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# Fish bone diagenesis in different soils

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ABSTRACT: Fish bone decomposition was investigated using bones recovered after groups of cooked and uncooked fish had been buried in one of five locations for seven years. The results indicated that neither soil pH nor drainage was paramount in determining bone survival, and that fish bones were in general less likely to survive than similar sized mammal and bird bones. Within fishes, smaller taxa were not necessarily liable to preferential bone decay. Boiling dramatically reduced bone survival, but baking did not. Neither organic content nor C/N ratios proved useful in describing bone preservation. It is suggested that commonly used quantitative methods for estimating original fish assemblage composition (MNI and NISP) are frequently unhelpful, and that simple presence/absence counts by context or sample may be often more appropriate.

KEYWORDS: FISH BONE, DIAGENESIS, SOIL pH, C/N RATIOS, COOKING, QUANTIFICATION

RESUMEN: Investigamos la descomposición de los huesos de peces a través de una serie de ejemplares frescos y cocidos que fueron enterrados durante siete años en una zona de entre cinco seleccionadas y posteriormente excavados. Nuestros resultados indican que ni el pH edáfico ni la irrigación del suelo han sido factores claves para determinar la supervivencia del hueso y que, en general, los huesos de pescado sobreviven en mucha menor medida que los de aves y mamíferos de talla similar. Dentro de peces, los taxones de menor tamaño no parecen ser más susceptibles de una degradación preferencial que los de mayor tamaño. La cocción reduce drásticamente la pervivencia del hueso pero no así el asado. Ni el contenido orgánico ni las relaciones C/N parecen servir en la caracterización de los patrones de pervivencia. Sugerimos que los métodos clásicos de cuantificación de fauna encaminados a estimar la composición original de la muestra de peces (el número de restos y el número mínimo de individuos) pueden resultar de poca ayuda a tal efecto por lo que quizás sea más beneficioso recuentos simples basados en presencia/ausencia por contexto o muestra.

PALABRAS CLAVE: HUESO PEZ, DIAGÉNESIS, pH EDÁFICO, PROPORCIÓN C/N, COCINADO, CUANTIFICACIÓN

## INTRODUCTION

Recent publications demonstrate a developing interest in biostratinomy –pre-burial modifications to death assemblages– among those working with archaeological fish bone. There have been a number of papers dealing with various processes which may influence the composition of a fish bone assemblage (for some examples: Jones, 1984; Butler, 1987; Nicholson, 1991 & forthcoming a; Stewart & Gifford-González, 1994). Particular attention has been paid to distinguishing «natural» from «cultural» accumulations of fish bones. Unfortunately, in common with other branches of archaeozoology, this interest has so far not been accompanied by comparable studies into fish bone diagenesis –changes occurring after burial. Little is really known about fish bone decomposition, particularly regarding relative rates of decay between different fish taxa and between the different body parts, although there has been some evidence to suggest that bones from fatty or oily fishes are likely to be lost preferentially due to the autolysis of the fats and oils (Mézes & Bartosiewickz, 1994). Discussions concerning archaeologically

recovered fish bone assemblages often consider the possible extent of bone loss, and occasionally authors may suggest which taxa and/or skeletal parts may be under-represented. These interpretations are often based on the superficial appearance of the archaeological bone assemblage and/or upon untested, but commonly held, assumptions. Usually it is considered that small bones will degrade first; some bones (such as from herring) appear fragile and therefore less likely to survive archaeologically than larger bones (such as from gadids); see for example Bigelow (1984). Differences in the representation of body parts are often used to imply fish processing, particularly the production of stockfish (e.g. Wilkinson, 1979). It is obvious, however, that arguments based on archaeologically recovered material will always be circular. The reliance upon quantitative units, particularly Minimum Number of Individuals (MNI) and Fragment Counts (NISP), in the comparison and interpretation of fish bone assemblages is founded on the implicit assumption that some characteristics of the original assemblage species composition remain, and therefore that the excavated sample is a true representation of the originally deposited whole.

