, Spearman's rank correlations were calculated for the proportional representation of skeletal elements for each modern spraint group and for the archaeological assemblages from Pool and Tofts Ness. This gives an indication of the similarity of the assemblages, but as noted above, relative frequencies obtained using the minimum numbers of individuals will vary according to sample size, although the ranks will not change.

As another, crude, method of investigation, relative frequencies were obtained simply by dividing the actual counts of the easily identified bones by the expected number in one animal. These were then plotted against the ranks, and the shape of the curves gives an indication of the relative rates of skeletal element loss, or their "decay trajectory" (*sensu* Carver, unpublished).

Shape categories were assigned to the skeletal elements recovered from the combined otter spraints (by location) and the archaeological material (by site), the raptor pellets (by species) and the human faeces (all experiments), as described in Chapter 2. Only bones which could be identified from a wide range of species were included. Chi-squared tests were used to test the null hypothesis that shape is not related to preservation potential. For these tests only shape categories describing over 5% of the bones were utilised and assemblages with very few bones were excluded.

7.4.3 Results and discussion

Raptor Pellets.

How do raptors modify bone? How much variation is there between species of raptor?

Tables 7:1 and 7:2, and Fig. 7:1 give the numbers and proportional representation of skeletal elements for the pellets from each predator species. Table 7:3 gives the fragment completeness values for the larger skeletal elements, with the proportion of whole bones, per predator. Tables 7:4-7:7 detail the areas of the long bones, pelvis, mandible and skull present in the pellets of each raptor (areas of the bones are as detailed in Fig. 2:2, p.35). "Decay trajectories" for each raptor species are illustrated by Fig. 7:2; buzzard is not included in these Figures owing to the small number of pellets examined. The species identified in the pellets included shrew, mouse and

field vole. Vole was the most commonly represented animal in all cases. Several bones of rat and bird were found in some of the pellets, but in no case was it clear that whole animals had been ingested. The Tables and Figures presented here deal with the small mammals (under 200 grams body weight) only.

Table 7:1
Numbers of small mammal skeletal remains recovered from modern bird pellets. Species identified included vole, shrew and field mouse.

ELEMENT	n.	s.	Kestrel	Barn owl	Tawny owl	Little owl	Buzzard	Hen harrier
total pellet weight			60g.	15g.	32g.	39g	6g	59.5g.
mni =			42	19	23	15	2	14
Mandible	2	F	81	29	44	29	0	27
Cranium (>50%)	1	I	12	15	12	0	0	0
Humerus	2	TU	55	38	25	10	3	11
Radius	2	TU	37	23	20	7	1	5
Ulna	2	TU	37	22	19	12	1	7
Femur	2	TU	52	27	30	24	3	15
Tibio-fibula	2	TU	60	26	22	23	1	15
Pelvis	2	F	34	19	20	10	1	1
Scapula	2	F	9	25	18	5	1	3
Sacrum	1	R	8	8	4	1	0	0
Calcaneum	2	S	7	15	5	2	0	5
Astragalus	2	S	7	8	4	0	0	1
Vertebrae	50	S	129	489	163	20	15	19
Total	73		528	744	386	143	146	109
% survival			17.3	53.6	23.0	13.1	17.8	10.7

MNI = Minimum number of individuals, based on a count of the most commonly represented side of the most commonly represented skeletal element.

N. = number of bones in one individual. Because several species have been included this figure has been given an arbitrary value of 50 for vertebrae, but it should be noted that this figure will vary depending upon species, and will be less for vole and shrew.

S = Shape (F = Flat, I = Irregular, TU = Tubular, S = Spherical).

N.B. The number of pellets could not be exactly ascertained for most species, as the collections of pellets (courtesy of Peter Andrews, Natural History Museum) had broken up. Where possible, however, intact pellets were selected.

Table 7:2
Proportional Representation of small mammal skeletal remains recovered from modern bird pellets.
Species identified included vole, shrew and field mouse.

ELEMENT		Proportional Representation					
		Kestrel	Barn owl	Tawny owl	Little owl	Buzzard	Hen harrier
total pellet weight		60g.	15g.	32g.	39g	6g	59.5g.
mni =		42	19	23	15	2	14
	n.						
Mandible	2	96.42	76.31	95.65	96.67	0	96.42
Cranium (>50%)	1	28.57	78.94	52.17	0	0	0
Humerus	2	65.47	100	54.35	66.67	75.0	39.28
Radius	2	44.00	60.52	43.48	23.33	25.0	17.85
Ulna	2	44.00	57.89	41.30	40.00	25.0	25.00
Femur	2	61.90	71.05	65.22	80.00	75.0	53.57
Tibio-fibula	2	71.42	68.42	47.83	76.67	25.0	53.57
Pelvis	2	40.47	50.00	43.48	33.33	25.0	3.57
Scapula	2	10.71	65.78	39.13	16.66	25.0	10.71
Sacrum	1	19.00	42.10	17.39	6.67	0	0
Calcaneum	2	22.14	36.84	10.87	6.67	0	17.85
Astragalus	2	8.33	21.05	8.70	0	0	3.57
Vertebrae	50	6.14	51.46	14.20	2.66	4.86	2.71
Mean		38.62	55.11	37.97	34.56	21.53	24.93
St. Dev.		28.66	23.02	25.43	34.36	26.42	28.74

MNI = Minimum number of individuals, based on a count of the most commonly represented side of the most commonly represented skeletal element.

n. = number of bones in one individual. Because several species have been included this figure has been given an arbitrary value of 50 for vertebrae, but it should be noted that this figure will vary depending upon species.

Proportional Representation is based on the formula:

$$PR = \frac{\text{observed}}{\text{MNI x expected}} \times 100$$

N.B. The number of pellets could not be exactly ascertained for most species, as the collections of pellets (courtesy of Peter Andrews, Natural History Museum) had broken up. Where possible, however, intact pellets were selected.

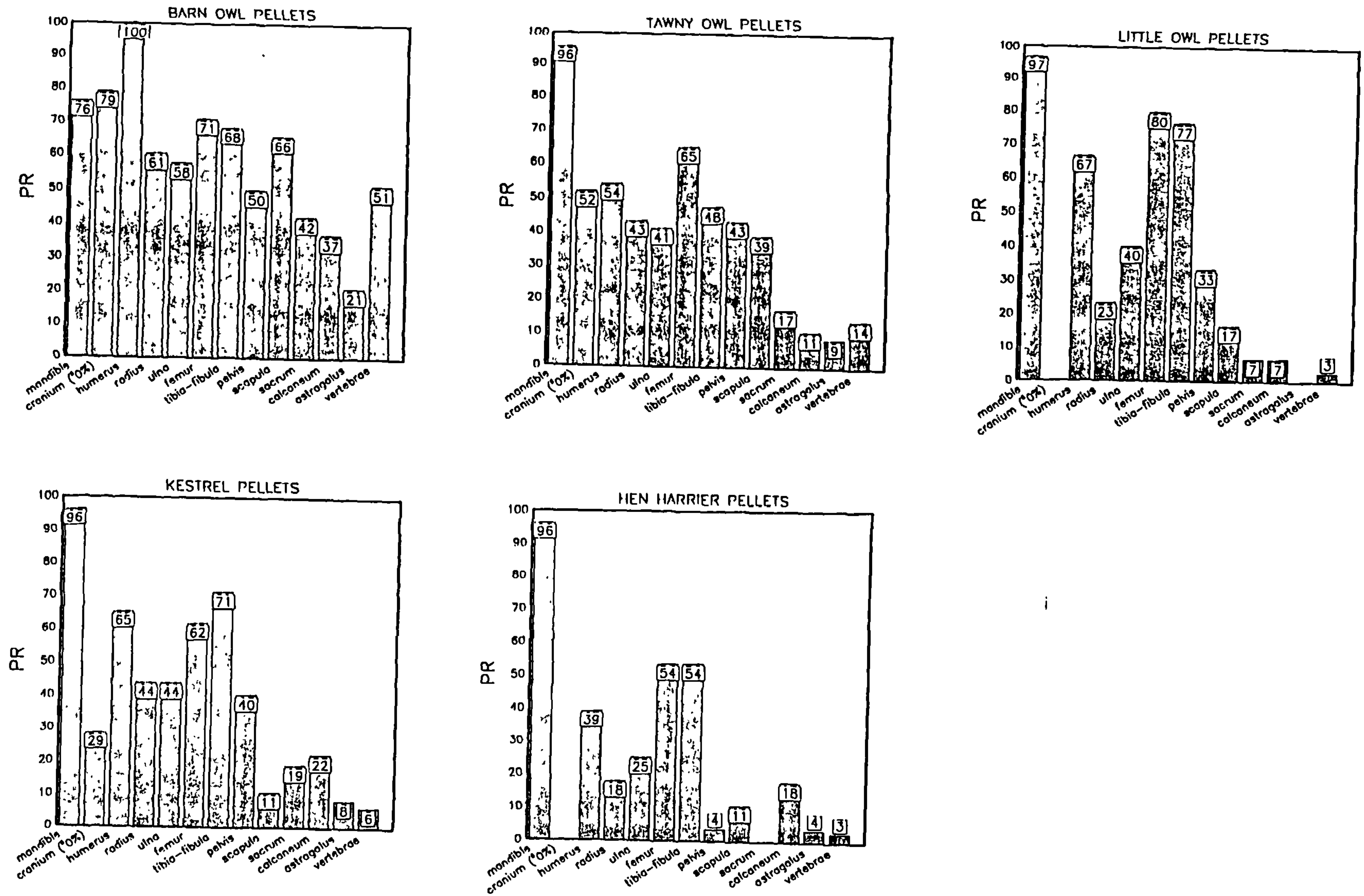


Fig. 7:1 Proportional Representation of Small Mammal Skeletal Elements in Raptor Pellets.

Table 7:3 Fragment Completeness of Small Mammal Bones from Raptor Pellets, by Raptor Species.

	Tawny owl					Barn owl					Little Owl				
Size	0-30	40-60	70-90	100	%whole	0-30	40-60	70-90	100	%whole	0-30	40-60	70-90	100	%whole
Mandible	4	10	17	13	29.5	0	2	3	24	82.8	5	11	11	2	6.9
Humerus	1	1	15	8	32.0	0	3	3	32	88.9	2	4	9	5	25.0
Ulna	0	2	4	13	68.4	0	0	0	22	100	0	3	5	4	36.4
Femur	0	1	15	14	46.7	0	1	0	27	96.4	3	3	15	3	12.5
Tibio-fibula	0	0	18	4	18.2	0	0	8	18	69.2	7	7	8	1	4.3
Pelvis	0	0	18	2	10.0	0	0	1	18	94.7	2	8	0	0	0
Total/Mean	5	14	87	54	34.1	0	6	15	141	88.7	19	36	48	15	14.2

	Kestrel					Buzzard					Hen Harrier				
Size	0-30	40-60	70-90	100	%whole	0-30	40-60	70-90	100	%whole	0-30	40-60	70-90	100	%whole
Mandible	12	42	23	4	4.9	0	0	0	0	0	9	12	6	0	0
Humerus	4	11	35	5	9.1	1	1	0	1	33.3	2	5	4	0	0
Ulna	0	0	23	14	37.8	0	0	0	1	100	0	1	6	1	12.5
Femur	7	19	19	7	13.5	2	1	0	0	0	3	8	5	0	0
Tibio-fibula	6	18	34	2	3.3	0	0	1	0	0	5	6	5	0	0
Pelvis	4	23	13	0	0	0	0	1	0	0	1	0	0	0	0
Total/Mean	33	113	147	32	11.4	3	2	2	2	22.2	20	32	26	1	2.1

Fragment completeness is calculated as the percentage of the whole bone that the fragment represents.
Figures represent individual fragments.
The buzzard sample is particularly small, and should not be taken as necessarily representative of the extent of bone destruction by buzzards.

Table 7:4

Areas of the humerus, femur and tibio-fibula of small mammals from modern bird pellets.

Description	Kestrel			Tawny owl			Barn owl			Little owl			Buzzard			Hen harrier		
	Hu	Fe	Tb	Hu	Fe	Tb	Hu	Fe	Tb	Hu	Fe	Tb	Hu	Fe	Tb	Hu	Fe	Tb
Complete (p1-d4)	5	7	2	8	11	2	32	27	18	0	4	0	1	0	0	0	0	0
Complete, but some erosion	11	5	10	5	10	17	1	0	1	8	4	2	0	0	0	1	1	0
p1-4	6	13	8	1	6	2	0	0	0	8	3	2	0	0	1	2	1	2
1-d4	13	1	9	0	0	1	1	0	0	0	3	3	0	0	0	0	0	0
1-4	2	0	6	3	2	1	0	0	0	0	0	3	0	0	0	0	3	3
p1-3	1	9	3	1	1	0	1	1	0	3	1	2	0	1	0	4	4	0
2-d4	4	0	1	4	0	0	0	0	0	0	1	0	0	0	0	0	0	3
2-4	4	3	8	2	0	0	1	0	0	0	1	0	0	0	0	0	2	2
p1-2	0	8	2	0	0	0	2	0	0	5	0	3	1	0	0	0	2	0
3-d4	4	3	2	0	0	0	0	0	0	0	3	0	1	0	0	3	2	1
1-3	1	1	5	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
2-3	4	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	3
1-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-4	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
p1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0
d4	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1
Total	55	52	60	23	30	23	38	28	19	24	20	23	3	3	1	12	16	15

Hu = Humerus, Fe = Femur, Tb = Tibio-fibula.

tibio-fibula classed as complete but eroded when the length of the shaft is complete but the fibula is entirely or partly missing.

Table 7:5

Area of the mandible of small mammal remains recovered from modern bird pellets.

Description	Number of bones				
	Kestrel	Tawny owl	Barn owl	Little owl	Hen harrier
complete (1-6)	4	13	24	2	-
1-6, but eroded	6	8	2	-	-
1-3,5,6	3	3	-	2	-
1-5	2	4	-	-	-
1-3,4,6	1	1	-	-	-
1-3,5	1	1	-	3	1
1-3,6	-	-	-	-	1
1-4	1	2	-	-	1
1-3	18	7	2	6	13
1-2	10	2	-	5	2
2-6	4	-	1	3	1
2,3(+ any of 4,5,6)	5	1	-	3	1
2-3	23	2	-	3	3
3	1	-	-	-	-
2	1	-	-	4	4
Total	80	44	29	31	27

Table 7:6

Areas of the pelvis of small mammals represented in modern bird pellets.

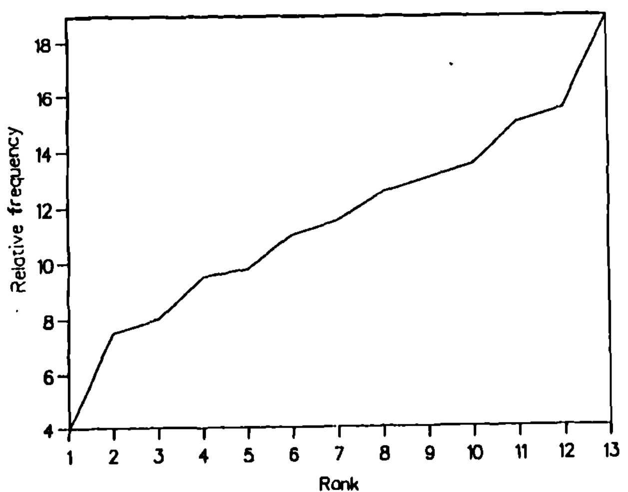
Description	Kestrel	Tawny owl	Barn owl	Little owl	Buzzard	Hen Harrier
Complete (1-5)	0	1	18	0	0	0
80% complete	3	3	1	0	0	0
2-5	1	0	0	0	0	0
1-4	2	12	0	0	0	0
2-3	5	0	0	1	0	0
2-4	25	1	0	0	1	0
1-3	0	3	0	2	0	0
1-2	2	0	0	6	0	0
3,4,5	1	0	0	0	0	0
3,4	0	0	0	0	0	1
2	4	0	0	1	0	0
Total	43	20	19	10	1	1

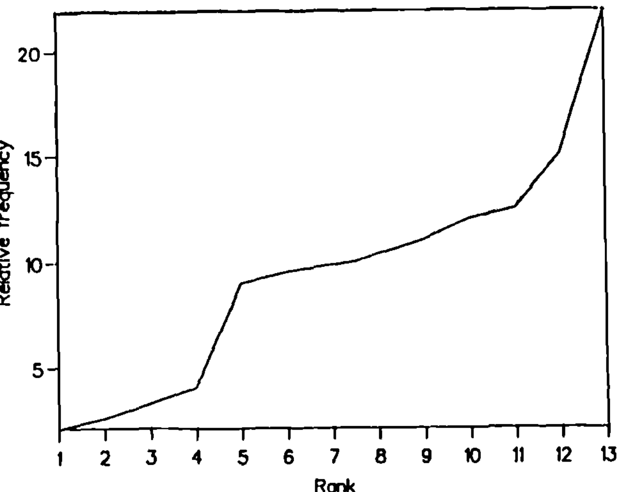
Table 7:7

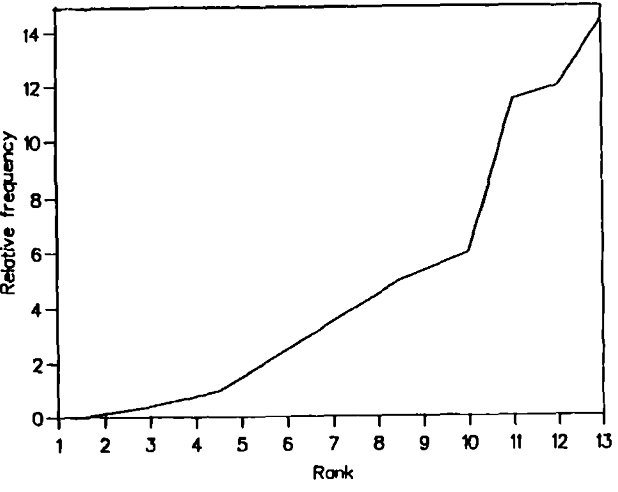
Areas of the skull of small mammals from modern bird pellets.

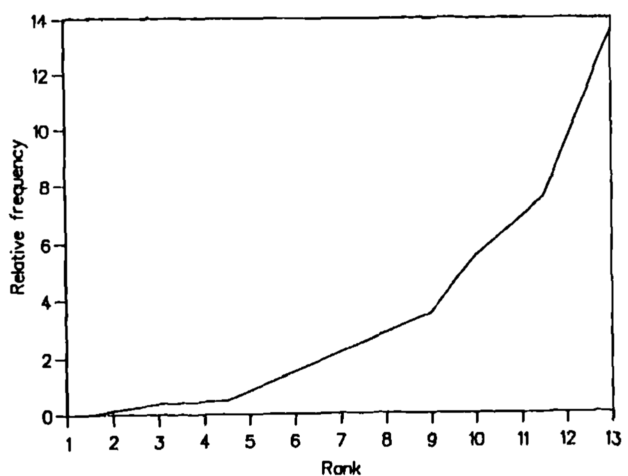
Description	Kestrel	Tawny owl	Barn owl	Little owl	Buzzard	Hen harrier
Complete	0	1	0	0	0	0
80 % Complete	0	0	4	0	0	0
anterior frag 1	0	5	6	0	0	0
anterior frag 2	0	2	1	0	0	0
anterior frag 3	0	1	0	0	0	0
mid frag	0	2	0	0	0	0
2 maxillas	10	2	0	5	0	4
maxilla >50%	0	1	0	0	0	8
maxilla >50% (frags)	0	5	0	7	0	22
premaxilla and maxilla	0	0	0	0	0	3
2 frontals	0	0	0	0	0	0
frontal + parietal	0	0	0	0	0	0
tympanic bulla	6	5	9	0	0	0
parietal	28	14	12	2	1	0
premaxilla	3	0	0	0	0	0
interparietal	0	4	0	0	0	0
occipital	4	8	8	0	1	0
nasal	4	0	2	0	0	0
other isolated bones	8	8	10	4	0	0
Total	63	58	52	18	1	37

anterior frag 1 - broken at the fronto-parietal suture
anterior frag 2 - broken behind M3.
anterior frag 3 - broken behind the pterygoid bones, just infront of the tympanic bullae
mid frag - broken behind M3 or at the fronto-parietal suture and behind the nasal









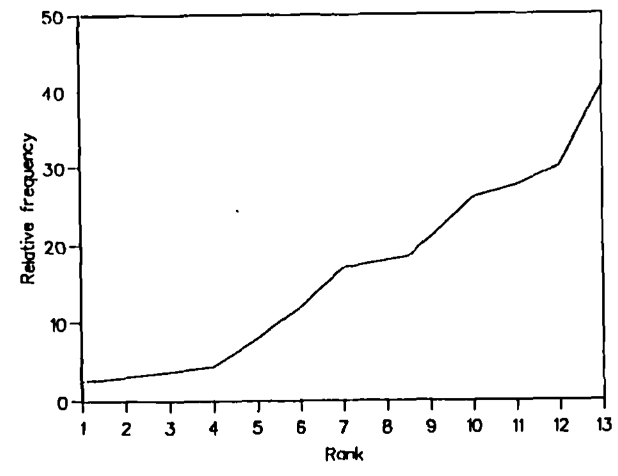


Fig. 7:2 The "Decay Trajectories" for Small Mammal Bones in Raptor Pellets.

As can be seen from the Tables and Figures, different raptors inflicted very different amounts of damage to the bones of small mammals. The types of destruction exhibited are comprehensively illustrated by Andrews (1990), so further Plates are not given here. The relative destruction rates are illustrated by the slope of the "decay trajectory": the steeper the slope, the greater the difference in representation between the various parts of the skeleton, so the greater the relative destruction.

Of all the species, the barn owl inflicted the least damage to the bones, followed by the tawny owl. Most bones from the barn owl pellets were intact, but polished. Several virtually complete skulls were recovered, lacking only the nasals. Most pelves and mandibles were complete. Of the long bones, the tibio-fibula was the most damaged, frequently missing the fibula and with one or both ends of the bone eroded. Bones from the tawny owl pellets were more fragmented and more eroded than those from the barn owl. Only one skull was recovered complete, and most other bones were fragmented. The little owl, kestrel and buzzard inflicted much greater amounts of damage on the bones of the prey species. Most bones were very fragmented, and limb bones were frequently represented by a thinned, polished portion of the shaft, with the epiphyses, if present, eroded to a point. The hen harrier inflicted the heaviest damage to bones. Many of the hen harrier pellets contained only fur and occasionally feathers. Those pellets which did contain bone often contained only tiny, eroded fragments of small mammal maxilla or mandible, with loose teeth.

Although the raptor species differed in the extent to which they inflicted mechanical and chemical damage to the bones of the prey species, the relative susceptibilities of the various skeletal elements remained remarkably similar. This pattern was also observed by Dodson and Wexlar (1979) for bones recovered from pellets from three species of owl after feeding experiments. Presumably it relates to the intrinsic structure of the bone, in terms of size, shape,

degree of mineralisation and distribution of cancellous : compact bone. The most resilient bone proved to be the mandible, in almost all cases, followed by the femur, or in some cases the humerus. The least well-represented elements were the pelvis, scapula, sacrum, calcaneum, astragalus and vertebrae. The last three are much less well represented than in the assemblages studied by Dodson and Wexlar (*ibid.*). All of these elements are better represented in the barn owl pellets than in those of the other raptor species. This point is further developed by looking at bone shape, below.

In common with the results of Dodson and Wexlar (*ibid.*) the proximal humerus was more likely to be missing than the distal humerus in kestrel pellets, though this trend was less clear from other species (in barn and tawny owl pellets most humeri were intact, in little owl the trend was reversed). In the femur the proximal end stood at least as good a chance, and much better in kestrel, of survival than the distal end. More ulnae were intact than any of the other major limb bones, although the slender radius, surprisingly, was also usually intact (a trend also noticed by Dodson and Wexlar). Damage to the ulna was usually by erosion to the distal end. The tibio-fibula was usually missing the fibula in all but the barn owl pellets, the proximal end was rather more likely to survive than the distal end in the kestrel pellets, but there was no obvious trend observed in the other raptor pellets. Many tibio-fibulae from the kestrel, little owl and hen harrier pellets lacked both ends. The pelvis was usually fragmented in all but the barn owl pellets, areas of damage were usually the tip of the ilium and the caudal border of the ischium. The blade of the scapula was usually broken in all species, leaving a broken 'feathery' end or just the articulating facet. Damage to the mandible was common in all but the barn owl pellets. The most common areas of loss were at the proximal and distal ends, with erosion to either or both of the rami. More severe erosion was seen in the kestrel, little owl and hen harrier pellet assemblages,

frequently the incisor and most molars had fallen out and the lower margin was eroded. Damage to the enamel and dentine of the teeth was common in these pellets.

The results of these investigations show that there is a difference in the amounts of damage inflicted to bone assemblages by different raptors, and that, within limits, it may be possible to suggest the raptor responsible for an assemblage of bones. The differences in amounts of damage inflicted relates, at least in part, to the difference in pH in the stomach. The basal pH in the stomachs of owls is commonly in the region of 2.2 - 2.5, whereas it is 1.3 to 1.8 in falconiformes and eagles (Duke *et al.* 1975). The assemblage of bones produced by barn owls may not be easily distinguished from a natural death assemblage, although a concentration of small mammal remains in one area, particularly if beneath a possible roosting spot, may support the interpretation. As Andrews (1990, 34) points out, differences in age of the birds may also affect the rates of digestion within species, however, so interpretation may always have to be cautious. The species composition of prey animals did not show much variation between raptors, despite the different geographical collection points for the pellets. Species variation may reflect natural species abundance within the locality more than predator selection, although nocturnal birds will be more likely than day-flying raptors to catch nocturnal mammals.

Can bone from raptor pellets be distinguished from bone subjected to mechanical abrasion?

The bone assemblages produced by the raptors other than barn owl were characterised by heavy erosion and polishing rather than fragmentation. Long bones were frequently thinned all over, with the ends reduced to points. Some pitting was observed, especially around the epiphyses, and broken edges were rounded. Tumbled bone, by comparison, was generally polished but broken rather than thinned. While

the ends of bones may be worn away they tend to leave a flat or torn and feathery, rather than a pointed end to the shaft. Long bones were often squashed by prolonged tumbling in gravel or pebbles/ballbearings. Damage to the mandible occurred at both ends simultaneously during tumbling, whereas ingested mandibles were often eroded at the proximal end only. Pitting of the tooth enamel and sometimes dentine, particularly clear on the incisors, was never seen on teeth which had been tumbled, which tended to be thinned rather than pitted. Erosion to the lower margin of the mandible, exposing the root of the incisor in places, was never seen on tumbled bone.

Is the extent of bone loss related to skeletal element shape?

Chi-squared tests comparing the recovered numbers of each of the commonly represented shape *categories (flat,* tubular and spherical) with the expected values (i.e. the numbers of each group in a complete animal) indicated that in all cases bone loss was influenced by shape. The results are given below, Table 7:8.

Table 7:8 Chi-Squared tests, the relationship between bone shape and survival.

	Shape	Observed	Expected	Residual
Barn Owl				
	Flat	73	62	11
	Tubular	136	103	33
	Spherical	512	556	-44

chi-squared = 16 2 df. significance p= <0.001

	Shape	Observed	Expected	Residual
Tawny Owl				
	Flat	82	32	50
	Tubular	116	53	63
	Spherical	172	285	-113

chi-squared = 200 2 df. significance p= <0.001

Little Owl

	Flat	44	11	33
	Tubular	66	19	47
	Spherical	22	102	-80

chi-squared = 275 2df. significance p= <0.001

Kestrel

	Flat	124	44	80
	Tubular	241	73	168
	Spherical	143	392	-249

chi-squared = 698 2 df. significance p= <0.001

Hen Harrier

	Flat	31	9	22
	Tubular	53	16	37
	Spherical	25	84	-59

chi-squared = 182 2 df. significance p= <0.001

While the results of all the tests were highly significant, indicating the preferential loss of the spherical bones (mainly the vertebrae), the much lower chi-squared figure for the barn owl indicates that the trend was less apparent. As the figure for the expected numbers of vertebrae was based on a mouse skeleton (after Dodson and Wexlar 1979) yet many voles were also present in the pellet assemblages, the expected figure for spherical bones may be too high. This would have the effect of lessening the significance of the results, but only the barn owl result would be likely to become non-significant (p= >0.05).

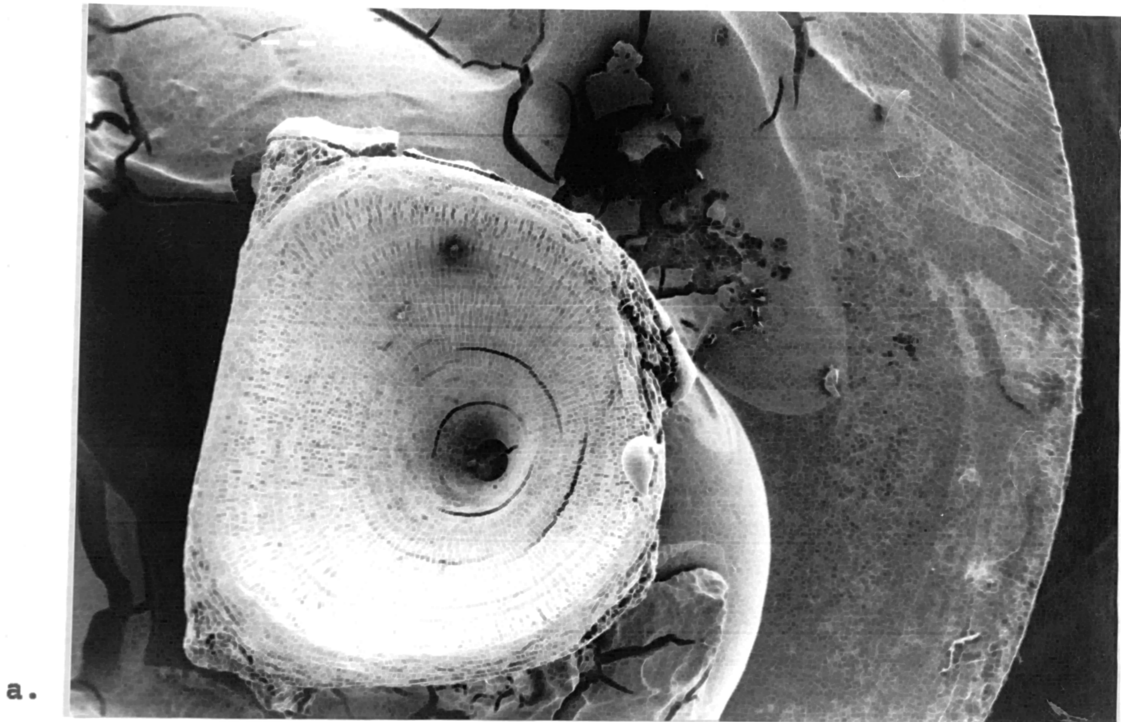
Gull pellets

The following is a summary of observations on the contents of gull pellets collected from four coastal sites during several days in the summers of 1988 and 1989 at the marine station on the island of Great Cumbrae in the Firth of Clyde. Unfortunately, while 84 pellets were examined, only six pellets contained fish bones. The majority of pellets contained, either singly or in combination, mollusc shell, crustacean exoskeleton, Coleoptera exoskeleton,

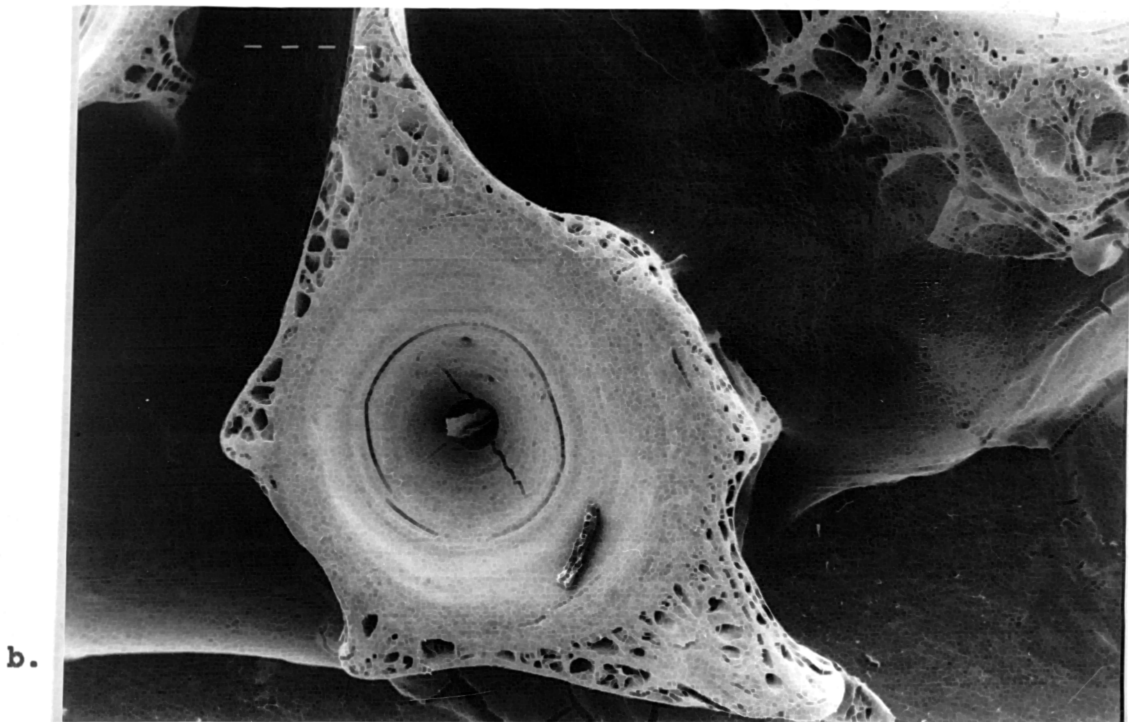
algae, or fragments of human refuse. Many of the pellets comprised tiny fragments of mussel shell. Mollusc and crustacean shells were usually extremely fragmented, although examples of complete mussel and gastropod shells were observed. The pellets containing fish bone were recovered from two sites: the Eileans (small rocky islands in Millport harbour) and Skate Point (to the North West of Great Cumbrae). The gulls observed frequenting these sites were the herring gull (*Larus argentatus* L.) and the greater black-backed gull (*Larus marinus* L.). The scarcity of pellets containing fish bones when compared with pellets comprising invertebrate remains has also been noted by students collecting pellets over a number of *seasons* (unpublished information).

Unfortunately too few bone-containing pellets were obtained to enable a study of intra-species variation, either between predators or prey. The contents of each of the six are detailed in Table 7:9, but no statistics are presented because of the low numbers of pellets involved. Those pellets which did contain bones included elements from both large (over about 500 mm.) and small (under about 150 mm.) fish, but no pellet appeared to contain bones from more than two individuals, and in several cases only a few bones were present. The bones showed very variable amounts of damage, in the form of bone breakage and acid erosion. Presumably the length of time that animal hard parts remain in the gizzard before regurgitation varies considerably. When head bones and vertebrae were present, the head bones showed little damage while some vertebrae had a rounded and slightly polished appearance, as a result of acid erosion. No bone had the characteristic medio-lateral crushing typical of chewed bones, although some bones were broken, including the rims of some vertebral centra. None of the otoliths present in the pellets appeared modified by the gastric juices. Many of the larger (Gadidae) vertebrae had lost their spines and processes, and some centra were similar in appearance to tumbled bones (see Plate 7:1 a and b). The contents of the pellets were rarely evenly eroded,

a.



b.



Plates 7:1a and 7:1b Gadid Vertebrae from Gull Pellets showing Squared (a), Eroded (a&b) Articulating Facets.

so that some bones appeared rounded while others did not. In this way a pellet assemblage should be distinguishable from a mechanically abraded assemblage. While assemblages of bones from small fish, such as butterfish, may appear similar to the contents of otter spraints, the lack of chewed bones may distinguish assemblages of spraint origin. It is clear that interpretations based on small numbers of bones may be erroneous, however.

Table 7:9 Fish Remains from Gull Pellets

Pellet 1. : The Outer Eilean

Species = Saithe (*Pollachius virens* (L.)), estimated size 500-600 mm. total length.

2 complete squamosals (right and left)
1 complete exoccipitals
1 complete parasphenoid and 1 complete basioccipital, still articulated
1 right dentary, complete
1 left maxilla, proximal half
1 right maxilla, complete
2 complete cleithra (right and left)
2 complete articulars (right and left)
2 complete premaxillae (right and left)
1 left quadrate, chipped edges
1 left hyomandibular fragment (20%)
1 chipped left interopercular
1 right ceratohyal, complete
1 right epihyal, complete
1 right post-temporal, complete
1 right supracleithrum, complete
1 almost complete postcleithrum
2 complete infrapharyngeals
2 complete suprapharyngeals
1 complete first vertebra
2 complete upper abdominal vertebrae
1 chewed/eroded abdominal vertebra
6 ceratobranchials
1 branchiostegal ray
2 complete otoliths.

Pellet 2: The Outer Eilean

From Poor Cod (*Trisopterus minutus* (L.)), estimated size 150-200 mm. total length.

1 complete frontal
1 complete parasphenoid
2 complete (right and left) premaxillae
1 complete but cracked right dentary
1 complete left dentary
2 complete (right and left) ceratohyals

2 complete (right and left) maxillae
1 complete left quadrate
1 complete left palatine
1 complete left supracleithrum
2 complete upper abdominal vertebrae
1 complete left otolith

from Hake (*Merluccius merluccius* (L.)) estimated length 300 mm.

7 acid-eroded abdominal vertebrae, centra only
8 acid-eroded caudal vertebrae, centra only

also about 100 barnacle fragments and one echinoderm spine.

Pellet 3: The Inner Eilean

From Saithe (*Pollachius virens*) estimated total length 600 mm.

1 frontal, all edges chipped
1 left dentary, complete but slightly eroded tooth row

also tiny fragments of mussel and barnacle shell.

Pellet 4: The Inner Eilean

From Pollack (*Pollachius pollachius* (L.)) estimated size 450-500 mm.

1 complete right dentary
2 complete (left and right) premaxillae
1 complete right articular
1 complete right quadrate
1 right cleithrum proximal fragment (50%)

Pellet 5: Skate Point

From Butterfish (*Pholis gunnellus* (L.)), estimated total length 100 mm.

2 complete frontals
1 complete supraoccipital
3 complete cranial bones
1 complete prevomer
1 complete parasphenoid
1 complete basioccipital
2 complete (right and left) dentaries
2 complete (right and left) premaxillae
2 complete (right and left) articulars
2 complete (right and left) maxillas
2 complete (right and left) quadrates
2 complete (right and left) hyomandibulars
1 complete right palatine
2 complete (right and left) but warped operculars
1 slightly eroded preopercular
1 complete interopercular
2 complete (right and left) suboperculars
2 complete (right and left) ceratohyals
2 complete (right and left epihyals)

1 complete left post-temporal
72 vertebrae, complete or just lacking parts of the neural and/or haemal spines.
1 complete hypural

also Coleoptera (*Geotrupes* sp.) leg elements.

Pellet 6: Skate Point

From Poor Cod (*Trisopterus minutus*) estimated length 250 mm.

28 extremely acid-eroded vertebral centra
1 complete right otolith.

As sea birds tend to regurgitate pellets near the site of feeding this is frequently on coastal rocks, in the case of fish-eating. These rocks are subject to tidal incursions, and this, as well as rain, washes the pellets away on a regular basis. It is therefore fairly unlikely that large accumulations of bones would build up on the shore, although areas under nesting sites or perching posts may accumulate debris from pellets. Otters, by contrast, often accumulate piles of spraints at particular spots, especially around the entrance to holts. The position of accumulations of small bones may therefore aid interpretation of their origin.

Seal scats.

Of the twenty two scats examined, twenty produced identifiable fish remains. The components of these assemblages are given in Table 7:10. The relative abundances, proportional representation and decay trajectory of the skeletal elements are given in Table 7:11 and illustrated by Fig. 7:3. Almost all bones were small, and the majority were vertebrae. The larger vertebrae appeared chewed and thinned towards the middle of the centrum (Plate 7:2a). Smaller vertebrae were sometimes very crushed and/or reduced by surface erosion, rendering them unidentifiable to even family level. Some of the vertebrae (several probably from sand eel, Ammodytidae) had a fibrous appearance. Many of the unidentifiable bone fragments and

some of the identifiable fragments, had a chalky texture.

Several large groups of otoliths, mostly from members of the Gadidae, were recovered. The condition of the otoliths varied, the larger ones were usually broken and thinned, with characteristic sculpting of the thinned surface and edges (see Plate 7:2b). Many of the small otoliths (from fish estimated to be less than 150 mm. long) were complete and uneroded, however. Teeth, mostly from members of the Gadidae, were also found in many of the droppings. These were characteristically reduced at the base and along the length, leaving an upstanding "nob" on the end of the tooth (Plate 7:2c). Some teeth were characterised by pitting.

Although the amount of damage seen on the bones varied between scats, in general few bones were recovered, even though the diet of the grey seal is predominantly fish, and most of those bones which were recovered were eroded and/or crushed. The dominance of small otoliths in these assemblages, some undamaged, indicates that these parts survive digestion better than the bones. Occasional fragments of mollusc shell were also recovered, from one dropping.

Further details about digestion rates in seals are *given* by Bigg and Fawcett (1985), which indicates the efficiency of the seal's digestive system. In keeping with this study, otoliths were found to be the most commonly identified fish parts in scats. Larger otoliths remain in the stomach longer than small otoliths, which pass through rapidly. This accounts for the greater amounts of erosion observed on the larger otoliths, which exhibited rounded edges and loss of surface topography, and sometimes were broken.