Clearly, the extreme diversity of body forms and skeletal organisation among fishes renders it extremely unlikely that decomposition will be uniform among this heterogeneous group. It is not sufficient to presume that bone size or bone density ($g/cm^3$) are the major determinants of bone preservation in the absence of independent evidence. To complicate the matter further, most fish caught for human consumption are likely to have been processed in one way or another - most likely by cooking. By observation alone it is not often clear whether a bone has been cooked or not, although exceptionally an archaeological context may prove conclusive (eg. Andersen & Malmros, 1984, where cod bones were recovered from charred food crusts within cooking pots). The effects of different cooking methods upon bone survival are poorly understood, yet, as it is likely that most fish prepared for human consumption would be cooked in one way or another, this question is clearly crucial to our understanding of the archaeological material. If cooked bone only survives in exceptional circumstances, then a recovered assemblage of fish bones may not be representative at all of the utilised resource.

Arguably, to make meaningful statements about fish bone assemblages we need, at the very least, to understand:

1. Whether bones of similar size from different taxa will decay at similar rates.

2. Whether small-boned species are likely to be drastically under-represented.

3. Whether some body parts are likely to be lost in preference to others.

4. How cooking affects rates of bone decay.

5. How variation in burial conditions affects bone loss.

The research presented in this paper represents a preliminary step towards a better understanding of fish bone decay by actualistic experiment. It forms part of a wider investigation of bone taphonomy undertaken by the author (Nicholson, 1991, 1992, 1993, forthcoming b).

## THE EXPERIMENTS: METHODS AND MATERIALS

### *Burial*

As a first step in looking at bone diagenesis, suites of animal remains were buried at 18 locations in the UK, encompassing a range of different soil types. The experiments were set up in the summer of 1987 and five sites were excavated in 1994. At each site a similar suite of remains was buried (Table 1), including the following fish: cod (one boiled, one complete); plaice (one baked, one complete); herring (one baked, one complete), whiting (one filleted). Of the baked fish, only the fins were charred. The fish species and sizes were selected on the grounds of ease of availability in quantity as well as their ubiquity on many British archaeological sites, making the experiments directly applicable to many archaeological assemblages. All of the five excavated sites were in North Yorkshire, UK, within a 50 $Km^2$ area; they had therefore experienced similar climatic events during the seven years that the remains were buried. Burials were at a depth of 0.32-0.45 m; at two of the excavated sites bedrock restricted the available depth of soil. The location and a brief description of each excavated site is given in Table 2, with more details of the soils presented in Table 3. Each site has been assigned a site number for reference.

| IDENTIFICATION | DESCRIPTION | SOIL pH (Mean) | DRAINAGE | BURIAL(Depth) |
|---|---|---|---|---|
| Site 10 | Heather Moorland | pH 4.0 | Moderate-Poor | 0.32 m |
| Site 14 | Garden Soil | pH 6.8 | Moderate-Good | 0.43 m |
| Site 15 | Deciduous Woodland | pH 3.9 | Moderate-Poor | 0.45 m* |
| Site 16 | Chalk Wasteland (formerly cultivated) | pH 7.8 | Well drained | 0.36 m |
| Site 18 | Urban Compost Heap (ongoing deposition) | pH 7.0 | Moderate-Poor | see below |

N.B. At site 15 while the burial depth was 0.45 m some two years after burial soil slip added extra material, so that the remains were excavated at a depth of 0.5-0.8 m. At site 18, the compost heap, organic matter was continuously added so that while the remains were buried in 0.25 m of well-rotted humus, with approximately 60 cm of unrotted vegetable matter placed above, at excavation the depth of humified material above the buried remains was 0.58 m. The surrounding matrix included ash, pottery fragments, eggshell and other non-organic material as well as humic soil.