It is unlikely that assemblages of fish remains from seal scats would survive archaeologically, given their scant number and fragmentary state. Seals also tend to defecate in the water or near to the shore, where the tide would wash away the scats. On coastal sites, seal gut

contents may have found their way into middens, however. If bones from seal guts or faeces did survive into the archaeological record, they may be confused with remains which have passed through the guts of dogs, or possibly man, but should not be confused with assemblages of bone from otter spraint. The last, when coastal, generally comprising bones from small shore-dwelling species and including relatively few acid-eroded bones (see below).

Table 7:10 Skeletal Hard Parts Recovered from Grey Seal Droppings from Orkney.

Reference No.	Components	Fragment Size (%)	Eroded?	Chewed?
E119	4 Elasmobranch vertebrae	90	Yes	Yes
	2 ?Gadid caudal vertebrae	40	Yes	Yes
	1 unidentified vertebra	30	No	Yes
	35 unidentified frags.	-	-	-
	1 Gadid (<150mm) otolith	90	Yes	-
E113	3 Sand Eel abdominal vertebrae	100	No	No
	2 Sand Eel caudal vertebrae	100	No	No
	1 Sand Eel caudal vertebra	80	No	No
	2 Sand Eel abdominal vertebrae	70	No	Yes
	1 Sand Eel vertebra	50	No	Yes
	1 Sand Eel vertebra	30	No	Yes
	2 unidentified skull bones	100	No	No
E114	2 Elasmobranch teeth	100	No	-
	1 Ray (Rajidae) dermal denticle	90	No	-
	1 Ray dermal denticle	70	No	-
	1 unidentified vertebra	60	Yes	No
	7 unidentified frags.	-	-	-
E115	2 Flatfish supraoccipitals	100	No	No
	1 ?Cottid post-temporal	90	Slight	No
	1 unidentified supracleithrum	100	No	No
	2 unidentified vertebrae	50	Yes	No
	14 unidentified frags.	-	-	-
E117	4 ?Gadid teeth	90	Yes	-
	1 unidentified cleithrum	40	No	No
	28 unidentified frags.	-	-	-
E118	1 unidentified basioccipital	90	Yes	No
	1 unidentified vertebra frag.	10	No	Yes
	1 ?Gadid tooth	90	Yes	-
	10 unidentified frags.	-	-	-
	17 ?Trisopterus sp.(p.) otoliths	100	Few	-
	5 ?Trisopterus sp(p.) otoliths	60	Yes	-
	1 ?Whiting otolith	50	Yes	-
	1 unidentified otolith frag.	30	Yes	-

E116	58 ?Trisopterus sp(p.) otoliths	100	Few	-
	21 unidentified (<150mm) otoliths	30-60	Some	-
	1 ?Whiting otolith	70	Yes	-
	4 Gadid teeth	100	Slight	No
	1 unidentifed ceratohyal	90	Yes	No
	1 unidentified vertebra	60	Yes	No
	1 ?Flatfish caudal vertebra	70	Yes	No
	1 Gadid infrapharyngeal	100	Slight	No
	1 unidentified vertebra fragment	10	Yes	Yes
	29 unidentified frags.	-	-	-
E121	1 Flatfish anal pterygiophore	50	Slight	No
	13 unidentified frags.	-	-	-
E124	1 unidentified vertebra	40	Yes	No
	1 unidentified frag.	-	-	-
	1 bivalve shell	100	Yes	-
	1 gastropod shell	60	No	-
	6 mollusc frags	-	-	-
E122	3 frags. of Gadid (c.400mm) otolith	30	Yes	-
	1 Gadid tooth	90	Yes	-
	1 ?Zoarces viviparus vertebra	70	Slight	Yes
	1 unidentified vertebra	20	No	Yes
	1 ?Zoarces viviparus vertebra	60	Yes	Yes
	1 unidentified cleithrum	60	Slight	No
	4 unidentified frags.	-	-	-
E128	12 Gadid teeth	100	Slight	-
	1 ?Elasmobranch vertebra	80	Yes	Yes
	5 ?Elasmobranch vertebrae	80	Yes	No
	1 ?Gadid ceratohyal	50	Yes	No
	27 unidentified frags	-	-	-
	1 Flatfish otolith	100	No	-
E127	7 Gadid teeth	90	Yes	-
	1 Gadid infrapharyngeal	70	Yes	No
	1 Gadid suprapharyngeal	90	Slight	No
	1 ?Gadid abdominal vertebra	80	Yes	No
	1 unidentified vertebra	?	Yes	No
	13 unidentified frags.	-	-	-
E129	1 Gadid tooth	80	Yes	-
	1 Gadid suprapharyngeal	90	No	No
	8 unidentified frags.	-	-	-
E126	2 Flatfish abdominal vertebrae	70	Yes	No
	2 ?Gadid branchiostegal rays	80	No	No
	1 Gadid (<150mm) otolith	90	Yes	-
	5 frags of Gadid (c.400mm) otolith	20	Yes	-
	25 unidentified frags.	-	-	-
E125	1 ?Sand Eel vertebra	80	Yes	Yes
	1 unidentified suprapharyngeal	90	Yes	No
	1 ?Sand Eel caudal vertebra	70	Yes	Yes
	11 unidentified frags.	-	-	-

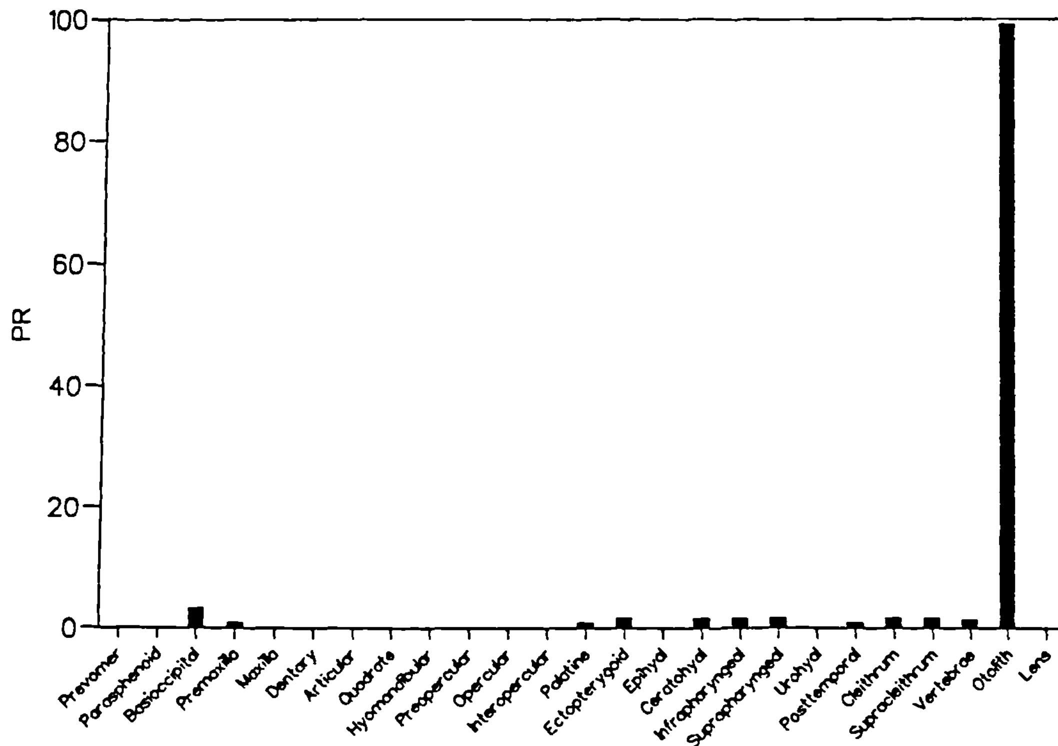
	3 unidentified vertebrae	50	Yes	Yes
	1 unidentified vertebra	30	Yes	Yes
	1 unidentified basioccipital	80	Yes	Yes
	1 unidentified ectopterygoid	100	No	No
	1 Trisopterus esmarkii premaxilla	100	No	No
	1 Gadid palatine	100	No	No
	6 Gadid teeth	100	No	No
	1 ?Gadid suprapharyngeal	80	Yes	No
	6 Gadid branchiostegal rays	100	No	No
	8 unidentified spines, rays + ribs	100	No	No
	30 unidentified frags.	-	-	-
	2 Gadid (300-400mm) otoliths	90	Yes	No
	2 ?Trisopterus sp. otoliths	100	Slight	No
	3 frags of Gadid (c.400mm) otolith	30	Yes	No
	1 unidentified (<100mm) otolith	-	Yes	No
E132	1 Gadid abdominal vertebra	80	Yes	No
	1 Gadid suprapharyngeal	90	Yes	No
	1 unidentified vertebra	40	Yes	Yes
	3 Gadid teeth	100	No	No
	3 unidentified spines	100	No	No
	1 Gadid radial	100	No	No
	1 ?Gadid branchiostegal ray	80	No	No
	15 unidentified frags	-	-	-
E132	1 ?Gadid abdominal vertebra	50	Yes	No
	1 Gadid abdominal vertebra	80	No	No
	1 Flatfish abdominal vertebra	70	No	No
	5 Gadid teeth	90	Yes	-
	1 unidentified vertebra	40	Yes	-
	1 Sand Eel caudal vertebra	70	Yes	-
	1 Gadid ceratohyal	80	No	Yes
	1 Molva sp. (<200mm) supracleithrum	80	No	Yes
	1 Gadid ectopterygoid	80	No	Yes
	11 unidentified frags.	-	-	-
E130	1 ?Gadid vertebra	40	Yes	Yes
	1 Gadid stylohyal	100	Slight	No
	1 unidentified vertebra	70	Yes	No
	1 unidentified cleithrum	50	Yes	No
	4 Gadid teeth	100	No	No
	1 ?Zoarches viviparus post-temporal	100	No	No
	1 unidentified vertebra	60	Yes	No
	3 unidentified spines	100	No	No
	12 unidentified frags.	-	-	-
	1 ?Sand Eel otolith	90	Yes	No
	1 ?Trisopterus sp. otolith	90	Yes	No
E133	1 Gadid vertebra	100	No	No
	1 Gadid (<200mm) first vertebra	90	No	No
	2 unidentified vertebra	40	Severe	No

Table 7:11

Numbers, relative frequency and proportional representation of fish remains from contemporary seal droppings. (pooled figures).

Bone	No. Exp.	No. Recovered	Relative frequency	Proportional Representation (mni = 58)
Prevomer	1	0	0	0
Parasphenoid	1	0	0	0
Basioccipital	1	2	2	3.4
Premaxilla	2	1	0.5	0.9
Maxilla	2	0	0	0
Dentary	2	0	0	0
Articular	2	0	0	0
Quadrate	2	0	0	0
Hyomandibular	2	0	0	0
Preopercular	2	0	0	0
Opercular	2	0	0	0
Interopercular	2	0	0	0
Palatine	2	1	0.5	0.9
Ectopterygoid	2	2	1	1.7
Epihyal	2	0	0	0
Ceratohyal	2	2	1	1.7
Infrapharyngeal	2	2	1	1.7
Suprapharyngeal	6	6	1	1.7
Urohyal	1	0	0	0
Posttemporal	2	1	0.5	0.9
Cleithrum	2	2	1	1.7
Supracleithrum	2	2	1	1.7
Vertebrae	45	36	0.8	1.4
Otolith	2	115	57.5	99.1
Lens	2	0	0	0
Total	93	172	3.2	

Exp. = Number of bones expected, in one fish.
MNI is based on the pooled results from all scats , ie. treating them as one recovered assemblage, it therefore greatly under-estimates the true MNI.



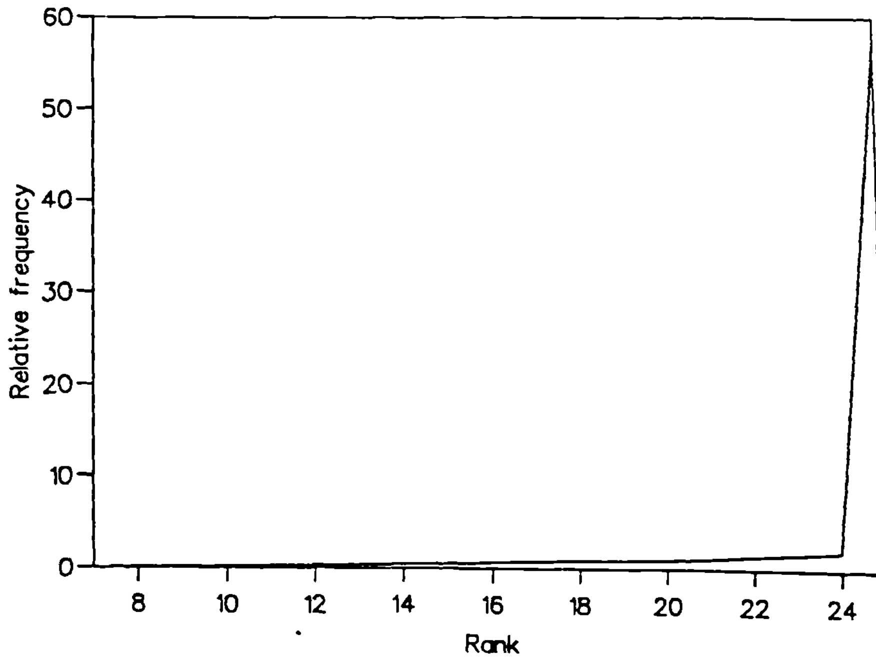


Fig. 7:3 Proportional Representation (above) and the "Decay Trajectory" (below) for Fish Remains in Seal Scats.

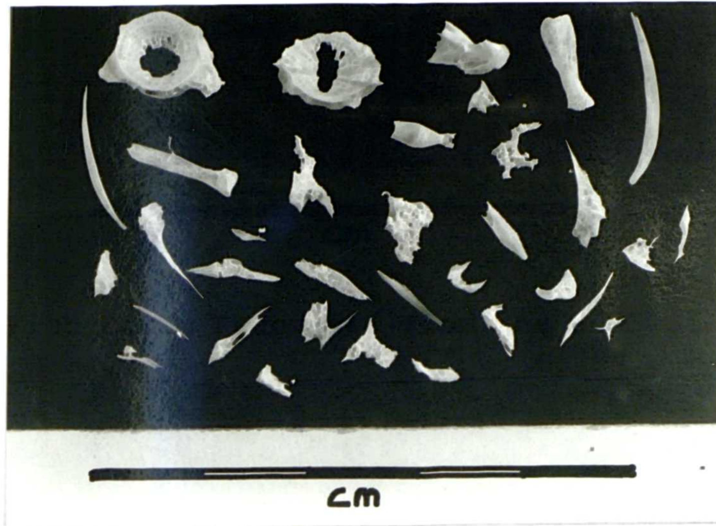


Plate 7:2a Fish Bones Recovered from one Seal Scat.

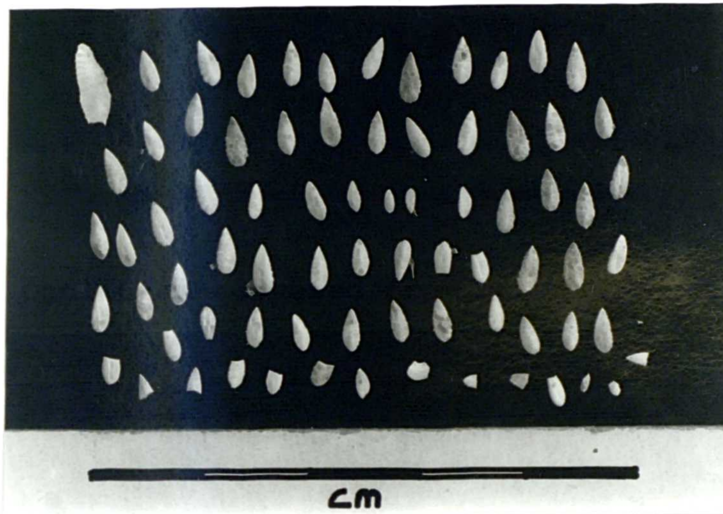


Plate 7:2b. Otoliths Recovered from one Seal Scat.

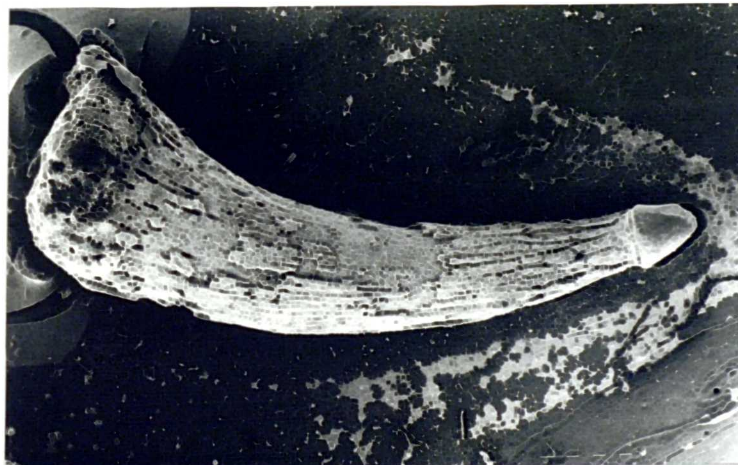


Plate 7:2c. Fish Tooth from a Seal Scat (S.E.M).

Otter spraints: modern material compared with archaeologically-derived assemblages of small fish bones

Details of the fish species present in each of the assemblages is given in Table 7:12, with an indication of relative abundance. The species composition of fish represented in these spraints obviously varies between the inland and coastal sites, but the prey species at the coastal sites were very similar for all the spraints, and was similar to those represented in the archaeological material. The size of fish was also similar in all the assemblages. When comparing the spraint components, the Bidno, Tywi and Wye assemblages were pooled together because all are from inland sites in the River Wye catchment, and because of the small number of spraints from each site. This group comprised freshwater species (mainly cyprinids (Cyprinidae) and trout *Salmo* sp.(p)). Anuran bones and a few bird and mammal bones were also identified in the spraints from these Welsh sites. Non-fish bone recovered from the spraint assemblages is detailed in Table 7:13. The bird and mammal (rabbit-sized) bones were very fragmented, while the anuran bones varied from complete to extremely fibrous and broken.

Commonly represented species from the Shetland and Freswick spraints, as well as from the Pool and Tofts Ness assemblages included small gadids (e.g. saithe *Pollachius virens* (L.) and rocklings *Ciliata* sp(p.)), viviparous blenny *Zoarces viviparus* (L.), butterfish *Pholis gunnellus* (L.), small flatfish, cottids (Cottidae), lumpsucker *Cyclopterus lumpus* L., eel *Anguilla anguilla* L., wrasse (Labridae) and stickleback *Gasterosteus aculeatus* L.. In all cases most of the fish represented would have been under 150 mm. in length. Anuran bones were present in some of the spraints from Freswick, but only fish bones were present in the spraints from Shetland. The archaeological material contained a few fragments of mammal bone, but none was present in the samples studied.

Table 7:12 Taxa present in the contemporary otter spraints, and in the archaeological material from Pool (PL 0487/0431) and Tofts Ness (TN 0619).

(A = abundant, many elements represented; P = Present; R = Rare)

SHETLAND

Spraint 1.

Indeterminate Gadid: (A) length ca. 200-300 mm. MNI. = 1

Spraint 2.

Viviparous blenny: (A) MNI = 6, lengths ca. 100-150 mm.
Butterfish (P) MNI = MNI = 1, length ca. 100-120 mm.
Indeterminate rockling: (P) MNI = 1, length ca. 150 mm.
Indeterminate cottid: (R) MNI = 1, length ca. 100-150 mm.

Spraint 3.

Viviparous blenny: (A) MNI = 7, lengths ca. 100-180 mm.
Indeterminate flatfish: (R) MNI = 1, length ca. 100-150 mm.

Spraint 4.

Viviparous blenny: (A) MNI = 11, length ca. 100-150 mm.
5-bearded rockling (R), MNI = 1, length ca. 150 mm.
Indeterminate flatfish: (R), MNI = 1, length ca. 100-150 mm.

Spraint 5.

Indeterminate flatfish: (P) MNI = 1, length c. 200 mm.

Spraint 6.

Viviparous blenny: (P) MNI = 3, lengths ca. 100-150 mm.
5-bearded rockling: (P) MNI = 2, lengths ca. 80-200mm
Butterfish: (P) MNI = 1, length ca. 50-70 mm.

Spraint 7.

Viviparous blenny: (A) MNI = 7, lengths ca. 80-150 mm.
5-bearded rockling: (P) MNI = 1, lengths ca. 100-200 mm.
Butterfish: (P) MNI = 1, length ca. 80-120 mm.
Indeterminate cottid: (P) MNI = 2, length ca. 100-150mm.

Spraint 8.

Viviparous blenny: (P) MNI = 3, lengths ca. 100-150 mm.
5-bearded rockling: (P) MNI = 1, length ca. 150 mm.
Butterfish: (P) MNI = 3, lengths ca. 100-120 mm.
Haddock or Saithe: (R) MNI = 1, length ca. 150-200 mm.

Spraint 9.

Viviparous blenny: (A) MNI = 6, lengths ca. 150-250 mm.
Butterfish: (A) MNI = 5, lengths ca. 100-120 mm.
3-spined stickleback: (P) MNI = 3, length ca. 500-800 mm.
Indeterminate Wrasse: (R) MNI = 1, length >200 mm.
Indeterminate Flatfish: (R) MNI = 1, length ca. 200-250 mm.

Table 7:12 cont'd....

FRESWICK

Spraint 1

Butterfish: (A) MNI = 2, length ca. 80-150 mm.
5-bearded rockling: (P) MNI = 1, length ca. 150-200 mm.

Spraint 2

5-bearded rockling: (P) MNI = 3, length ca. 150-250 mm.
Eel: (R) MNI = 1, length ca. 100-150 mm.
Butterfish: (P) MNI = 1, length ca. 120-150 mm.
? Snake blenny: (R) MNI = 1, length ca. 150-200 mm.

Spraint 3

Eel: (P) MNI = 1, length ca. 100-200 mm.
Cod: (P) MNI = 1, length ca. 100-150 mm.
Indeterminate salmonid: (P) MNI = 1, length ca. 100-200 mm.
Viviparous blenny: (P) MNI = 1, length ca. 150-200 mm.

Spraint 4.

5-bearded rockling: (P) MNI = 2, length ca. 150 mm.
Viviparous blenny: (P) MNI = 1, length ca. 150 mm.

Spraint 5.

Indeterminate rockling: (P) MNI = 1, length ca. 100-150 mm.
Eel: (P) MNI = 2, length ca. 100-300 mm.
Viviparous blenny: (P) MNI = 1, length ca. 150 mm.
3-spined stickleback: (P) MNI = 1, length ca. 70-100 mm.

Spraint 6.

Sea scorpion: (P) MNI = 1, length ca. 150-250 mm.
Indeterminate Rockling: (P) MNI = 1, length ca. 150 mm.
Eel: (P) MNI =1, length = 100-200 mm.
3-spined stickleback: (P) MNI = 1, length 80-100 mm.
Butterfish: (P), MNI = 1 length 100-150 mm.
Viviparous blenny: (P) MNI = 1, length ca. 150-200 mm.
Frog: (P) MNI = 1.
Small mammal: (R) MNI = 1 (frag only)

TYWI

Spraint 1

Frog: (A) MNI = 4
Indeterminate cyprinid: (P) MNI = 1

WYE

Spraint 1

Frog: (A) MNI = 2
Salmonid: (R) MNI = 1
Indeterminate cyprinid: (R) MNI = 1
Mammal: (R) MNI = 1 (frag only)

Spraint 2

Trout (?brown): (P) MNI = 1, length ca. 150-250 mm.
Bullhead: (P) MNI = 2, length ca. 60-70 mm.
Anuran: (P) MNI = 1

Table 7:12 cont'd...

Spraint 3

Chub: (P) MNI = 1, length ca. 100-150 mm.
Indeterminate cyprinid: (P) MNI = 1
Bullhead: (P) MNI = 1, length ca. 70-80 mm.
3-spined stickleback: (R) MNI = 1, length ca. 60-100 mm.
Anuran: (P) MNI = 2
Bird: (R) MNI = 1 (frags only)

Spraint 4

Chub: (P) MNI = 1, length ca. 100-150 mm
Anuran: (P) MNI = 1
Mammal: (R) MNI = 1 (frag only)

BIDNO

Spraint 1

Dace/chub: (P) MNI = 1
Indeterminate cyprinid: (P) MNI = 1
Anuran: (P) MNI = 1

POOL ARCHAEOLOGICAL MATERIAL (PL 0487/0431)

Viviparous blenny: (P) MNI = 4, lengths ca. 150-200 mm.
5-bearded rockling and indeterminate rockling : (P) MNI= 4, lengths ca. 150-200 mm.
Saithe and saithe/pollock: (P) MNI = 6, lengths ca. 100-150 mm.
Poor cod: (R) MNI = 1, length ca. 200 mm.
?Bib: (R) MNI = 1, length ca. 100-150 mm.
Sea scorpion/bullrout: (P) MNI = 3, lengths ca. 250 mm.
Plaice and indeterminate right sided flatfish: (P) MNI = 2, lengths ca. 100-150 mm.
Eel: (R) MNI = 1, length ca. 100-150 mm.
Snake blenny (R) MNI = 1, *length ca. 100-200 mm.*
3-spined stickleback (R) MNI = 1, length c. 60-80 mm.
?Wrasse (R) MNI = 1, length indet.

TOFTS NESS ARCHAEOLOGICAL MATERIAL (TN 0619)

5-bearded rockling: (A) MNI = 12, lengths ca. 100-200 mm.
3-bearded rockling: (P) MNI = 6, lengths ca. 150-250 mm.
Saithe: (P) MNI = 2, lengths ca. 150-250 mm.
Viviparous blenny: (P) MNI = 2, lengths ca. 150-200 mm.
Butterfish: (P) MNI = 1, length ca. 100 mm.
Sea scorpion: (P) MNI = 4, lengths 150-250 mm
?Bullhead: (P) MNI = 2, lengths ca. 100 mm.
Indeterminate cottid: (A) MNI = 13, lengths ca. 100-250 mm.
Eel: (P) MNI = 1, length > 200 mm.
Corkwing wrasse: (P) MNI = 4, lengths ca 150 mm.
Ballan wrasse: (R) MNI = 1, length > 300 mm.
Dab: (R) MNI = 1, length ca. 200-300 mm.

Table 7:13
Numbers and Mean Fragment Size of the Non-Fish Remains from Modern Otter Spraints.

	Freswick		Bidno, Tywi and Wye.	
	no.	Frag. size	no.	Frag. size
ANURAN				
Maxilla	0	0	16	50
Parietofrontal	0	0	1	90
Head bone indet.	0	0	3	90
Skull frags.	1	-	7	-
Scapula	1	80	2	40
Humerus	0	50	3	30
Radio-ulna	5	65	3	40
Ilium	1	40	3	55
Femur	1	40	3	40
Tibio-fibula	2	25	4	30
Long bone indet.	11	20	40	25
Vertebrae	1	10	4	30
Lower limb *	10	75	42	75

* comprising calcaneum, astragalus, metapodials and phalanges.

MEDIUM MAMMAL				
Unidentified frag.	-	-	1	-
SMALL MAMMAL				
Vertebra	1	90	-	-
SMALL BIRD				
Unidentified limb bone frags	-	-	2	-

As indicated by studies on the feeding habits of otters (e.g. Erlinge 1967; Mason and MacDonald 1986; Chanin 1987) prey species vary according to the time of year as well as location. Especially around inland sites, amphibians, birds and mammals may play increasingly important roles in the diet of otters in certain seasons. Large piles of spraints may accumulate at sites, particularly around holts or at rolling spots (Mason and MacDonald 1985, 31), and substantial piles of spraint may also be found at "spraint stations" along otter's paths, at junctions and at conspicuous or important places such as freshwater pools or dens (Chanin 1987, 10-11).

Skeletal element representation: modern spraints and archaeological material

Tables 7:14 and Figs 7:5 and 7:6 give the proportional representation of the most common skeletal elements from the fish represented in the modern assemblages of otter spraints from Shetland, Freswick, and the inland sites of Bidno, Tywi and Wye, and for the archaeologically recovered material from Pool and Tofts Ness. Actual counts are given in Appendix 7.1. To compare the fish component of the assemblages more objectively, Spearman's Rank Correlations were performed between the proportional representation scores for the modern spraint assemblages and the archaeological assemblages. Because of the different species involved, and the problems of identifying all elements from all species to an equal level of certainty, only the bones which could be identified to skeletal element with ease from a wide number of different taxa were included in the analyses. Otoliths and eye lenses were excluded from the statistical comparisons because of the possibility that they may be lost in preference to bones in some soils.

Table 7:14
Proportional Representation of skeletal elements from modern otter spraints from Shetland, Freswick (Caithness), Bidno, Tywi and Wye (Wales) and archaeological material from context PL 0431/0487 from Pool, and TN 0619 from Tofts Ness, *Sanday (Orkney), with Spearman's* Rank Correlations between pairs.

(includes only those skeletal elements readily identified from a large number of species. Lenses and otoliths are excluded from the statistics as preservation factors may cause preferential destruction in archaeological deposits)

			POOL		TOFTS		Freswick		Shetland		Bidno/Wye	
mni=			18		30		8		47		5	
	n.	s.	no.	pro.	no.	pro.	no.	pro.	no.	pro.	no.	pro.
Prevomer	1	R	6	33.3	9	30.0	7	87.5	38	80.9	0	0.0
Parasphenoid	1	I	1	5.6	2	6.7	6	75.0	30	64.4	1	20.0
Basioccipital	1	S	10	55.6	17	56.7	8	100	25	53.2	2	40.0
Premaxilla	2	R	29	80.6	33	55.0	13	81.3	75	79.8	1	10.0
Maxilla	2	R	16	44.4	30	50.0	9	56.3	68	72.3	0	0.0
Dentary	2	R	14	38.9	37	61.7	14	87.5	72	76.6	5	50.0
Articular	2	R	33	91.7	50	83.3	11	68.8	86	91.5	3	30.0
Quadrate	2	R	23	63.9	34	56.7	4	25.0	65	69.1	4	40.0
Hyomandibular	2	F	18	50.0	9	15.0	10	62.5	70	74.5	4	40.0
Preopercular	2	F	17	47.2	13	21.7	7	43.8	53	56.4	9	90.0
Opercular	2	F	17	47.2	32	53.3	11	68.8	73	77.6	1	10.0
Interopercular	2	F	9	25.0	12	20.0	11	68.8	42	44.7	7	70.0
Epihyal	2	F	6	16.7	23	38.3	2	2.5	51	54.3	1	10.0
Ceratohyal	2	F	17	47.2	14	23.3	7	43.8	79	84.0	2	20.0
Infrapharyngeal	2	I	7	19.4	8	13.3	8	50.0	53	56.4	8	80.0
Suprapharyngeal	6	I	7	5.6	29	16.1	6	13.0	16	5.7	1	3.3
Posttemporal	2	R	7	19.4	8	13.3	3	18.8	12	12.8	0	0.0
Cleithrum	2	I	13	36.1	9	15.0	7	43.8	91	96.8	7	70.0
Supracleithrum	2	R	6	16.7	6	10.0	7	43.8	40	42.6	0	0.0
Vertebrae	45	S	662	81.7	1032	76.41	546	151.7	2885	136.4	129	57.3
Otolith	2		1	2.8	29	48.3	1	6.3	75	79.8	5	50.0
Lens	2		0	0	0	0	14	87.5	43	45.7	4	40.0
TOTAL/MEAN			918	41.31	1436	35.79	712	60.14	4042	66.50	194	32.03
St. Dev.				24.82		23.79		33.24		28.66		29.36

vertebrae numbers are counts of vertebrae of at least 50% complete.
pro. = Proportional representation.

Shetland = all spraints from Shetland treated together.
Freswick = all spraints from Freswick treated together.
Bidno/Wye = all spraints from Bidno, Tywi and Wye treated together.
POOL = archaeological material from PL 0431/0437 - hypothesised otter spraint origin.
TOFTS = archaeological material from TN 0619 - hypothesised spraint origin.

Spearman's Rank Correlation coefficients, at 18 df:

Pool and Freswick, rho = 0.440, significant at 94%
Pool and Shetland, rho = 0.622, significant at 99%
Pool and Bidno/Tywi/Wye, rho = 0.295, not significant.
Tofts Ness and Pool, rho = 0.752, significant at 99%
Tofts Ness and Freswick, rho = 0.445, significant at 95%
Tofts Ness and Shetland, rho = 0.488, significant at 95%
Tofts Ness and Bidno/Tywi/Wye, rho = 0.110, not significant.
Freswick and Shetland, rho = 0.463, significant at 95%
Freswick and Bidno/Tywi/Wye, rho = 0.185, not significant.
Shetland and Bidno/Tywi/Wye, rho = 0.199, not significant.

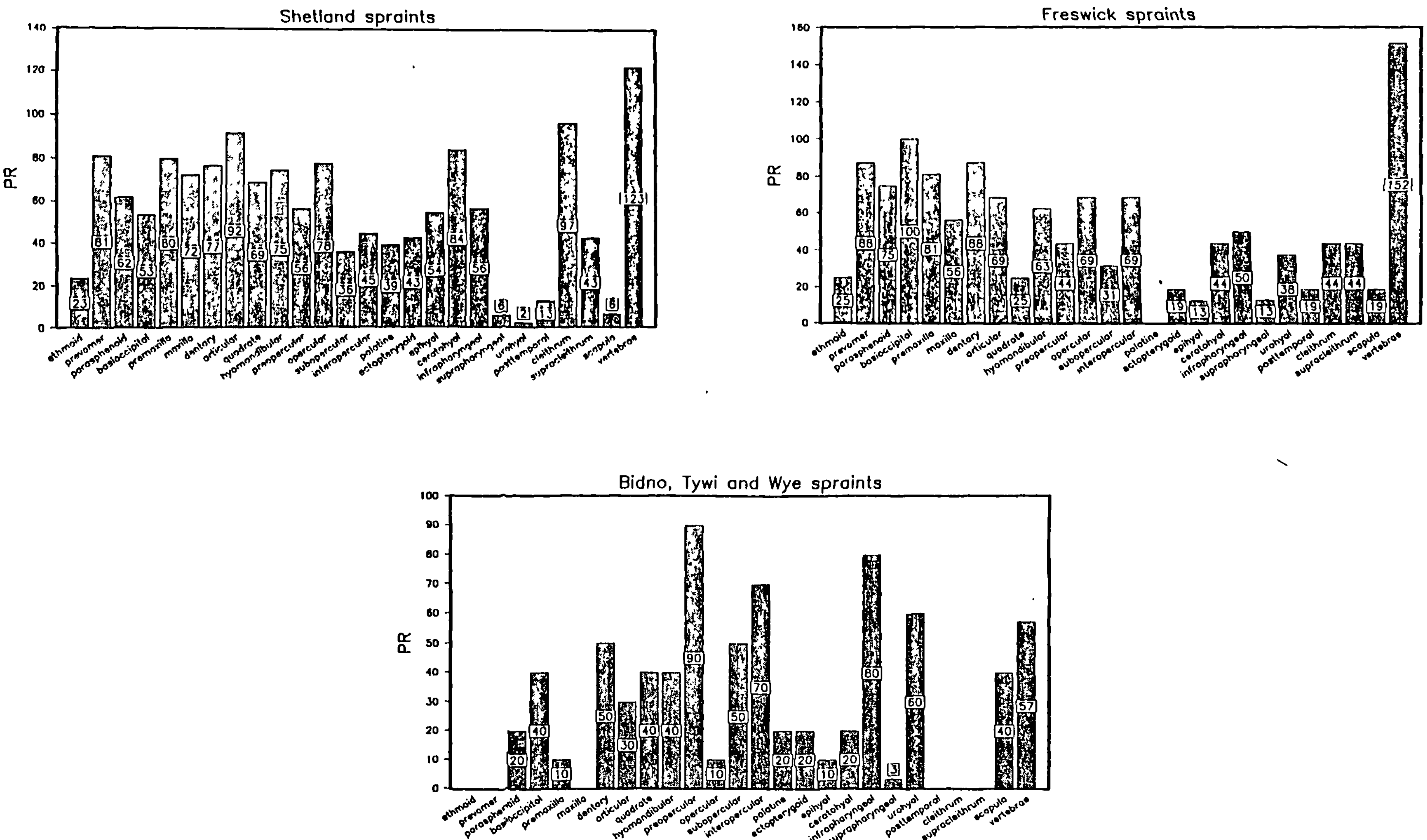


Fig. 7:4 Proportional Representation of Skeletal Elements for Fish Bone Assemblages from Contemporary Otter Spraints.

Tofts Ness (TN 0619) archaeological material

Pool (PL 0431/0437) archaeological material

Fig. 7:5 Proportional Representation of Skeletal Elements for Assemblages of Small Fish Bones from Excavations at Pool and Tofts Ness, Sanday, Orkney.

As Figs. 7:4 and 7:5, and Table 7:14 show, the patterns of skeletal element distribution between the modern otter spraint assemblages had trends in common, but also differences. As Table 7:14 demonstrates, the components of the Bidno, Tywi and Wye spraints differed significantly from all the other spraint groups. As the species involved were different to those represented by the coastal otter spraint assemblages this was to be expected. Of the fish represented in the spraints from Wales, the cyprinids have very large and robust pharyngeal bones, while trout have lighter head bones than most other teleosts. In fact, strictly speaking this difference in species composition renders the use of statistical correlation tests invalid (see Chapter 2, p. 37). The differences between the assemblage from Bidno, Tywi and Wye compared with the assemblages from Shetland and Freswick were also probably a result of the low numbers of individual fish, and of spraints in total, in the Welsh samples.

Being coastal, the assemblages from Freswick and Shetland had many features in common with each other. As the archaeological material also comprises the bones of marine species from around the Orkney Isles the similarities and differences between the Shetland and Freswick assemblages are more interesting and pertinent to its study. In both the Freswick and Shetland assemblages vertebrae are the most commonly represented bones, followed by the basioccipital in the case of the Freswick assemblage and the cleithrum in the Shetland assemblage. Other elements well represented in both the Freswick and Shetland assemblages include the articular, premaxilla, parasphenoid, dentary and, to a lesser extent, hyomandibular and opercular. Poorly represented bones included the suprapharyngeal, post-temporal and supracleithrum. Otoliths are well represented in the Shetland assemblage but very poorly represented in the Freswick assemblage.

The archaeological assemblages were composed of similar

species of fish. As illustrated, the Pool and Tofts Ness assemblages were significantly similar to each other (99% confidence), to the Shetland assemblage (99% and 95% confidence) and to the Freswick assemblage (94% and 95% confidence). In both the archaeological assemblages the most commonly recovered bone was the articular, followed by the other jaw elements and vertebrae. Unlike the modern spraint assemblages, the parasphenoid was very poorly represented, as was the prevomer. The epihyal, supracleithrum, post-temporal, suprapharyngeal, infrapharyngeal and interopercular were also poorly represented, as in the modern spraint assemblages. The dentary was proportionately less well represented in the Pool assemblage when compared with the modern assemblages. Only one otolith was recovered from the Pool material, but this may have been the result of the soil conditions, as the otoliths were proportionately better represented at Tofts Ness. Despite the differences, the similarities between the two modern assemblages from Scotland and the archaeological assemblages are substantial. It may be that this is a result of the relative robustness of the skeletal elements, but the loss of some bones, in particular the post-temporal and supracleithrum, is at variance with the robustness of these elements when subjected to physical force, as indicated by the trampling and tumbling experiments (Chapter 5).

Is the extent of bone loss related to skeletal element shape?

To investigate this question chi-squared tests were performed by each assemblage group, to test the null hypothesis that the skeletal element loss was not influenced by shape. Only bones easily identified from a wide range of species, and of similar shapes between species, were included. The results are given in Table 7:15, below:

Table 7:15. A comparison of bone shape with survival

	Shape	Observed	Expected	Residual
Freswick				
	"Robust"	68	124	-56
	Irregular	27	91	-64
	Flat	48	100	-52
	Spherical	554	382	172

chi-squared = 175 3 df. significance , P= <0.001

	Shape	Observed	Expected	Residual
Shetland				
	"Robust"	456	701	-244
	Irregular	190	514	-324
	Flat	368	561	-193
	Spherical	2910	2149	761

chi-squared = 625 3 df. significance, p= <0.001

	Shape	Observed	Expected	Residual
Bidno, Tywi, Wye				
	"Robust"	13	33	-20
	Irregular	17	24	-7
	Flat	24	26	-2
	Spherical	131	101	30

chi-squared = 23 3 df. significance <0.001

	Shape	Observed	Expected	Residual
Pool archaeological material				
	"Robust"	134	164	-30
	Irregular	28	120	-92
	Flat	84	131	-47
	Spherical	672	502	169

chi-squared = 150 3 df. significance <0.001

	Shape	Observed	Expected	Residual
Tofts Ness archaeological material				
	"Robust"	207	251	-44
	Irregular	48	184	-136
	Flat	103	201	-98
	Spherical	1049	771	279

chi-squared = 257 3 df. significance <0.001

As illustrated, in all cases the null hypothesis was rejected, at over 99% probability. The same trend was apparent in all the assemblages: the spherical bones (vertebrae) were over-represented in relation to the head bones, and within the head bones those classed as "irregular" were the least well represented. In all except the Bidno, Tywi and Wye assemblage (containing a small number of bones) the "robust" bones of the head (mainly jaw and jaw support elements) were the best surviving head bones.

Bone condition: modern spraints and archaeological material.

A number of bones from all the assemblages were crushed or chewed. Table 7:16 gives the numbers and proportions of chewed bones from the modern otter spraint assemblages and from the archaeological assemblages from Pool and Tofts Ness. Tables 7:17-7:19 detail the size of fragments and proportions of whole bones represented by the fragments from the Shetland spraints, the Freswick spraints, and the spraints from Bidno, Tywi and Wye, as an indication of the extent to which bones have been modified by passage through the digestive system of otters. Similar parameters are given for the bone assemblage recovered archaeologically from Pool and Tofts Ness, to enable comparisons (Tables 7:20-7:21).

All of the modern spraint assemblages contained some chewed bones. These were more often vertebrae than head bones, and tended to be crushed in the medio-lateral plane, a consequence of which is to break the struts which support the two articulating facets. This breakage was rarely sufficient to separate the two facets. Larger vertebrae in particular sometimes had chewed articular surfaces (Plate 7:3). A proportion of the bones recovered from the archaeological assemblages were also crushed in a similar manner.

The "decay trajectories" exhibited by each assemblage is illustrated by Fig. 7:6. The profiles for the two archaeological assemblages are very similar, and both increase gradually. The profiles for the Freswick and Shetland spraint assemblages are also very similar to each other, and show an even more gradual increase, indicating relatively little loss of skeletal elements. The Welsh assemblage shows the steepest trajectory, indicating the greatest difference between the relative abundance of the best and least most frequently represented elements.

Table 7:16
Numbers and proportions of chewed fish bones from modern otter spraints and from archaeological material (context PL 0431/0487 from Pool, Sanday) of hypothesised otter spraint origin.

		Head Bones	Vertebrae
POOL	no.	20	516
	%	7	51
TOFTS NESS	no.	12	421
	%	3	41
Shetland	no.	82	636
	%chewed	6	22
Freswick	no.	3	82
	%chewed	2	15
Bidno/Tywi/Wye	no.	1	16
	%chewed	1	12

Table 7:17 Fragment Completeness Scores for Fish Bones from the Contemporary Otter Spraints from Shetland.

SHETLAND SPRAINTS.

Bone	0-30	40-60	70-90	100	%whole
Frontal	0	11	20	12	27.9
Supraoccipital	0	0	0	13	100
Prevomer	0	1	4	25	83.3
Parasphenoid	0	7	8	14	48.3
Basioccipital	0	0	5	19	79.2
Premaxilla	0	4	11	41	73.2
Maxilla	0	2	6	41	83.7
Dentary	0	5	11	43	72.9
Articular	1	4	12	47	73.4
Quadrate	2	3	21	28	51.9
Hyomandibular	0	2	26	26	48.1
Preopercular	0	1	33	12	26.1
Opercular	0	19	36	15	21.4
Subopercular	0	0	11	18	62.1
Interopercular	0	0	10	22	68.8
Palatine	0	0	4	25	86.2
Ectopterygoid	0	0	9	24	72.7
Epihyal	0	0	8	24	75.0
Ceratohyal	0	1	13	49	77.8
Hypohyal	0	0	0	39	100
Infrapharyngeal	0	2	5	34	82.9
Suprapharyngeal	0	0	2	5	71.4
Posttemporal	0	0	2	10	83.3
Cleithrum	0	11	26	23	33.3
Supracleithrum	1	0	4	33	86.8
Vertebrae	139	142	*245	1848	77.9
Otolith	2	3	2	56	88.8
Total/mean%	145	218	534	2546	73.9

* = most of these have only spines and/or processes broken or missing.

Percentage of bones 70% complete or above = 89.5

Table 7:18 Fragment Completeness Scores for Fish Bones from Contemporary Otter Spraints from Freswick.

FRESWICK SPRAINTS

Bone	0-30	40-60	70-90	100	%whole
Frontal	0	0	1	5	83.3
Supraoccipital	0	0	0	2	100
Prevomer	0	1	1	5	71.4
Parasphenoid	0	1	1	3	60.0
Basioccipital	0	0	3	3	50.0
Premaxilla	0	2	3	9	64.3
Maxilla	0	1	3	6	66.7
Dentary	0	1	4	9	64.3
Articular	0	1	3	6	60.0
Quadrate	0	1	2	3	50.0
Hyomandibular	0	1	0	8	88.9
Preopercular	0	1	1	4	66.7
Opercular	1	1	3	4	44.4
Subopercular	0	1	2	2	40.0
Interopercular	0	2	3	5	50.0
Ectopterygoid	0	1	1	1	33.3
Epihyal	0	0	1	2	66.7
Ceratohyal	0	1	1	5	71.4
Hypohyal	0	0	0	3	100
Infrapharyngeal	0	1	6	2	22.2
Suprapharyngeal	0	1	1	4	66.7
Posttemporal	0	0	1	3	33.3
Cleithrum	0	1	4	5	50.0
Supracleithrum	0	0	0	7	100
Vertebrae	69	38	138*	129	34.5
Otolith	0	0	1	0	0.0
Total/mean%	70	57	184	235	43.0

* most of these have just the spines and/or processes missing.

Percentage of bones 70% complete or more = 76.7

Table 7:19 Fragment Completeness Scores for Fish Bones from Contemporary Welsh Otter Spraints.

BIDNO. TYWI AND WYE SPRAINTS.

Bone	0-30	40-60	70-90	100	%whole
Supraoccipital	0	0	0	1	100
Parasphenoid	0	0	1	0	0.0
Basioccipital	0	0	0	2	100
Premaxilla	0	0	0	1	100
Dentary	0	0	0	5	100
Articular	0	1	1	2	50.0
Quadrate	0	0	0	4	100
Hyomandibular	1	0	2	1	33.3
Preopercular	0	0	3	6	66.7
Opercular	1	1	3	4	44.4
Subopercular	0	0	4	2	50.0
Interopercular	0	0	1	6	85.7
Ectopterygoid	0	0	1	1	50.0
Epihyal	0	0	1	0	0.0
Ceratohyal	0	0	0	2	100
Hypohyal	0	0	0	1	100
Infrapharyngeal	0	2	2	4	50.0
Suprapharyngeal	0	0	0	1	100
Cleithrum	0	1	4	2	28.6
Vertebrae	7	4	88*	37	27.2
Otolith	0	0	0	5	100
Total/mean%	9	9	111	87	40.3

* most of these have just the spines and/or processes missing

Percentage of bones 70% complete or more = 91.7

Table 7:20 Fragment Completeness Scores for Fish Bones from Pool.

BONES FROM POOL, CONTEXT 0431/0487

Bone	0-30	40-60	70-90	100	%whole
Supraoccipital	0	0	1	2	66.7
Prevomer	0	3	2	1	16.7
Parasphenoid	0	1	0	0	0
Basioccipital	0	1	7	3	27.3
Premaxilla	7	6	9	9	29.0
Maxilla	2	3	5	6	37.5
Dentary	6	4	5	4	21.1
Articular	3	10	17	3	9.1
Quadrate	1	10	11	1	4.3
Hyomandibular	0	10	9	0	0
Preopercular	0	6	9	2	11.8
Opercular	0	3	14	0	0
Subopercular	0	0	0	2	100
Interopercular	0	1	8	0	0
Palatine	0	5	7	2	14.3
Ectopterygoid	0	2	2	0	0
Epihyal	0	0	2	6	75.0
Ceratohyal	2	2	10	3	17.6
Hypohyal	0	0	0	1	100
Infrapharyngeal	0	2	4	1	14.3
Suprapharyngeal	0	0	4	3	75.0
Posttemporal	0	1	5	1	14.3
Cleithrum	2	4	6	1	7.7
Supracleithrum	0	0	4	2	33.3
Scapula	0	0	0	2	100
Vertebrae	342	234	*427	0	(42.6)**
Otolith	0	0	1	0	100
Total/Mean %	365	342	569	55	4.1

* This figure comprises bones with only the spines and/or processes broken and/or missing.

** Based on vertebrae 80% or more complete, i.e. centra intact.

Percentage of bones 70% or more complete = 48.2

Table 7:21 Fragment Completeness Scores for Fish Bones from Tofts Ness.

BONES FROM TOFTS NESS, CONTEXT 0619

Bone	0-30	40-60	70-90	100	%whole
Prevomer	3	4	0	2	22.2
Parasphenoid	1	1	0	0	0
Basioccipital	0	5	12	0	0
Premaxilla	11	5	8	9	27.3
Maxilla	4	10	11	5	16.7
Dentary	15	11	10	1	2.7
Articular	3	21	15	11	22.0
Quadrate	12	5	12	5	14.7
Hyomandibular	2	5	2	0	0
Preopercular	0	8	5	0	0
Opercular	5	24	3	0	0
Subopercular	0	0	2	0	0
Interopercular	0	5	7	0	0
Palatine	0	0	1	1	50.0
Ectopterygoid	0	0	3	0	0
Epihyal	0	7	11	5	21.7
Ceratohyal	0	4	10	0	0
Hypohyal	0	0	0	3	100
Infrapharyngeal	0	4	4	4	33.3
Suprapharyngeal	0	0	14	15	51.7
Posttemporal	0	0	5	3	37.5
Cleithrum	0	4	5	0	0
Supracleithrum	0	0	3	3	50.0
Basipterigium	0	0	1	0	0
Urohyal	0	0	4	0	0
Vertebrae	183	338	*814	0	(60.9)**
Otolith	2	5	5	17	58.6
Total/Mean %	241	466	967	84	4.8

* This figure comprises bones with only the spines and/or processes broken and/or missing.

** Figure based on vertebrae 80% or more complete, i.e centra intact.

Percentage of bones 70% or more complete = 59.8

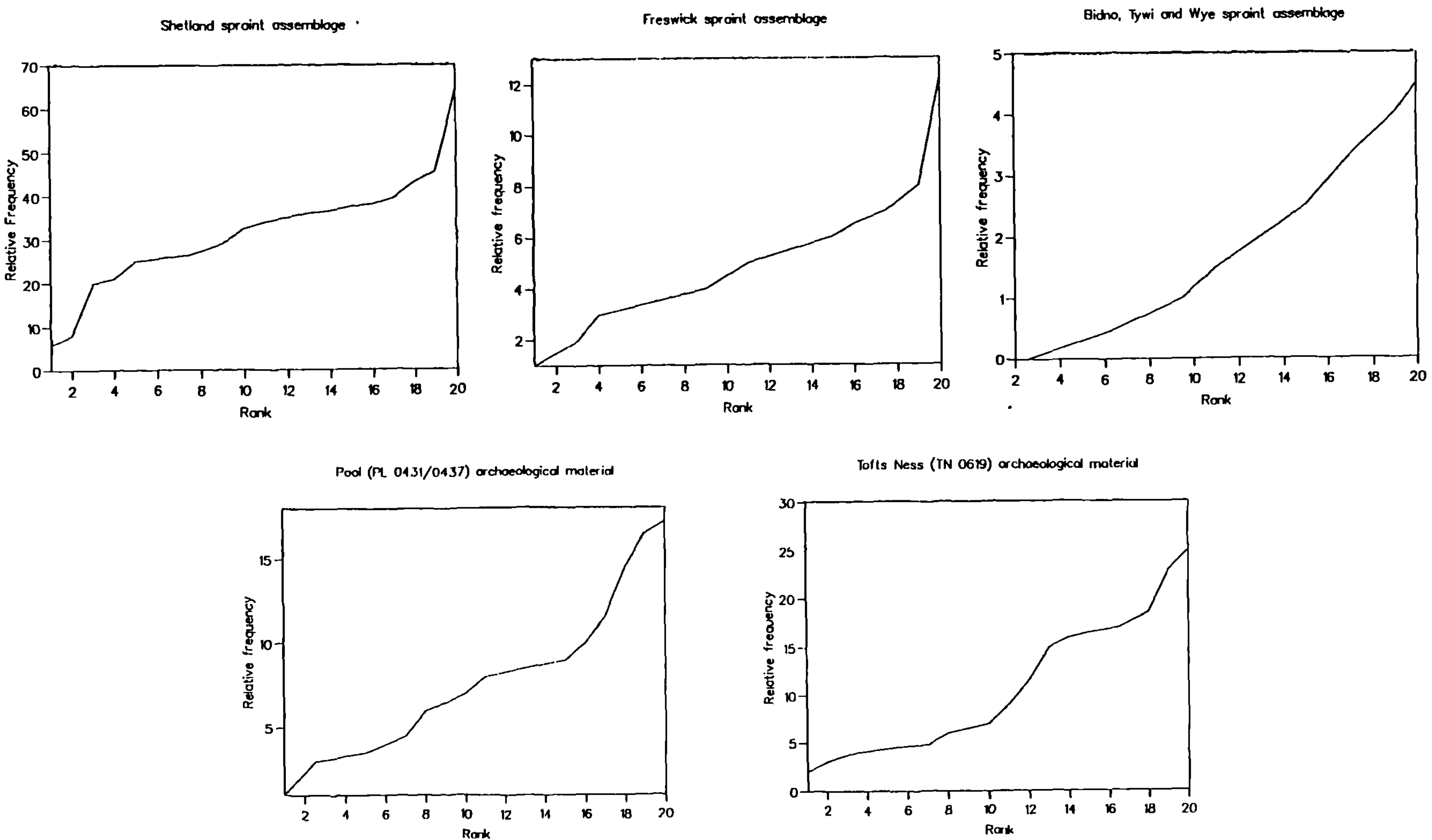


Fig. 7:6 The "Decay Trajectories" for Fish Bone Assemblages from Contemporary Otter Spraints (above) Compared with Assemblages of Small Bones from excavations at Pool and Tofts Ness, Sanday, Orkney (below).

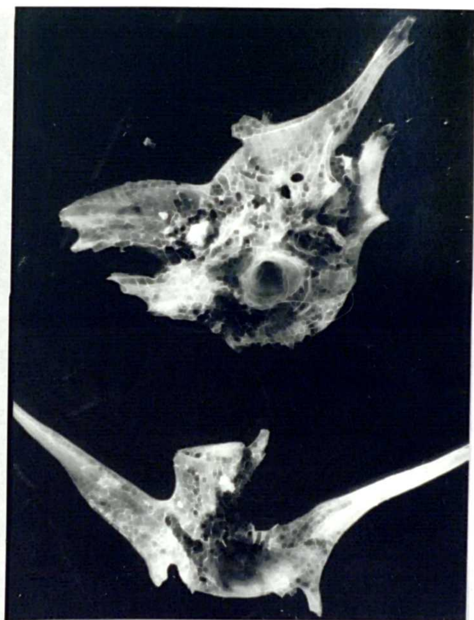
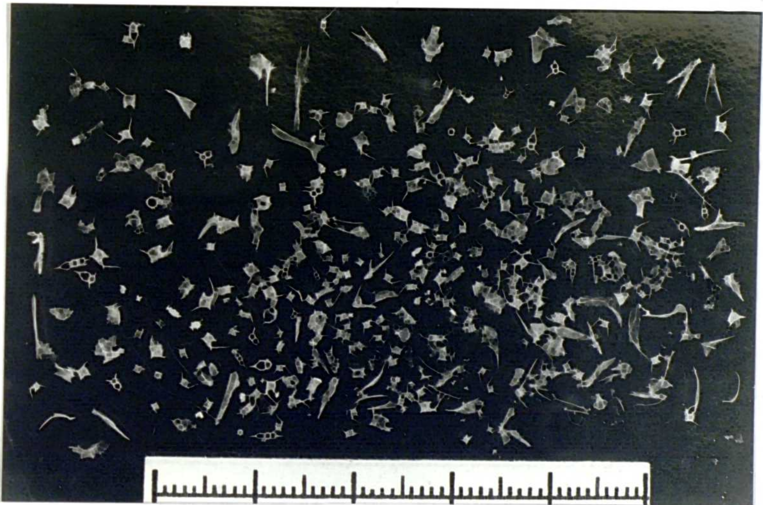



Plate 7:3 Fish Bones Recovered from Otter Spraint.

The greater amount of bone loss and fragmentation of the archaeological assemblages when compared to the modern spraint assemblages from Freswick and Shetland may be attributable to the greater length of time that the latter had been on the ground surface, although the bones did not appear weathered. When comparing the modern assemblages with archaeological material it must be remembered that the latter may have been subject to other taphonomic processes in addition to possible passage through the gut. Loss may have occurred as a result of trampling or a number of other pre-depositional factors. After burial soil conditions may have influenced the preservation of the assemblage. Assemblage composition is also affected by the methods employed for, and standards of, recovery. The overall condition of the bones from the archaeological material is very good, however, and some bones appear almost fresh. This gives hope that the assemblage may not have been much altered by the many centuries which have passed since the fish died. As the samples were sieved through fine mesh recovery is unlikely to be a source of error.

Can bones from otter spraints be distinguished from assemblages formed by other predepositional processes?

There was no evidence on the fish vertebrae from otter spraints of the worn edges of the centrum faces seen on the vertebrae of all fish species used in the tumbling experiments. Apart from the chewed and crushed bones, small fish bones from the individual modern spraints were generally complete, or nearly so. This trend is apparent in the Tables giving the combined spraint assemblage fragment completeness values (Tables 7:17-7:21). The most commonly fragmented bones included the cleithrum and opercular. Complete bones, unfortunately, do not allow the elucidation of origin for the assemblage. Bones found in gull pellets are often also complete (see below), and do not display chewing marks. Piles of discarded small fish from a fishing expedition would leave assemblages of complete bones, none

of which should be acid eroded or chewed. Small fish bones from fish guts could be expected to show a variety of erosional states, depending on which part of the gut they were in, though a detailed study of fish gut contents would be very useful to investigate this hypothesis.

Despite these negative remarks, there are ways in which otter spraint material may be identified, however. Otter spraint material may be characterised by large numbers of small fish bones, many undamaged but a proportion appearing chewed. The larger bones in an assemblages will probably be more damaged and chewed than the smaller bones. While most areas of the fish skeleton will be present, there is a marked over-representation of vertebrae. Amphibian, bird and mammal bone fragments may also be present, but may be more damaged than the fish remains.

7.5 Experiments into the Effects on Fish Bone of Passage Through the Human Gut, and Comparisons with Archaeological Material.

7.5.1 Materials and methods.

The experiments

Whole fish, lightly cooked, were eaten by the author on five separate occasions. On the first occasion one kipper (total length 300 mm.) and 25 whitebait (young herrings *Clupea harengus* and sprats *Sprattus sprattus* (L.), of lengths from 60 mm. to 80 mm.) were eaten. On the second, third, fourth and fifth occasions five sardines *Sardina pilchardus* (Walbaum) of total lengths from 160 mm. to 190 mm. were consumed. Each fish was eaten in its entirety, after frying or grilling for up to five minutes; this caused charring to the fins, but otherwise the bones appeared undamaged. With each fish meal, approximately 200 grams of tinned sweetcorn was eaten which acted as a marker

to indicate when the entire meal had passed through the gut, as recommended by Calder (1977). Bread was also consumed, as the bones (especially the kipper's head bones) were found to be sometimes difficult to swallow. It was found that the fish heads required more mastication than the vertebrae. Many vertebrae were probably swallowed unchewed. Human faeces were collected for five or six days after fish had been eaten. The faeces were soaked in warm water for up to 24 hours. Disaggregation proved to be possible without recourse to the chemicals described by Calder (*ibid.*), by passing a stream of hot water over the faeces, held in a 500 micron mesh. The residue was further cleaned by moving the base of the sieve up and down in a shallow bowl of warm water. The residues were sorted either wet or after drying at 40°C. Bones were picked out using a dissecting microscope (x10).

On another occasion six briefly boiled haddock otoliths were swallowed. These were recovered from faeces as above. All of the otoliths were passed on the second day after consumption. Otoliths were weighed and measured before and after the experiment, after drying at 40°C overnight.

<u>Archaeological material.</u>

Fish bones were recovered from waterlogged organic rich layers with a cess component, excavated from beneath structures of Viking Age date at Viborg Sonderso, Denmark (Robinson pers. comm.). The bones were recovered from two soil samples of weights 458 grams and 375 grams (wet weight). These samples were submitted for analysis by David Robinson of the Copenhagen Museum and were sieved to 500 microns and the residues sorted by myself using a low-powered binocular microscope. Further details are given in Nicholson (forthcoming c.)

Fish bones were also recovered archaeologically from possible cess-pit deposits from excavations at Thetford Redcastle Furze. These were submitted by Peter Murphy,

Department of Continuing Studies, University of East Anglia. The bones had been recovered from soil samples wet sieved through a 1 mm. mesh (further details in Nicholson forthcoming d.).

7.5.2 Results and discussion

The experiments

Of all the complete fish eaten, very few bones survived the digestive process. Details of the recovered fragments are given in Tables 7:22 and 7:23, and Table 7:24 gives summary descriptive statistics. The extremely low numbers of bones which survived digestion are of similar proportions to those reported by Jones (1986; and Wheeler and Jones 1989, 73-4). All bones were damaged, and many would not be identifiable to species had I not known what was swallowed. None of the whitebait bones survived in any form. Because of the few bones which survived, and the relatively low numbers of fish ingested, no conclusions can be drawn about the relative survival rates of different parts of the skeleton, except in the very crudest terms by calculating the percentage rates for vertebrae and for the entire skeleton as a unit (Table 7:24). The proportional representation of the different bones is illustrated by Fig. 7:7, which demonstrates the extreme bone loss. As an alternative measure, the decay trajectory was plotted, based on the relative abundance of remains compared with their rank. The steep profile indicates the extreme bone loss.

The destruction of almost all head bones is interesting, as it indicates that it may not be possible to say whether complete fish were consumed from assemblages of bones contained in cess. The lower survival rate for the larger kipper (herring) when compared with the sardines may be due to the greater amount of mastication necessary to enable swallowing of the kipper bones. As all whitebait bones were lost, chewing clearly does not provide the whole

Table 7:22 Fish Remains recovered after ingestion by a human.

Experiment 1. Fish ingested = 1 kippered herring, total length 300mm.
20 small clupeids, total lengths 60-80mm.

Day 1: No remains.
Day 2: 1 crushed vertebra, 3 vertebra fragments all from the kipper, 3 unidentified fragments.
Day 3: 1 otic bulla, 2 vertebra fragments all from the kipper. 3 unidentified fragments.
Day 4: No remains.
Day 5: No remains.

Experiment 2. Fish ingested = 5 sardines, total lengths 170-185 mm.

Day 1: 1 crushed vertebral centra, 3 scale fragments.
Day 2: 1 eye lens, 2 cleithra fragments, 1 ?preopercular fragment, 1 complete articular, 1 blackened hyomandibular fragment, 2 palatines (1 acid eroded), 1 complete uncrushed vertebral centra, 8 laterally crushed vertebrae, 1 acid eroded, blackened and crushed vertebrae; 11 vertebra fragments, 11 scale fragments, 2 branchiostegal rays, about 30 unidentified fragments.
Day 3: 4 crushed, blackened and acid eroded vertebral centra, 8 medio-laterally broken, acid eroded and blackened vertebrae, 12 acid eroded and blackened vertebra fragments, 4 scale fragments, 20 unidentified fragments.
Day 4: 2 unidentified fragments.
Day 5: No remains.

Experiment 3. Fish ingested = 5 sardines, total lengths 170-190 mm.

Day 1: 1 eye lens, 1 complete uncrushed vertebral centra, 2 laterally crushed vertebrae, 1 vertebra fragment, 2 unidentified fragments.
Day 2: 5 eye lenses, 2 chewed epihyals, 1 chewed ceratohyal, 1 complete but blackened articular, 1 cleithra fragment, 6 scale fragments, 2 complete uncrushed vertebral centra, 5 complete laterally crushed vertebral centra, 1 acid eroded and blackened vertebral centra, 1 incomplete centra, 15 vertebra fragments, about 50 unidentified fragments.
Day 3: 1 eye lens, 1 complete, crushed vertebral centra, 2 acid eroded and crushed vertebral centra, 3 vertebra fragments, 3 scale fragments, 17 unidentified fragments.
Day 4: 1 acid eroded vertebra fragment.
Day 5: No remains.

Experiment 4. Fish ingested = 5 sardines, total lengths 180-190 mm.

Day 1: 2 crushed vertebral centra, 2 vertebra fragments, 1 scale, 3 unidentified fragments.
Day 2: 2 eye lenses, 1 crushed vertebral centra, 1 acid eroded and blackened vertebral centra, 2 vertebra fragments, 1 acid eroded epihyal, 1 otolith fragment.
Day 3: 4 eye lenses, 1 vertebra fragment, 3 unidentified fragments.
Day 4: 2 eye lenses, 1 unidentified fragment.
Day 5: No remains.

Experiment 5. Fish ingested = 5 sardines, total lengths 170-180 mm.

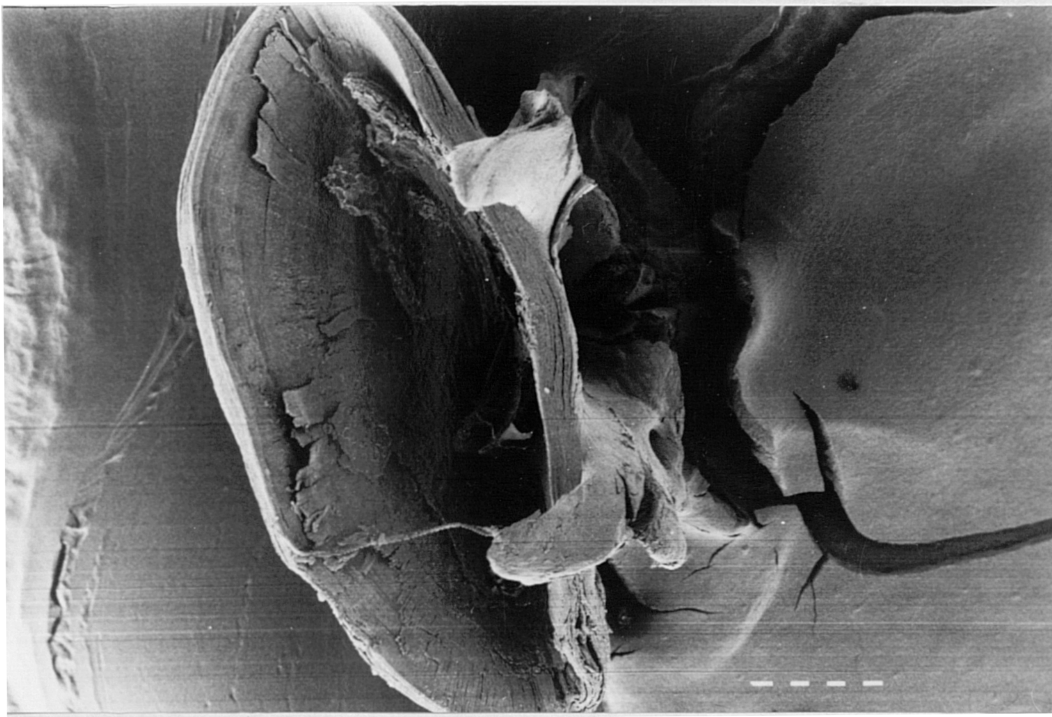
Day 1: 2 crushed vertebral centra, 1 complete uncrushed vertebral centra, 3 vertebra fragments, 3 scale fragments, 2 unidentified fragments.
Day 2: 4 crushed vertebral centra, 2 complete uncrushed vertebral centra, 4 eye lenses, 16 vertebra fragments, 1 torn hyomandibular, 10 scale frags, about 50 unidentified fragments.
Day 3: 1 crushed and acid eroded, blackened vertebra; 5 vertebra fragments, 2 eye lenses, 7 unidentified fragments.
Day 4: No remains.
Day 5: No remains.

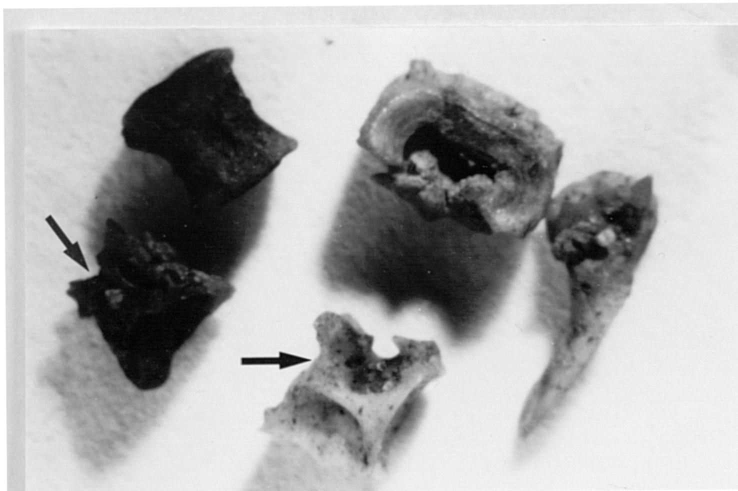
Table 7:23 Numbers, relative frequencies and proportional representation of bones recovered after ingestion by a human. All experiments (from a total of 1 kippered herring, 20 small herring/sprat, 20 sardines).

Bone element	Shape	No. in 1 fish	Recovered No.	Relative Frequency	Proportion Representation (MNI taken as 6)
Ethmoid	I	1	0	0	0
Frontal	F	2	0	0	0
Prevomer	I	1	0	0	0
Parasphenoid	I	1	0	0	0
Basioccipital	S	1	0	0	0
Premaxilla	F	2	0	0	0
Maxilla	R	2	0	0	0
Supramaxilla	F	2	0	0	0
Dentary	F	2	0	0	0
Articular	F	2	2	1	16.7
Quadrate	F	2	0	0	0
Hyomandibular	F	2	2	1	16.7
Palatine	R	2	2	1	16.7
Preopercular	F	2	1	0.5	8.3
Opercular	F	2	0	0	0
Subopercular	F	2	0	0	0
Interopercular	F	2	0	0	0
Ectopterygoid	F	2	0	0	0
Metapterygoid	I	2	0	0	0
Epihyal	F	2	3	1.5	25.0
Ceratohyal	F	2	1	0.5	8.3
Urohyal	F	1	0	0	0
Posttemporal	F	2	0	0	0
Cleithrum	I	2	2	1	16.7
Supracleithrum	F	2	0	0	0
Scapula	F	2	0	0	0
Coracoid	I	2	0	0	0
Basipterygium	F	2	0	0	0
Vertebrae	S	57	40	0.7	11.7
Otolith	-	2	1	0.5	8.3
Otic bulla	S	2	1	0.5	8.3
Eye lens	S	2	22	11	91.7
TOTAL		114	77	0.7	

Relative frequency = observed no. / expected no. in one fish.

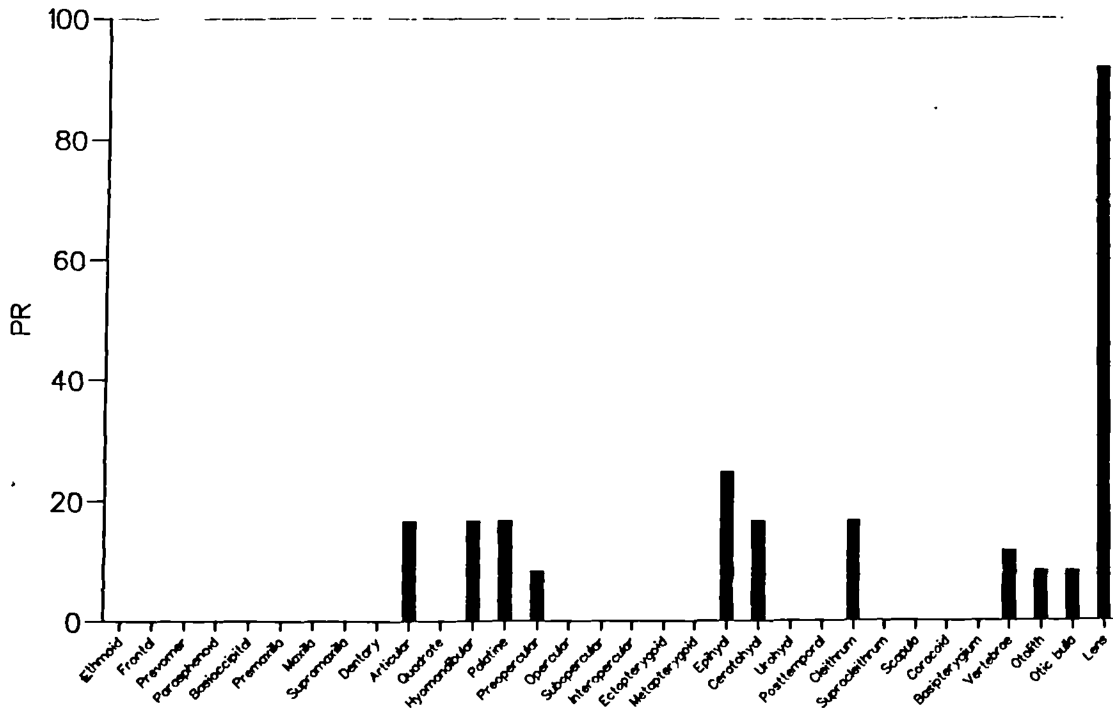
MNI is taken as 6 from the recovered bones, treating the assemblages together, as one unit.





arrows indicate
crenellated edge

Plate 7:4a and 7:4b. Detail of Herring Bones after Passage Through the Human Gut.



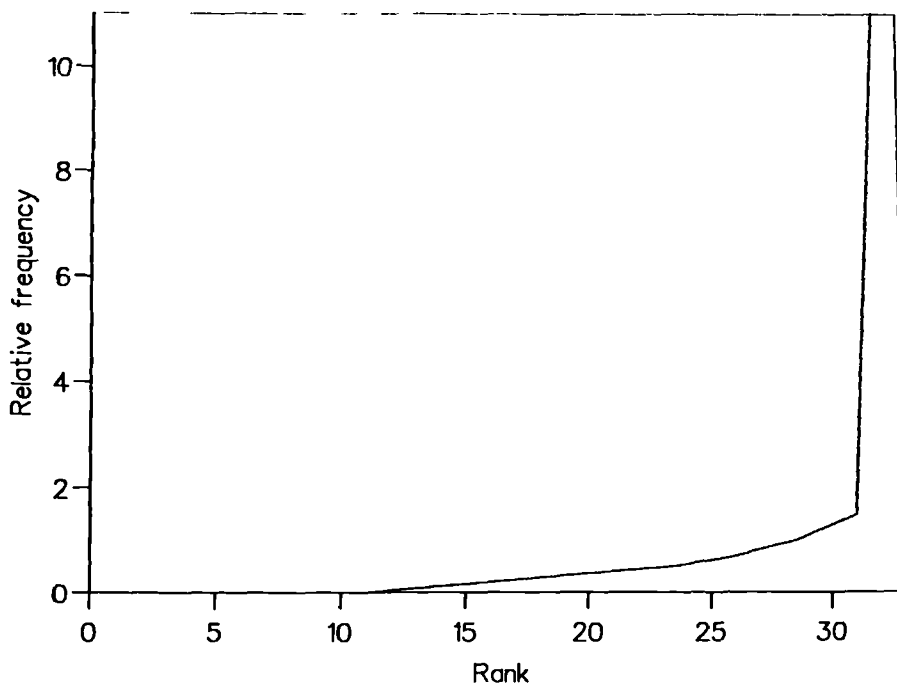


Fig. 7:7 Clupeid Remains after Ingestion by a Human. a) Proportional Representation, b) the "Decay Trajectory".

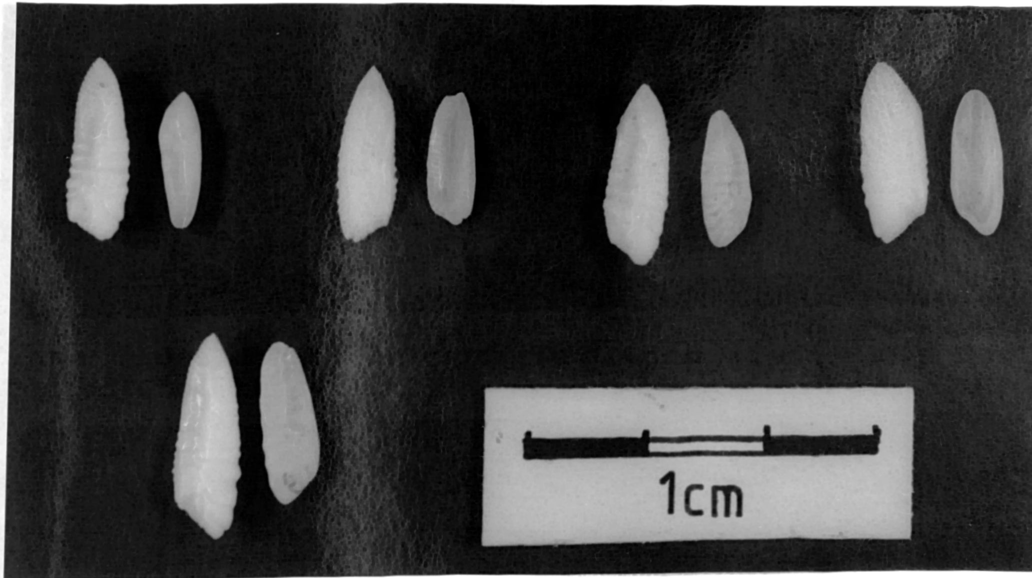


Plate 7:5a. Fresh Haddock Otoliths (left) and Human-Digested Otoliths (right).

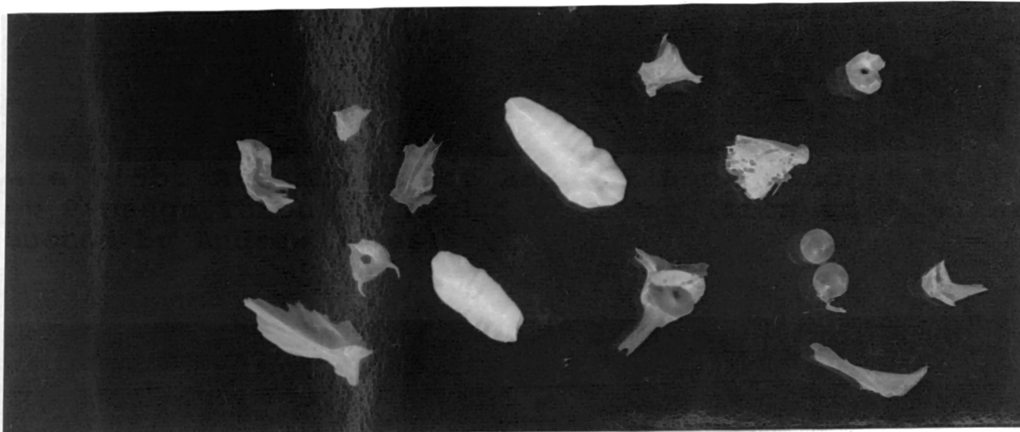


Plate 7:5b. Assemblage of Haddock Bones and an Otolith after Passage Through the Gut of a Dog (from an experiment conducted by Andrew Jones). x2

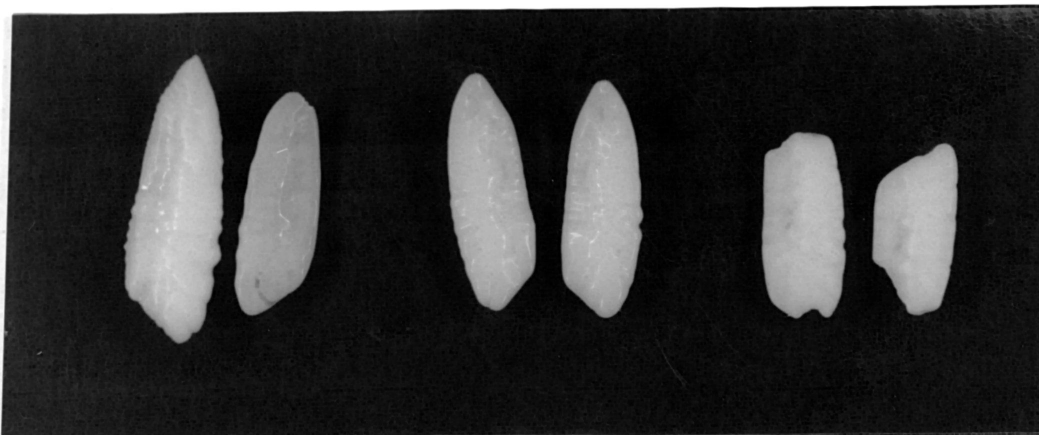


Plate 7:5c. Mechanically Abraded Haddock Otoliths (right) Compared with fresh otoliths (centre) and a Human-Digested Otolith (second left). x2

explanation for differences in survival, however. The best surviving part of the skeleton was the eye lens, in all cases. This could be a useful feature for identifying human cess archaeologically, but unfortunately fish eye lenses cannot be identified to species and also may easily be mistaken for seeds. The survival of scale fragments is contrary to the results given by Calder (1977), who found that no fish scales survived digestion.

Most of the vertebrae recovered were crushed: the most common form of damage was compression and breakage of the struts supporting the two articulating facets (Plate 7:4a). This commonly resulted in the two halves being separated. Many fragments of the centrum rim were also recovered. Several vertebrae were stained black or dark brown. These specimens commonly exhibited extreme acid dissolution, causing crenellation and rounding to the edges of the articulating facets (Plate 7:4b). Acid erosion causing smooth crenellated edges was also observed on other fragments, not all of them indentifiable. There was no obvious correlation between extent of bone dissolution and the length of time before the bone was passed in the faeces. Complete, unstained and uneroded vertebrae were recovered with stained and eroded specimens.

Evidently the efficiency of the digestive system varies, even in one individual. As only fish of the Clupeidae were consumed in these experiments it would be useful to use fish of other families in order to compare the results. Eel and stickleback bones are commonly found in deposits of probable human cess origin, and other small fish could also potentially be consumed whole. It is to be expected that the efficiency of the digestive system will vary between individuals and depending on the health of the individual. Archaeological cess deposits are frequently identified by the presence of abundant intestinal parasite eggs (see below), and heavily parasitised individuals may digest food differently to healthy individuals. Stomach upsets would also be likely to reduce the efficiency of digestion.