TABLE 1
The sites: location, soil pH and drainage.

| No. | DESCRIPTION | TREATMENT |
|---|---|---|
| 2 | Cod (*Gadus morhua)* | 1 x None$^{+}$; 1 x boiled for 1 hour (including 25-30 min for the water to boil) |
| 2 | Plaice (*Pleuronectes platessa)* | 1 x None$^{+}$: 1 x *baked for 20 min at 200°C and the edible flesh removed |
| 2 | Herring (*Clupea harengus)* | 1 x None$^{+}$; 1 x *baked for 15 mins at 200°C and the edible flesh removed |
| 1 | Whiting *(Merlangius merlangus)* | Gutted and filleted |

*+Animals complete, with internal organs*
** Baking resulted in charring of the skin and fins only*

TABLE 2
Details of the fish buried at each site.

*Recovery*

Owing to the remote location of some of the sites water sieving on site was impractical. Excavation was exclusively by hand; once the topsoil had been removed excavation was by careful trowelling. When bones were seen entire soil blocks were lifted with the aid of metal plates and these blocks were excavated in the laboratory. Finally, all the soil taken to the laboratory was wet-sieved to 1 mm to aid the recovery of bones and scales.

*Recording*

Each skeleton was weighed after most adhering soil had been removed by gentle rinsing in tap water followed by drying at room temperature for 48 hours; this weight is termed «skeletal weight» below. Before washing, the bones were photographed and any adhering organic matter (for example fungal growths) and staining of the bones were noted. Bone fragments were recorded by size - a percentage figure indicating the proportion of the

| Site Identification | Mean Moisture Content* (% Volume) | Mean Bulk Density (g/cm-3) | Mean Organic Matter (% weight) | Mean $CaCO_3$ (% weight)# | pH |
|---|---|---|---|---|---|
| 10 upper | 46.1 | 1.1 | 9.6 | | |
| 10 lower | 30.1 | 1.7 | 5.0 | 0.8 | 3.5-4.5 |
| 14 upper | 25.4 | 0.9 | 12.4 | | |
| 14 lower | 21.1 | 1.2 | 6.3 | 1.4 | 6.5-7.0 |
| 15 upper | 29.4 | 1.1 | 8.2 | | |
| 15 lower | 27.7 | 1.2 | 4.2 | 1.0 | 3.3-4.5 |
| 16 upper | 17.0 | 0.9 | 11.4 | | |
| 16 lower | 18.1 | 1.0 | 6.7 | 4.5 | 7.5-8.0 |
| 18 middle | 25.4 | 0.8 | 8.8 | | |
| 18 lower | 27.7 | 0.7 | 12.8 | 2.1 | 7.0-7.3 |

* At time of excavation

# These values may have been increased by the loss of air trapped in the soil

At site 18, the upper layer comprised poorly rotted vegetable matter, and so was not sampled

TABLE 3
Bulk parameters for the soil from the upper (or middle) and lower horizons at each site.

whole bone represented by the fragment (i.e. fragment size: 100 = complete, 50 = 1/2 bone). The proportion of each skeleton which was recovered, referred to below as «skeletal completeness», was calculated by the formula:

$$\text{Skeletal Completeness} = \Sigma\, n / 100 \times tb$$

where «n» is the fragment size (% of whole bone) of each recovered bone, and «tb» is the total number of major bones per skeleton.

This number enables direct comparison between skeletons of the proportion of bone material remaining, irrespective of the size of fish, in a way that skeletal weight does not. Bone «condition» was also recorded on a subjective scale of:

1 (excellent, as fresh),

2 (no longer greasy, but uneroded),

3 (some erosion, but bone generally complete),

4 (substantial erosion, some bone missing),

5 (extensive erosion, bone friable and incomplete).

Estimations of the possible extent of bone loss from a recovered archaeological assemblage are often based on some subjective assessment of assemblage «condition», not necessarily using a numerical score. In this study the extent of bone loss could be calculated, a circumstance very rarely encountered archaeologically. Therefore the value of using a subjective assessment of «bone condition» to predict the extent of bone loss could be examined.

All bones were then stored at 4°C until samples were taken for Scanning Electron Microscopy, thin section observation and chemical analyses. This paper will not deal with the microscopical aspects of this study.