The experiment described here only provides a starting point; ideally many more experiments should be undertaken, using a number of different individuals, to establish the variation in digestive efficiency.

Table 7:24 Survival of Fish Bones Through the Human Digestive Tract.

Excluding the 20 small herring/sprats eaten with the kipper in experiment 1, from which no identifiable bones survived.

The expected number of bone is based on Jones' figures (Wheeler and Jones 1989, 71) and is lower than that which could be expected were all the potentially identifiable skeletal elements included.

Experiment No.	1	2	3	4	5
Fish ingested:	1 kipper (herring)	5 sardines	5 sardines	5 sardines	5 sardines
Expected no. of identifiable bones in 1 fish.	80	80	80	80	80
No. head bones recovered.	1	6	4	1	1
No. whole vertebrae recovered	1	18	14	4	8
No. eye lenses recovered	0	1	7	8	7
No. otoliths recovered	0	0	0	1	0
% survival of all bones	3	6	6	4	2
Proportional representation of whole vertebrae	2	8	5	2	3

All of the ingested otoliths were considerably reduced by passage through the gut. The extent of reduction is detailed in Table 7:25. All appeared thinned and polished, and surface sculpturing was diminished. Plate 7:5a illustrates the effects of digestion on otoliths, in each case the left otolith was consumed while the right was not eaten, to enable comparisons. No otolith showed crenelated sculpturing to the edges, as was found on one dog-ingested otolith (Plate 7:5b) after an experiment by Andrew Jones (1986). Ingested otoliths may be distinguished from mechanically abraded specimens by their overall thin appearance, which will make them susceptible to breaking. Severe mechanical abrasion will also break otoliths, but they will always appear rounded rather than thinned, even though both processes reduce the surface sculpturing and cause polishing (Plate 7:5c).

<u>Table 7:25. Sizes (mm.) and Weights (g.) of Otoliths Before and After Ingestion.</u>

Fish Size (mm.)	430	400	400	390	380	360
Length before	17.0	15.9	15.6	15.0	14.5	15.5
after	13.5	11.4	12.5	11.5	11.2	11.3
% loss	20.6	28.3	19.9	23.3	22.8	27.1
Width before	5.9	5.9	5.8	5.1	4.9	5.1
after	4.6	4.4	4.5	4.0	3.7	3.9
%loss	20.0	25.4	22.4	21.6	24.5	23.5
Depth before	2.7	2.6	2.7	2.3	2.3	2.8
after	2.0	1.8	1.8	1.9	1.6	2.0
%loss	25.9	30.8	33.3	17.4	30.4	28.6
Weight before	0.307	0.271	0.285	0.254	0.232	0.254
after	0.145	0.084	0.126	0.094	0.082	0.092
%loss	52.8	69.0	55.8	63.0	64.7	63.8

The archaeological material

a. Viborg Søndersø.

A total of 201 bones were examined from context 1677 and 143 bones from context 1682, from soil samples recovered during excavations at Viborg Søndersø. Full details of the samples are given in Nicholson (forthcoming c). Both contexts comprised waterlogged organic material. These deposits were interpreted as having a cess component from the botanical remains and from the presence of human parasite eggs from the whipworm *Trichuris trichiura* (Robinson and Boldsen 1989).

The fish species represented included eel *Anguilla anguilla*, herring *Clupea harengus* and possibly sprat *Sprattus sprattus*, flounder *Platichthys flesus* (L.), perch *Perca fluviatilis* L., bleak *Alburnus alburnus* (L.), possibly dace *Leuciscus leuciscus* (L.) and other not further identified cyprinids. With the exception of some of the herring bones, from individuals between 300-350 mm. length, and the flounder dermal denticles representing fish of at least 400 mm. long, all bones were from fish of less than 150 mm. total length.

A small number of bones appeared charred, as indicated by a layer of black peeling char seen under the light microscope and confirmed under the scanning electron microscope. Only slight charring was observed, consistent with burning during cooking rather than resulting from rubbish disposal. Both assemblages also included a proportion of distorted vertebral centra (Table 7:26) but the majority of bones were complete. No bones appeared to have been partially dissolved or acid-eroded. Complete centra included a number from very small (under 100 mm. total length) herring or sprat. The survival of these bones through the gut seems unlikely given the results of the experiments detailed above. No bones from the small clupeids (the whitebait) survived digestion, in the

experiment, although, as discussed above, digestive disorders may affect the extent of bone destruction. Without many more experiments it is not possible to state with certainty that undistorted, complete tiny clupeid vertebrae could not withstand digestion, but the results of those experiments that I have undertaken indicates that it is unlikely. More probably the remains in the layers include a cess component mixed with table waste.

Table 7:26. The Fish remains from Viborg Søndersø, contexts 1677 and 1682.

1677

Eel: 24 vertebrae (8 crushed/chewed).
Herring: 2 otic bullae (charred), 1 basioccipital, 22 vertebrae (3 crushed/chewed).
Perch: 1 interopercular, 2 preoperculars, 1 prevomer (charred), 1 articular (crushed), 1 quadrate, 1 scale, 5 spines, 73 vertebrae (13 charred, 9 crushed/chewed).
?Perch: 1 infrapharyngeal.
Bleak: 1 premaxilla.
?Dace: 1 dentary.
Cyprinid: 15 vertebrae (2 charred)
Unidentified: 1 epihyal, 1 basioccipital, 46 vertebrae (12 charred, 8 crushed), 1 hypural, est. 70 spines, rays, ribs and 150 fragments.

1682.

Eel: 2 epihyals, 30 vertebrae (14 crushed/chewed).
Herring: 1 mesethmoid, 28 vertebrae (1 charred, 3 crushed).
Clupeid: 46 vertebrae (2 ?crushed).
Perch: 2 spines.
?Perch: 2 vertebrae (1 charred, both crushed/chewed).
Cyprinid: 6 vertebrae (1 charred).
Flounder: 2 dermal denticles.
Unidentified: 1 eye lens, 1 ceratohyal, 2 hyomandibulars, 1 cleithrum, 1 post-cleithrum, 18 vertebrae (2 charred, 13 crushed/chewed), est. 40 rays, spines, ribs and 50 fragments.

---

b. Thetford Redcastle Furze.

The fish bones considered here were recovered from soil samples from five contexts: 795 (dated to the early Saxon period), 565 and 1677 (late Saxon), 1719 and 1720 (medieval, probably fourteenth century). All but the first

were considered to possibly have been cess pits by the excavator (Murphy pers. comm.), and bones from context 565 were covered in a calcareous concretion presumed to be mineralised cess. Further details are given in Nicholson (forthcoming d).

Species included eel *Anguilla anguilla*, herring *Clupea harengus*, Clupeidae (probably small herring or sprat), stickleback *Gasterosteus aculeatus*, Cyprinidae (not further identified), and possibly ruffe *Gymnocephalus cernuus* L. and perch *Perca fluviatilis*. Apart from the herring and eel bones, the bones were from fish of under 150 mm. total length. Table 7:27 details the bones recovered, and the numbers of charred and crushed or chewed bones. Each of these contexts contained a proportion of bones crushed in a manner consistent with passage through the gut (Plate 7:6). No bones appeared to have been dissolved by acids as did some of the bones from the human digestion experiments, however. Small samples from contexts 1719 and 1720 were also examined for parasite eggs by the author (details Nicholson forthcoming d.). Both deposits were found to contain eggs of the human whipworm *Trichuris trichiura*, supporting the conclusion that these were contexts were cess pits, and that therefore the fish bones had passed through the human gut. The similarity in the condition of the fish bones from the other contexts listed above indicates that these too had originated in cess. Bones from other contexts at Redcastle Furze did not appear crushed, although similar species and sizes of fish were represented.

Table 7:27. The Fish Remains from Redcastle Furze, contexts 795, 565, 1677, 1719, 1720.

Context	Remains
795:	Eel: 6 vertebrae (1 crushed/chewed);
	Unidentified : 4 vertebrae.
565:	Eel: 62 vertebrae (8 crushed/chewed, 10 burnt or charred), 1 prevomer.
	Herring: 71 vertebrae (4 charred, 14 crushed/chewed), 1 basioccipital, 1 cleithrum, 1 interopercular, 1 otic bulla.
	Unidentified: 1 tooth, 1 parasphenoid, 20 vertebrae, 11 fragments.
1677:	Eel: 1 vertebra.

	Herring: 4 vertebrae.
	Unidentified: 1 vertebra, 1 fragment.
1719:	Eel: 8 vertebrae (3 crushed/chewed), 1 cleithrum.
	Herring: 15 vertebrae (1 burnt, 7 crushed/chewed), 1 otic bulla.
	Clupeidae: 11 vertebrae (2 crushed/chewed).
	Stickleback: 2 spines, 3 basipterygia, 1 skull frag.
	Cyprinidae: 2 vertebrae.
	?Perch: 2 vertebrae.
	Unidentified: 2 vertebrae, 17 fragments.
1720:	Eel: 2 vertebrae (crushed/chewed).
	Herring: 11 vertebrae (2 charred).
	?Ruffe: 1 otolith.
	Stickleback: 2 spines, 6 basipterygia.
	Unidentified: 1 cleithrum, 8 fragments.

7.5.3 Discussion

As the experiments into human digestion have only concerned fish of the Clupeidae, comparisons of body part abundance can only properly be made with similar species recovered archaeologically.

In both the Viborg and the Thetford assemblage fish remains from contexts not interpreted as containing cess were few, so no comparisons between the fish components of probable cess-pit and non cess-pit origin could be made. The relatively low numbers of clupeid remains recovered also limits the possibilities for comparison between the archaeological and experimental material.

Herring remains are frequently recovered from archaeological deposits where they do not appear to have been a component of cess, however. Two sites which produced herring remains interpreted as market or table waste are the sites of Queen's Street and Crown Court, Newcastle-upon-Tyne. Clupeid bones were recovered by sieving large (usually 60 litre) samples through a 1 mm. or a 0.5 mm. mesh. The deposits were of mixed origin, but most of the herring remains from Queen Street were recovered from waterlogged deposits interpreted as medieval urban refuse tips. Further details of the deposits and fish bone from them are given in Nicholson (1988 and 1989).

Details of the clupeid bones for each site are given in Tables 7:28 and 7:29, for which the results from all contexts have been pooled.

Statistical comparisons were not feasible owing to the low numbers of bones recovered from the experiments and from Viborg and Thetford.

As crude measures of the extent of destruction the "decay trajectories" have been plotted for the clupeid remains from Viborg and Thetford (Fig. 7:8a,b.), and these can be compared with those from the ingestion experiments (Fig. 7:7) and with archaeological material from Newcastle, not believed to be of faecal origin (Fig. 7:8c,d.). The proportional representation of skeletal elements is also illustrated by Fig. 7:9 for the Viborg and Thetford bones, by Fig. 7:7 for the experimentally ingested assemblage, and by Fig. 7:10 for the Newcastle material. The low numbers of head bones recovered from the archaeological material from Viborg and Thetford is similar to the results from the experimental series, and not in keeping with the trend observed for the Newcastle assemblages. The Viborg and Thetford material include a greater proportion of vertebrae than in the experimental assemblage, however. Possible explanations for this include further preferential destruction of the few surviving head bones after incorporation as cess, or insufficient replication in the experiments. As vertebrae are proportionately better represented than most head bones in both of the archaeological assemblages, the former explanation may be likely. Additionally, in the case of the Viborg assemblage, as discussed above, a proportion of the vertebrae do not appear to have been ingested.

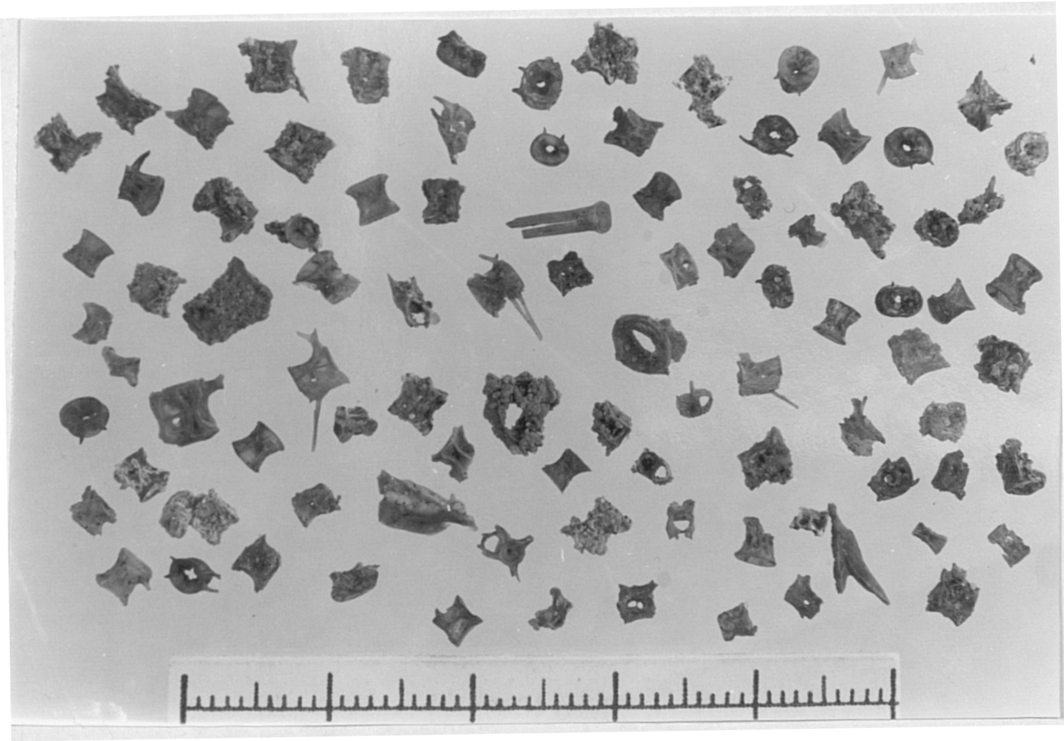


Plate 7:6 Fish Bones Recovered from Thetford Redcastle Furze.

Table 7:28
The Major Clupeid Bones from Newcastle Queen Street, all contexts.

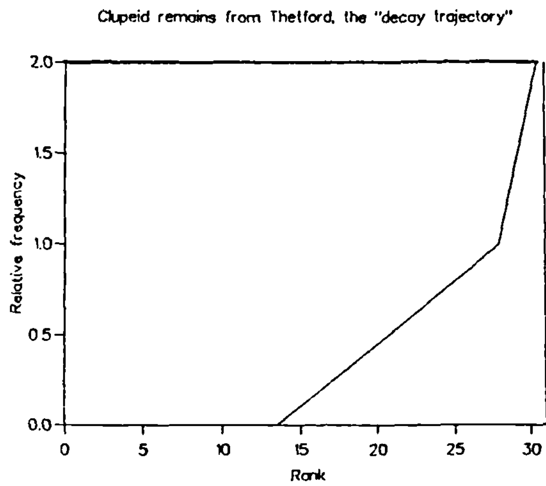
	No. Exp.	No. Recovered	Relative frequency	Proportional representation (pooled mni=8)
Ethmoid	1	0	0	0
Frontal	2	2	1	12.5
Prevomer	1	0	0	0
Parasphenoid	1	0	0	0
Basioccipital	1	1	1	12.5
Premaxilla	2	0	0	0
Maxilla	2	5	2.5	31.3
Supramaxilla	2	1	0.5	6.3
Dentary	2	7	3.5	43.8
Articular	2	6	3	37.5
Quadrate	2	4	2	25.0
Hyomandibular	2	9	4.5	56.3
Preopercular	2	6	3	37.5
Opercular	2	10	5	62.5
Subopercular	2	6	3	37.5
Interopercular	2	3	1.5	18.8
Palatine	2	0	0	0
Ectopterygoid	2	0	0	0
Metapterygoid	2	0	0	0
Epihyal	2	0	0	0
Ceratohyal	2	7	3.5	43.8
Urohyal	1	0	0	0
Posttemporal	2	1	0.5	6.3
Cleithrum	2	6	3	37.5
Supracleithrum	2	0	0	0
Scapula	2	0	0	0
Coracoid	2	0	0	0
Basipterygium	0	0	0	0
Vertebrae	57	380	6.7	83.2
Otic bulla	2	15	7.5	93.8
Total	110	469	4.3	

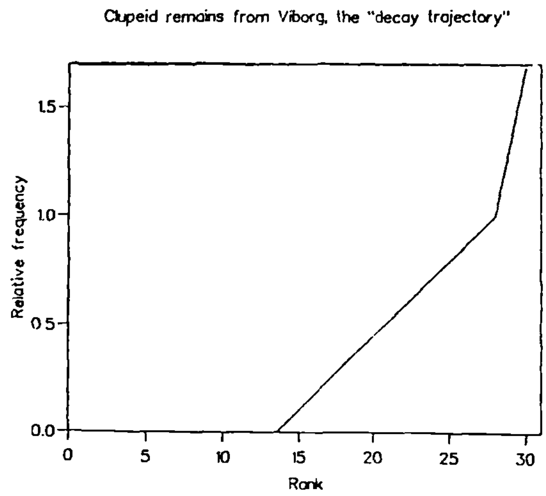
* otoliths and lenses excluded, as their absence may be attributable to preferential decay after burial and/or the difficulty in identifying them to species.

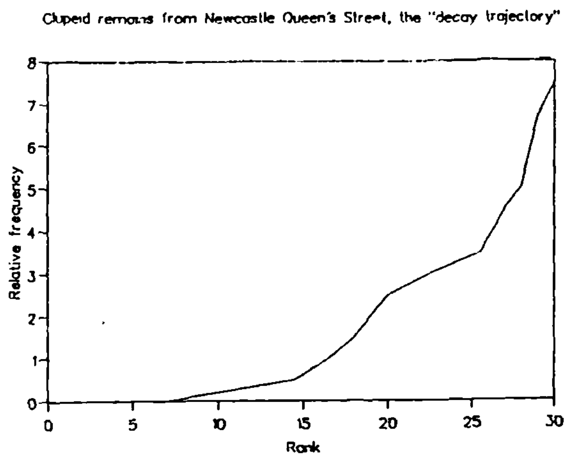
Table 7:29
The Major Clupeid Bones from Newcastle Crown Court, all contexts.

	No. Exp.	No. Recovered	Relative frequency	Proportional representation (pooled mni=5)
Ethmoid	1	0	0	0
Frontal	2	0	0	0
Prevomer	1	0	0	0
Parasphenoid	1	0	0	0
Basioccipital	1	1	1	20
Premaxilla	2	0	0	0
Maxilla	2	2	1	20
Supramaxilla	2	0	0	0
Dentary	2	8	4	80
Articular	2	10	5	100
Quadrate	2	2	1	20
Hyomandibular	2	3	1.5	30
Preopercular	2	2	1	20
Opercular	2	1	0.5	10
Subopercular	2	4	2	40
Interopercular	2	0	0	0
Palatine	2	0	0	0
Ectopterygoid	2	0	0	0
Metapterygoid	2	0	0	0
Epihyal	2	0	0	0
Ceratohyal	2	8	4	80
Urohyal	1	1	1	20
Posttemporal	2	2	1	20
Cleithrum	2	3	1.5	30
Supracleithrum	2	0	0	0
Scapula	2	0	0	0
Coracoid	2	0	0	0
Basipterygium	0	0	0	0
Vertebrae	57	230	4	80.7
Otic bulla	2	1	0.5	10
Total*	110	278	2.5	

* otoliths and lenses excluded, as their absence may be attributable to preferential decay after burial and/or the difficulty of identifying them to species.







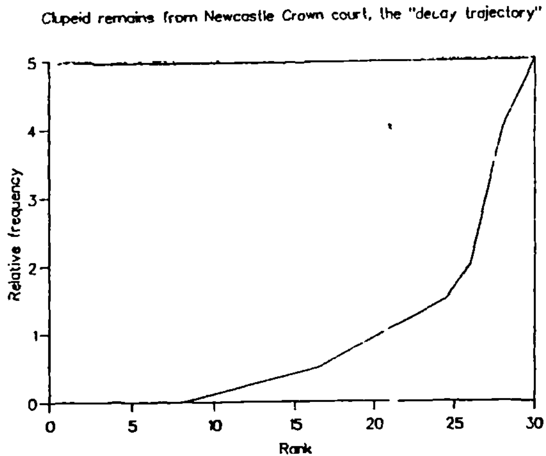
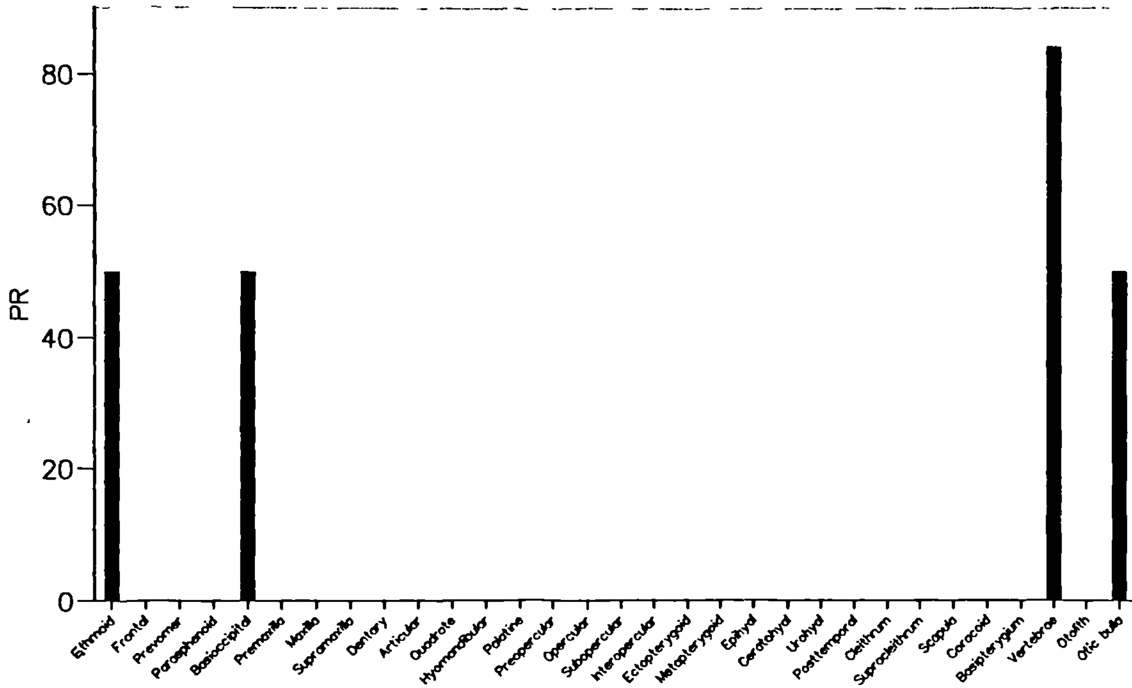


Fig. 7:8 The "Decay Trajectories" for Clupeid Remains from the Archaeological Assemblages. a) Thetford. b) Viborg. c) Newcastle Queen's Street. d) Newcastle Crown Court.

Proportional representation of herring remains from Viborg
(contexts 1677 and 1682, mni. = 2)



Proportional representation of clupeid remains from Thetford, Redcastle Furze
(contexts 565, 1677, 1719, 1720, mni. = 4)

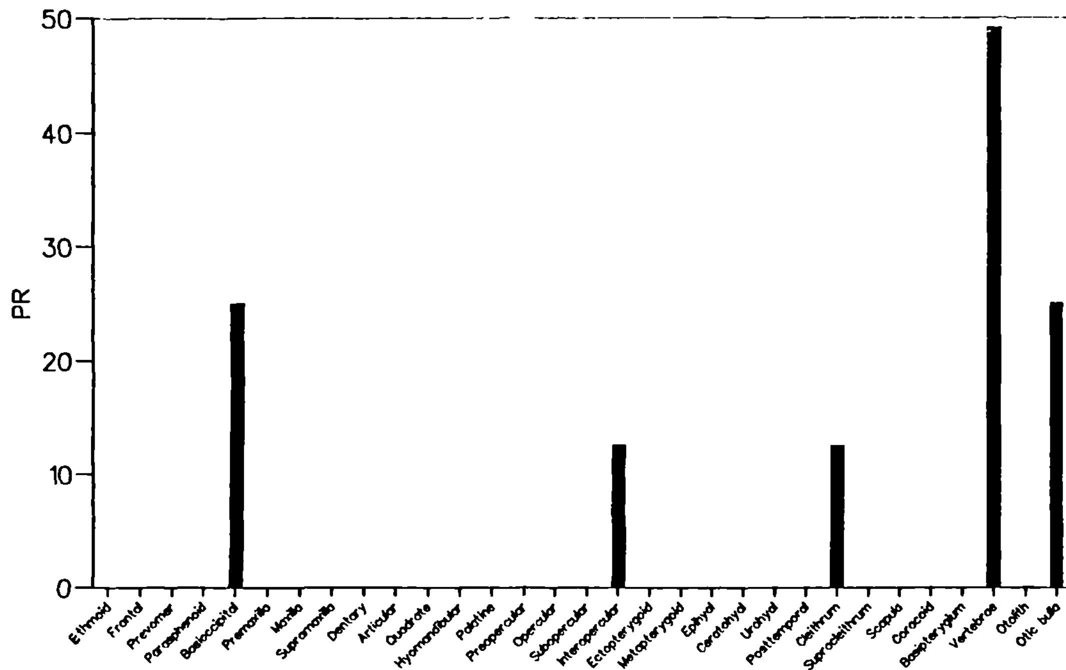
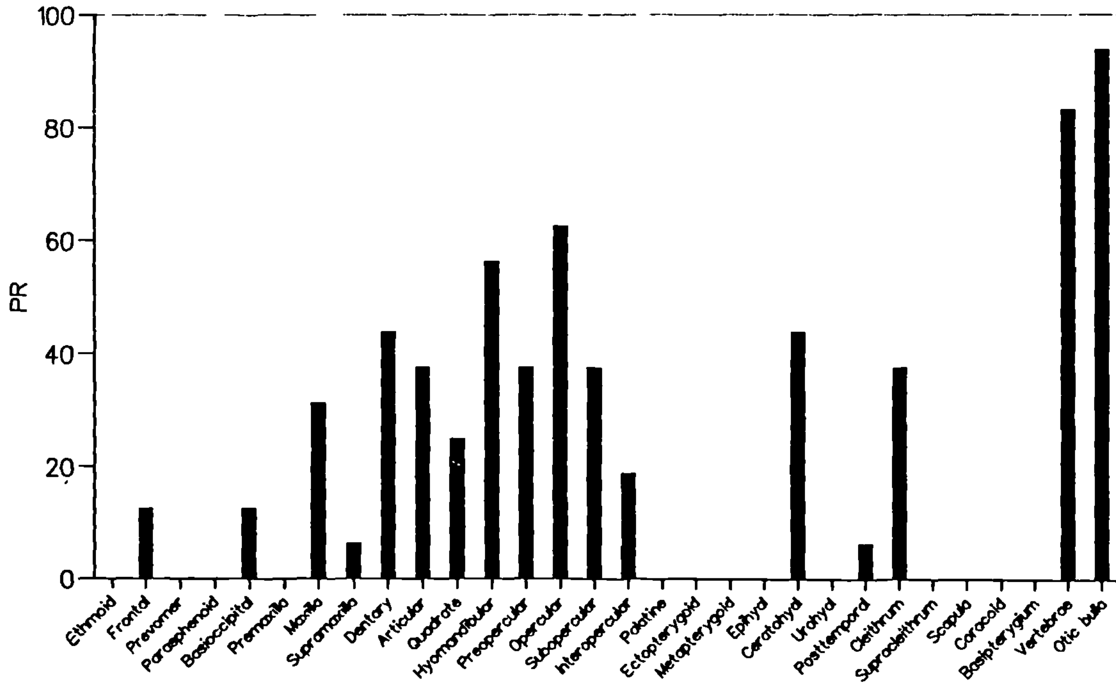


Fig. 7:9 Proportional Representation of Clupeid Remains from a) Viborg and b) Thetford Redcastle Furze.



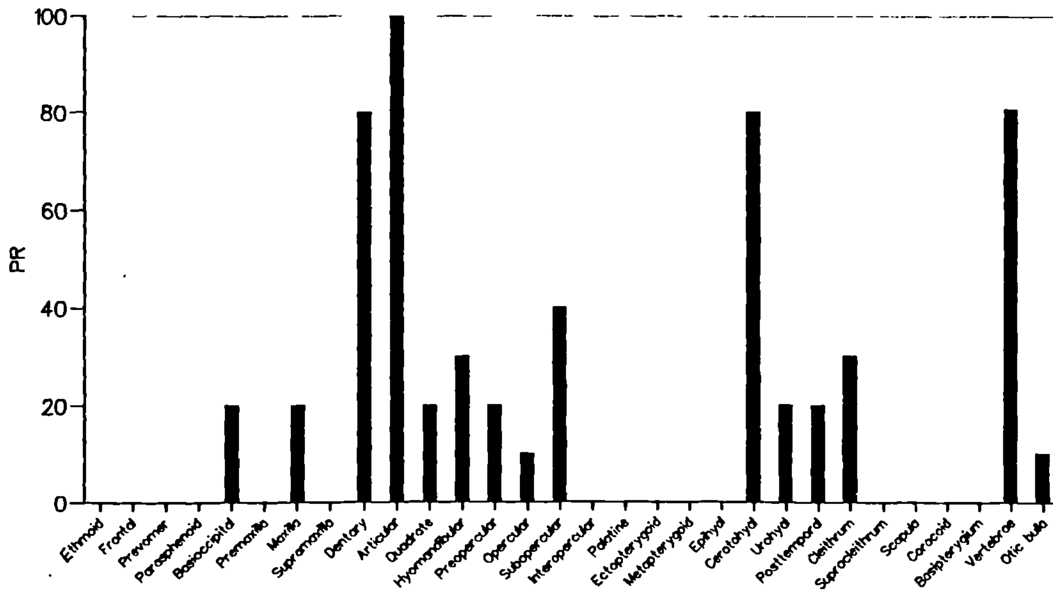


Fig. 7:10 Proportional Representation of Clupeid Remains from a) Newcastle Queen's Street and b) Newcastle Crown Court.

7.6 Experiment to Investigate the Effects on Different Types of Bone of Digestion in Pepsin

7.6.1 Methods and materials

To examine the relative rates of bone and calcified cartilage disintegration by hydrolysis of the organic portion, animal remains were placed in a sealed tank in a proteolytic enzyme solution maintained at 37-39°C and removed after two and four months.

A plastic tank was used, measuring 300 x 300 x 600 mm. Powdered pepsin was made up as 1 gram per litre of tap water, at pH 6.3. The tank was filled to approximately 2/3 capacity with the pepsin solution and vertebrate remains, in mesh bags, added. The remains included: two sheep lower limbs (metapodial and below, cleaned bones only), two partially defleshed pigeons, two complete frogs, two partially defleshed rats, one partially defleshed cod, two partially defleshed haddock, three partially defleshed plaice and three partially defleshed herrings. The tank was sealed and the temperature thermostatically maintained at 37-39°C. This method was routinely used for animal skeletonisation in the laboratory, and during the experimental period a substantial portion of a large opah *Lampris guttatus* (Brünnich) was added. This took up much of the space in the tank, and would have reduced the efficiency of the pepsin solution, as anoxic conditions may have obtained. Another problem encountered with the tank was that the water near the heating element remained warmer than the rest, due to poor circulation. Regular agitation helped to alleviate this problem, but once the opah had been put in agitation was impossible.

After two months the mesh bags were removed and their contents examined. As insufficient change was observed, the bags were replaced and removed finally after six months. The bones were recorded as a data-base, as detailed in Chapter 2.

Table 7:30 Mean values for condition amd fragment size for fish bones, after six months in pepsin (excluding otoliths and eye lenses).

	no. bones	Condition		Fragment size (%)	
		Mean	St. deviation	Mean	St. deviation
Cod	133	4.3	2.9	87.7	9.7
Haddock 1	135	3.9	2.6	91.6	17.2
Haddock 2	128	4.9	2.7	93.7	10.9
Herring 1	89	4.9	3.1	82.2	23.6
Herring 2	80	6.1	3.8	67.3	30.7
Herring 3	85	7.6	3.9	68.6	31.5
Plaice 1	116	2.1	0.5	99.5	3.2
Plaice 2	119	4.2	2.7	95.9	9.2
Plaice 3	119	2.8	1.4	99.5	2.2
Totals					
All Gadids	396	4.4		91.0	
Herring	254	6.2		72.7	
Plaice	354	3.0		98.3	

Table 7:31 Mean values for condition of fish head bones and vertebrae, after six months in pepsin (excluding otoliths and eye lenses).

	Head Bones		Vertebrae	
	Mean	St. deviation	Mean	St.deviation
Cod	3.9	1.0	4.5	0.6
Haddock 1	3.9	2.8	3.7	1.6
Haddock 2	4.5	2.5	6.3	2.7
Herring 1	6.1	4.5	4.1	1.1
Herring 2	7.7	4.9	4.8	2.0
Herring 3	10.0	4.7	6.1	2.5
Plaice 1	2.1	0.5	2.2	0.8
Plaice 2	2.9	1.5	6.6	2.7
Plaice 3	2.4	0.8	3.6	1.9
Totals				
All Gadids	4.1		4.8	
Herring	7.9		5.0	
Plaice	2.5		4.1	

7.6.2 Results and discussion

Even after six months in pepsin solution, the sheep, rat, pigeon and frog bones showed little change, though as noted above, the efficiency of the pepsin solution was probably reduced by anoxic conditions. The fish skeletons deteriorated more rapidly than non-fish bones, and Tables 7:30 and 7:31 summarise the scores for "condition" and "fragment completeness", by animal and by each taxon. As shown, the herring had the greatest dissolution rate, but within the skeleton the head bones deteriorated more rapidly than the vertebrae. The gadid skeletons disintegrated more rapidly than the similar sized plaice, and in this case the vertebrae showed more rapid dissolution than the head bones.

Increased deterioration rates could be expected if the pepsin were dissolved in a hydrochloric acid solution, as pepsin works best at pH 2.5, and hydrochloric acid is a naturally occurring gastric component (Bigg and Fawcett 1985). As the tank was in constant use at the time of this experiment for purposes where the dissolution of bones was not required, this was not possible. It was felt that despite the longer period required by using pepsin at the higher pH, the relative rates of decay should be similar.

7.7 Conclusions from the Experiments and Observations into the Effects of Digestion

The experiments and observations described in this chapter are rather diverse, but illustrate the range of useful approaches which may provide information about the ways in which skeletal remains may be modified by passage through the gut, and how these assemblages may be recognised archaeologically.

The recognition of remains which have passed through the gut may be based on the surface appearance of skeletal

tissues, if they possess the characteristic features of acid-dissolution or chewing, but in many cases may be more convincingly identified by a combination of surface appearance and the extent of loss of certain skeletal elements. This combined approach, together with an assessment of the prey species, has greater potential for determining the predator involved.

Where fish bones and mammal, bird or amphibian bones are ingested, the fish bones may be preferentially destroyed by gut action, though the relative sizes of the bones should be considered: larger bones appear to be more frequntly destroyed or rendered unidentifiable by chewing and/or breakage. Bone loss also appears to be affected by bone shape, in both fish and mammals.

Inevitably in a study of this kind, several potentially useful avenues have not been sufficiently investigated. A quantitative study of species present in pellets and scats, as well as the destruction of insect body parts by mammals and birds would clearly be very valuable. While many insect remains were present in the raptor pellets, and could be recovered from the scats and the droppings of insectivorous mammals and birds, it was not possible to record sufficient assemblages in the detail necessary to warrant analysis. Those pellets which were examined proved to contain a range of fragmentary remains of coleoptera, and notably many sclerites were squashed inside the thorax area, an observation also noted by Girling (1977). Trampled insect remains also showed the same tendency. However large accumulations of fragmentary, diverse, insect corpses are only likely to be found in closely packed aggregates if they originated in pellets or insectivore scats.

CHAPTER 8. ASSESSMENT AND ARCHAEOLOGICAL IMPLICATIONS.

This thesis has been concerned with investigating the variable responses of different skeletal tissues to a number of pre-depositional processes. Additionally, certain intrinsic properties of the tissues themselves have been investigated to assess their value as explanatory variables by which the responses of the tissues or skeletal elements may be better understood.

While the preceding chapters have been concerned with establishing and documenting these responses and intrinsic characteristics, this chapter addresses the major findings to emerge, and looks at ways in which the results may be usefully applied to archaeological material. Because the scope of this thesis is wide, and taphonomy a very complex and imprecise science, it has not been possible to erect the kind of "laws" that Schiffer would prefer. In many cases the types of experiments conducted were not amenable to the formulation of "laws" from the results, as the conditions were not always exactly those which could be demonstrated to have obtained in a specific archaeological situation. This does not mean that hypothesis testing has been ignored, just that it is not reasonable to over-state the applicability of the results by defining them as rigid, pseudo-scientific "laws". Obviously the development of standardised criteria upon which hypotheses can be formulated and tested is desirable, and it has been a goal of this work.

The identification of a pre-depositional taphonomic process on archaeologically recovered material requires that certain conditions are met. These conditions include (modified from Shipman 1981, 365 - italics mine):

1. Do features of the unknown mark or distribution show the same features as skeletal material or assemblage damaged by a single *known* cause?
2. Are those features *demonstrably distinct* from those produced by other known taphonomic agents?

The following sections discuss how these points relate to the work described in this text.

An additional consideration is that the features enabling identification of the process should be recordable, as far as possible in a standard way. This recording should also employ at least ordinal scales wherever possible, so that trends can be quantified and statistically compared.

The standard recording categories listed in Chapter 2, and used throughout the recording of the assemblages included in this work, enable these conditions to be met. As long as the definitions for the assigned stages are explicitly stated, inter- and intra-site comparisons may be made, even if the number of categories used is different. Depending on the site, other categories relating to preservational state may be appropriate, such as the presence of mineral concretions or stains (as discussed by Stallibrass 1985). All data relating to preservation could be held in a separate database, linked by a common field to the main archaeozoological record.

8.1 An Assessment of the Value of the Various Approaches.

This study has incorporated a selection of methods as heuristic devices to investigate predepositional modification. Some of these approaches proved more fruitful than others. These approaches include laboratory experiments, field experiments and observation-based or "actualistic" study. Laboratory experiments have also been utilised to investigate the intrinsic variability within skeletal tissues.

8.1.1 The observational or "actualistic" approach

In theory, the value of the "actualistic" studies are that they enable investigation of "real life" situations, in which a number of processes may be responsible for the

outcome. By careful monitoring, the number and variety of these processes should be identifiable. One limitation of the approach is that the individual effects of the various processes may not be discernible from the overall effect, and so the identification of material exposed to some, but not all, of the suite of processes involved in creating the outcome may not always be possible. Additionally the loss of evidence, i.e. by total destruction, may not always be evident if the original assemblage composition was not known (which it never will be on an archaeological site).

The observations or actualistic studies used in this analysis include the investigation of the composition of animal remains within bird pellets and mammal scats. In this case disadvantages included the lack of information concerning what was originally ingested. It had therefore to be assumed that complete animals were eaten, based on observations of the feeding habits of contemporary animals. The ages and condition of the predators were also unknown, but could have affected the digestive efficiency. Although the history of the assemblages before collection was unrecorded, pre-depositional modifications to the bone components other than those resulting from digestion were probably minimal. The advantages were that the material was easily obtained, without the time-consuming constraints of feeding animals and collecting the droppings. Ideally, known animals of various ages should be fed known diets in a natural (i.e. not caged) environment and the droppings/ pellets collected, though in practise this would be difficult to accomplish.

8.1.2 Field experiments

Field experiments have the advantage that the original assemblage is known and that the number of possible variables acting on the material is reduced by the experimental design. The limitations include the inability in some cases to separate out the results of individual causes of modification. While cause and effect can be

observed, rather than inferred (as is the case for archaeological material) it must be remembered that the environment in which the experiment is set may be very different from that which influenced an archaeological assemblage. It must also be remembered that archaeozoological assemblages may have been subjected to more than one suite of attritional processes, the interaction of which may have been limited in the experimental situation by the design constraints. Experiments in this category include the experimental fires and the trampling experiment (as it was conducted outdoors, and so was subject to climatic influence) as well as the exposure experiment.

Practical disadvantages in these experiments involved, in the case of the exposure experiment, the length of time available for the study, which was insufficient to allow sufficient deterioration of most skeletal materials to occur. As a general rule, the larger the animal, the longer the time nec essary to see any changes. This makes field experiments into the disintegration of large mammal remains impractical for a research project.

The trampling experiment would also, in retrospect, have been better had it been subjected to a greater number of tramples; but it was not possible to assess the extent of damage without excavating and examining the contents of the tray. Once excavated the remains could not be replaced in the same position. Ideally the remains should be monitored at regular intervals, so that the relative loss of skeletal elements may be assessed. As this would disrupt the burial of items, many replicates would have to be made, and each one trampled for different lengths of time. This field experiment also had the problem of differential substrate compaction, caused in part at least, by variable weather conditions. This may have had some effect on the extent of loss between the two trampling experiments (boiled and unboiled). This effect would be reduced were the experiments to be undertaken indoors or under a polythene

cover: however a totally dry substrate is not a realistic analogy for sites in temperate climates.

The experimental fires suffered from instrument failure, but otherwise the major limitation was that the number of variables involved was too great for detailed assessment of the effects of each, given the amount of replication. The results obtained depended not only on the condition of the animal pre-burning but also on its position within the fire. In order to make inter-taxon or inter-treatment conclusions, a very large number of replicates would be needed. In general this is true of all the field experiments: the greater the number of possible contributory variables, the greater the amount of replication needed. This can become impractical when most experiments require a fairly large site, study over a relatively long period, and an amount of excavation and recording before the remains are taken into the laboratory. If intra-skeleton comparisons are to be made (i.e. for the effects on different skeletal elements) whole animals must be used, which can lead to problems in obtaining sufficient corpses. Despite these logistical problems, field experiments can provide clear analogies for real life situations while allowing some control over the variables involved.