*Chemical Analyses*

Changes to the chemical composition of the samples were examined by looking at changes to the ratio of organic: mineral material, and by CHN analysis of the organic «collagen» fraction, a technique often used to investigate bone diagenesis before isotopic analysis of collagen (see for example

Ambrose, 1990). Small samples of bone were taken, in the case of the fish (excluding the whiting) several vertebrae and one jaw bone (selection dependant upon survival) from each specimen were used. These samples were cleaned by air abrasion and by ultrasonication for 15 minutes in deionised water. Modern «control» samples were taken from freshly killed specimens. These bones had been deep frozen at -20°C before use, but were cleaned manually and ultrasonicated as above. The samples were then dried for 48 hours in a vacuum dessicator over silica gel, following which they were weighed. All samples were demineralised in 0.3M HCl for 7-14 days, or until they became fully transparent. After washing in deionised water to neutrality, the samples were placed in 0.125M NaOH for 24 hours to remove humic material and some lipids, before washing again and drying for 48 hours in a vacuum dessicator over silica gel. The dried samples were ground to as near to a powder as was possible, and submitted to Dr. G. Wolff in the Department of Oceanography, University of Liverpool, UK, for CHN analysis. A Carlo Erba 1106 CHN Elemental Analyser was used.

## RESULTS AND DISCUSSION

Despite the relatively short burial period, there was considerable variation in the state of bone preservation both between individual taxa/treatments from the same site and between the same taxa/treatments from different sites. In most instances fish bone survived less well than mammal and bird bone from individuals of similar, or lighter, body weight (for further details concerning mammal, bird and fish bone preservation at these sites see Nicholson, forthcoming b). As illustrated by Tables 4 and 5 and Figure 1, which respectively present bone survival in terms of the proportion of bone visibly present («skeletal completeness»), the superficial appearance of the bones («bone condition»), and by overall bone weight per skeleton («skeletal weight»), fish bone preservation was very different at each of the five sites. At the extremes, almost no fish bone survived at the moorland site (Site 10); only both sets of cod otoliths and several cod vertebrae were recovered. Dense coverings comprising matted rootlets and fungal hyphae surrounded the areas where the fish would have been (illustrated in Nicholson, forthcoming

| | Animal total body length and weight | Total n.° of bones considered | Site 10 | Site 14 | Site 15 | Site 16 | Site 18 |
|---|---|---|---|---|---|---|---|
| Fresh Cod | 445-460 mm 670-780 g | 113 | 1 | 98 | 58 | 85 | 97 |
| Boiled Cod | 422-460 mm 665-735 g | 113 | 2 | 16 | 13 | 38 | 44 |
| Fresh Plaice | 295-352 mm 230-340 g | 113 | 0 | 93 | 60 | 58 | 92 |
| Baked Plaice | 321-340 mm 295-365 g | 113 | 0 | 76 | 46 | 74 | 91 |
| Fresh Herring | 279-286 mm 145-160 g | 98 | 0 | 89 | 39 | 71 | 90 |
| Baked Herring | 276-307 mm 155-205 g | 98 | 0 | 56 | 5* | 82 | 95 |
| Filleted Whiting | 300-360mm 220-325 g | 113 | 0 | 44 | 42 | 58 | 95 |

* scores may be reduced by bones lost during excavation

TABLE 4
Mean «skeletal completeness» scores.

| | SITE 10 | | SITE 14 | | SITE 15 | | SITE 16 | | SITE 18 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range |
| Fresh Cod | 5 | 5 | 2 | 2 | 3 | 2-4 | 3 | 2-4 | 2 | 2 |
| Boiled Cod | 5 | 5 | 5 | 3-5 | 4 | 3-5 | 4 | 3-5 | 3/4 | 3-5 |
| Fresh Plaice | - | - | 3 | 2-4 | 3 | 2-4 | 3/4 | 3-4 | 2 | 2 |
| Baked Plaice | - | - | 2 | 1-3 | 3 | 2-5 | 3 | 2-4 | 2 | 2 |
| Fresh Herring | - | - | 3 | 2-4 | 3/4 | 2-5 | 3 | 2-4 | 2 | 2 |
| Baked Herring | - | - | 3 | 3-5 | 3 | 2-5 | 2/3 | 2-4 | 2 | 2-3 |
| Filleted Whiting | - | - | 4 | 2-4 | 3 | 2-4 | 3 | 3-4 | 2 | 2 |

TABLE 5
«Bone condition» scores (range 1: as fresh, to 5: extremely friable and degraded).

b). These fungal and root «shells» were not observed at any of the other excavated sites. The best bone preservation occurred in the compost heap, a finding which was initially of surprise to this author who had expected the warm, aerobic conditions within the compost heap to accelerate bone decomposition. Presumably the bones were preserved as a consequence of the rapid accumulation of humics within the bone structure, inhibiting bacterial action (and evident from the dark brown colour of the bones). Subsequent publication of the effects of humics on collagenase digestion (van Klinken & Hedges, 1995) supports this conclusion. Almost no bone was lost in the compost heap, and the excellent bone condition was similar to that observed from many organic-rich urban deposits. In this case it would appear that waterlogging was not the key to bone preservation, an explanation which is often used with regard to bone recovered from organic-rich urban deposits.

Despite their similar pH (3.5-4.5) and drainage (moderate –poorly drained), skeletons were very differently preserved in the moorland and woodland soils (Sites 10 and 15). Again, this finding indicates that neither pH nor drainage, either individually or in combination, sufficiently describes a burial environment in terms of its potential for bone preservation.

It was evident in every one of the burial environments that boiling dramatically reduced fish bone survival. Baking did not appear to have the same effect, at least for the methods, temperatures and heating durations used in these experiments. In most cases there were no clear differences in preservational state between those individuals which had been baked when compared with similar individuals which had not been cooked. There was some indication that filleting accelerated bone decomposition, however direct comparison between the filleted and complete individuals (whiting and cod) was not justified because of the different fish sizes.

Fish scales were not found at any of the sites, however it is possible that a few fragments may have been recovered had flotation been employed as a recovery method. During excavation a «silvery» skin-like covering was visible over the heads of both the herrings at site 16 (chalk); however once exposed to the air this silvering disappeared. At all sites the cod, whiting and plaice otoliths survived well, although the tiny herring otoliths were rarely recovered. The preferential survival of otoliths over bone at Site 10 (acid moorland) was rather surprising, and may indicate the importance of micro-organisms in decomposition. The lack of organic material within otoliths, as well as their structural density, probably explain their preferential survival over bone. Any dissolution of their calcium carbonate matrix by the acidic groundwater appeared to have been minimal, and none of the otoliths appeared polished and eroded around the edges in the manner illustrated for mammal-digested otoliths by Jones (1986).

Although there was some correlation between the variables «bone condition» and «skeletal completeness» (for example a condition score of «2» indicated a «skeletal completeness» score of 90% or more) there was considerable variation within

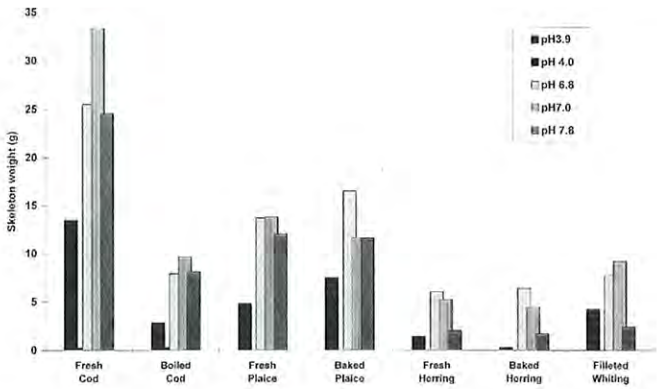


FIGURE 1
Total weight of bone by species/treatment and soil pH at each site.