8.1.3 Laboratory experiments

Laboratory experiments enable the variable(s) under consideration to be controlled and the effects carefully monitored. Individual causes and effects can therefore be isolated. This method of study therefore has the greatest potential for the erection of scientific "laws". The experiments which fall into this category include: the burning of bones in the muffle furnace; tumbling; freezing and thawing, and wetting and drying; exposure of material to chemical solutions and digesting enzymes; and the examination of faecal material after ingestion by a human of a known number of fish. These experiments have the

advantage of being relatively quick, as the variables of interest can be studied at a pace determined by the operator rather than that set by the natural environment. For this reason, however, the effects may not always be exactly those which would be experienced in the natural environment.

Archaeological assemblages are not created in a laboratory, however, and it is often the interaction of several variables which produce the effect of interest. By only considering single cause and effect interactions it is possible to misinterpret variability in the archaeological record. For example in the case of burnt bone the laboratory experiments indicated the temperature which the fragment had reached when it attained a certain colour. Field experiments demonstrated that a natural fire may reach very different temperatures in different areas. To interpret individual bones only on the basis of the laboratory experiments, in terms of their colour and/or surface morphology, and then extrapolate to the mode of burning, could lead to misinterpretation. Bones exhibiting different colours or surface morphologies could be thought to originate from different fire types when in fact all had been subjected to the same fire, but were in different parts of it.

Laboratory experiments of this type are valuable in that they allow detailed investigation of cause and effect, and can provide relatively rapid answers to specific questions. Replication may be easier than in experiments conducted in the field.

8.1.4 Laboratory experiments into the intrinsic properties of skeletal tissues

Experiments in this area have been limited in terms of range and application. Because these investigations involve interval or ratio scale measurements the results are more easily formulated into "laws" than is the case with the

methods described above. Although superficially attractive in this respect, there is a serious danger that such "laws" may be based on insufficient evidence, but may become accepted because they appear to present simple solutions. As the answer may in fact be much more complex, the erection of "laws" may lead to inflexibility of approach and stagnation of ideas. Any conclusions based on this type of experiment should therefore be interpreted in an investigative manner, i.e. as a working hypothesis based on the available evidence, rather than as the complete explanation.

Investigations in this area concern bone "density", the organic:mineral composition of bone, and the strength of heated bone. Studies of this nature have obvious attraction because they produce fairly unambiguous results within the constraints of the experimental design, under carefully controlled conditions, and may have clear relevance to the explanation of variability. Limitations concern, in some cases, the need to standardise the samples of skeletal tissues in order to make the results comparable. This is difficult when the sizes and design of skeletal elements are very different between different groups of vertebrates and invertebrates. Some physical properties of skeletal tissues, such as "density" must be clearly defined if the values derived are to have useful application, and their relationship with bone survival under defined conditions must be tested before the results are applied.

In real life a multitude of factors such as shape and microstructure will vary according to criteria such as skeletal element (and position within it), species, age of specimen, sex and health of the individual. All of these factors may influence the intrinsic properties of skeletal hard tissues, so care must be exercised when drawing conclusions from measurements taken from single or few specimens.

Notwithstanding, the investigation of intrinsic

characteristics of skeletal tissues both between taxa and within the skeleton provides perhaps the greatest potential for understanding variability within archaeological assemblages. The values, either absolute or more often relative, can provide measures against which experimentally derived and archaeologically recovered groups may be compared and interpretations refined. The better understanding of the physical properties of skeletal tissues can also lead to the formulation of hypotheses which can be tested by laboratory or field experiments, field observation and/or archaeological material.

8.2 An Assessment of the Principal Results from the Experiments and Observations.

8.2.1 Do the skeletons of different taxa stand an equal chance of survival?

It is clear from the results of all the experiments that different taxa do not all stand an equal chance of survival when exposed to a variety of pre-depositional processes. To an extent, survival was dependent upon the simulated biostratinomic process involved. In the tests of resistance to mechanical abrasion (tumbling) for example, frog bones survived particularly well, and outlasted larger fish bones and similar-sized small mammal bones. In the investigation of otter spraints, however, it was clear that anuran bones were rarely preserved intact, and were frequently reduced to unidentifiable fragments. Small fish bones, by contrast, were generally complete and superficially unaltered by ingestion. Larger fish bones were frequently fragmentary and chewed. Trampling tended to preserve small bones intact at the expense of larger bones, but clearly the cut-off levels for small and large would depend on the size and weight of the body doing the trampling. Bones from large mammals would be unlikely to be broken, when fresh, by trampling by all but very large mammals. Small bones were also preferentially preserved by burial in the trampling experiment, which in a real-life situation would protect

them from not only fragmentation due to trampling but also weathering and scavenging. This "rate of burial" will vary according to the substrate, and would be difficult to define or measure but is obviously an important factor to be considered.

Experiments into weathering, including freezing and thawing, and wetting and drying indicated that fish bones were less resistant than mammal and bird bones. This trend was also apparent when bones were digested in a pepsin solution. As fish are not subject to gravitational force in the same way as terrestrial vertebrates, and bone breakage is less likely in an aquatic environment, their bones do not need to be as mechanically strong.

The bones of different fish families also did not survive equally well under the various conditions of testing. Most interestingly, the bones of the gadid family (cod and haddock) disintegrated more rapidly than the bones of plaice and salmon as well as the vertebrae of the herring under a number of regimes. These included mechanical abrasion, freezing and thawing/wetting and drying and digestion in pepsin. The more rapid decay of gadid bones when compared with other fish bones occurred even though the bones of plaice and herring were smaller.

Dogfish calcified cartilage proved to be at least as resistant as bone to all the processes under investigation except for burning (calcified cartilage was not included in the exposure experiment, although its inclusion would have been useful). As calcification proceeds with age, the mechanical properties and susceptibility to dissolution could be expected to show great variation depending upon the age of the fish.

Following on from this study, it would be interesting to test bones from fish known to be of similar age. The cod used in this experiment were from fish of size groups consistent with two or three year old fish (Rowell pers.

comm.). The ages of the haddock, plaice and herring were unknown, but it is possible that the plaice and herring may have been older as the maximum size for herring in the North sea is about 430 mm (Wheeler 1978) and plaice are long-lived, slow growing fishes. As mineralisation of bone increases with age, and the bone microstructure may also alter, it is probable that decay rates will be affected to a large degree by the age of the individual, as are the mechanical properties of bone.

From these experiments it is clear that, using fishes of similar sizes, bones from fish of the Gadidae will disintegrate more rapidly than bones of herring and plaice. This conclusion is also supported by a study by Easom (1988) in which she compared the mechanical properties of saithe and salmon vertebrae, from fish of similar sizes. Her study demonstrated that salmon vertebrae withstand approximately double the load that can saithe bones, taken from a similar area of the spine. The salmon bones were both stronger and stiffer than the saithe. This was partly, but not completely, explained by the structural design of the two types of vertebra: salmon vertebrae are more compact, while saithe vertebrae possess struts.

Within the mollusc groups examined, the garden snail *Helix aspersa* was the most fragile when subjected to physical forces such as trampling and expansion and contraction of the surroundings during to freezing and thawing. Mussel valves also fragmented when exposed to these forces, but limpet shells, cockles and periwinkles proved very resistant. Garden snails and mussels also suffered the greatest amount of fragmentation during burning. In many circumstances very few, or no, fragments of *Helix aspersa* were identifiable, whereas even small fragments of mussel shell can be recognised by their colour.

In all the experiments in which insects were included, the *Tenebrio* beetles outlasted the other remains.

Bluebottle corpses rapidly disintegrated under all conditions of testing, and the papery thin sclerites were soon rendered unidentifiable and crumbled to dust. Mealworms, once dried out, crumbled rapidly although the head capsules generally outlasted the body parts. Fly puparia also fragmented when allowed to dry out: their presence on archaeological sites must be attributable to fairly rapid burial in waterlogged conditions. Exposure to strongly acidic and alkaline solutions also affected the bluebottles more rapidly than the *Tenebrio* adults or the fly puparia.

8.2.2 How does the treatment of the corpse influence its chance of preservation?

Boiling greatly reduces the resistance of bones to both physical force and to weathering. The resistance of fish bones proved to be more dramatically reduced than mammal bone by boiling, however, as demonstrated in the tumbling, trampling and weathering experiments. This may relate to the more open texture of fish bone, which enables greater water penetration, and/or to differences in bone microstructure between fish bone and the bone of terrestrial vertebrates.

Baking or roasting will also denature the collagen fibrils within bone if the temperature of the bone is raised above about 80°C. A covering of flesh may insulate the bone and prevent it from reaching a high temperature, however. When exposed to the sort of temperatures used in baking or roasting, the flesh would be charred and ruined were the temperature of the bone to be allowed to reach that of the heating device. In boiling the flesh is either removed from the bone prior to boiling (if a bone is to be used for stock), or is progressively removed by the action of boiling. As a result the bone will reach the temperature of the water more rapidly. Von Endt and Ortner (1984) have also shown that (almost by definition) water is necessary for hydrolysis of protein, and that water weakens the

collagen-apatite bonding. The speed of these chemical and structural changes in bone is temperature-dependent: the higher the temperature the faster the bone is hydrolysed, chemically altered and destroyed. The presence of abundant water in direct contact with the bone during boiling will enable maximum destruction of the bone, and removal of the denatured organic fraction. This may explain the much more rapid weathering observed on boiled bone when compared with baked or burnt bone.

Completely calcined bone no longer possesses any organic material, and recrystallization of the mineral fraction renders the bone less porous, and so less susceptible to leaching of the mineral. That calcined bone weathers more slowly than incompletely calcined bone was demonstrated by the exposure experiment. The physical resistance of the bone to breakage was demonstrated in bending tests to be greater for completely calcined bone than for partially calcined bone. All burnt bone was mechanically much weaker in bending than fresh or boiled bone, however.

Apart from by observation of surface morphology, bone may be determined as unheated by the presence of intact collagen fibres, which are often present in archaeological bone (Ascenzi 1963). However, although the absence of collagen may indicate bone which has been calcined, diagenetic alteration must be considered too. Collagen which has been denatured by heating will be preferentially attacked by proteolytic enzymes (Snowden and Weidemann 1976). Consequently boiled bone or bone heated to temperatures below that required for complete calcining may also lose their organic component much more rapidly than unheated bone. As Richter (1986) points out, even when denatured collagen is present, it may not be clear whether the damage was incurred before burial (by cooking) or afterwards (during diagenesis) if the melted portions have been removed by enzymes. Whether boiled bone can be separated from fresh bone by its appearance after burial in some soils, as Coy (1975) suggests, may be elucidated after

excavation of the buried assemblages detailed in Appendix 6.1, and by the material buried at Overton Down (Jewell and Dimbelby 1966).

8.2.3 Within a skeleton do all elements stand an equal chance of survival?

As has been demonstrated, in all the experimental situations certain groups of skeletal elements survive better than others. The best surviving elements may vary between taxa within the same class of animals, according to element design. It would obviously be desirable to construct general "Indices of Survival", or relative robustness, for the skeletal elements of all the taxa investigated. In practise not all experiments are amenable to this kind of treatment, however.

Ranking skeletal elements with respect to their survival potential demands that all elements were subjected to identical conditions. This may not always be the case. In the exposure experiment bones, for example, were sometimes sheltered by other bones, particularly if on the underside of the animal. In the trampling experiment some items (particularly small bones) were preferentially buried and so, in this circumstance, protected. In addition, because of the diversity of experimental situations, and because most experiments included little or no replication, it was impractical to try to provide general "Indices of Survival" for each species. Additionally, each experimental situation provided potentially different patterns related to the effects of the different processes under consideration.

Nevertheless, these factors should not be viewed as totally invalidating the grouping of skeletal parts based on their relative resistence to destruction. It does argue for caution in interpretation, however, and consistent patterns should be sought. For this reason it is valuable to investigate whether particular intrinsic properties consistently affect the resistance of a skeletal tissue, as

more confidence can be placed on groupings if it can be explained by reference to an independant variable. As shape was consistently related to bone disintegration in most of the experimental situations (as demonstrated by chi-squared tests) there clearly is some consistency in the patterning. However, given the disparate nature of the biostratinomic processes investigated by the experiments it would be misleading to pool the results to obtain an overall "Index of Survival" for each species. It should not be decided in advance that all processes leading to disintegration will act in the same way. Conversely, it should not be assumed that different processes will produce distinctive patterns. Both premises must first be established, so the results from a range of experimental circumstances must be evaluated separately, and then broad trends examined.

Not all archaeozoologists have recognised these points, Binford (1981) for example, has analysed the assemblage of bones recovered from Olduvai Gorge in terms of the relative survival of skeletal parts from contemporary corpses remaining at carnivore kill sites, and assemblages of bones transported to dens. Apart from formidable problems associated with the initial data recording, which Binford admits but then ignores (1981, 262-3), he has assumed that modification and transport by animals is the only possible cause of the patterning within bone assemblages (other than by man). This assumption clearly requires investigation. Rankings based on limited contemporary observations are viewed as the "natural" (as opposed to "cultural") pattern of loss, but it is implicitly assumed that only carnivores will produce such assemblages. Further limitations to the value of the comparative material result from the way in which it was gathered. The contemporary assemblages used for comparison with the Olduvai material were taken from a very wide geographical area and from a variety of predators and prey. Furthermore, the "contemporary" assemblage included excavated material from South Africa which was assumed to have been from a carnivore den and had been "corrected" using anatomical information obtained from

density measurements from bones of domestic sheep and Arctic caribou (*ibid.*, 232). Binford defines five groups, termed "factors 1 - 5", based on factor analysis of the Olduvai material, which describe five sorts of skeletal element part distributions. The groups are attributed to different sorts of carnivore-modified assemblages (e.g. transported, residual and *in situ* for large and smaller mammals) and to the "natural" survivorship potential based on density. Only if archaeological assemblages do not fit into one of these groups is an alternative interpretation considered.

Obviously it can not be assumed that all agents of modification produce distinctive patterning on skeletal assemblages, or conversely that they all produce the same patterns of loss. Consequently, and because greater amounts of replication are needed if more detailed rankings are to be obtained, in Appendix 8.1 broad survival groups have been assigned by biostratinomic process. The survival rates of the skeletal elements from complete corpses subjected to burning, tumbling and trampling, have been grouped into classes (usually four, but less if the diversity in scores was low), ranging from best to worst surviving. Each taxon and treatment is considered separately. The groupings have been based on the mean proportion of the bone represented by the fragment (here called fragment completeness) and missing bones have been scored as 0, as discussed in the preceding chapters. The mean values take into account the expected numbers of bones, so that an element represented by four individual bones, three of which are 80% complete but one of which was completely destroyed (fragment completeness 0) would have a mean fragment completeness score of 60%, again as discussed in earlier chapters. The cut-off points for each category vary according to the extent of bone loss. Only experiments which used whole animals are included, and in the burning experiment only completely combusted corpses have been considered. For the tumbling experiment, the experimental results used were based on the stage at which bone loss was felt to show the greatest inter-skeleton variation. Only the boiled cod

bones from the exposure experiment showed enough bone loss to warrant inclusion.

In fact the groupings given in Appendix 8.1 show a great deal of consistency for each species and for related species, irrespective of the experiment. This grouping reflects the bone shape to a large extent, which is not surprising given the relationship demonstrated throughout this study, and further discussed below. For this reason the groupings may be usefully applied to archaeologically recovered bone assemblages, to indicate the extent of loss which has occurred and to highlight deviations from the expected. However it also illustrates the point that skeletal element distributions can not be used alone to demonstrate the operation of a taphonomic process.

It is important to stress this point. As different experiments yielded similar results in terms of relative skeletal element representation, the groupings observed cannot alone be used to indicate the dominant taphonomic pathway which has been followed by the archaeological remains. Skeletal element representation can only be used alongside other criteria, such as surface morphology, erosion or fragmentation patterns to indicate the major pre-depositional influences. Equally usefully, deviations from the expected patterns of loss may be recognised by comparison with the general patterns of relative survival rates, and these deviations may be useful indications of a specific taphonomic pathway or of selective removal of body parts, possibly resulting from man's influence.

8.3 Which Endogenous Properties Relate to the Survival of the Skeletal Material?

8.3.1 Organic:mineral ratio

Although brief, this investigation has indicated that there appears to be a relationship between the amount of organic : mineral material in a bone and its survival rate.

The most interesting results relate to the difference between gadid bones and other fish bones. Gadid bones proved to have proportionately less organic matter, both lipid and protein, than the other fish species tested. This is in spite of the possibly younger age of the gadid fish compared with the plaice and herring. Contrary to popular belief, the more mineralised gadid bones appear to be weaker in mechanical tests than more highly organic fish bones. They also appear to be less resistant to weathering. Why this should be so is not clear, but may be due to the extent of bonding of the mineral and organic fractions, or to a protective effect afforded by oil within the bones. A higher collagen content will make a bone more resistant to impact, which could explain the resistance of the more highly organic fish bones to physical force. More tests, including experiments relating to diagenetic effects such as submersion in different pH solutions, are clearly required.

8.3.2 Shape

Throughout this study comparisons have been made between bone survival and bone shape, and between survival and density. In the context of the experimental situation it has been demonstrated that bone shape is frequently an important determinant of bone survival.

In all the experiments for which an assessment of shape with survival was appropriate, similar trends emerged. Within fish, spherical bones (mostly vertebrae) survived best, followed by those classified as "robust". Flat bones and "irregular" bones were destroyed preferentially. For small mammals, however, spherical bones survived least well, while tubular bones were overall the most resistent to destruction. Of the flat bones, the mandible survived well, but the pelvis and scapula were prone to destruction. Part of this trend must be explicable by bone size: the vertebrae of small mammals are much smaller than the limb bones, and the mandible is relatively large, both in

surface area and thickness.

Survival is also related to fragment identifiability. Some elements possess more characteristic features than others; small fragments may therefore be identifiable from some bones whereas relatively large fragments from others may be unidentified. As bones fragment their shape also changes, as will any measure based on ratios between mass, surface area or volume, such as density. Indices based on the characteristics of whole bones such as density measurements (see Chapter 3) and Hill and Walker's shape index (1972, used by Shipman 1981, 26-27 and references therein) may therefore over-simplify the real situation.

8.3.3 Density.

The term "density" is open to a number of different definitions, not all of which involve measurement of the same, or closely related, property, as discussed above in Chapter 3. In this study, the density property measured has been shown to be closely related to bone porosity, and as such is a measure of the ratio of compact : spongey bone, as pointed out by Shipman (1981, 25).

Investigations into large mammal bone density applied to recovered bone assemblages have indicated that the lower density cancellous ends of bone are destroyed in preference to the shaft. In some cases this may be due to predator attack: the soft spongey ends of bones are easily gnawed, and give access to the marrow within. This pattern will not affect most small mammal, amphibian, reptile, bird and fish bones, as animals may be consumed intact or do not possess marrow-rich bones. The experiments detailed in this thesis have shown that the epiphysial ends of small mammal bones were preferentially destroyed when compared with the shaft during mechanical abrasion and digestion, however, and the lower density (but also small) vertebrae and sacrum were also readily destroyed. It appears that bone density or porosity may be influential in determining the relative

rates of erosion (both mechanical and chemical) of small mammal skeletal parts, but the influence of other factors, such as size and shape may complicate the relationship. The relationship between bone density and relative survival in fish bone is even harder to establish: here size and, especially, shape appear to be more important.

Although often cited as important (e.g. Butler 1987; forthcoming; Colley 1984; Morales 1984; Maltby 1985, 42) density values have been shown to be of limited value in explaining the fragmentation of bones in the experimental situations under discussion.

Bone fragmentation may not be the best indicator of overall loss, however. Some bones will break into fragments, but portions will be very resistent. Other bones may remain intact for longer, but finally break into many unidentifiable pieces. This property can be illustrated by comparing the categories of "condition" with "fragment completeness", which together best describe the exposed bone assemblages. Both these categories are presented for the boiled cod bones, after 109 weeks exposure, in Table 6.7 (p. 271). It can be seen that the two categories do not closely agree. Some bones, owing to their design, remained complete even when extremely cracked and crumbly. Other bones broke after the propagation of only one or two cracks.

In order to better assess the relationship between the intrinsic properties of skeletal elements to their chances for survival it is preferable to compare the relative survival of elements in terms of relative abundances. This was not generally possible in the context of the experiments undertaken in this study, where because of the nature of many of the experiments monitoring either could not be carried out on a continuum (e.g. for trampling), or insufficient bone loss was experienced to enable rankings based on the relative disappearance of elements. In addition, for a proper assessment of the value of density

(or any other intrinsic property) as an interpretative tool to explain the relative loss of skeletal elements and/or between taxa, each experiment should involve many replicates for each skeletal element and/or taxon. Obviously, only measurements obtained from the same, or closely related species should be used for the comparison.

8.4 Archaeological Applications

Of course, predepositional factors can not be divorced from post-depositional changes when considering archaeological material. Both will affect the ways in which material is preserved and will contribute to the taphonomic print which is left by the organic remains.

Any study which includes a comparison of experimental work with archaeological assemblages will, in the archaeological material, be looking at an assemblage which may have been modified after burial as well as before.

When assessing the effects of density, biostratinomic and diagenetic processes are both important in the formation of the archaeological assemblage. Therefore the case studies below, in which both biostratinomy and diagenesis may have been important in the formation of the recovered assemblage, provide useful data against which to test the hypothesis that density is an important factor in overall bone preservation (rather than bone fragmentation, with which it has been shown not to be closely related, see above). This analysis has been done because most studies which cite density as important in bone preservation (e.g. Jarman *et al.* 1982, 85; Muniz-Morales 1984; Maltby 1985, 42) are dealing with archaeological assemblages, for which fragmentation was only one of the factors involved in modifying the original assemblage.

8.5 The Value of Density and Shape to Explain Bone Survival: Three Archaeological Case Studies Using Fish Bone.

As discussed above, a better way of investigating the value of "density" (assuming a standard definition is used) is to compare the relative values or rankings of skeletal elements within an assemblage containing the remains of many individuals. Density rankings may then be compared with the relative abundances of skeletal elements, as long as care is taken to record each bone only once (i.e. by recording standard areas of the elements). I have done this for archaeologically recovered assemblages of gadid remains from three sites; Newcastle Queen Street, Newcastle Crown Court and Pool, *Sanday*. *Fuller* descriptions of the fish bone assemblages from these sites is given in Nicholson (1988, 1989 and forthcoming a). For convenience all gadid remains have been pooled, irrespective of species, and compared with the density measurement (m1) *obtained for cod* (see Chapter 3). In all cases, the numbers of bones which were identified as ling (*Molva cf. molva*) or haddock (*Melanogrammus aeglefinus*) were relatively small. For these assemblages, these are the only two species in the Gadidae in which some bones are likely to be of different relative density than in the cod skeleton. All bones of whiting, saithe (*Pollachius virens*) and pollack (*Pollachius pollachius*) are morphologically very similar to cod, and these were the only other gadid species identified from more than one or two bones.

The remains from the two Newcastle sites include only bones recovered after sieving to 1 mm. or 0.5 mm. As relatively little sieving was carried out at Pool, the assemblage studied includes both sieved (to 10 mm. or to 3mm.) and hand-picked material. The context containing small bones discussed in Chapter 7 (context PL 0481/0437) was not included.

By taking into account the area(s) of bone represented by

the fragment, and the fragment completeness, only individual bones were recorded. In other words, if a fragment could have come from the same bone as another fragment from the same archaeological context, only one was counted. This selection was done after recording was complete. This is important, as some bones break into more recognisable fragments than others, so inflating the score for that bone if all fragments are counted. In retrospect it would have been simpler, given that recording was not begun until all bones were available (which is not always the case) to try to pair up fragments from the same bone by eye, and to score as a separate category a code relating to the potential of a fragment to be a duplicate record of another bone. This would in practise probably have increased the number of fragments counted as individual bones.

In none of these case studies is there any reason to believe that entire skeletons were not deposited, and as such the assemblages are felt to be representative samples of the remains left from whole animals. There were also very few indications of any processes such as butchery or gnawing on the bones which may indicate that skeletons were modified by animals, including man. As is usually the case when dealing with archaeological material, however, the removal of bones by forces other than decay can not be ruled out.

No account has been taken of context type in this analysis, although preservational differences between bones in different context types are clearly to be expected, and indeed the study of them is one goal of a study of this type. For this investigation, however, in order to obtain sufficiently large samples, all contexts had to be treated as one. On all the sites there are no clear differences in preservation between bones from different context types (apart from occasionally poorly preserving contexts, from which little bone was recovered). This lack of intra-site variation in preservation has been demonstrated by chi-

squared tests between condition and fragment completeness with context type and phase for the Pool assemblage (Nicholson forthcoming a).

As shown in Tables 8:1-8:3 and the Figures below them (Figs. 8:1-8:3) there was no correlation between density and the relative abundance of the gadid skeletal elements from all of the sites. There was a significant correlation between shape and survival in all cases, however, as illustrated by chi-squared tests (Table 8:4). In common with the consistent results from the experiments and observations documented in the present study, spherical bones were over-represented compared with the other groups, and irregular and flat bones were the least well preserved.

As Fig. 8:4 shows, the proportional representation of skeletal elements was similar for all three of the archaeological gadid assemblages. This was verified by Spearman's Rank Correlations, all of which were significant at 99%, indicating that the assemblages were more similar in terms of rank than could be attributed to chance (Table 8:5). Evidently, as the ranks of skeletal element abundances in all three assemblages were not significantly correlated with density, density as measured was not the most important determinant of bone survival. Bone shape is obviously important, and this, coupled with the size of the bone, is probably the most influential property.

Table 8:1
Actual counts and relative abundance of gadid bones from Newcastle Queen Street, compared with density measurement (ml) of cod bones.

	Counts	Relative Abundance	Rank	Density	Rank
Ectopterygoid	4	2	15	1.48	36
Subopercular	0	0	5	1.38	35
Interopercular	1	0.5	11	1.33	33.5
Urohyal	0	0	5	1.33	33.5
Postcleithrum	5	2.5	17	1.31	32
Cleithrum	12	6	25.5	1.30	31
Maxilla	14	7	27	1.29	30
Ceratohyal	6	3	20	1.27	29
Dentary	17	8.5	29	1.25	28
Basipterygium	0	0	5	1.21	27
Parasphenoid	10	10	30	1.20	26
Epihyal	11	5.5	24	1.18	24.5
Palatine	6	3	20	1.18	24.5
Symplectic	3	1.5	14	1.16	23
Supraoccipital	0	0	5	1.15	22
Premaxilla	25	12.5	32.5	1.15	20.5
Prevomer	6	6	25.5	1.15	20.5
Hypohyal	1	0.3	10	1.14	18
Infrapharyngeal	6	3	20	1.14	18
Scapula	0	0	5	1.14	18
Ethmoid	0	0	5	1.08	16
Caudal vert.	471	13.9	35	1.07	15
Posttemporal	7	3.5	22	1.06	13.5
Quadrate	26	13	34	1.06	13.5
Lacrimal	0	0	5	1.05	12
Supracleithrum	10	5	23	1.04	10.5
Suprapharyngeal	7	1.2	13	1.04	10.5
Articular	25	12.5	32.5	1.03	9
Coracoid	0	0	5	1.00	8
Abdominal vert.	306	17	36	0.91	7
Basioccipital	12	12	31	0.88	6
Opercular	5	2.5	17	0.85	4.5
Preopercular	5	2.5	17	0.85	4.5
Hyomandibular	15	7.5	28	0.72	2.5
Frontal	1	1	12	0.72	2.5
Prefrontal	0	0	5	0.70	1

Spearman's Rank Correlation between relative abundance and density measurement ml, rho = -0.12, at 34 df. not significant.

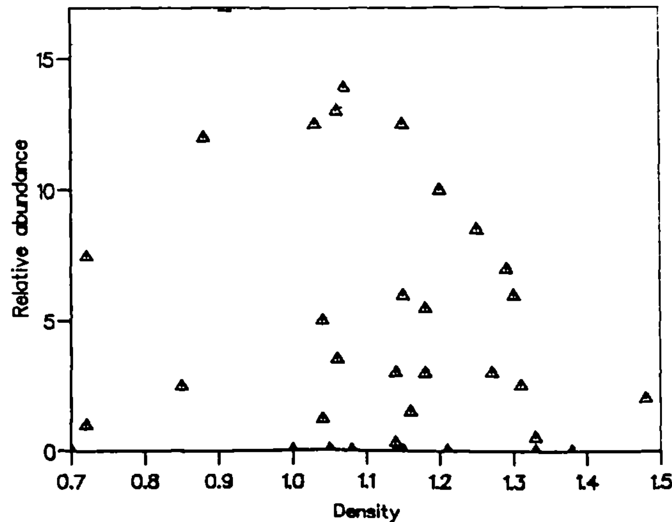


Fig. 8:1

Table 8:2

Actual counts and relative abundance of gadid bones from Newcastle Crown Court, compared with density measurement (ml) of cod bones.

	Counts	Relative Abundance	Rank	Density	Rank
Ectopterygoid	4	2	18	1.48	36
Subopercular	1	0.5	11	1.38	35
Interopercular	7	3.5	23.5	1.33	33.5
Urohyal	1	1	14.5	1.33	33.5
Postcleithrum	5	2.5	19.5	1.31	32
Cleithrum	3	1.5	17	1.30	31
Maxilla	10	5.5	27	1.29	30
Ceratohyal	5	2.5	19.5	1.27	29
Dentary	19	9.5	33	1.25	28
Basipterygium	0	0	4.5	1.21	27
Parasphenoid	6	6	28	1.20	26
Epihyal	6	3	21.5	1.18	24.5
Palatine	7	3.5	23.5	1.18	24.5
Symplectic	1	0.5	11.0	1.16	23
Supraoccipital	0	0	4.5	1.15	22
Premaxilla	31	15.5	36	1.15	20.5
Prevomer	3	3	21.5	1.15	20.5
Hypohyal	1	0.3	9	1.14	18
Infrapharyngeal	2	1	14.5	1.14	18
Scapula	0	0	4.5	1.14	18
Ethmoid	0	0	4.5	1.08	16
Caudal vert.	238	7	30	1.07	15
Posttemporal	16	8	31.5	1.06	13.5
Quadrate	13	6.5	29	1.06	13.5
Lacrimal	0	0	4.5	1.05	12
Supracleithrum	9	4.5	25.5	1.04	10.5
Suprapharyngeal	6	1	14.5	1.04	10.5
Articular	26	13	34	1.03	9
Coracoid	0	0	4.5	1.00	8
Abdominal vert.	246	13.5	35	0.91	7
Basioccipital	8	8	31.5	0.88	6
Opercular	9	4.5	25.5	0.85	4.5
Preopercular	1	0.5	11	0.85	4.5
Hyomandibular	0	0	4.5	0.72	2.5
Frontal	1	1	14.5	0.72	2.5
Prefrontal	0	0	4.5	0.70	1

Spearman's Rank Correlation between relative abundance and density measurement ml, rho = 0.059, at 34 df. not significant.

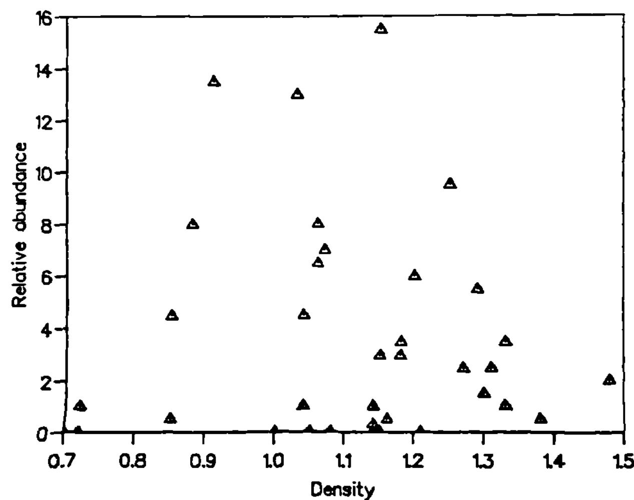


Fig. 8:2

Table 8 :3
Actual counts and relative abundance of gadid bones from Pool, Sanday, compared with density measurement (ml) of cod bones.

	Counts	Relative Abundance	Rank	Density	Rank
Ectopterygoid	67	33.5	18	1.48	36
Subopercular	36	18	14	1.38	35
Interopercular	35	17.5	13	1.33	33.5
Urohyal	17	17	12	1.33	33.5
Postcleithrum	7	3.5	6	1.31	32
Cleithrum	186	93	30	1.30	31
Maxilla	191	95.5	31	1.29	30
Ceratohyal	201	100.5	33	1.27	29
Dentary	125	62.5	24	1.25	28
Basipterygium	0	0	1.5	1.21	27
Parasphenoid	210	210	36	1.20	26
Epihyal	45	24.5	17	1.18	24.5
Palatine	85	42.5	22	1.18	24.5
Symplectic	48	24	16	1.16	23
Supraoccipital	14	7	9.5	1.15	22
Premaxilla	199	99.5	32	1.15	20.5
Prevomer	80	80	28	1.15	20.5
Hypohyal	11	5.5	7	1.14	18
Infrapharyngeal	44	22	15	1.14	18
Scapula	0	0	1.5	1.14	18
Ethmoid	19	9.5	11	1.08	16
Caudal vert.	1367	40	20	1.07	15
Posttemporal	132	66	26	1.06	13.5
Quadrate	150	75	27	1.06	13.5
Lacrimal	12	6	8	1.05	12
Supracleithrum	107	53.5	23	1.04	10.5
Suprapharyngeal	6	1.5	5	1.04	10.5
Articular	305	152.5	35	1.03	9
Coracoid	1	0.5	3	1.00	8
Abdominal vert.	2161	120	34	0.91	7
Basioccipital	85	85	29	0 88	6
Opercular	69	34.5	19	0.85	4.5
Preopercular	81	40.5	21	0.85	4.5
Hyomandibular	129	64.5	25	0.72	2.5
Frontal	7	7	9.5	0.72	2.5
Prefrontal	2	1	4	0.70	1

Spearman's Rank Correlation between relative abundance and density measurement ml, rho = 0.03, at 34 df. not significant.

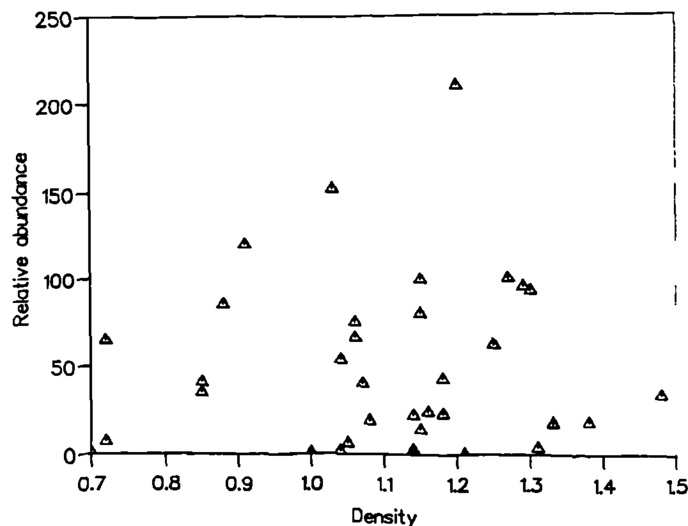
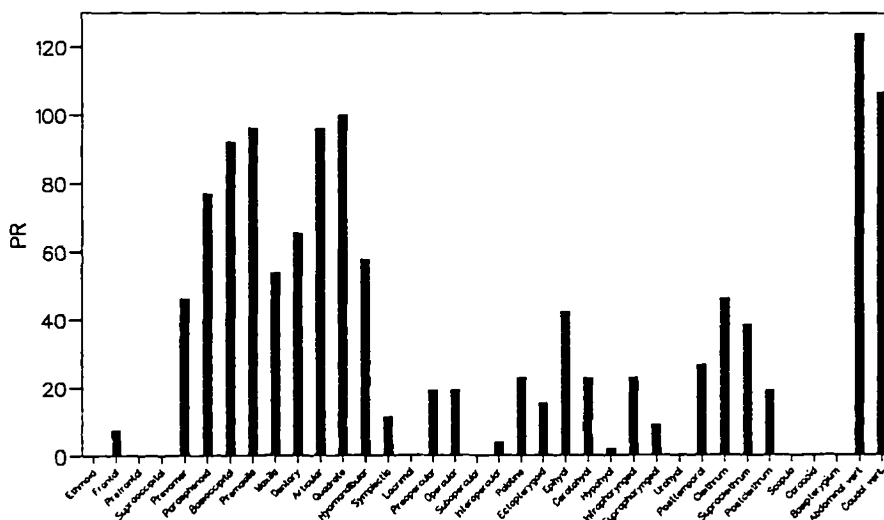
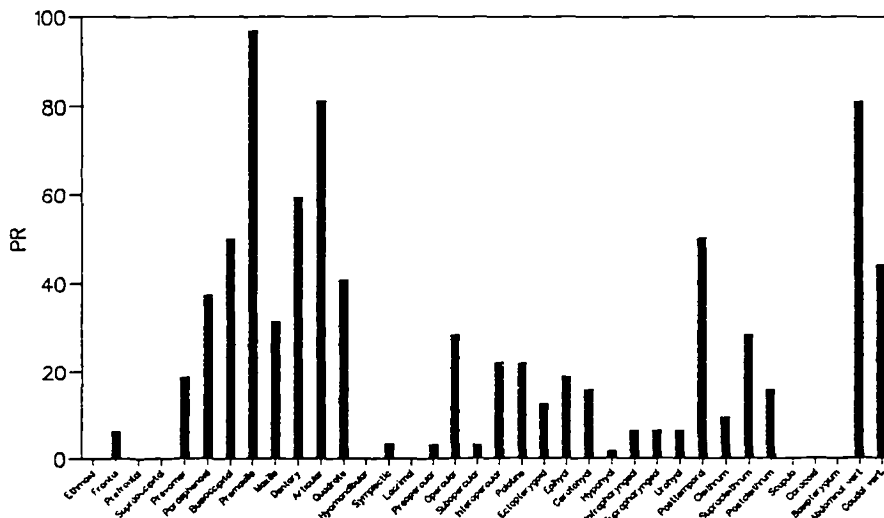


Fig. 8:3

Proportional Representation of gadid skeletal elements from Queen Street



Proportional Representation of gadid skeletal elements from Crown Court.



Proportional representation of gadid skeletal elements from Pool.

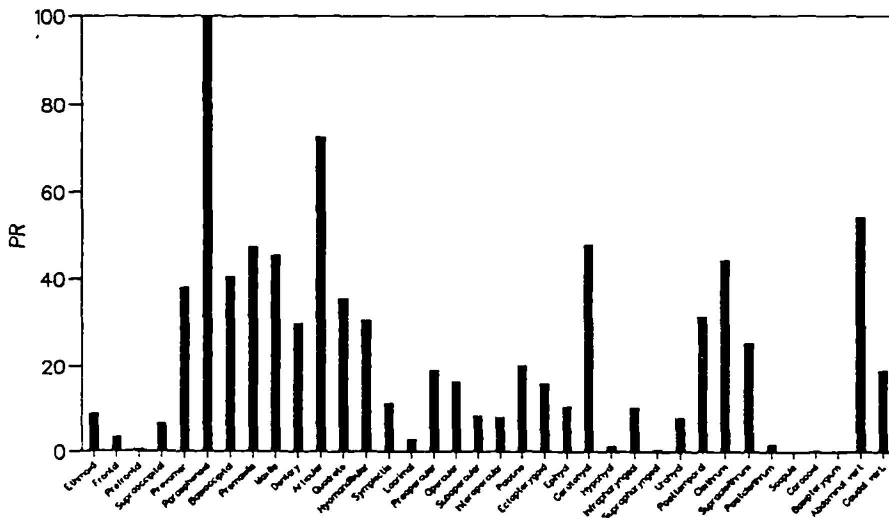


Fig. 8:4 Proportional Representation of Gadid Skeletal Elements from Three Archaeological Sites.

Table 8:4 A chi-squared analysis of shape and recovery rate of gadid bones from sieved samples from excavations at Newcastle Crown Court.

	Recovered	Expected	Residual
Robust	135	129	6
Irregular	17	100	-83
Flat	41	141	-100
Spherical	492	316	176
Total	685		

Chi-Square	D.F.	Significance
237.01	3	<.001

Table 8:5 A chi-squared analysis of shape and recovery rate of gadid bones from sieved samples from excavations at Newcastle Queen Street.

	Recovered	Expected	Residual
Robust	137	187	-50
Iregular	21	145	-124
Flat	50	205	-155
Spherical	789	460	329
Total	997		

Chi-Square	D.F.	Significance
471.24	3	< .001

Table 8:6 A chi-squared analysis of shape and recovery rate of gadid bones from sieved samples from excavations at Pool, Sanday, Orkney.

	Recovered	Expected	Residual
Robust	1385	1172	213
Irregular	610	906	-296
Flat	626	1279	-653
Spherical	3613	2877	736
Total	6234		

Chi-Square	D.F.	Significance
656.6	3	<.001

Table 8:5
Proportional Representation of Gadid Skeletal Elements from Three Archaeological Sites, with ranks.