the 3-4 range, moderate to poor condition. Mean condition did not clearly discriminate between skeletons from the acid woodland, the garden soil and the alkaline chalk, although «skeletal completeness» as well as «skeletal weight» clearly showed the first to be much less well preserved. Evidently some surviving bones may appear quite well preserved when, in fact, quite a considerable amount of bone loss has taken place. This fact was also clear from direct observation of the variation in bone condition within a skeleton, and is of direct archaeological relevance because differences in bone condition (however defined) are usually the only means by which preservation can be assessed. Other measures of preservation, such as those based upon differences in the representation of certain skeletal elements or comparison of bone weights, are only useful if it can be independently established that whole individuals were originally deposited, which is rarely the case. Archaeologically, very poorly preserved assemblages are likely to be unsuitable for detailed comparative study, particularly by interpretation of differences in species representation by NISP or MNI. It is therefore essential that such assemblages should be recognised.

*Chemical analyses*

As the superficial appearance (condition) of a bone did not appear to adequately indicate the overall state of preservation of an individual skeleton it was hoped that chemical analyses might provide a criterion for identifying poorly preserved assemblages - that is those in which quite a lot of loss has taken place, even though those bones which had survived appeared reasonably intact.

Calculation of the «collagen» content, and of the amounts of Carbon and Nitrogen within the «collagen», were made not only for the fish bones discussed in this paper but also for bird and mammal bones from the same burial experiments. While fish bone is the subject of this paper, the results from the mammal and bird bones are of relevance here. In almost every case the mammal (including small mammal) and bird bones showed «collagen» concentrations within the expected range for dry bone (roughly 25-30%), atomic C/N ratios within the expected range for collagen (2.9 - 3.6) and very similar values for the amount of C and N in the «collagen» (38-48% C, 13-17% N). By contrast, the fish bones produced very diverse results in all of the above three categories (see Table 6 and Figure 2). Some of this diversity may be explained by differences in fish bone design and composition; fresh cod bones had, for example, an organic content on average of only 13.4% (a low yield verified by thermal analysis). However, even with low «collagen» yields in the case of cod, the uncooked control samples from freshly killed fish all possessed C/N ratios and concentrations within the ranges given above. In comparison to other types of bone, it must be concluded that fish bone in general is subject to much more rapid diagenesis and loss of the organic fraction. This finding has implications for the suitability of ancient fish bone for a range of chemical analyses.

| | % Organic | C/N Ratio |
|---|---|---|
| *Uncooked Cod* | | |
| Fresh | 13.4 | 3.37 |
| Acid Woodland (Site 15) | 11.0 | 3.49 |
| Neutral Garden (Site 14) | 9.2 | 3.74 |
| Neutral Compost (Site 18) | 15.5 | 3.35 |
| Alkaline Chalk (Site 16) | 10.4 | 3.78 |
| *Boiled Cod* | | |
| Acid Woodland | 0.0 | Insufficient Sample |
| Neutral Garden | 0.0 | Insufficient Sample |
| Neutral Compost | 0.4 | 4.03 |
| Alkaline Chalk | 1.1 | 4.82 |
| *Uncooked Plaice* | | |
| Fresh | 27.8 | 3.21 |
| Acid Woodland | 15.8 | 3.27 |
| Neutral Garden | 13.2 | 3.4 |
| Neutral Compost | 14.5 | 3.39 |
| Alkaline Chalk | 9.2 | 4.05 |
| *Baked Plaice* | | |
| Acid Woodland | 27.4 | 3.33 |
| Neutral Garden | 11.9 | 3.19 |
| Neutral Compost | 20.1 | 3.38 |
| Alkaline Chalk | 9.1 | 3.91 |
| *Uncooked Herring* | | |
| Fresh | 21.6 | Missing |
| Acid Woodland | 7.6 | 3.49 |
| Neutral Garden | 7.7 | 3.32 |
| Neutral Compost | 12.1 | 3.34 |
| Alkaline Chalk | 10.2 | 3.34 |
| *Baked Herring* | | |
| Acid Woodland | 0 | Insufficient Sample |
| Neutral Garden | 2.3 | 3.53 |
| Neutral Compost | 10.4 | 3.23 |
| Alkaline Chalk | 12.6 | 3.41 |

TABLE 6
Fish bone «collagen» content and atomic C/N ratios. (Note that insufficient material was available for analysis from site 10, acid moorland).