	Pool	Rank	Queen Street	Rank	Crown Court	Rank
Ethmoid	9.0	14	0	5	0	4.5
Frontal	3.3	9	7.7	12	6.3	14.5
Prefrontal	0.5	4.5	0	5	0	4.5
Supraoccipital	6.7	10	0	5	0	4.5
Prevomer	38.1	28	46.2	25.5	18.8	21.5
Parasphenoid	100	36	76.9	30	37.5	28
Basioccipital	40.5	29	92.3	31	50	31.5
Premaxilla	47.4	32	96.2	32.5	96.9	36
Maxilla	45.5	31	53.9	27	31.3	27
Dentary	29.8	24	65.4	29	59.4	33
Articular	72.6	35	96.2	32.5	81.3	35
Quadrate	35.7	27	100	34	40.6	29
Hyomandibular	30.7	25	57.7	28	0	4.5
Symplectic	11.4	17	11.5	14	3.2	12
Lacrimal	2.9	8	0	5	0	4.5
Preopercular	19.3	21	19.2	17	3.1	10.5
Opercular	16.4	19	19.2	17	28.1	25.5
Subopercular	8.6	13	0	5	3.1	10.5
Interopercular	8.3	12	3.8	11	21.9	23.5
Palatine	20.2	22	23.1	20	21.9	23.5
Ectopterygoid	16.0	18	15.4	15	12.5	18
Epihyal	10.7	16	42.3	24	18.8	21.5
Ceratohyal	47.9	33	23.1	20	15.6	19.5
Hypohyal	1.3	6	1.9	10	1.6	9
Infrapharyngeal	10.5	15	23.1	20	6.3	14.5
Suprapharyngeal	0.5	4.5	9.0	13	6.3	14.5
Urohyal	8.1	11	0	5	6.3	14.5
Posttemporal	31.4	26	26.9	22	50	31.5
Cleithrum	44.3	30	46.2	25.5	9.4	17
Supracleithrum	25.5	23	38.5	23	28.1	25.5
Postcleithrum	1.7	7	19.2	17	15.6	19.5
Scapula	0	1.5	0	5	0	4.5
Coracoid	0.2	3	0	5	0	4.5
Basipterygium	0	1.5	0	5	0	4.5
Abdominal vert	54.2	34	123.9	36	80.9	34
Caudal vert.	19.1	20	106.6	35	43.8	30

Spearman's Rank Correlations, at 34 df. :

Pool with Queen Street, rho = 0.85, significant at 99%
Pool with Crown Court, rho = 0.75, significant at 99%
Queen Street with Crown Court, rho = 0.83, significant at 99%

8.6 Recommendations for the Recording and Analysis of Archaeozoological Data

Colley (forthcoming b.) points out: *"If we don't know exactly what we are looking for in a faunal assemblage, how do we know what to record and in what detail?"*. Taphonomic studies at the archaeological level must go hand in hand with an appreciation of the archaeological context. Some parameters may be of more interest on some sites than on others, and an appreciation of the archaeological context may help to narrow down or to widen the taphonomic possibilities. While some categories of information may be pertinent to any site or context, such as bone texture and extent of erosion, other categories such as acid erosion may be only important in some instances. It is not practical to record every possible category of information for every assemblage. It is important that archaeologically relevant questions should be formulated before recording begins, so that recording can incorporate categories for the appropriate features which may be important at the site. Additional records may then be made for contexts which appear to be of particular interest. In this circumstance the value of the "scan" level of recording is important, and at the scan level the recognition of classes of preservation, or the assessment of the degree of assemblage incompleteness, is at a premium.

At the most basic level for bones, the categories of texture, erosion and flaking, as well as some measure of the relative proportion of a skeletal element represented by the fragment, and for large mammal bones an estimate of actual fragment size (i.e. maximum dimension) will enable the preservational state of material from different contexts to be objectively compared. When dealing with archaeologically recovered material, categories of colour and mineral encrustation may also be useful for some sites. Analysis of these parameters can indicate whether assemblages are of mixed origin in the absence of other evidence, as well as indicating the likely magnitude of

loss of remains between deposition and recovery. Likewise, evidence of burning, acid erosion and gnawing may elucidate specific biostratinomic pathways. Where the assemblage appears to warrant detailed analysis, microscopic observation should be employed, as examination of bone (or shell or cuticle) surfaces may elucidate specific aspects of the pre-depositional history of individual specimens, and again this may elucidate reasons for aspects of assemblage composition (i.e. the relative abundances of skeletal elements).

As a visual method of comparing bones from different contexts or samples in terms of their skeletal representation, and so potentially the extent of taphonomic loss (though other evidence of poor preservation should be sought) "decay trajectories" can be compared, based on relative abundances. Categories of "condition" and "fragment size" (i.e. proportion of the whole bone) may also be compared between contexts to explain preservation.

Having established whether preservation is good or poor, the composition of recovered assemblages should be compared with "survival groups" such as those given in Appendix 8.1, so that deviations from the expected patterns of loss may be recognised. Also, crucially, erroneous interpretations based on missing skeletal parts may be avoided if reference is made to these "survival groups".

8.7 What Distinctive Surface Features May Be Used To Recognise Specific Biostratinomic Processes?

Where possible, observations of physical modifications have relied on low-power microscopy or features visible by eye, in order to make it feasible to score the distinctive criteria during routine archaeozoological recording. Features distinctive to weathering of bone include split lines, surface exfoliation and erosion of surfaces by wearing away of the outer layers. Both of these characteristics may be scored as standard records during

archaeozoological analysis and given a severity level. The level suggested in this work is 0-5, but as long as the scales used to record severity are clearly stated and defined at the beginning of a report the range may be varied to suit the recorder.

Acid erosion as a product of digestion may be recognised by an overall polished appearance to the ingested item, and by an overall thinning of bone surfaces, particularly at the edges of flat bones and the ends of long bones. The ends of long bones may be eroded to a point. Where broken, edges are smooth and rounded. Surface patterning is diminished, and on otoliths the areas of high relief are reduced. Some bone surfaces may appear pitted, and the edges of bones and otoliths may be crenellated. Bones and otoliths are often stained brown. The extent of acid erosion and of bone breakage or gnawing will depend on the species both of predator and prey. Bones which have been chewed may be recognised either by puncture marks or, in the case of fish vertebrae, by lateral squashing. Other marks indicative of predation or scavenging of bones have been documented in detail for example by Binford (1981), Shipman and Rose (1983), Stallibrass (1986; 1990) and Brain (1981).

It should be noted that thinning of bone may occur during erosion in an acidic environment other than in the stomach. The experiments detailed in Chapter 7 suggest that in such circumstances thinning of bones and otoliths is regular, and not accompanied by pitting or crenellation of edges, even when accompanied by enzyme attack. Further experiments are required, however, and in this area the results after excavation of the assemblages buried in acid environments (Appendix 6.1) should prove valuable.

Mechanical abrasion is also typified by rounding of edges and reduction of sculpturing. The emphasis is on rounding rather than thinning, however. All bones in an abraded assemblage could be expected to appear rounded, while a

digested assemblage is usually typified by a wide range of conditions, with some bones appearing unaffected while others are stained, pitted, chewed and thinned. Pitting or crenellation of edges is not a characteristic of abraded bone, but surface flaking and erosion of cancellous bone may be produced by moderate amounts of mechanical abrasion, and may look like weathered bone, however (see Shipman 1981, 114). Some severely abraded bones may have torn, fibrous ends (e.g. Plate 5:1k p. 162).

In a trampled assemblage most bone modification involves breakage. Some bones may appear scuffed, with localised areas of disruption to the outer layers of bone. Trampling marks have been investigated under the S.E.M. and are illustrated by Olsen and Shipman (1988).

Apart from by colour, burning may be identified by the surface morphology of bone. Colour may be a deceptive criterion, as chemicals within the burial sediment may stain bones, as may passage through the gut. Burning produces characteristic polygonal cracking on the articular surfaces of long bones, and may cause parabolic cracks to the shaft. These forms of cracking are distinctive to heating. Examination of surface morphology of blackened bone under a low-powered microscope may reveal areas of peeling organic char, indicative of heating to temperatures between about 250-450°C. Sintered bone is characterised by a ceramic-like appearance, with infilling of surface pores to create a flawless surface. Higher magnifications, under the S.E.M. can reveal changes in the surface morphology of the bone, especially visible after sintering, when the apatite crystals coalesce. This property is visible on mammal, bird and fish bone, and can also be observed on archaeological material presumed to have been heated. As a cautionary note, it has been found that weathering also causes enlargement of the hydroxyapatite crystals, which may produce surface patterns similar to that of sintered bone (Plate 4:3m p. 116). For this reason it is advisable to interpret surface morphology as seen at high

magnification with a degree of caution until further studies of weathered bone have been carried out, although from the observations I have made it seems unlikely that similar enlarged regular crystal forms would be observed over a large portion of weathered, unheated bone.

8.8 Some Current Opinions Reviewed.

This study has generated a number of results which are at odds with some commonly held beliefs. Perhaps the most widely held of these is that small animals are likely to be lost preferentially to larger animals as a result of taphonomic processes. While this may be true for processes related to weathering, when similar species or taxa are involved, it is not always true. Under certain circumstances small skeletal parts may survive better than larger remains. For example, during trampling small bones are buried in preference to larger ones, and so may escape destruction. Small fish bones are generally in better condition than large ones in otter spraint, and small mammal remains are usually more complete than larger mammal and bird bones in raptor pellets. Within fish, the bones of larger individuals of some species may be lost in preference to those of smaller individuals of another species, depending on the extent of mineralisation within the bone and its mechanical properties. These results indicate that Maltby's view, that the bones most likely to be destroyed are *"the small or more porous and less dense fragments"* (Maltby 1979, 4) may be too simplistic, especially when applied to non-mammal remains. It is also possible that within other vertebrates bones from juveniles of one species may be lost in preference to smaller adult bones from another species, although this has yet to be examined.

In many circumstances, particularly during mechanical abrasion, weathering, and protein-digestion, fish bone from a range of species is lost more rapidly than bone from other vertebrate taxa. This provides some evidence to

challenge the statement by Jarman *et al.* (1982, 85) that the "*assumption that fish bones are especially vulnerable to destruction ... has little to recommend it*".

The supposition that bone density is the most important factor in bone preservation is also questioned. Again, the view of Jarman *et al.* (1982,85) that: "*Preservation is largely a matter of bone density, which is independent of size and the ease with which bones are trampled into the underlying deposit*" appears to have little foundation. Their view that small fish bones may be saved from destruction by trampling into the substrate (*ibid.*) does appear to be justified, however, and directly contradicts their statement concerning preservation in general.

Fish beheading or processing is commonly argued on the basis of skeletal element distributions. Instances may be based on very few fragments (e.g. Jonsson forthcoming), in which case they are suspect on sample size alone. Where arguments are based on studies of large assemblages, taphonomic investigations can provide useful clues. One example concerns the beheading of salmon. Ryder (1963, 311) advocates the use of skeletal element distributions to indicate fish processing. He interprets the lack of salmon skull bones in a Magdelenian cave site in the Dordogne (France) as evidence that salmon were beheaded (*ibid. 301-302*). The presence of salmon vertebrae but no head bones, compared with the existence of both vertebrae and head bones from other fish species, is cited as evidence that fish species were dealt with differently. Butler (forthcoming) compares assemblages of salmon remains from a 'natural point bar' death assemblage with a "cultural" assemblage, in which heads and bodies of salmon were disposed of separately (the head being cooked whole). She then extrapolates the results in terms of skeletal element distribution to an archaeological midden site. She concludes that the archaeological specimens had been beheaded, as the natural assemblage contained proportionately many more head bones. The difference in

time between deposition and recovery of the modern point bar samples (which had collected over several years prior to excavation) and the archaeological material (age only given as early Holocene) is not considered. Morales-Muniz *et al.* (forthcoming) in the same volume consider the absence of salmonid head bones from Iberian sites to be a result of preferential taphonomic loss. None of the studies is supported by experiment, but the last is based on a classification of robustness based on various integral bone properties, such as bone size, shape, compactness, lipid impregnation, and the presence/absence of foramina. These properties were measured by subjective ratio scales, but the importance of each of the categories has been assumed rather than tested. Although salmon bones were not used extensively in the experiments detailed in the present study, it was apparent from the freeze/thaw, wet/dry experiments that of the head bones and vertebrae used, the head bones exfoliated and disintegrated considerably in advance of the vertebrae. This was particularly noticeable in the case of the two sets of male salmon head bones, presumably due to calcium depletion after spawning. This provides some support for the view expressed by Morales-Muniz *et al.* (*ibid.*) that salmon head bones may be lost preferentially by "natural" mechanisms, and beheading need not be invoked for the preponderance of vertebrae on a site.

Loss of bone by a suite of taphonomic factors, especially if these factors act selectively for different taxa and sizes/ages of animals, has obvious implications for the assessment of meat weights. Any attempt to use bone weights or abundances to indicate the amount of meat consumed, or the relative component of different meat types to the diet (e.g. Shawcross 1967) may be flawed.

It is also commonly implicitly assumed in many discussions of species composition in archaeozoological assemblages that the diversity of species recovered reflects the diversity deposited. Preferential disin-

tegration of some species is not considered. For all the reasons given above, the application of diversity indices to excavated assemblages (e.g. Izquierdo and Morales-Muniz forthcoming) in the absence of investigations into taphonomic loss may therefore be misguided. Only if reasonable grounds can be established for assuming that the range of species in question have not been subject to differential preservation can diversity indices validly be used. Diversity indices are also dependent on sample size, up to a certain point (Grayson 1984). The smaller the assemblage the more relatively diverse it will appear. Before using diversity indices sample size effects should be examined by investigating the degree of correlation between diversity and sample size. If significantly correlated, appropriate steps should be first taken to alleviate the effect of sample size, for example by grouping small samples together, or normalising the diversity indices.

8.9 Suggested Directions for Future Studies.

The diverse, often necessarily rapid, exploration of a number of processes on a variety of tissues has thrown up a number of potentially fruitful areas for further investigation. Some of these areas have been explored in this thesis, but all could warrant further, more detailed study.

1. In this study of variability it has become evident that the survival of various vertebrate tissues is not solely related to size or porosity. Other factors, in particular the relationship between total organic content and lipid content with bone survival require further investigation. A more detailed examination of the chemical and physical properties of bird bone compared with mammal bone may explain why, when present, bird bone frequently appears in much better condition than much larger mammal bone. The extent to which bones from animals of different ages differ in their "survival potentials" should also be examined,

both by long-term experiments and by accelerated laboratory experiments.

2. By investigating the breakdown of skeletons from a single species in detail, it should prove possible to build up an "Index of Robustness" such as is advocated by Jones (Wheeler and Jones 1989), for each type of biostratinomic process (e.g. for trampling and for weathering), although grouping elements is more reasonable than examining each individual relationship. The Index can then be compared with archaeologically recovered assemblages in more detail than was possible in the present study.

3. Classification by shape and density could be refined if portions of bones, rather than whole bones, were considered. This could be accomplished by considering bones to be composed of several diagnostic areas, as has been proposed by, for example, Watson (1972) and Dobney and Reilly (1988) for large mammal bones. X-Rays, histological analysis and image analysis of complete bones and/or bone sections could be used to investigate bone porosity and to classify more objectively skeletal parts by size and shape.

4. By examining how the intrinsic properties of size, shape, organic content (protein and lipids) and porosity affect the preservation of skeletal *elements under* different regimes, it should be possible to group skeletal elements and species in terms of their potential (from good to poor) for preservation under the given regime. These groupings may then be tested against archaeological data. This technique has already been suggested by Morales-Muniz et *al.* (forthcoming), but the criteria used to group bones had not been shown experimentally to relate to bone preservation. Their assumptions about the relative importance and direction of importance are made on subjective grounds alone (for example they believe a high lipid content will lead to poor preservation, but do not present any data in support of this assumption). In fact their groupings are largely implicitly grounded in their

experience of the relative abundance of bones and species in archaeological deposits, thus creating a circular argument when their results are compared with archaeologically recovered material. Additionally, it is implicitly assumed that the groupings will relate to all preservational processes, which may not be true. It is only by basing the grouping of skeletal elements on objective results from experiments that the importance of individual intrinsic characteristics can be established, and the relevance of the taphonomic process under investigation to an archaeological assemblage assessed.

5. Having established what an assemblage subjected to a particular pre-depositional process may look like, examination of the archaeological context, both archaeological and sedimentological, should provide further clues to the taphonomic history of the assemblage. Intra-site comparisons of archaeological material, using categories of fragment size and condition (with other classifications as relevant) as well as skeletal part distribution, should indicate whether the assemblage is homogenous or whether *different contexts contain* remains which have different taphonomic histories. Intra-site comparisons of this sort have already been carried out, for example by Stallibrass (1985) and Wilson (1985), but with little data to indicate how the specific taphonomic processes postulated as responsible for modifying the assemblages have acted.

6. More specifically, with regard to sedimentary abrasion, the experiments detailed in Chapter 5 revealed that little macroscopically observable modification to skeletal remains may occur even after quite prolonged periods of tumbling in a fine-grained substrate. This has implications for recognising assemblages which have accumulated as a consequence of aeolian or water action. It is possible that size-sorting or orientation will characterise assemblages subjected to these processes (for example, as Voorhies 1969 and Hanson 1980 have illustrated) but it would be useful

to excavate "natural" bone accumulations (e.g. from a beach), and assemblages from middens subjected to wind and tidal action, to assess the degree to which these assemblages may be distinguished.

7. Finally, despite the potential scope given by its title, this investigation has been mainly concerned with vertebrate remains. Further investigations into the taphonomy of invertebrate remains is required. Land snails have been investigated from a taphonomic perspective by Carter (1990) but insect remains have received scant attention, yet deserve more. As insect remains from archaeological sites are generally only preserved under waterlogged conditions, investigations into the relative survival of insect body parts would be better to combine diagenetic studies with biostratinomic investigations. This would inevitably involve some biochemistry, if the breakdown of insect cuticle, leading to a pale-and-rubbery or dark-and-brittle state, is to be understood.

CHAPTER 9. OVERVIEW.

The methodologies for quantifying archaeozoological remains, which are the mainstay of any archaeologically relevant interpretation, are founded on the implicit assumption that the remains recovered, especially if they are recovered by sieving, represent the diversity present at the time of deposition. This assumption may often be invalid, as this study has demonstrated. This research has shown how the relative abundances within a sample of vertebrate or invertebrate remains may be altered by a number of factors before burial, which may act in a non-random fashion and so render the diversity within the sample completely different from that originally deposited. The investigation of patterning consequent upon biostratinomic processes is therefore crucial to our understanding of archaeologically recovered samples of faunal remains.

It has been demonstrated in this study that the rate of destruction may depend not only on the size of an anatomical part, but also, and often more importantly, on its design at both the morphological and chemical level. In general terms, fish bone appears to be destroyed more rapidly than comparably sized mammal bone under most circumstances, and amphibian bone appears to be remarkably resistant to mechanical attrition.

The recognition of the action of agents of biostratinomic modification and the extent of assemblage distortion may rest, in part at least, on analyses of the relative abundances of skeletal elements and extent of fragmentation. For this reason it is necessary to record all bones, not just those which may be easily identified to species. This inevitably will increase costs, and may not always be appropriate given the nature of the excavation (e.g. if conducted under "rescue" conditions) or the quality of the material. Clearly, research strategies must be carefully formulated before analysis begins. By using a

"scan" or "assessment" level of recording in the first instance, the importance, and general condition of the assemblage should be diagnosable.

It is not always easy to separate biostratinomic and diagenetic factors, with regard to the processes as well as the effects. Hodder (1982, 47) asks, *is trampling of artifacts into the ground by human feet or by animal hooves depositional or post-depositional?* Furthermore, is it, in Schiffer's terminology, a cultural or non-cultural transform? (*ibid.*). I have taken trampling to be a pre-depositional factor because the action takes place above ground, pushing remains into the burial environment, or breaking them on the ground surface. I also suggest that it is a non-cultural transform, as even if human feet are involved it is not a deliberate action. However, these points serve to demonstrate the dangers of the nomothetic approach, aiming to classify every process. If we are to understand the processes of taphonomy upon archaeological material then it is important to maintain an open, flexible approach. Particularly dangerous is the use of what Hodder (1982, 16) terms "formal" analogy, defined as the suggestion that *"if two objects or situations have some common properties, they probably also have other similarities"*. This approach has commonly been used to explain the patterning of skeletal assemblages on archaeological sites, and includes the interpretation of archaeological material based on comparison with a single contemporary observation.

In many instances it may not be necessary to understand each step in the taphonomic pathway in order to extract information of archaeological relevance. If different processes lead to similar results then it may be most important to recognise the combined effect in order to recognise the extent to which the archaeological assemblage has been modified from the deposited assemblage. Again, reference to the relative chances of survival of given skeletal parts (e.g. by looking at their position in a

survival group) or the skeletal parts of different taxa, will be crucial.

Of course, while the absence of certain skeletal parts may be a result of differential destruction, there are other possible explanations (i.e. that they were never there). Absence of evidence is not evidence of absence in this circumstance. While biostratinomic processes may lead to the total destruction of some skeletal remains, it does not follow that the absence of these skeletal remains necessarily implies destruction. However, an assessment of the overall assemblage condition and fragmentation state, as well as the position of the missing element(s) in the "relative survival" groupings, should enable a reasoned argument to be put forward to explain the likelihood of loss as opposed to original absence. It is also crucial that the archaeozoological assessment considers the sedimentological, geological, and climatic setting, as well as the archaeological context, assemblage composition and surface modifications, when evaluating the history of an assemblage.

In conclusion, considering the number of processes, both by humans and by other "natural" agents, which may influence an assemblage it is not surprising that most archaeological assemblages are non-random samples of what was originally deposited. Understanding why and how these assemblages vary is fundamental to any archaeological interpretation and should be recognised as such when work is undertaken, and when it is funded.

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APPENDIX 2:1 INSECT RECORDING SHEETS.

Explanation of codes used on the Insect Recording Sheets.

All records refer to the general assemblage appearance: individual deviations are noted under "comments".

Articulation: Scored on a scale of 1 (complete) to 7 (fully disarticulated, for beetles:

where over 50% are of the condition:

1 = Complete
2 = Only head or head+pronotum disarticulated
3 = Elytra separated
4 = Abdominal sclerites separated into groups, Meso+metathorax/notum separated but articulated in pairs.
5 = Meso+metathorax/notum and episterna disarticulated
6 = Completely disarticulated except for some legs and some sternites.
7 = Completely disarticulated.

Scored on a scale of 1 (complete) to 5 (fully disarticulated, for flies:

where over 50% are of the condition:

1 = Complete
2 = Heads disarticulated
3 = Heads, thorax and abdomen disarticulated
4 = Abdominal sclerites separated into groups
5 = Completely disarticulated.

Colour: A scale to show chemical erosion, on a scale of 1 (as fresh) through 2-4 (increasing redness/paleness) to 5 (completely transparent).

Fragmentation: scored on a scale of 1 (none) - 5 (extreme)

1 = No sclerites broken.
2 = <25% broken, generally only into 2 or 3 pieces.
3 = 25-50% broken, some into several pieces.
4 = 50-75% broken, commonly into several pieces.
5 = > 75% broken, generally into several or many pieces.

APPENDIX 2:1

Recording Sheet for Insects.

Experiment:
Duration:

BEETLES

Original number: Articulation: Colour:
Fragmentation:

Articulated elements	No:	Complete	Torn	Comments
Complete Bodies				
Abdomen+Pronotum/thorax+Elytra				
Elytra + Sternites				
Elytra + Meso+metathorax/notum				
Pronotum/thorax + Head				
Pronotum/thorax				
Head				
Elytra				
All Abdominal Sternites				
2-4 Abdominal Sternites				
1 Abdominal Sternite or Pygideum				
Meso + Metathorax				
Meso + Metanotum				
Mesothorax				
Metathorax				
Mesonotum				
Metanotum				
Episternum 2				
Episternum 3				
Complete legs (estimated no.)				
2 leg elements (estimated no.)				
Single leg elements (est. no.)				
Coxae				
Trochanter				
Internal Strut				

Comments:

FLIES

Original No: Articulation: Colour:
Fragmentation:

Articulated elements	No:	Complete	Torn	Comments
Complete Bodies				
Abdomen + Thorax				
Thorax				
Abdomen				
Head				
Individual Abdominal Sclerites				
Thorax fragments		-		
2+ leg elements (estimated no.)		-		
Single leg elements (est. no.)		-		

Comments:

FLY PUPARIA

Original no: Colour: Fragmentation:

State	Number
Complete	
Squashed but complete	
Cracked but complete	
Squashed, cracked but complete	
In 2 parts	
In 3+ parts	

MEALWORMS Original no:

State	Number
Complete	
6+ segments including head capsule	
3-5 segments including head capsule	
1-2 segments including head capsule	
1-2 segments without head capsule	
3-6 segments without head capsule	
6+ segments without head capsule	

Appendix 2.2 Experiments Conducted into the Chemical Decomposition of Insect Cuticle, and Erosional States Resulting from them.

Aim

To investigate the chemical breakdown of insect cuticle, with the aim of providing a description of the colours and physical characteristics.

The remains of insects recovered archaeologically may be paler or redder and more flexible than fresh insect cuticle. Darker and more brittle sclerites are also recovered (Kenward, pers. comm.). These changes must be related to the chemical breakdown of cuticle, which may occur as a result of processes before or after burial.

When the condition of archaeologically recovered insect remains is recorded, a note may be made of the colour and general appearance of the cuticle. During some of experiments described in this thesis colour changes were also observed, particularly in the experiments related to weathering. In order to objectify the recording of these observations, and to try and better understand the processes involved, a series of experiments was conducted into the chemical erosion of insect cuticle. These experiments involved putting insect remains in a range of chemical solutions. Initially the intention had been to mimic soil environments, but it soon became apparent that the rate of change was extremely slow under these circumstances. To speed up the process, strongly acidic and alkaline solutions were used, even though these would not occur in the soil. Additionally two experiments were conducted using substances which were known to break down specific bonds within the cuticle.

Materials and methods

The solutions used were, firstly, 50:50 hydrogen

peroxide: hydrochloric acid. This solution was recommended by Professor J. Phipps as one which rapidly caused cuticle to lighten and become more flexible. It was felt that this would provide a useful and rapid method of obtaining a series of reference stages to correlate with the changes observed in other experiments, and could be used to document states observed in archaeological material. Secondly, 1 molar sodium hydroxide was used, initially cold but finally boiled to obtain the later stages of chemical breakdown. This was to examine the effects of a strongly alkaline environment on insect cuticle. Thirdly, lactic acid, an organic acid, was utilised at concentrations of: 1 molar, 2.5 molar and 5 molar, to examine the effects of a naturally occurring acid on cuticle. Additionally, insect remains were placed in a solution containing chitinase, an enzyme which breaks down chitin (made up using 0.7 mg. of enzyme to 15 mg of cuticle).

As urea is a naturally occurring compound which breaks down hydrogen bonds in protein, a solution of 7 molar urea was used, as this is the concentration recommended by Neville (1975) for breaking hydrogen bonds in insect cuticle. Urea would be a common compound in many archaeological contexts, especilly cess pits, from which insect remains are commonly recovered. The insects were agitated for five days on a mechanical shaker, during which time the solution was renewed three times. At the end of this period the remains were examined, rinsed in distilled water for one day and then placed in a 0.16 molar solution of sodium sulphate, to break the Van der Waals bonds within the cuticle (Neville 1975). Following five days in this solution, renewed three times, the remains were again examined before placing in a molar solution of sodium hydroxide, again at room temperature, to break the double covalent, electrovalent or Schiffs bases (again as recommended by Neville 1975).

The insects used for all experiments were *Tenebrio* adults and larvae and *Calliphora vomitoria* adults and puparia.

Five complete specimens from each were used for all but the chitinase experiment, for which only a *Tenebrio* elytron and prothorax, and one blowfly puparium were used (for reasons of expense).

Results and discussion

The stages of erosion observed for insect cuticle after immersion in 50:50 $HCl:H_2O_2$ and after immersion in molar NaOH are given below. These stages describe the average state, in some cases variation was observed, probably due to the age of the cuticle (time since emergence).

It was clear from all these experiments that insect cuticle is extremely resistant to chemical erosion. In no solution (except for boiling in sodium hydroxide) was any change visible in under 24 hours. Extensive decolouration was only achieved after the insect remains which had been in cold sodium hydroxide for one month, were boiled for one hour, and after cuticle had been in cold 50:50 hydrochloric acid and hydrogen peroxide for 18 days. It was evident that different forms of cuticle break down at different rates. The puparia decolorised more rapidly than the adult beetle cuticle in both solutions. Between the adult *Tenebrio*, differences in the rates of decoloration probably reflect the degree of tanning within the cuticle, which depends on the time since emergence from the pupa. Within the skeleton the thick pronotum was generally darker in colour than the thinner elytra and other sclerites, and consequently retains its colour longer under conditions of chemical attack. The transparent metanotum is never tanned, but is shielded by the elytra.

Cuticle lightens as a result of the breakage of protein bonds within the cuticle, many of which are quinone linked (Wainwright *et al.* 1976, 158). Tanning of the cuticle has the same effect of increasing stiffness as drying (Vincent 1982). When the protein cross-links are broken, and the tanning agents released, the cuticle becomes transparent,

soft and pliant. From a mechanical point of view the main variability within arthropod cuticle is in the proportion of tanned to untanned cuticle (Wainwright *et al.* 1976, 163). In addition, cuticle includes the polysaccharide chitin, in the form of long fibres of high stiffness and high strength, bound together in sheets. This polysaccharide can be broken down by bacteria and fungi which secrete enzymes which attack beta 1-4 links. For this reason the use of such an enzyme, chitinase, appeared to promise useful results. In fact the results of this experiment were inconclusive, as no visible alteration to the *Tenebrio* or *Calliphora vomitoria* adults or puparia which were placed in the solution were observed, although it is possible that the mechanical properties of the cuticle would have changed.

The experiment utilising urea and other naturally-occurring chemicals also had an unremarkable effect. Although the urea solution turned a dark brown colour after the first two extractions, the cuticle was not visibly altered. Despite extractions in the other solutions detailed above, no paling or textural changes were noticeable. After two weeks in molar, 2.5 molar and even in five molar lactic acid no changes were observed, even though the solutions appeared brown.

Conclusions

The results from these experiments proved to be of limited value, particularly those designed to use chemicals which could be found under natural circumstances. The most useful results were obtained from the experiments using $HCl:H_2O_2$ and NaOH, as these caused changes in insect cuticle which could be used as reference stages. To look at naturally eroded insect cuticle it would be useful to collect insects from different natural environments, such as on chalk and acid soil, but this was beyond the scope of the present study. The condition could then be compared with the experimentally chemically eroded groups.

Erosional Stages in Insect Cuticle, based on the results of immersion in solutions of 50:50 H_2O_2, and HCL and NaOH.
(Colours are taken from the Munsell Soil Colour Chart)

STAGE 1 Fresh material.

Blow fly puparia. The dry puparia are slightly brittle, and uniformly opaque very dusky red (2.5YR 2.5/2) to reddish black (10R 2.5/1).
Blow fly adults. All are black (N2).
***Tenebrio* mealworms.** When dry the mealworms cuticle is flexible and brown (7.5YR 5/4) to brownish yellow (10YR 6/6).
***Tenebrio* adults.** All the cuticle is slightly brittle and shades of dusky red (2.5YR 3/2, 2.5/2), dark reddish brown (2.5YR 2.5/4) and reddish black (5YR 2.5/1).

STAGE 2. After 30 minutes - ≤ 24 hours in 50:50 HCL and in H_2O_2, and NaOH.

Blow fly puparia. Slightly paler, dark red (2.5YR 3/6) and red (2.5YR 4/6).
Blow fly adults. As fresh, except for a slight paleness of the eye region.
***Tenebrio* mealworms.** Similar to fresh material. Dark brown (7.5YR 4/4, 5/4 and strong brown 7.5YR 5/6).
***Tenebrio* adults.** Slightly paler or redder than when fresh, especially on the less well sclerotinised areas, such as the elytra. Colours vary from dusky red (2.5YR 3/2 and 2.5/2), through dark reddish brown (2.5YR 3/4), dark red (2.5YR 3/6) to yellowish red (5YR 5/8).

STAGE 3. After 24 - <64 hours in 50:50 HCL, and in H_2O_2 and NaOH.

Blow fly puparia. These are considerably paler and mottled with areas of red (2.5YR 4/6 and 4/8) and transparent reddish yellow (7.5YR 6/8).
Blow fly adults. The entire body appears dark reddish brown (2.5YR 3/4) or very dusky red (2.5YR 2.5/1). The area of the eyes is paler.
***Tenebrio* mealworms.** The cuticle is slightly paler, mainly strong brown (7.5YR 5/8) and reddish yellow (7.5 YR 6/8).
***Tenebrio* adults.** Very similar to stage 2, the thicker elements are dark reddish brown (2.5YR 2.5/4 and 3/4) and the thinner sclerites yellowish red (5YR 5/8).

STAGE 4. After 64 hours - ≤ 7 days in 50:50 HCL and in H_2O_2 and NaOH.

Blow fly puparia. Mottled and transparent, yellow (10YR 7/6) with areas of red (2.5YR 4/6).
Blow fly adults. The flies are all red (2.5YR 4/6, 4/8, 5/8) and yellowish red (5YR 4/6).
***Tenebrio* mealworm.** Pale and flexible, the cuticle is strong brown (7.5YR 5/6) and yellow (10YR 8/8).
***Tenebrio* adults.** Very slightly paler than previous stage, the predominant colour is yellowish red (5YR 5/8), although

darker red and reddish brown colours are maintained on the more highly tanned areas (e.g. pronotum, head and legs).

Stage 5. After 7 - <18 days in 50:50 HCl and H_2O_2, and ≥ 7 - ≥ 28 days in cold NaOH.

Blow fly puparia. All are transparent and flexible, and yellow (2.5Y 8/8 and 8/6).
Blow fly adults. Transparent, flexible and yellow (2.5YR 7/6).
***Tenebrio* mealworms.** Also yellow (2.5Y 7/6), transparent and flexible.
***Tenebrio* adults.** The beetle elytra are considerably paler and redder (2.5YR 4/8) and slightly transparent, and the less robust sclerites are strong brown (7.5YR 5/6).

Stage 6. After 28 days in cold NaOH followed by 1hr boiling in NaOH.

Blow fly puparia. These are very similar to those of stage 5. Transparent, but mottled reddish yellow (7.5YR 6/8), brownish yellow and yellow (10YR 6/8, 7/8).
Blow fly adults. Again similar to stage 5. The flies are yellow (10YR 7/8), brownish yellow (10YR 6/6) and very pale brown (10YR 8/4).
***Tenebrio* mealworms.** Transparent and yellow (10YR 7/8) or pale yellow (2.5Y 8/4).
***Tenebrio* adults.** The more robust elements are now strong brown (7.5YR 5/8) and yellowish red (5YR 4/6, 5/6), while the elytra are yellowish brown (10YR 5/8) and brownish yellow (10YR 6/6).

Stage 7. After 18 days in 50:50 HCl and H_2O_2.

All the cuticle is completely transparent, flexible and white (2.5Y 8/2) or pale yellow (2.5Y 8/4). The only exceptions are the *Tenebrio* adult beetle legs, which are still yellowish red (5YR 5/8) and red (2.5YR 5/8), and the pronota which have slight reddish tinges.

Appendix 2.3 Insect Disarticulation Stages.

To provide reference stages for insect disarticulation and fragmentation the results of all the experiments involving insect disarticulation under "natural" conditions (in this case meaning without external force being applied) were utilised. In general all the experiments described under the heading "weathering" (Chapter 6) gave comparable disarticulation stages, it was just the rate of disarticulation that differed.

Stages of Insect Disarticulation

Based on the stages observed in the weathering, wet/dry and freeze/thaw experiments. Colours natural or darkened throughout.

STAGE 0

Fresh material. Complete.

STAGE 1.

Blow fly Puparia. More than half are intact, some are "squashed" and/or cracked or torn.
Blow fly adults. Most heads are separate. Many thoraces and abdomens are articulated, but several abdomens may be separate and fragmented into individual sclerites. Hairs visible. Most legs disarticulated into one or two elements.
***Tenebrio* mealworms.** Shrivelled and generally in several pieces.
***Tenebrio* adults.** Most heads and most prothoraces separate, although several heads may be still articulated with the prothoraces. A few elytra may be disarticulated. A proportion of the legs are disarticulated, but most have two or three articulated elements.

STAGE 2.

Blow fly puparia. Brittle. More than half are broken, usually into two pieces.
Blow fly adults. All flies are disarticulated. Most heads are cracked, Several thoraces are cracked, some hairs remain visible. All abdomens are disarticulated, and some individual sclerites may be fragmented. The legs are often completely disarticulated.
***Tenebrio* mealworms.** Generally in two or three pieces, with many individual head capsules.
***Tenebrio* adults.** Many elytra are separate, a small number are torn. Some elytra have inner wings intact. All heads and prothoraces are separate. More than half the abdomen

have all sternites and tergites intact, the rest are disarticulated into two or more pieces. Several of the meso- and metathoraces and nota are disarticulated from the abdomen, but about half the meso- and metathoraces are articulated, some with the meso- and metanotum. Several trochanters are disarticulated, and legs are generally disarticulated into articulated pairs of femora and tibiae.

STAGE 3.

Blow fly puparia. More than half are broken, many into three or more pieces. Most are brittle and may be darker than when fresh.
Blow fly adults. About half the heads and half the thoraces are completely fragmented and unidentifiable. Most of the abdomens have broken up, leaving occasional recognisable abdominal sternites. Most leg elements are separate, and many have disintegrated.
***Tenebrio* mealworms.** Generally in groups of 2-5 segments. Most head capsules separate.
***Tenebrio* adults.** Most elytra are separate, and a proportion may be torn. Several mesonota are torn, and *less than half* the abdomen have all sternites articulated together. The pygideum and anal sternite are frequently separate. Most trochanters and a few coxae are separate.

STAGE 4.

Blow fly puparia. Most or all are broken, less than half are identifiable.
Blow fly adults. Increasingly fragmented. Less than one third of the original assemblage are represented by identifiable pieces
***Tenebrio* mealworms.** Head capsules separate. Body segments thin and papery, many torn, most in groups of 2, 3 or 4 segments.
***Tenebrio* adults.** The episterna are starting to become disarticulated from the main body, as the abdomen and meso- and metathorax and notum *disarticulate further. Many* separate metanota are torn. Several internal struts are disarticulated. The legs generally in groups of articulated tibiae and femora, individual trochanters and some coxae have separated.

STAGE 5.

Blow fly adults. Very little remaining. Several fragments of abdominal tergites, thorax and legs survive.
***Tenebrio* mealworms.** About 2/3 of the head capsules identified. Body segments are very papery and generally individual, or in groups of 2-4.
***Tenebrio adults*.** Increasing numbers of episterna have disarticulated, and many internal struts, or fragments of strut can be observed. Most metathoraces and mesothoraces are still joined together. Legs as before. All or most of the heads, prothoraces and elytra are still identifiable, although a small proportion of elytra and prothoraces may be torn.

STAGE 6.

***Tenebrio* adults.** Most abdomens are completely disarticulated. Many identifiable, separate metanota are torn, and most abdominal sternites are in groups of two or three, or individual. Several episterna are torn, as are several metathoraces. Many femurs and tibiae are separate, and increasing numbers of coxae are disarticulated.

APPENDIX 3.1
Descriptive Statistics for Weight Loss by Temperature of Heating (in degrees C): experiment 1.

	Temp.	No	MEAN	MEDIAN	STANDARD DEVIATION	STANDARD ERROR
sheep	200	10	14.14	13.44	3.38	1.07
	300	10	46.96	49.27	8.02	2.54
	400	10	61.28	64.86	7.07	2.23
	500	10	64.26	65.74	5.56	1.76
	600	10	61.30	60.93	4.10	1.30
	700	10	64.86	67.44	6.49	2.05
	800	10	65.56	68.42	8.14	2.57
	900	10	62.60	63.55	4.27	1.35

	Temp.	MINIMUM	MAXIMUM	QUARTILE 1	QUARTILE 3
sheep	200	10.05	21.42	11.90	16.35
	300	35.18	56.92	38.78	54.66
	400	45.71	67.05	58.14	66.03
	500	54.56	71.22	59.47	69.34
	600	53.88	66.77	58.26	65.14
	700	50.20	72.15	60.94	69.61
	800	50.79	73.47	56.87	72.22
	900	56.21	68.32	57.59	65.75

	Temp.	No	MEAN	MEDIAN	STANDARD DEVIATION	STANDARD ERROR
pigeon	200	10	9.80	10.11	2.99	0.95
	300	10	33.46	33.33	6.87	2.17
	400	10	42.24	45.67	13.20	4.17
	500	10	48.01	48.06	5.54	1.75
	600	10	58.24	55.42	10.66	3.37
	700	10	57.95	57.69	4.06	1.28
	800	10	59.76	59.54	9.93	3.14
	900	10	55.99	56.19	5.82	1.84

	Temp.	MINIMUM	MAXIMUM	QUARTILE 1	QUARTILE 3
pigeon	200	5.52	13.90	6.93	12.92
	300	22.71	46.37	29.76	38.03
	400	22.22	59.86	29.74	53.11
	500	41.17	55.29	42.59	52.95
	600	44.25	77.27	51.77	64.06
	700	50.13	65.44	55.67	60.51
	800	44.87	73.83	51.65	70.74
	900	47.73	63.65	49.50	61.49

	Temp.	No	MEAN	MEDIAN	STANDARD DEVIATION	STANDARD ERROR
cod	200	10	10.69	11.11	2.72	0.86
	300	10	23.64	22.15	5.54	1.75
	400	10	34.20	34.49	2.22	0.70
	500	10	39.93	40.33	4.22	1.33
	600	10	42.28	41.57	2.86	0.90
	700	10	46.12	46.92	4.96	1.57
	800	10	46.14	46.48	3.03	0.96
	900	10	46.62	47.54	3.20	1.01

	Temp.	MINIMUM	MAXIMUM	QUARTILE 1	QUARTILE 3
cod	200	6.19	15.60	8.61	12.29
	300	16.33	31.01	18.94	30.09
	400	30.49	37.02	32.58	36.03
	500	33.42	45.08	36.84	44.59
	600	37.98	46.91	40.23	45.29
	700	40.00	52.93	41.10	50.25
	800	41.53	51.82	43.96	47.71
	900	41.14	51.25	43.65	48.75

	Temp.	No	MEAN	MEDIAN	STANDARD DEVIATION	STANDARD ERROR
haddock	200	10	10.49	11.72	3.38	1.07
	300	10	28.33	28.23	6.25	1.98
	400	10	30.70	30.31	4.35	1.37
	500	10	40.27	40.38	4.30	1.36
	600	10	40.90	40.81	2.88	0.91
	700	10	39.91	39.21	2.74	0.87
	800	10	41.37	40.97	1.51	0.48
	900	10	44.54	42.81	6.30	1.99

	Temp.	MINIMUM	MAXIMUM	QUARTILE 1	QUARTILE 3
haddock	200	4.81	15.60	6.97	12.53
	300	21.36	42.86	22.37	31.15
	400	25.00	36.90	26.36	34.64
	500	33.33	47.67	36.87	43.42
	600	35.77	44.91	38.96	44.05
	700	36.07	45.56	38.27	41.15
	800	39.17	43.98	40.32	42.93
	900	40.35	62.01	41.75	44.28

	Temp.	No	MEAN	MEDIAN	STANDARD DEVIATION	STANDARD ERROR
plaice	200	10	10.54	11.66	3.12	0.99
	300	10	26.70	25.70	3.56	1.13
	400	10	44.95	46.35	9.40	2.97
	500	10	49.84	50.88	8.58	2.71
	600	10	53.55	54.28	3.64	1.15
	700	10	54.74	55.38	4.48	1.42
	800	10	54.09	54.58	5.02	1.59
	900	10	55.53	55.34	3.06	0.97

	Temp.	MINIMUM	MAXIMUM	QUARTILE 1	QUARTILE 3
plaice	200	5.41	15.71	8.28	12.19
	300	23.56	35.71	24.50	28.17
	400	23.08	54.29	41.31	53.10
	500	32.53	64.00	44.28	55.29
	600	46.64	58.43	51.11	56.60
	700	46.79	61.57	50.94	57.66
	800	47.21	60.67	49.31	58.55
	900	50.65	60.36	53.23	57.58

	Temp.	No	MEAN	MEDIAN	STANDARD DEVIATION	STANDARD ERROR
salmon	200	10	17.45	16.57	5.27	1.67
	300	10	42.40	42.67	4.31	1.36
	400	10	55.23	52.35	5.02	1.59
	500	10	56.44	56.72	7.26	2.30
	600	10	60.11	59.03	4.74	1.50
	700	10	62.96	62.89	5.26	1.66
	800	10	64.09	62.03	6.19	1.96
	900	10	67.29	66.00	5.71	1.81

	Temp.	MINIMUM	MAXIMUM	QUARTILE 1	QUARTILE 3
salmon	200	8.52	26.32	14.52	20.97
	300	36.62	50.26	38.56	45.64
	400	50.43	63.77	51.52	59.11
	500	47.34	67.10	48.00	62.89
	600	53.77	67.90	56.59	65.26
	700	55.05	74.15	59.87	64.79
	800	59.71	80.80	60.41	65.02
	900	61.37	81.74	63.69	69.14

	Temp.	No	MEAN	MEDIAN	STANDARD DEVIATION	STANDARD ERROR
herring	200	10	12.67	11.45	4.19	1.33
	300	10	27.66	31.17	8.96	2.83
	400	10	39.81	39.23	10.80	3.42
	500	10	53.55	54.35	8.23	2.60
	600	10	56.47	54.72	13.57	4.29
	700	10	52.64	49.74	8.82	2.79
	800	10	61.35	62.50	8.10	2.56
	900	10	55.72	55.22	11.12	3.52

	Temp.	MINIMUM	MAXIMUM	QUARTILE 1	QUARTILE 3
herring	200	6.66	19.35	9.18	16.88
	300	16.00	37.78	18.13	35.99
	400	22.22	57.65	32.23	48.49
	500	36.67	63.16	46.93	60.44
	600	37.50	75.21	46.13	70.31
	700	40.41	68.58	46.40	61.31
	800	48.04	70.83	54.69	68.75
	900	32.70	72.01	49.86	62.80

	Temp.	No	MEAN	MEDIAN	STANDARD DEVIATION	STANDARD ERROR
frog	200	10	14.35	14.72	4.67	1.48
	300	10	31.87	32.10	6.32	2.00
	400	10	43.11	44.78	8.89	2.81
	500	10	54.87	54.49	7.21	2.28
	600	10	52.64	51.10	10.22	3.23
	700	10	52.37	52.51	6.59	2.08
	800	10	58.34	58.97	7.36	2.33
	900	10	55.03	55.74	8.98	2.84

	Temp.	MINIMUM	MAXIMUM	QUARTILE 1	QUARTILE 3
frog	200	7.00	20.00	9.76	18.50
	300	21.23	40.28	26.40	37.42
	400	23.08	56.52	37.59	47.85
	500	46.51	68.48	48.28	59.37
	600	42.47	74.55	43.76	59.73
	700	43.64	61.79	45.16	57.45
	800	43.08	70.17	54.02	62.67
	900	41.71	68.42	47.24	61.89

APPENDIX 3.2. Descriptive statistics for weight loss in bone after degreasing and ashing.

WEIGHT LOSS AFTER DEGREASING

TAXON	No	MEAN	MEDIAN	STANDARD DEVIATION	STANDARD ERROR
Sheep	10	7.685	7.525	2.908	0.920
Pigeon	10	14.31	14.89	7.80	2.47
Frog	10	9.06	8.94	3.50	1.11
Salmon	10	22.78	22.96	4.94	1.56
Plaice	10	24.85	25.86	5.25	1.66
Herring	10	23.37	22.85	6.45	2.04
Cod	10	3.675	3.615	2.290	0.724
Haddock	10	5.232	4.650	2.709	0.857
Dogfish	10	9.054	9.105	2.799	0.885
Carp	10	21.85	22.80	5.84	1.85

	MINIMUM	MAXIMUM	QUARTILE 1	QUARTILE 3
Sheep	3.72	11.80	4.61	10.95
Pigeon	3.28	24.58	5.33	21.95
Frog	4.29	16.15	5.77	11.16
Salmon	15.72	29.44	18.10	27.23
Plaice	16.15	31.20	20.74	28.39
Herring	11.22	33.10	19.32	28.45
Cod	1.23	8.42	1.59	5.14
Haddock	1.03	9.17	3.14	8.00
Dogfish	4.68	13.21	6.44	11.82
Carp	12.66	29.11	17.11	27.57

WEIGHT LOSS AFTER ASHING

TAXON	No	MEAN	MEDIAN	STANDARD DEVIATION	STANDARD ERROR
Sheep	10	33.59	33.75	3.56	1.13
Pigeon	10	37.18	37.72	3.94	1.25
Frog	10	43.22	44.92	5.70	1.80
Salmon	10	47.47	46.31	1.91	0.61
Plaice	10	41.15	40.98	2.46	0.78
Herring	10	48.56	48.05	5.34	1.69
Cod	10	38.95	37.31	3.64	1.15
Haddock	10	37.62	37.03	5.23	1.65
Dogfish	10	63.34	63.56	5.92	1.37
Carp	10	53.47	52.75	5.78	1.83

	MINIMUM	MAXIMUM	QUARTILE 1	QUARTILE 3
Sheep	26.21	38.68	31.39	36.72
Pigeon	30.61	42.86	34.61	39.92
Frog	33.33	49.40	38.20	48.24
Salmon	45.36	50.00	45.73	49.57
Plaice	36.36	45.35	39.36	42.76
Herring	40.35	57.58	44.57	52.42
Cod	34.21	44.09	35.92	43.01
Haddock	29.52	45.63	33.04	42.90
Dogfish	52.00	72.00	60.10	67.65
Carp	42.75	63.19	50.22	58.00

WEIGHTS BEFORE AND AFTER ASHING (grams) AND % MINERAL COMPONENT

	No	ORIG WT.	FINAL WT.	% MINERAL
Sheep	10	0.518	0.318	64.4
Pigeon	10	0.500	0.271	54.2
Frog	10	0.488	0.251	51.4
Salmon	10	0.519	0.211	40.7
Plaice	10	0.504	0.223	44.3
Herring	10	0.481	0.196	40.8
Cod	10	0.492	0.287	58.3
Haddock	10	0.497	0.325	65.4
Dogfish	10	0.498	0.166	33.3
Carp	10	0.501	0.193	38.5

APPENDIX 3.3

Table of Mean Volumes (cubic cms), Weight (g.) and Density (ml) of cod bones. Fish total length 1.09 m (except hyomandibular and frontal from a fish of total length 0.67 m.)

	Volume	Weight	Density	Rank
Otolith	0.15	0.36	2.40	37
Ectopterygoid	1.0	1.48	1.48	36
Subopercular	2.0	2.06	1.38	35
Interopercular	1.0	1.33	1.33	33.5
Urohyal	0.6	0.80	1.33	33.5
Postcleithrum	0.8	1.05	1.31	32
Cleithrum	6.5	8.45	1.30	31
Maxilla	3.0	3.87	1.29	30
Ceratohyal	4.3	5.47	1.27	29
Dentary	5.0	6.23	1.25	28
Basipterygium	0.5	0.43	1.21	27
Parasphenoid	5.0	5.98	1.20	26
Epihyal	1.8	2.13	1.18	24.5
Palatine	1.0	1.18	1.18	24.5
Symplectic	1.1	1.28	1.16	23
Supraoccipital	2.5	2.88	1.15	22
Premaxilla	3.0	3.45	1.15	20.5
Prevomer	2.0	2.30	1.15	20.5
Hypohyal	0.9	1.02	1.14	18
Infrapharyngeal	0.5	0.57	1.14	18
Scapula	0.8	0.70	1.14	18
Ethmoid	2.0	1.85	1.08	16
Caudal vert.	0.92	0.99	1.07	15
Posttemporal	1.5	1.59	1.06	13.5
Quadrate	2.0	2.11	1.06	13.5
Lacrimal	1.5	1.58	1.05	12
Supracleithrum	2.1	2.18	1.04	10.5
Suprapharyngeal	0.25	0.26	1.04	10.5
Articular	4.3	4.41	1.03	9
Coracoid	0.6	0.60	1.00	8
Abdominal vert.	3.3	3.00	0.91	7
Basioccipital	6.0	5.29	0.88	6
Opercular	2.5	2.13	0.85	4.5
Preopercular	5.0	4.27	0.85	4.5
Hyomandibular	1.3	0.93	0.72	2.5
Frontal	2.5	1.80	0.72	2.5
Prefrontal	0.6	0.42	0.70	1
Haddock cleithrum (fish 0.47 m)	1.0	1.35	1.35	

Appendix 3.3

Table of Mean Volumes (cubic cms), Weight (g.) and Density (ml) of cod bones. Fish total length 0.63m.

	Volume	Weight	Density	Rank
Otolith	0.15	0.36	2.40	37
Ectopterygoid	0.15	0.27	1.80	34
Supraoccipital	0.7	0.57	0.81	5
Subopercular	0.3	0.39	1.30	26
Interopercular	0.25	0.28	1.11	17
Urohyal	0.15	0.19	1.25	24.5
Postcleithrum	0.15	0.18	1.20	22.5
Cleithrum	1.0	1.70	1.70	32
Maxilla	0.53	0.97	1.83	36
Ceratohyal	1.05	1.19	1.13	19.5
Dentary	1.0	1.43	1.43	30
Basipterygium	0.05	0.09	1.80	34
Parasphenoid	1.8	1.79	0.99	11
Frontal	3.0	2.11	0.70	1
Epihyal	0.4	0.37	0.93	8.5
Palatine	0.2	0.25	1.25	24.5
Symplectic	0.2	0.21	1.03	12
Premaxilla	0.6	0.90	1.50	31
Prevomer	0.8	0.60	1.33	28
Hypohyal	0.08	0.11	1.38	29
Infrapharyngeal	0.15	0.16	1.04	13
Scapula	0.05	0.09	1.80	34
Ethmoid	0.3	0.28	0.93	8.5
Caudal vert.	0.25	0.29	1.17	21
Posttemporal	0.25	0.33	1.32	27
Quadrate	0.5	0.44	0.88	7
Lacrimal	0.5	0.38	0.76	3
Supracleithrum	0.25	0.30	1.20	22.5
Suprapharyngeal	0.15	0.16	1.07	15.5
Articular	0.95	1.06	1.12	18
Coracoid	0.09	0.08	0.83	6
Abdominal vert.	0.6	0.64	1.07	15.5
Basioccipital	0.9	0.86	0.96	10
Opercular	0.4	0.45	1.13	19.5
Preopercular	0.85	0.90	1.06	14
Hyomandibular	1.0	0.73	0.73	2
Prefrontal	0.6	0.48	0.79	4

Appendix 3.3

Table of Mean Volumes (cubic cms), Weight (g.) and Density (ml) of cod bones. Fish total length 0.62 m.

	Volume	Weight	Density	Rank
Otolith	0.1	0.33	3.3	37
Ectopterygoid	0.25	0.28	1.12	17.5
Supraoccipital	0.8	0.51	0.63	1.5
Subopercular	0.15	0.30	2.0	33
Interopercular	0.15	0.25	1.66	28.5
Urohyal	0.2	0.19	2.30	36
Postcleithrum	0.15	0.19	1.24	24
Cleithrum	0.95	1.64	1.72	30
Maxilla	0.8	0.92	1.15	19
Ceratohyal	1.0	1.03	1.03	13.5
Dentary	1.0	1.57	1.57	27
Basipterygium	0.05	0.09	1.80	31.5
Parasphenoid	2.0	1.58	0.79	5
Frontal	2.5	1.77	0.71	3
Epihyal	0.25	0.30	1.20	21
Palatine	0.25	0.24	0.96	11
Symplectic	0.2	0.20	1.00	12
Premaxilla	0.5	0.83	1.66	28.5
Prevomer	0.5	0.56	1.12	17.5
Hypohyal	0.05	0.11	2.20	35
Infrapharyngeal	0.15	0.13	0.87	9
Scapula	0.05	0.09	1.80	31.5
Ethmoid	0.4	0.25	0.63	1.5
Caudal vert.	0.2	0.24	1.22	22
Posttemporal	0.3	0.32	1.06	16
Quadrate	0.5	0.43	0.86	8
Lacrimal	0.25	0.35	1.40	26
Supracleithrum	0.25	0.26	1.04	15
Suprapharyngeal	0.06	0.08	1.36	25
Articular	0.5	1.01	2.01	34
Coracoid	0.15	0.19	1.23	23
Abdominal vert.	0.5	0.59	1.18	20
Basioccipital	1.0	0.83	0.83	7
Opercular	0.4	0.32	0.80	6
Preopercular	0.95	0.90	0.95	10
Hyomandibular	0.8	0.62	0.78	4
Prefrontal	0.4	0.41	1.03	13.5

Appendix 3.3

Table giving saturated weight (in air) (wsat), dry weight (wa) and total porosity (fp) of cod bones. Fish total length = 0.62 m.

Bone	wsat	wa	fp	%bone:pore	Rank
Otolith	0.36	0.34	0.02	94.44	1
Cleithrum	2.42	1.63	0.79	68.41	2
Maxilla	1.35	0.93	0.43	68.27	3
Dentary	2.39	1.62	0.77	67.71	4
Subopercular	0.45	0.30	0.15	67.63	5
Ectopterygoid	0.43	0.29	0.15	66.28	6
Premaxilla	1.26	0.83	0.43	66.04	7
Interopercular	0.39	0.26	0.13	65.49	8
Postcleithrum	0.30	0.19	0.11	64.37	9
Articular	1.58	1.01	0.57	64.13	10
Posttemporal	0.52	0.32	0.20	62.29	11
Prevomer	0.91	0.56	0.35	61.54	12
Quadrate	0.71	0.43	0.28	61.00	13
Hypohyal	0.31	0.19	0.12	60.73	14
Opercular	0.53	0.32	0.21	60.00	15
Lacrimal	0.58	0.35	0.24	59.48	16
Nasal	0.20	0.12	0.08	59.13	17
Palatine	0.41	0.24	0.17	58.17	18
Urohyal	0.26	0.15	0.11	57.69	19
Supraoccipital	0.94	0.51	0.43	54.26	20
Infrapharyngeal	0.24	0.13	0.11	53.17	21
Parasphenoid	3.00	1.58	1.42	52.67	22
Supracleithrum	0.51	0.27	0.24	52.49	23
Ceratohyal	1.99	1.03	0.96	51.89	24
Caudal vert.	0.56	0.29	0.27	51.34	25
Symplectic	0.39	0.20	0.19	51.32	26
Ethmoid	0.49	0.25	0.24	51.02	27
Epihyal	0.60	0.31	0.30	50.84	28
Metapterygoid	0.23	0.11	0.12	48.92	29
First vert.	1.58	0.77	0.81	48.73	30
Coracoid	0.19	0.09	0.10	48.69	31
Suprapharyngeal	0.70	0.34	0.36	48.57	32
Hyomandibular	1.30	0.63	0.68	48.08	33
Abdominal vert.	1.31	0.62	0.69	47.33	34
Prefrontal	0.89	0.42	0.47	47.19	35
Preopercular	1.98	0.90	1.08	45.32	36
Scapula	0.24	0.10	0.14	44.47	37
Frontal	4.12	1.77	2.35	42.96	38
Basipterygium	0.23	0.10	0.13	42.50	39
Basioccipital	2.04	0.83	1.21	40.69	40

APPENDIX 5.1 Condition of Insect Remains after Tumbling in 1. Sand and 2. Gravel.

Experiment: Tumbling in sand.
Duration: 300 hours

BEETLES

Original number: 20 Articulation: 5 Colour: 1
Fragmentation: 1

Articulated elements	No: Complete	Torn	Comments
Complete Bodies			
Abdomen+Pronotum/thorax+Elytra			
Elytra + Sternites			
Elytra + Meso+metathorax/notum	1		
Pronotum/thorax - Head	1		
Head	19		
Pronotum/thorax	16	3	some - legs
Elytra	35	3	
All Abdominal Sternites	10		
2-4 Abdominal Sternites	10		
1 Abdominal Sternite or Pygideum.	6		
Meso + Metathorax	13		sev.-e.sterna
Meso + Metanotum	6		
Mesothorax	5	2	
Metathorax	4	3	
Mesonotum	13		
Metanotum	8		
Episternum 2	16		
Episternum 3	21		
Complete legs (estimated no.)	40		
2 leg elements (estimated no.)	40		
Single leg elements (est. no.)	60		
Coxae (est.)	40		
Trochanters	6		
Internal Strut	4	2	

Comments: also several wing fragments.

FLIES

Original No: 20 Articulation: 5 Colour: 1
Fragmentation: 5

Articulated elements No:	Complete	Torn	Comments
Complete Bodies			
Abdomen + Thorax			
Thorax			
Abdomen			
Head	12	4	
Individual Abdominal Sclerites		8	
Thorax fragments	11	-	
2+ leg elements (estimated no.)		-	
Single leg elements (est. no.)	20		

Comments:

FLY PUPARIA

Original no: 20 Colour: 1 (or darkened) Fragmentation: 4

State	Number
Complete	
Squashed but complete	
Cracked but complete	4
Squashed, cracked but complete	
In 2 parts	15
In 3+ parts	1

MEALWORMS Original no: 20

State	Number
Complete	2
6+ segments including head capsule	6
3-5 segments including head capsule	8
1-2 segments including head capsule	4
1-2 segments without head capsule	7
3-6 segments without head capsule	11
6+ segments without head capsule	2

Experiment: Tumbling in gravel.
Duration: 300 hours

BEETLES

Original number: 20 Articulation: 7 Colour: 2
Fragmentation: 3

Articulated elements No:	Complete	Torn	Comments
Complete Bodies			
Abdomen+Pronotum/thorax+Elytra			
Elytra + Sternites			
Elytra + Meso+metathorax/notum			
Pronotum/thorax + Head			
Head	19	1	
Pronotum/thorax	17	3	
Elytra	27	10	some abraded
All Abdominal Sternites	1		
2-4 Abdominal Sternites	16	5	
1 Abdominal Sternite or Pygideum	12	15	
Meso + Metathorax	3	5	
Meso + Metanotum			
Mesothorax	11	2	
Metathorax	7	2	
Mesonotum	19	1	
Metanotum	0	2	
Episternum 2	32		
Episternum 3	30		
Complete legs (estimated no.)			
2 leg elements (estimated no.)	50		
Single leg elements (est. no.)	100		
Coxae (est.)	70		
Trochanters (est)	10		
Internal Strut			

Comments:

FLIES

Original No: 20 Articulation: - Colour: - Fragmentation: 5

Articulated elements	No:	Complete	Torn	Comments
Complete Bodies				
Abdomen + Thorax				
Thorax				
Abdomen				
Head				
Individual Abdominal Sclerites				
Thorax fragments			-	
2+ leg elements (estimated no.)			-	
Single leg elements (est. no.)			-	

Comments: nothing left!

FLY PUPARIA

Original no: 20 Colour: 1 (or darkened) Fragmentation: 5

State	Number
Complete	
Squashed but complete	
Cracked but complete	
Squashed, cracked but complete	
In 2 parts	
In 3+ parts	4 torn frags

MEALWORMS Original no: 20

State	Number
Complete	
6+ segments including head capsule	
3-5 segments including head capsule	
1-2 segments including head capsule	11
1-2 segments without head capsule	3
3-6 segments without head capsule	2
6+ segments without head capsule	

APPENDIX 5:2 TABLES TO ACCOMPANY CHAPTER 5, THE TRAMPLING EXPERIMENT.

Table 5:12

Mean fragment completeness of bones for gadid fish remains after trampling (to nearest 5%)

	Cod (n=3)				Haddock (n=7+)		
	Shape	No	Exp	Mean %	No	Exp	Mean %
Ethmoid	I	3	3	100	7	7	95
Frontal	F	5	3	55	5	7	45
Prefrontal	I	3	6	50	7	14	45
Supraoccipital	I	3	3	80	6	7	60
Prevomer	R	4	3	75	10	14	45
Parasphenoid	I	4	3	65	6	7	45
Basioccipital	S	3	3	90	6	7	70
Premaxilla	R	6	6	100	31	28	90
Maxilla	R	6	6	95	28	28	75
Dentary	R	6	6	90	27	28	70
Articular	R	6	6	75	28	28	80
Quadrate	R	6	6	90	33	28	90
Hyomandibular	I	5	6	60	25	28	65
Symplectic	F	6	6	100	12	14	80
Lacrimal	F	2	6	30	5	14	30
Nasal	I	2	6	35	5	14	30
Preopercular	F	6	6	70	30	28	70
Opercular	F	5	6	75	28	28	70
Subopercular	F	4	6	60	7	14	50
Interopercular	F	5	6	75	11	14	60
Palatine	R	5	6	80	14	14	95
Ectopterygoid	F	4	6	65	12	14	65
Entopterygoid	F	0	0	0	0	0	0
Metapterygoid	F	0	0	0	5	14	35
Epihyal	F	6	6	100	14	14	95
Ceratohyal	F	6	6	90	27	28	85
Hypohyal	R	9	12	75	27	28	95
Infrapharyngeal	I	3	6	50	21	14	75
Suprapharyngeal	I	6	18	30	18	42	40
Urohyal	F	3	3	90	5	7	70
Posttemporal	R	6	6	100	13	14	90
Cleithrum	I	6	6	95	41	26	45
Supracleithrum	R	6	6	100	14	14	100
Postcleithrum	F	4	6	55	9	14	50
Scapula	F	0	6	0	11	14	80
Coracoid	F	2	6	30	2	14	10
Basipterygium	F	4	6	65	2	14	10
First vert.	S	3	3	100	7	7	90
Abdominal vert.	S	49	54	85	119	126	95
Caudal vert.	S	67	84	80	169	182	90
Ultimate vert.	S	1	3	15	1	7	10
Otolith	F	2	6	50	12	14	50
Mean		282	357	67	860	978	63

* where there were more fragments recovered than the number of bones expected. due to several fragments coming from the same bone (usually easy to tell from the record which gives the position of fragment) the fragment completeness scores from each bone were averaged to give one figure for %bone. Where this was not possible e.g. for otoliths. the average value = the sum of the fragment completeness scores divided by the number of fragments recorded.

Shape : R = Robust. F = Flat. I = Irregular. S = Spherical.
No = Number of fragments recovered.
Exp. = Number of bones expected.
Mean % = Mean of all the fragment completeness scores for each skeletal element.

Table 5:13

Number of identified bones, expected number of bones and mean fragment completeness (to nearest 5%) of plaice bones after trampling (n=6+).

	Shape	No	Exp	Mean %
Frontal	R	5	12	40
Prefrontal	I	4	12	30
Supraoccipital	I	2	6	30
Prevomer	R	4	6	65
Parasphenoid	I	4	6	60
Basioccipital	S	6	6	95
Premaxilla	R	22	23	90
Maxilla	R	23	23	95
Dentary	R	26	24	80
Articular	R	23	24	95
Quadrate	R	19	24	70
Hyomandibular	F	21	22	90
Symplectic	F	3	12	20
Preopercular	F	23	24	80
Opercular	F	21	24	70
Subopercular	F	5	12	40
Interopercular	F	11	12	80
Palatine	R	8	12	65
Ectopterygoid	F	5	12	40
Entopterygoid	F	2	12	15
Metapterygoid	F	1	12	5
Epihyal	F	12	12	100
Ceratohyal	F	22	24	90
Hypohyal	R	12	24	50
Infrapharyngeal	R	12	12	100
Suprapharyngeal	R	15	36	45
Urohyal	F	5	6	80
Posttemporal	R	11	12	90
Cleithrum	I	23	24	75
Supracleithrum	R	12	12	100
Scapula	R	11	12	90
Coracoid	F	1	12	10
Basipterygium	F	10	12	70
First vert.	S	5	6	75
Abdominal vert	S	71	72	85
Caudal vert.	S	169	174	95
Ultimate vert.	S	6	6	95
Otolith	F	12	12	85
Anal pteryg.	R	16	15	90
Total/Mean		663	803	69

* where there were more fragments than the number of bones expected, fragments coming from the same bone (usually easy to tell from the record which gives the position of the fragment) were averaged to give one figure for fragment completeness. Where this was not possible the average value was obtained by dividing the sum of the fragment completeness scores by the number of fragments recorded, rather than by the expected number of fragments.

Shape: R = Robust, F = Flat, I = Irregular, S = Spherical
No = Number of fragments recovered.
Exp = Number of bones expected.
Mean % = Mean fragment completeness, calculated by summing the fragment completeness scores for each skeletal element each skeletal element and dividing by the expected numbers of each skeletal element.

Table 5:14

Nuber of identified fragments, expected number of bones and mean fragment completeness of herring bones (n=7) after trampling (to nearest 5%)

	Shape	No	Exp	Mean%
Ethmoid	I	4	7	55
Frontal	F	1	14	5
Prevomer	I	3	7	45
Parasphenoid	I	5	7	65
Basioccipital	S	4	7	55
Premaxilla	F	1	14	5
Maxilla	R	11	14	70
Supramaxilla	F	13	14	90
Dentary	F	12	14	55
Articular	F	10	14	50
Quadrate	F	8	14	55
Hyomandibular	F	10	14	60
Preopercular	F	7	14	45
Opercular	F	9	14	55
Subopercular	F	3	14	20
Interopercular	F	3	14	20
Ectopterygoid	F	1	14	5
Metapterygoid	I	2	14	10
Epihyal	F	10	14	70
Ceratohyal	F	14	14	100
Urohyal	F	6	7	50
Posttemporal	F	8	14	55
Cleithrum	I	10	14	45
Supracleithrum	F	5	14	35
Scapula	F	0	0	0
Coracoid	I	3	14	35
Basipterygium	F	2	14	30
First vert.	S	7	7	80
Abdominal vert	S	167	168	80
Caudal vert.	S	230	231	90
Ultimate vert.	S	6	7	85
Otolith	F	0	0	0
Otic bulla	S	6	14	60
Total/Mean		581	756	47.9

* where there were more fragments than the number of bones expected, fragments coming from the same bone (usually easy to tell from the record which gives the position of the fragment) were averaged to give one figure for fragment completeness. Where this was not possible the average value was obtained by summing the fragment completeness scores and dividing by the number of fragments recorded.

Shape: R = Robust, F = Flat, I = Irregular, S = Spherical.
No = Number of fragments recovered.
Exp = Number of bones expected.
Mean % = Mean fragment completeness, calculated by summing the fragment completeness scores (recorded as percentages of the complete bone represented by the fragment) for each skeletal element and dividing by the expected number of that skeletal element from n skeletons.

Table 5:15

Mean Fragment Completeness of salmon bones (n=2) after trampling (to nearest 5%).

	Shape	No	Exp	Mean %
Prevomer	I	0	0	0
Parasphenoid	I	1	2	35
Basioccipital	S	2	2	100
Premaxilla	R	0	4	0
Maxilla	R	4	4	90
Dentary	R	4	4	75
Articular	R	4	4	80
Quadrate	R	3	4	75
Hyomandibular	F	3	4	75
Preopercular	F	2	4	40
Opercular	F	1	4	15
Subopercular	F	2	4	50
Interopercular	F	4	4	90
Ectopterygoid	F	1	4	20
Metapterygoid	F	2	4	40
Epihyal	F	4	4	100
Ceratohyal	F	4	4	100
Hypohyal	R	8	8	100
Urohyal	F	2	2	90
Posttemporal	F	3	4	75
Cleithrum	I	1	4	10
Supracleithrum	F	4	4	90
Scapula	F	4	4	75
Coracoid	F	3	4	60
Innominate	I	3	4	75
Atlas vert.	S	2	2	90
Abdominal vert	S	52	52	80
Caudal vert.	S	54	54	90
Ultimate vert.	S	2	2	90

* where there were more fragments than the expected number of bones, fragments coming from the same bone (usually easy to tell from the record which gives the area of the fragment) the fragments were averaged to give one figure for %bone.

Shape : R = Robust, F = Flat, I = Irregular, S = Spherical.
No = Number of fragments recovered.
Exp = Number of bones expected.
Mean % = Calculated by summing all the fragment sizes for each skeletal element (recorded by the percentage of the whole bone represented by the fragment) and dividing by the expected number of that skeletal element in n skeletons.

Table 5:16

Numbers of identified fragments, expected numbers of bones and mean fragment completeness (%) of bones after trampling (to nearest 5%).

		Rat (n=3)				Mouse (n-4)			
	Shape	No	Exp.	Mean %	Mean % based on recovered frags only	No	Exp.	Mean %	Mean % based on recovered frags only.
Mandible	F	7	6	80	80	12	8	80	80
Scapula	F	6	6	65	65	6	8	55	55
Humerus	TU	5	6	75	75	8	8	95	95
Radius	TU	6	6	100	100	8	8	100	100
Ulna	TU	6	6	100	100	8	8	80	80
Pelvis	F	6	6	85	85	3	8	35	35
Femur	TU	6	6	95	95	8	8	95	95
Tibio-fibula	TU	7	6	85	85	9	8	85	85
Sacrum	R	3	3	50	50	0	4	0	0
Astragalus	S	6	6	100	100	8	8	100	100
Calcaneum	S	6	6	100	100	7	8	90	100
Cervical vert.	S	24	24	95	95	22	32	65	95
Lumbar/Thoracic v.	S	77	78	85	85	31	104	25	90
Caudal vert.	S	61	63	95	100	47	84	55	100
Metapodials	TU	37	60	60	100	22	80	25	100
Phalanges	SH	91	168	50	100	91	224	40	100
Total/Mean		354	456	83	88	290	608	64	82

Shape : F = Flat, TU = Tubular, R= Robust, S = Spherical, SH = Short.

No = number of fragments recovered, not necessarily whole bones.
Exp = Expected number of bones, based on the number of bones in n skeletons.
Mean % = mean fragment completeness, obtained by summing the fragment completeness scores (recorded as percentages of the whole bone represented by the fragment) for each skeletal element and dividing by the expected number of that skeletal element from n skeletons.
Mean % based on recovered fragments only = mean fragment completeness based on recovered, rather than expected, numbers of bones. This figure takes into account the possibility of loss due to retrieval deficiencies.

Table 5:17

Mean fragment completeness of pigeon and frog bones after trampling (to nearest 5%).

	Pigeon (n-2)			
	Shape	No	Exp	Mean %
Mandible	I	6	2	20
Maxilla	I	2	2	70
Scapula	F	5	4	65
Coracoid	F	5	4	60
Humerus	TU	4	4	100
Radius	TU	5	5	95
Ulna	TU	6	4	70
Carpometacarpus	TU	5	4	85
Phalanx Im	F	4	4	100
Sternum	I	2	2	100
Pelvis	F	3	4	55
Synsacrum	R	2	2	95
Femur	TU	4	4	100
Tibiotarsus	TU	8	4	60
Tarsometatarsus	TU	4	4	90
Vertebrae	S	38	38	95
Phalanges	SH	45	56	85*
Total/Mean		148	53	79

	Frog (n-3 + 3 headless)			
	Shape	No	Exp	Mean%
Parieto-frontal	F	2	6	35
Maxilla	F	6	6	80
Humerus	TU	12	12	100
Radio Ulna	F	12	12	85
Femur	TU	10	12	70
Tibio-fibula	TU	12	12	90
Ilium	F	12	12	95
Urostyle	I	6	6	70
Vertebrae	S	54	54	100
Lower limb	TU+SH	181	312	55*
Total/Mean		307	434	78

* These figures are 100% (pigeon) and 90% (frog) if based on the recovered bones only. Expected counts for frog phalanges excludes the tiny ultimate phalange, as these would undoubtedly be lost through the 1 mm mesh. Other phalanges may also have been lost.

Lower limb = Calcaneum, astragalus, metapodials and phalanges.

Shape: R = Robust, F = Flat, I = Irregular, TU - Tubular, S = Spherical, SH - Short.

Mean fragment completeness calculated as detailed in previous tables.

Table 5:18
Numbers, expected numbers and percentage of whole bones for fish remains after trampling.

	Cod			Haddock			Plaice			Herring			Salmon		
n =	3			7			6			7			2		
	no	exp	%whole	no	exp	%whole	no	exp	%whole	no	exp	%whole	no	exp	%whole
Ethmoid	3	3	100	6	7	85.7	-	-	-	3	7	42.9	-	-	-
Frontal	1	3	33.3	3	7	42.9	5	12	41.7	0	14	0	-	-	-
Prefrontal	3	6	50.5	5	14	35.7	4	12	33.3	-	-	-	-	-	-
Supraoccipital	2	3	66.7	2	7	28.6	2	6	33.3	-	-	-	-	-	-
Prevomer	1	3	33.3	1	7	14.3	4	6	66.7	3	7	42.9	0	2	0.0
Parasphenoid	1	3	33.3	1	7	14.3	3	6	50.0	4	7	57.1	0	2	0.0
Basioccipital	3	3	100	5	7	71.4	6	6	100	4	7	57.1	2	2	100
Premaxilla	6	6	100	27	28	96.4	22	23	95.7	1	14	7.1	0	4	0.0
Maxilla	6	6	100	18	28	64.3	23	23	100	6	14	42.9	4	4	100
Supramaxilla	-	-	-	-	-	-	-	-	-	12	14	85.7	-	-	-
Dentary	4	6	66.7	13	28	46.4	21	24	87.5	4	14	28.6	2	4	50.0
Articular	3	6	50.0	17	28	60.7	23	24	95.8	5	14	35.7	2	4	50.0
Quadrate	6	6	100	16	28	57.1	13	24	54.2	5	14	35.8	3	4	75.0
Hyomandibular	2	6	33.3	13	28	46.4	20	22	90.9	8	14	57.1	3	4	75.0
Symplectic	5	6	83.3	10	14	71.4	3	12	25.0	-	-	-	-	-	-
Lacrimal	2	6	33.3	4	14	28.6	-	-	-	-	-	-	-	-	-
Nasal	2	6	33.3	3	14	21.4	-	-	-	-	-	-	-	-	-
Preopercular	3	6	50.0	12	28	42.9	18	24	75.0	6	14	42.9	2	4	50.0
Opercular	5	6	83.3	16	28	57.1	15	24	62.5	7	14	50.0	0	4	0.0
Subopercular	4	6	66.7	7	14	50.0	5	12	41.7	3	14	21.4	2	4	50.0
Interopercular	5	6	83.3	8	14	57.1	7	12	58.3	3	14	21.4	4	4	100
Palatine	5	6	83.3	13	1	92.9	8	12	66.7	-	-	-	3	4	75.0
Ectopterygoid	4	6	66.7	8	14	66.7	5	12	41.7	1	14	7.1	1	4	25.0
Entopterygoid	0	6	0	0	14	0	1	12	8.3	-	-	-	0	0	0
Metapterygoid	0	6	0	5	14	35.7	0	0	0	1	14	7.1	2	4	50.0
Epihyal	6	6	100	14	14	100	12	12	100	10	14	71.4	4	4	100
Ceratohyal	6	6	100	21	28	75.0	21	24	87.5	14	14	100	4	4	100
Hypohyal	9	12	66.7	26	28	92.9	12	24	50.0	1	28	3.6	8	8	100
Infrapharyngeal	3	6	50.0	8	14	57.1	12	12	100	0	14	0.0	-	-	-
Suprapharyngeal	6	18	33.3	15	42	35.7	16	36	44.4	0	42	0.0	-	-	-
Urohyal	2	3	66.7	5	7	71.1	5	6	83.3	3	7	42.9	2	2	100
Posttemporal	6	6	100	13	14	92.9	11	12	91.7	7	14	50.0	3	4	75.0
Cleithrum	6	6	100	7	26	26.9	14	24	58.3	3	14	21.4	0	4	0.0
Supracleithrum	6	6	100	14	14	100	12	12	100	5	14	35.7	4	4	100
Postcleithrum	3	6	100	6	14	42.9	-	-	-	-	-	-	-	-	-
Scapula	2	6	33.3	11	14	78.6	11	12	91.7	0	14	0.0	2	4	100
Coracoid	2	6	33.3	1	14	7.1	0	0	0	4	14	28.6	2	4	50.0
Basipterygium	4	6	66.7	0	14	0	8	12	66.7	5	14	35.8	3	4	75.0
First vert.	3	3	100	7	7	100	5	6	83.3	7	7	100	2	2	100
Abdominal vert	49	54	90.7	119	126	94.4	71	72	98.6	167	168	99.4	52	52	100
Caudal vert.	67	84	79.8	169	182	92.9	169	174	97.1	230	231	99.6	54	54	100
Ultimate vert.	1	3	33.3	1	7	14.3	6	6	100	6	7	85.7	2	2	100
Otolith	2	6	33.3	10	14	71.4	10	12	83.3	0	14	0.0	-	-	-
Anal Ptg.	-	-	-	-	-	-	12	15	80.0	-	-	-	-	-	-
Otic bulla	-	-	-	-	-	-	-	-	-	6	14	42.9	-	-	-

* whole = 80% and over.
No = Number of whole bones recovered
Exp = Expected number of bones.
- = not identified for this species.

Table 5:19

Number, expected number and percentage of whole bones after trampling.

Pigeon (n-2)	Shape	no	exp	%whole
Mandible	I	0	2	0
Maxilla	I	1	2	50.0
Scapula	F	3	4	75.0
Coracoid	F	3	4	75.0
Humerus	TU	4	4	100
Radius	TU	3	4	75.0
Ulna	TU	2	4	50.0
Carpometacarpus	TU	3	4	75.0
Phalanx Im	F	4	4	100
Sternum	I	2	2	100
Pelvis	F	1	4	25.0
Synsacrum	R	2	2	100
Femur	TU	4	4	100
Tibiotarsus	TU	1	4	25.0
Tarsometatarsus	TU	3	4	75.0
Vertebrae	S	38	38	100
Phalanges	SH	45	56	*80.4
Total/Mean		119	146	71

Frog (n= 3 + 3 headless)	Shape	no	exp	%whole
Maxilla	F	2	6	33.3
Humerus	TU	12	12	100
Radio-Ulna	F	11	12	91.7
Femur	TU	9	12	75.0
Tibio-fibula	TU	10	12	83.3
Ilium	F	12	12	100
Urostyle	I	2	6	33.3
Vertebrae	S	54	54	100
Parieto-frontal	F	2	6	33.3
Lower limb	TU+SH	181	312	*58.0
Total/Mean		295	444	71

* this figure is 100% if based on the recovered bones only, rather than the expected number.

No = Number of whole bones recovered (80% complete or more).
Exp = Number of bones from n skeletons.
Expected phalange counts for frog exclude the tiny ultimate phalanges, as these would certainly have passed through a 1 mm mesh. Other phalanges may also have been lost.
Lower limb = Calcaneum, astragalus, metapodials and phalanges.

Table 5:20

Number, expected number and percentage of whole rat (n=3) and mouse (n=4) bones after trampling.