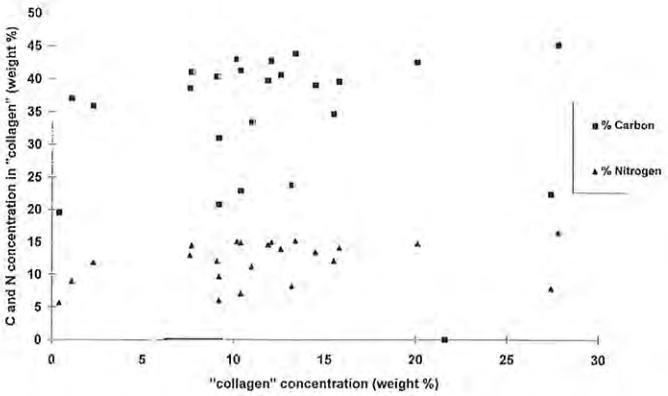


FIGURE 2
Carbon and Nitrogen concentration as % «collagen» weight, against «collagen» concentration, for fish bone from sites 14, 15, 16 and 18.

Those samples with C/N ratios outside the accepted range, so indicating extreme loss of the organic component, included all the boiled cod bones (several produced insufficient residue for analysis) as well as the uncooked cod bones from sites 14 (garden) and 16 (chalk). While the poor condition of the boiled cod bones was very evident upon excavation, it was not clear from looking at the uncooked cod bones from site 14 and 16 that the bones underwent extensive diagenesis; in terms of «skeletal completeness», both scored highly (98% and 85% complete), and in terms of «bone condition» both appeared well preserved. In this case, therefore, extensive changes to the organic fraction appear to have taken place in the bones without concurrent loss of bone, entirely the opposite of what might have been expected.

In other cases, for example the baked plaice bones from site 15 (woodland), an acceptable C/N ratio obscured a real loss of C and N, suggesting that some other non-organic component contributed to the «collagen» weight. Conversely, although containing only 2.3% «collagen» the baked herring bone from site 14 produced a C/N ratio within the range for collagen, and the small amount of remaining organic material contained 12% nitrogen and 36% carbon, suggesting that the small amount of organic material was still intact collagen. Although it was expected that bones from baked fish would be distinguished from bones from uncooked specimens by the extent of collagen degradation -as illustrated after heating fish bone to 60°C (Richter, 1987) - this did not prove to be the case. It may be hypothesised that in this case baking did not alter the collagen fibrils in a manner sufficient to enhance hydrolysis.

*Skeletal element representation*

Figure 3 illustrates the skeletal part representation for the Gadidae (cod and whiting), plaice and herring, cooked and uncooked. For the purposes of this discussion the results from all of the sites have been combined to provide an overall view. Despite the different treatments, both the baked and uncooked plaice and herring show remarkable similarity in terms of the relative survival of skeletal elements. While bones of the cranium were generally least well preserved in both the baked and uncooked plaice, there was little other evidence of differential survival of skeletal parts. By contrast, the plots for baked and uncooked herring both reflected the preferential survival of the basioccipital, parasphenoid, ceratohyal, hyomandibular, subopercular and vertebrae. Bones of the cranium were again generally least well preserved. The lower number of baked herring vertebrae can largely be attributed to one site (Site 15, the woodland) where other evidence would favour an interpretation of poor recovery rather than poor preservation. Turning to the gadid fish, there was conside-