		Rat				Mouse			
	Shape	No	Exp	%whole	%whole based on recovered frags only.	No	Exp	%whole	%whole based on recovered frags only.
Mandible	F	5	6	83.3	83.3	6	8	75.0	75.0
Scapula	F	1	6	16.7	16.7	2	8	25.0	25.0
Humerus	TU	4	6	66.7	66.7	7	8	87.5	87.5
Radius	TU	6	6	100	100	8	8	100	100
Ulna	TU	6	6	100	100	5	8	62.5	62.5
Pelvis	F	3	6	50.0	50.0	2	8	25.0	25.0
Femur	TU	5	6	83.3	83.3	8	8	100	100
Tibio-fibula	TU	5	6	83.3	83.3	7	8	87.5	87.5
Sacrum	R	0	3	0.0	0.0	0	4	0.0	0.0
Astragalus	S	6	6	100	100	8	8	100	100
Calcaneum	S	6	6	100	100	7	8	87.5	100
Cervical vert.	S	19	24	79.2	79.2	19	32	59.4	86.4
Lumbar/Thoracic v.	S	76	78	97.4	98.7	31	104	31.0	100
Caudal vert.	S	61	63	96.8	100	47	84	56.0	100
Metapodials	TU	37	60	61.7	100	22	80	25.0	100
Phalanges	SH	91	168	51.2	100	93	224	41.5	100
Total/Mean		331	456	73.1	78.8	272	608	60.2	78.1

No = number of whole bones (recorded as 80% complete or more) recovered.
Exp = expected number of bones from n skeletons.
%whole = number of whole bones divided by the expected number of bones from n skeletons.
%whole based on recovered frags only = proportion of whole bones based on the number of whoole bones divided by the number of recovered, rather than expected, bones. This figure takes into account the possibility of loss due to retrieval deficiencies.

SHAPE (Count / Row % / Column %)	TAXA: COD	FISH nfi.	FROG	GADID nfi.	HERR-ING	HADD-OCK	MOUSE	PIGEON	PLAICE	RAT	SALMON	Row Total
FLAT	73		32		126	204	21	17	155	19	39	686
	10.6		4.7		18.4	29.7	3.1	2.5	22.6	2.8	5.7	18.4
	24.9		10.4		21.2	22.6	7.2	12.1	23.2	5.3	21.4	
IRREGULAR	35		6		30	137		8	33		8	257
	13.6		2.3		11.7	53.3		3.1	12.8		3.1	6.9
	11.9		2.0		5.1	15.2		5.7	4.9		4.4	
ROBUST	61				11	225		2	220	3	23	545
	11.2				2.0	41.3		.4	40.4	.6	4.2	14.6
	20.8				1.9	24.9		1.4	32.9	.8	12.6	
SPHERICAL	124	1	54	2	426	336	115	38	260	175	112	1643
	7.5	.1	3.3	.1	25.9	20.5	7.0	2.3	15.8	10.7	6.8	44.0
	42.3	100.0	17.6	100.0	71.8	37.3	39.5	27.0	38.9	49.2	61.5	
SHORT			116				93	40		91		340
			34.1				27.4	11.8		26.8		9.1
			37.8				32.0	28.4		25.6		
TUBULAR			99				62	36		68		265
			37.4				23.4	13.6		25.7		7.1
			32.2				21.3	25.5		19.1		
Column Total	293	1	307	2	593	902	291	141	668	356	182	3736
	7.8	.0	8.2	.1	15.9	24.1	7.8	3.8	17.9	9.5	4.9	100.0

FISH = FISH BONES NOT IDENTIFIED TO SPECIES; GADID = HADDOCK OR COD - BONES ONLY IDENTIFIED TO FAMILY LEVEL.

TABLE 5:32 Number and proportion of bones assigned to each shape class: trampling experiment.

APPENDIX 5.3 Condition of Insect Remains after Trampling.

Experiment: Trampling
Duration: 3500 traverses (2 months)

BEETLES

Original number: 30 Articulation: 5/6 Colour: 1
Fragmentation: 4

Articulated elements	No: Complete	Torn	Comments
Complete Bodies			
Abdomen+Pronotum/thorax+Elytra			
Elytra + Sternites			
Elytra + Meso+metathorax/notum			
Pronotum/thorax + Head			
Head	18	8	
Pronotum/thorax		11	
Elytra	1	14	
All Abdominal Sternites	10	3	flattened
2-4 Abdominal Sternites	10	9	
1 Abdominal Sternite or Pygideum	6	6	
Meso + Metathorax		5	
Meso + Metanotum			
Mesothorax	9	3	
Metathorax		8	
Mesonotum	12	3	
Metanotum		4	
Episternum 2	23	5	
Episternum 3	41	6	
Complete legs (estimated no.)			
2 leg elements (estimated no.)	100	20	
Single leg elements (est. no.)	200	20	
Coxae (est.)	100		
Trochanters	44		
Internal Strut		3	

Comments: many groups of sclerites forced inside the abdominal cavity.

FLIES

Original No: 30 Articulation: - Colour: -
Fragmentation: 5

Articulated elements	No:	Complete	Torn	Comments
Complete Bodies				
Abdomen + Thorax				
Thorax				
Abdomen				
Head				
Individual Abdominal Sclerites				
Thorax fragments			-	
2+ leg elements (estimated no.)			-	
Single leg elements (est. no.)				

Comments: nothing survived!

FLY PUPARIA

Original no: 30 Colour: - Fragmentation: 5

State	Number
Complete	
Squashed but complete	
Cracked but complete	
Squashed, cracked but complete	
In 2 parts	
In 3+ parts	

nothing survived!

MEALWORMS Original no: 30

State	Number
Complete	
6+ segments including head capsule	
3-5 segments including head capsule	
1-2 segments including head capsule	2
1-2 segments without head capsule	
3-6 segments without head capsule	1
6+ segments without head capsule	

Appendix 6.1 The Buried Assemblages

During July, August and September 1987 eighteen assemblages comprising a variety of animal remains were buried in soils representing a range of soil conditions including: dry acid sand, acid bog, fen, woodland soil, good quality agricultural soil, clay, calcareous sand, humose soil overlying limestone pavement, calcareous rubble and a compost heap. Each assemblage was placed in a square hole of approximately $1m^3$ by $1m^3$, excavated to a depth of 0.5-1m., depending on the depth of subsoil available, and the difficulty experienced in digging it. The animal corpses used were the same at each site, and comprised:

1 cow's lower limb (metapodial and below), with skin and hoof.
1 sheep's lower limb (" " " " " ".
1 sheep's lower limb (" " "), boiled for 1 1/2 hours.
1 whole rat.
1 whole pigeon.
1 whole cod.
1 whole plaice.
1 whole herring.
1 whole cod, boiled for 1 hour.
1 baked (15 minutes, at 200°C) herring.
1 baked (" " ") plaice.
20 *Tenebrio* adults.
30 *Calliophora vomitans* adults.
30 *Calliophora vomitans* puparia.
8 limpet shells (*Patella vulgata*)
8 periwinkles (*Littorina littorea*)
8 cockle valves (*Cerastoderma edule*)
also: 150 charred wheat grains.

The sizes of the fish are similar to those given in Chapter 2.

The geographical location, soil type, land use, drainage regime, layout of the corpses and soil profile in the excavated hole was recorded using the form illustrated below. The position of each site was marked by a post in the lower right hand corner of the excavated square, and measurements were taken from nearby permanent fixtures to enable the area to be located if the post had been removed. The post was hammered in as far as possible, to try to prevent removal (however to date one has certainly been pulled out). A photograph was taken at each site showing the site in its' local context. The arrangement of the corpses was similar at each site, and a sketch and photograph of their positions was made prior to backfilling the hole (see Plate A6:1). The soil conditions were recorded using the standard terminology of the Soil Survey of England and Wales, and where possible soil series names were obtained. Help in describing soil types was obtained from Bob Palmer of the Soil Survey team in York. The drainage regimes were established at the time of burial, since when two very dry years have been experienced, which will have caused the water table at each site to fluctuate. The pH of small soil samples taken in the field was determined in the laboratory using a standard "Radiometer" pH meter. Details of each site, with soil details, are given below.

It had originally been intended to excavate these assemblages after 30 months, however it became apparent that this would be logistically difficult in the time available for this research. Furthermore, it was felt that more useful results would be obtained if the assemblages were allowed to remain buried for a longer period. It is therefore intended to excavate several sites in 1992 (i.e. after 5 years) and based on the results from these, an assessment will be made of the time-scale for excavating the remaining assemblages.

Soil Descriptions for the Sites used in the Burial Experiments

SITE No.	GENERAL SOIL DESCRIPTION	SOIL SERIES	pH
1	Medium sandy loam, well drained.	Stockbridge	6.3
2	Sandy gley, poorly drained.	Everingham	3.4
3	Fine sand underlying peat, poorly drained.	Everingham	3.8
4	Sand, well drained	-	7.4
5	Sand, well drained	-	8.0
6	Peat, well humified, waterlogged	-	5.3
7	Sphagnum peat, poorly humified, waterlogged.	-	4.5
8	Peat, poorly humified, poorly drained.	-	4.5
9	Fine sandy loam, moderately-poorly drained.	-	7.0
10	Humose sandy loam, poorly drained.	Maw	4.0
11	Sandy loam, well drained.	Rivington	4.5
12	Sandy loam + calcareous rubble, well drained.	-	8.0
13	Sandy loam, moderately well drained.	Wighill	4.7
14	Clay loam + calcareous fragments, moderately drained.	Bishampton	7.0
15	Clay loam (woodland soil), moderate drainage.	Heapy	3.6
16	Chalk rendzina, well drained.	Andover 1	7.6
17	Humic clay loam, moderate-poorly drained (over limestone).	Winter Hill	6.7
18	Humose sandy loam (compost heap)	-	-

NAME OF SITE.

BURIAL SQUARE NO.

DATE.

LANDOWNER.

PERMISSION FROM.

STATUS OF LAND - e.g. PRIVATELY OWNED. SSI. YWT.

GRID REF.

DETAILS OF EXACT POSITION OF SITE. (SEE SKETCH ON REVERSE).

NATURE OF MARKERS.

DIMENSIONS OF SITE: LENGTH WIDTH DEPTH OF BURIAL.

DETAILS OF STRATIGRAPHY.

SOIL TYPE.

DRAINAGE REGIME.

CONDITION OF SOIL AT TIME OF BURIAL: DRY MOIST WET WATERLOGGED.

pH OF DEPOSIT (TAKE 3/4 SAMPLES).

VEGETATION COVER. LIST SPECIES AND INDICATE ABUNDANCE - D=DOMINANT A=ABUNDANT, F=FREQUENT, O=OCCASIONAL, R=RARE.

PRESENT LAND USE.

SURROUNDING LAND.

DETAILS OF REMAINS BURIED AND EXACT POSITIONS IN TRENCH. (DRAW SKETCH).

Plate A6:1

Appendix 6:2 Means, maximum, minimum and standard deviations of values for: 1. Condition, 2. Texture, 3. Flaking, 4. Erosion and 5. Fragment completeness, of disarticulated, identifiable skeletal elements of boiled cod, plaice and herring and baked plaice and herring (excluding otoliths).

Fish	Treatment	Time (weeks)	Measurement	Mean	Max.	Min.	St. Dev.	
Cod	Boiled	16	1	2.5	5.0	1.0	0.90	
			2	0.7	4.5	0	1.00	
			3	0.4	3.0	0	0.77	
			4	3.6	12.0	1.0	2.45	
			5	87	100	30	20.30	
Cod	Boiled	32	1	2.9	5.0	1.0	0.99	
			2	0.6	4.5	0	1.45	
			3	0.8	3.0	0	0.49	
			4	5.0	10.5	1.0	2.70	
			5	87	100	30	21.50	
Cod	Boiled	52	1	2.8	5.0	1.0	0.83	
			2	1.1	5.0	0	1.16	
			3	0.6	3.0	0	0.74	
			4	5.0	13.0	2.0	2.10	
			5	85	100	40	15.04	
Cod	Boiled	64	1	3.4	5.0	2.5	0.55	
			2	1.1	5.0	0	1.44	
			3	1.5	4.5	0	1.06	
			4	5.9	11.0	3.0	2.36	
			5	85	100	50	14.78	
Cod	Boiled	89	1	3.5	5.0	2.5	0.42	
			2	1.5	5.0	0	1.41	
			3	2.0	4.5	0	0.96	
			4	7.0	11.0	3.0	1.99	
			5	85	100	50	13.83	
Cod	Boiled	109	1	4.5	5.0	3.0	0.94	
			2	2.5	5.0	0	1.82	
			3	3.1	5.0	0	1.20	
			4	10.0	5.0	4.0	2.84	
			5	75	100	50	16.79	
Plaice	Boiled	46	1	3.1	4.0	3.0	0.30	
			2	0.3	2.0	0	0.71	
			3	0.5	3.0	0	0.87	
			4	4.0	8.0	3.0	1.48	
			5	88	100	40	12.47	
Plaice	Boiled	75	1	4.0	5.0	3.0	0.43	
			2	1.0	4.0	0	1.15	
			3	1.4	4.0	0	1.20	
			4	6.3	11.0	4.0	2.21	
			5	86	100	50	15.33	
Herring	Boiled	46	1	3.3	4.5	3.0	0.52	*small
			2	0.0	0	0	0.00	sample
			3	0.3	1.0	0	0.52	
			4	4.3	8.0	3.0	1.89	
			5	88	100	70	12.58	
Herring	Boiled	75	1	3.4	4.5	3.0	0.52	
			2	0.1	4.0	0	0.65	
			3	0.4	4.0	0	0.99	
			4	3.9	8.0	2.0	1.50	

Appendix cont'd

			5	85	100	40	13.27
Plaice	Baked	32	1	1.5	3.0	1.0	0.30
			2	0.01	0	0	0.00
			3	0.01	0	0	0.00
			4	1.6	3.0	1.0	0.38
Plaice	Baked	52	1	1.9	3.0	1.0	0.33
			2	0.0	0	0	0.00
			3	0.0	0	0	0.00
			4	1.9	3.0	1.0	0.35
			5	99	100	90	2.62
Plaice	Baked	64	1	2.1	3.0	2.0	0.24
			2	0.0	0	0	0.00
			3	0.0	0	0	0.00
			4	2.1	3.0	2.0	0.23
			5	98	100	90	3.74
Plaice	Baked	89	1	2.2	3.0	2.0	0.30
			2	0.0	0	0	0.00
			3	0.0	0	0	0.00
			4	2.3	3.0	2.0	0.25
			5	98	100	90	3.74
Plaice	Baked	109	1	2.3	3.0	2.0	0.28
			2	0.01	1.0	0	0.11
			3	0.01	1.0	0	0.11
			4	2.4	3.0	2.0	0.24
			5	98	100	90	4.5
Herring	Baked	32	1	2.0	3.0	1.0	0.29
			2	0.01	1.0	0	0.11
			3	0.05	1.0	0	0.22
			4	2.0	5.0	1.0	0.46
			5	97	100	80	4.77
Herring	Baked	52	1	2.2	4.0	2.0	0.36
			2	0.05	2.0	0	0.26
			3	0.1	2.0	0	0.29
			4	2.3	6.5	2.0	0.74
			5	96	100	80	5.99
Herring	Baked	64	1	2.4	4.5	2.0	0.52
			2	0.2	4.0	0	0.62
			3	0.2	3.0	0	0.49
			4	2.7	9.0	2.0	1.31
			5	94	100	50	9.80
Herring	Baked	89	1	2.4	4.5	2.0	0.59
			2	0.4	4.0	0	0.88
			3	0.6	4.0	0	0.82
			4	3.3	9.0	2.0	1.66
			5	94	100	50	12.76
Herring	Baked	109	1	2.3	3.0	2.0	0.43
			2	0.0	1.0	0	0.00
			3	0.1	1.0	0	0.27
			4	2.3	4.0	2.0	0.61
			5	90	100	30	13.82

KEY TO MEASUREMENTS:

1 = Texture; 2 = Erosion; 3 = Flaking; 4 = Condition (the sum of 1-3);
5 = Fragment size (percent of the whole bone that the fragment represents).

APPENDIX 6:3

A comparison of bone and shell dry weights (in grams) before and after surface contact with a range of pH solutions and digestion in pepsin.

	Initial weight	Final Weight	%Weight loss	Mean species %weight loss
pH 2.5				
Sheep metapodial	25.52	23.81	6.7	7
Sheep 2nd phalanx	1.60	1.47	8.1	
Rabbit vertebra	0.19	0.16	15.8	10
Rabbit scapula	0.98	0.87	11.2	
Rabbit femur	3.78	3.71	1.9	
Mouse scapula	0.01	-	100.0	83
Mouse femur	0.03	0.01	66.7	
Pigeon femur	0.64	0.49	23.4	25
Pigeon radius	0.31	0.23	25.8	
Frog femur	0.05	0.02	60.0	60
Cod lacrimal	0.40	-	100.0	89
Cod maxilla	0.85	0.29	65.9	
Cod abdominal vert.	0.60	0.05	91.7	
Cod caudal vert.	0.13	-	100.0	
Haddock lacrimal	0.10	-	100.0	100
Haddock maxilla	0.10	-	100.0	
Haddock abdominal vert.	0.11	-	100.0	
Haddock caudal vert.	0.08	-	100.0	
Salmon hyomandibular	1.06	0.69	34.9	41
Salmon abdominal vert.	1.20	0.69	42.5	
Salmon caudal vert.	0.99	0.54	45.5	
Plaice maxilla	0.07	-	100.0	79
Plaice subopercular	0.08	-	100.0	
Plaice abdominal vert.	0.19	0.08	57.9	
Plaice caudal vert.	0.39	0.16	59.0	
Herring hyomandibular	0.04	-	100.0	100
Herring subopercular	0.01	-	100.0	
Herring abdominal vert.	0.02	-	100.0	
Herring caudal vert.	0.02	-	100.0	
Haddock otolith	0.21	0.17	19.1	
Salmon vert. heated 300C	0.87	0.84	3.5	
Haddock vert. heated 300C	0.05	-	100.0	
Salmon vert. heated 900C	0.37	-	100.0	
Haddock vert. heated 900C	0.06	-	100.0	
Mussel L. valve	2.67	2.62	1.9	4
Mussel R. valve	2.46	2.30	6.5	
Periwinkle	1.96	1.92	2.0	2
Periwinkle	2.24	2.21	1.3	

	Initial Weight	Final Weight	%Weight loss	Mean species %weight loss
pH 5.0				
Sheep metapodial	36.48	35.20	3.5	5
Sheep 2nd phalanx	2.34	2.21	5.6	
Rabbit vertebra	0.25	0.24	4.0	4
Rabbit scapula	1.49	1.39	6.7	
Rabbit femur	5.12	5.05	1.4	
Mouse scapula	0.007	0.001	85.7	46
Mouse femur	0.014	0.013	7.1	
Pigeon femur	0.56	0.52	7.1	8
Pigeon radius	0.45	0.41	8.9	
Frog femur	0.07	0.05	28.6	29
Cod lacrimal	0.08	0.07	12.5	9
Cod maxilla	0.94	0.88	6.4	
Cod abdominal vert.	0.43	0.39	9.3	
Cod caudal vert.	0.25	0.23	8.0	
Haddock lacrimal	0.08	0.07	12.5	12
Haddock maxilla	0.10	0.08	20.0	
Haddock abdominal vert.	0.09	0.08	11.1	
Haddock caudal vert.	0.09	0.087	3.3	
Salmon hyomandibular	0.94	0.57	39.4	24
Salmon abdominal vert.	1.39	1.17	15.8	
Salmon caudal vert.	1.17	0.98	16.2	
Plaice maxilla	0.11	0.08	27.3	18
Plaice subopercular	0.16	0.14	12.5	
Plaice abdominal vert.	0.18	0.15	16.7	
Plaice caudal vert.	0.18	0.15	16.7	
Herring hyomandibular	0.03	0.02	33.3	61
Herring subopercular	0.01	0.004	60.0	
Herring abdominal vert.	0.02	0.01	50.0	
Herring caudal vert.	0.02	-	100.0	
Haddock otolith	0.23	0.23	0.0	
Salmon vert. 300C	0.57	0.55	3.5	
Haddock vert. 300C	0.02	0.02	0.0	
Salmon vert. 900C	0.40	-	100.0	
Haddock vert. 900C	0.03	-	100.0	
Mussel L. valve	4.33	4.43	-2.3	-3
Mussel R. valve	4.23	4.35	-2.8	
Periwinkle	1.85	1.98	-7.0	-8
Periwinkle	2.22	2.41	-8.6	

	Initial Weight	Final Weight	%Weight loss	Mean species %weight loss
pH 7.0				
Sheep metapodial	26.34	25.45	3.4	5
Sheep 2nd phalanx	1.69	1.58	6.5	
Rabbit vertebra	0.20	0.18	10.0	7
Rabbit scapula	0.61	0.55	9.8	
Rabbit femur	4.14	4.04	2.4	
Mouse scapula	0.01	0.01	0.0	0
Mouse femur	0.02	0.02	0.0	
Pigeon femur	0.64	0.58	9.4	11
Pigeon radius	0.40	0.35	12.5	
Frog femur	0.08	0.07	12.5	13
Cod lacrimal	0.37	0.29	21.6	20
Cod maxilla	0.85	0.69	18.8	
Cod abdominal vert.	0.66	0.46	30.3	
Cod caudal vert.	0.27	0.24	11.1	
Haddock lacrimal	0.12	0.11	8.3	11
Haddock maxilla	0.10	0.09	10.0	
Haddock abdominal vert.	0.10	0.09	10.0	
Haddock caudal vert.	0.06	0.05	16.7	
Salmon hyomandibular	1.11	0.43	61.3	39
Salmon abdominal vert.	1.20	0.90	25.0	
Salmon caudal vert.	1.19	0.84	29.4	
Plaice maxilla	0.07	0.06	14.3	22
Plaice subopercular	0.11	0.10	9.1	
Plaice abdominal vert.	0.14	0.09	35.7	
Plaice caudal vert.	0.25	0.18	28.0	
Herring hyomandibular	0.024	0.023	4.2	17
Herring subopercular	0.010	0.010	0.0	
Herring abdominal vert.	0.017	0.012	29.5	
Herring caudal vert.	0.020	0.013	35.0	
Haddock otolith	0.25	0.25	0.0	
Salmon vert. heated 300C	0.44	0.45	-2.3	
Haddock vert. heated 300C	0.09	0.08	11.1	
Salmon vert. heated 900C	0.41	0.36	12.2	
Haddock vert. heated 900C	0.044	0.040	9.1	
Mussel L. valve	4.32	4.39	-1.6	-1
Mussel R. valve	3.23	3.23	0.0	
Periwinkle	1.83	1.91	-4.4	-4
Periwinkle	1.56	1.63	-4.5	

	Initial Weight	Final Weight	%Weight loss	Mean species %weight loss
pH 9.0				
Sheep metapodial	30.23	29.38	2.8	4
Sheep 2nd phalanx	2.59	2.48	4.3	
Rabbit vertebra	0.32	0.29	9.4	
Rabbit scapula	1.05	1.01	3.8	4
Rabbit femur	3.91	3.92	-0.3	
Mouse scapula	0.010	0.010	0.0	-4
Mouse femur	0.013	0.014	-7.7	
Pigeon femur	0.52	0.50	3.9	3
Pigeon radius	0.45	0.44	2.2	
Frog femur	0.068	0.068	0.0	0
Cod lacrimal	0.37	0.37	0.0	-1
Cod maxilla	0.82	0.85	-3.7	
Cod abdominal vert.	0.49	0.49	0.0	
Cod caudal vert.	0.14	0.14	0.0	
Haddock lacrimal	0.12	0.12	0.0	-3
Haddock maxilla	0.08	0.08	0.0	
Haddock abdominal vert.	0.10	0.11	-10.0	
Haddock caudal vert.	0.06	0.06	0.0	
Salmon hyomandibular	0.51	0.50	2.0	6
Salmon abdominal vert.	1.50	1.32	12.0	
Salmon caudal vert.	1.47	1.41	4.1	
Plaice maxilla	0.05	0.05	0.0	9
Plaice subopercular	0.12	0.12	0.0	
Plaice abdominal vert.	0.22	0.18	18.2	
Plaice caudal vert.	0.29	0.24	17.3	
Herring hyomandibular	0.058	0.048	17.3	3
Herring abdominal vert.	0.013	0.014	-7.7	
Herring caudal vert.	0.010	0.010	0.0	
Haddock otolith	0.27	0.27	0.0	
Salmon vert. heated 300C	0.46	0.52	-13.0	
Haddock vert. heated 300C	0.030	-	100.0	
Salmon vert. heated 900C	0.416	-	100.0	
Haddock vert. heated 900C	0.041	-	100.0	
Mussel L. valve	2.15	2.16	-0.5	-0.2
Mussel R. valve	3.88	3.88	0.0	
Periwinkle	2.65	2.69	-1.5	-2
Periwinkle	2.10	2.17	-3.3	

	Initial Weight	Final Weight	%Weight loss	Mean species %weight loss
pH 11.0				
Sheep metapodial	27.77	27.85	-0.4	3
Sheep 2nd phalanx	2.67	2.51	6.0	
Rabbit vertebra	0.24	0.21	12.5	6
Rabbit scapula	1.47	1.37	6.8	
Rabbit femur	3.84	3.90	-1.6	
Mouse scapula	0.005	0.005	0.0	0
Mouse femur	0.031	0.031	0.0	
Pigeon femur	0.53	0.49	7.6	7
Pigeon radius	0.32	0.30	6.3	
Frog femur	0.043	0.044	-2.3	-2
Cod lacrimal	0.38	0.37	2.7	4
Cod maxilla	0.94	0.92	2.1	
Cod abdominal vert.	0.64	0.60	6.3	
Cod caudal vert.	0.42	0.40	4.8	
Haddock lacrimal	0.143	0.140	2.1	3
Haddock maxilla	0.093	0.091	2.2	
Haddock abdominal vert.	0.072	0.065	9.8	
Haddock caudal vert.	0.058	0.058	0.0	
Salmon hyomandibular	0.98	0.35	64.3	39
Salmon abdominal vert.	1.63	1.31	19.6	
Salmon caudal vert.	0.93	0.61	34.4	
Plaice maxilla	0.08	0.07	12.5	15
Plaice subopercular	0.11	0.10	9.1	
Plaice abdominal vert.	0.13	0.10	23.1	
Plaice caudal vert.	0.19	0.16	15.8	
Herring hyomandibular	0.038	0.024	36.8	13
Herring subopercular	0.010	0.010	0.0	
Herring abdominal vert.	0.020	0.018	10.0	
Herring caudal vert.	0.020	0.019	5.0	
Haddock otolith	0.23	0.23	0.0	
Salmon vert. heated 300C	0.50	-	100.0	
Haddock vert. heated 300C	0.03	-	100.0	
Salmon vert. heated 900C	0.39	0.38	2.6	
Haddock vert. heated 900C	0.042	-	100.0	
Mussel L. valve	4.09	4.09	0.0	-0.2
Mussel R. valve	4.70	4.72	-0.4	
Periwinkle	1.58	1.66	-5.1	-6
Periwinkle	1.72	1.84	-7.0	

	Initial Weight	Final Weight	%Weight loss	Mean species %weight loss
Distilled water (pH 6.5)				
Sheep metapodial	31.80	30.74	3.3	3
Sheep 2nd phalange	1.76	1.70	3.4	
Rabbit vertebra	0.40	0.38	5.0	5
Rabbit scapula	0.89	0.84	5.6	
Rabbit ulna	1.06	1.00	5.7	
Mouse humerus	0.010	0.010	0.0	0
Mouse femur	0.014	0.014	0.0	
Pigeon femur	0.63	0.58	7.9	8
Pigeon radius	0.88	0.81	8.0	
Frog humerus	0.05	0.05	0.0	0
Cod lacrimal	0.25	0.23	8.0	4
Cod maxilla	0.61	0.59	3.3	
Cod abdominal vert.	0.64	0.64	0.0	
Cod caudal vert.	0.33	0.32	3.0	
Haddock lacrimal	0.08	0.08	0.0	2
Haddock maxilla	0.11	0.10	9.1	
Haddock abdominal vert.	0.11	0.11	0.0	
Haddock caudal vert.	0.07	0.07	0.0	
Salmon hyomandibular	1.12	0.80	28.6	19
Salmon abdominal vert.	1.53	1.35	11.8	
Salmon caudal vert.	1.29	1.07	17.1	
Plaice articular	0.13	0.12	7.7	10
Plaice subopercular	0.16	0.14	12.5	
Plaice abdominal vert.	0.13	0.12	7.7	
Plaice caudal vert.	0.15	0.13	13.3	
Herring quadrate	0.013	0.012	7.7	7
Herring abdominal vert.	0.020	0.019	5.0	
Herring caudal vert.	0.018	0.018	0.0	
Haddock otolith	0.27	0.27	0.0	
Salmon vert. heated 300C	0.25	0.23	8.0	
Haddock vert. heated 300C	0.10	0.09	10.0	
Salmon vert. heated 900C	0.50	0.49	2.0	
Haddock vert. heated 900C	0.06	0.06	0.0	
Mussel L. valve	4.89	4.88	0.2	-0.1
Mussel R. valve	4.38	4.40	-0.5	
Periwinkle	1.80	1.78	1.1	-1
Periwinkle	1.70	1.75	-2.9	

Appendix 7.1

Raw Frequencies of bones recovered from individual spraints and combined spraint assemblages, from Freswick, Shetland, Bidno, Wye and Tywi and archaeologically recovered material from Pool and Tofts Ness, Sanday.

	PL	TN	s18	s97	s21	s24	s81	s22	s1[illegible]	s20	f1	f2	f3	f4	f5	f6	t10	b11	w12	fres	shet	bidno/wye
mni=	18	30	7	14	6	4	9	15	9	1,	2	3	4	3	2	2	3	3	1	8	47	5
Ethmoid	0	0	7	0	1	3	0	0	0	0	1	0	1	0	0	0	0	0	0	2	11	0
Frontal	0	0	10	18	0	0	9	6	6	0	2	0	2	0	2	0	0	0	0	6	49	0
Prevomer	6	9	7	13	2	1	3	8	4	0	1	0	3	0	1	2	0	0	0	7	38	0
Parasphenoid	1	2	0	7	1	0	8	4	9	0	0	3	1	2	0	0	1	0	0	6	29	1
Basioccipital	10	17	5	7	0	3	1	4	5	0	1	2	4	0	0	1	1	0	1	8	25	2
Premaxilla	29	33	5	19	6	5	12	21	7	0	3	2	5	1	2	0	0	1	0	13	75	1
Maxilla	16	30	4	17	8	2	10	22	5	0	2	3	2	1	1	0	0	0	0	9	68	0
Dentary	14	37	6	24	8	1	13	15	5	0	2	4	4	1	2	1	2	2	1	14	72	5
Articular	33	50	12	23	6	3	12	19	11	0	1	1	2	3	2	2	3	0	0	11	86	3
Quadrate	23	34	10	17	9	3	5	13	6	2	1	0	1	1	1	0	1	3	0	4	65	4
Hyomandibular	18	9	11	18	9	3	13	13	3	0	0	1	4	1	3	1	1	1	2	10	70	4
Preopercular	17	13	7	21	1	2	10	7	5	0	1	1	2	0	2	1	5	2	2	7	53	9
Opercular	17	32	11	17	8	5	10	13	9	0	0	5	3	0	1	2	0	1	0	11	73	1
Subopercular	2	1	4	12	2	3	5	5	2	1	0	2	1	1	0	1	2	1	2	5	34	5
Interopercular	9	12	3	12	6	1	7	10	2	1	0	5	2	1	3	0	3	2	2	11	42	7
Palatine	14	3	7	11	2	0	8	8	1	0	0	0	0	0	0	0	0	2	0	0	37	2
Ectopterygoid	4	3	7	12	3	2	8	7	1	0	0	1	2	0	0	0	1	1	0	3	40	2
Epihyal	6	23	3	10	8	3	12	10	5	0	0	0	1	0	1	0	0	0	1	2	51	1
Ceratohyal	17	14	9	22	5	2	14	17	9	1	0	1	3	2	1	0	1	1	0	7	79	2
Infrapharyngeal	7	8	2	22	4	3	8	10	4	0	1	3	1	2	1	0	7	1	0	8	53	8
Suprapharyngeal	7	29	1	5	0	0	0	9	1	0	0	5	0	1	0	0	0	1	0	6	16	1
Urohyal	5	4	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1	1	1	3	1	3
Posttemporal	7	8	1	5	1	0	4	1	0	0	0	0	1	0	0	2	0	0	0	3	12	0
Cleithrum	13	9	8	15	8	7	17	29	7	0	1	0	4	1	1	0	5	2	0	7	91	7
Supracleithrum	6	6	8	9	5	3	9	2	3	1	0	0	1	6	0	0	0	0	0	7	40	0
Scapula	2	0	2	4	0	0	0	0	0	0	0	0	2	0	1	0	3	1	0	3	6	4
Vertebrae	772	1032	312	607	449	124	342	631	419	0	51	69	295	35	62	34	76	50	6	546	2884	132
Otolith	1	29	3	18	11	5	13	11	13	1	1	0	0	0	0	0	0	5	0	1	75	5
Lens	0	0	4	6	7	0	1	14	9	2	1	4	3	5	1	0	4	0	0	14	43	4
Scutes	0	71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scales	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	0	0	5
Teeth	0	0	8	1	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	10	2
TOTAL	1059	1518	477	972	570	184	554	910	551	10	71	113	350	65	88	47	121	80	19	734	4228	220

APPENDIX 8.1 Relative Survival Groupings, by taxon and experiment.

Species	Experiment	Group 1	Group 2	Group 3	Group 4
Whiting	Burning (C)	Basioccipital Premaxilla Maxilla Dentary Articular Prevomer Abdominal vert.	Post-temporal Quadrate Ceratohyal Caudal vert. Otolith	Parasphenoid Supraoccipital Hyomandibular Symplectic Preopercular Ectopterygoid Epihyal Frontal Palatine Infrapharyngeal Supracleithrum	Coracoid Scapula Basipterygium Cleithrum Post-cleithrum Urohyal Suprapharyngeal Hypohyal Interopercular Subopercular Opercular Nasal Prefrontal Lacrimal Ethmoid
Cod	Burning (B)	Basioccipital Abdominal vert.	Articular Hyomandibular	Frontal Preopercular Caudal vert. Otolith	all other bones were completely destroyed.
Cod	Burning (F)	Ethmoid Supraoccipital Premaxilla Ectopterygoid Post-temporal Supracleithrum Abdominal vert.	Maxilla Quadrate Palatine Epihyal Prevomer Otolith	Dentary Ceratohyal Suprapharyngeal Caudal vert.	all other bones were completely destroyed.
Cod	Exposure (B)	Supraoccipital Prevomer Parasphenoid Basioccipital Premaxilla Maxilla Dentary Articular Quadrate Hyomandibular Symplectic Opercular Palatine Epihyal Ceratohyal Infrapharyngeal Post-temporal Cleithrum Scapula Otolith	Ethmoid Frontal Preopercular Interopercular Supracleithrum Postcleithrum Abdominal vert. Caudal vert.	Prefrontal Lacrimal Subopercular Ectopterygoid Metapterygoid Hypohyal Suprapharyngeal	Nasal Entopterygoid Urohyal
Cod	Trampling	Ethmoid Supraoccipital Basioccipital Premaxilla Maxilla Dentary Quadrate Symplectic Palatine Epihyal Ceratohyal Urohyal Post-temporal Cleithrum Supracleithrum Precaudal vert. Caudal vert.	Frontal Prefrontal Prevomer Parasphenoid Articular Hyomandibular Preopercular Opercular Subopercular Interopercular Ectopterygoid Hypohyal Infrapharyngeal Postcleithrum Basipterygium Otolith	Lacrimal Nasal Suprapharyngeal Coracoid	Entopterygoid Metapterygoid Scapula

APPENDIX 8.1 cont'd...

Species	Experiment	Group 1	Group 2	Group 3	Group 4
Haddock	Trampling	Ethmoid Premaxilla Articular Quadrate Symplectic Palatine Epihyal Ceratohyal Hypohyal Post-temporal Supracleithrum Scapula Abdominal vert. Caudal vert.	Supraoccipital Basioccipital Maxilla Dentary Hyomandibular Preopercular Opercular Subopercular Interopercular Ectopterygoid Infrapharyngeal Urohyal Postcleithrum	Frontal Prefrontal Prevomer Parasphenoid Lacrimal Nasal Metapterygoid Suprapharyngeal Cleithrum Otolith	Entopterygoid Coracoid Basipterygium
Haddock	Tumbling (3.1)	Premaxilla Maxilla Articular Infrapharyngeal Otolith	Prevomer Dentary Interopercular Quadrate Epihyal Hypohyal Supracleithrum Abdominal vert.	Hyomandibular Suprapharyngeal Post-temporal Cleithrum Caudal vert.	all other bones
Long Rough Dab	Burning (C)	Prevomer Basioccipital Premaxilla Articular Caudal vert.	Quadrate Dentary Maxilla Abdominal vert.	Parasphenoid Hyomandibular Preopercular Opercular Post-temporal Anal pteryg.	Basipterygium Coracoid Scapula Supracleithrum Urohyal Suprapharyngeal Infrapharyngeal Hypohyal Ceratohyal Epihyal Ectopterygoid Palatine Interopercular Subopercular Supraoccipital Prefrontal Frontal Ethmoid Otolith
Plaice	Burning (C)	Parasphenoid Basioccipital Infrapharyngeal Urohyal Supracleithrum Abdominal vert. Caudal vert. Anal pteryg.	Frontal Maxilla Epihyal Suprapharyngeal Post-temporal	Dentary Hyomandibular Preopercular Opercular Cleithrum	All other bones were destroyed.
Plaice	Trampling	Basioccipital Premaxilla Maxilla Dentary Articular Hyomandibular Interopercular Epihyal Ceratohyal Infrapharyngeal Urohyal Post-temporal Supracleithrum Scapula Abdominal vert. Caudal vert. Anal pteryg. Otolith	Prevomer Quadrate Preopercular Palatine Hypohyal Cleithrum Basipterygium	Frontal Prefrontal Supraoccipital Symplectic Subopercular Ectopterygoid Suprapharyngeal	Entopterygoid Metapterygoid Coracoid

APPENDIX 8.1 cont'd...

Species	Experiment	Group 1	Group 2	Group 3	Group 4
Plaice	Erosion (3:1)	Prefrontal Basioccipital Premaxilla Dentary Articular Quadrate Hyomandibular Preopercular Epihyal Infrapharyngeal Supracleithrum Scapula Anal pteryg. Otolith	Frontal Supraoccipital Prevomer Maxilla Opercular Interopercular Palatine Hypohyal Suprapharyngeal Urohyal Post-temporal Abdominal vert. Caudal vert.	Ceratohyal Cleithrum	Symplectic Parasphenoid Subopercular Ectopterygoid Entopterygoid Metapterygoid Coracoid Basipterygium
Herring	Burning (F)	Basioccipital Articular Hyomandibular Abdominal vert. Caudal vert. Otic Bulla	all other elements destroyed.		
Herring	Trampling	Maxilla Supramaxilla Epihyal Ceratohyal Abdominal vert. Caudal vert.	Ethmoid Prevomer Parasphenoid Basioccipital Dentary Articular Quadrate Hyomandibular Preopercular Opercular Urohyal Post-temporal Cleithrum Otic bulla	Supracleithrum Subopercular Interopercular Metapterygoid Coracoid Basipterygium	Scapula Ectopterygoid Premaxilla Frontal Otolith
Herring	Erosion (1:1)	Maxilla Basioccipital Supramaxilla Articular Opercular Epihyal Ceratohyal Urohyal Precaudal vert. Caudal vert. Otic bulla	Parasphenoid Hyomandibular Supracleithrum Otolith	Quadrate Preopercular Cleithrum	Ethmoid Frontal Prevomer Dentary Subopercular Interopercular Ectopterygoid Metapterygoid Post-temporal Scapula Coracoid Basipterygium Premaxilla
Salmon	Trampling	Basioccipital Maxilla Articular Interopercular Epihyal Ceratohyal Hypohyal Urohyal Supracleithrum Abdominal vert. Caudal vert.	Dentary Quadrate Hyomandibular Subopercular Post-temporal Scapula Coracoid Basipterygium	Parasphenoid Preopercular Opercular Ectopterygoid Metapterygoid	Prevomer Premaxilla Cleithrum
Rat	Burning (C)	Humerus Ulna Astragalus Calcaneum	Mandible Femur Tibio-fibula	Thoracic/Lumbar v. Phalanges	Scapula Radius Pelvis Sacrum Cervical v. Caudal v.

APPENDIX 8.1 cont'd...

Species	Experiment	Group 1	Group 2	Group 3	Group 4
Rat	Burning (OF)	Humerus Radius Astragalus Calcaneum	Mandible Ulna Pelvis Femur Tibio-fibula	Scapula Thoracic/Lumbar v. Caudal v. Metapodials Phalanges	Sacrum Cervical v.
Mouse	Trampling	Mandible Humerus Radius Ulna Femur Tibio-fibula Astragalus Calcaneum	Scapula Pelvis Cervical v. Caudal v.	Thoracic/Lumbar v. Metapodials Phalanges	Sacrum
Mouse	Tumbling (1:2)	Mandible Humerus Radius Ulna Femur Astragalus Calcaneum	Caudal v. Metapodials	Pelvis Tibio-fibula Cervical vert. Phalanges	Scapula Sacrum Thoracic/Lumbar v.
Pigeon	Burning (OF)	Coracoid Phalange 1m. Tibiotarsus Tarsometatarsus Phalanges	Humerus Radius Ulna Carpometacarpus Femur	Scapula Pelvis Vertebrae	Sternum Synsacrum Mandible Maxilla
Pigeon	Trampling	Humerus Radius Carpometacarpus Phalange 1m. Sternum Synsacrum Femur Tarsometatarsus Vertebrae Phalanges	Maxilla Scapula Coracoid Ulna Pelvis Tibiotarsus	Mandible	
Frog	Trampling	Maxilla Humerus Radio-Ulna Tibio-fibula Pelvis Vertebrae	Femur Urostyle Metapodials + Phalanges		
Frog	Tumbling (6:2)	Humerus Radio-Ulna Femur Tibio-fibula Scapula Pelvis Urostyle	Vertebrae	Metapodials + Phalanges	Maxilla