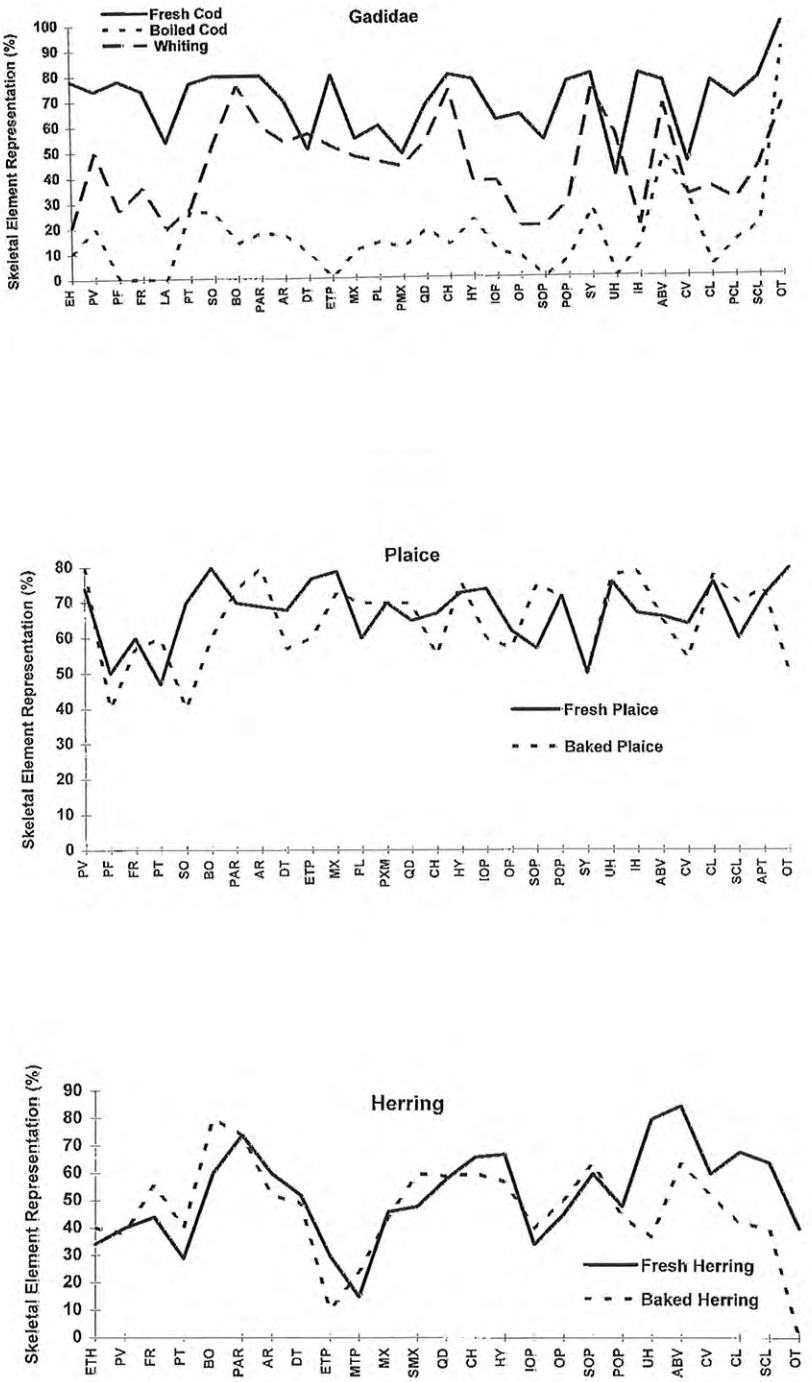


FIGURE 3
Skeletal element representation; a) Gadidae, b) Plaice, c) Herring.

rable variability between the specimens, not surprising perhaps given their different sizes as well as their different treatments. Where recovered, most of the uncooked cod skeletons were fairly complete, loss was greatest in the oromandibular region and the caudal portion of the spine. The basioccipital and parasphenoid proved to be among the most robust bones in both the uncooked cod and the whiting, while filleting appeared to be detrimental to the survival of vertebrae. Bone loss was severe among the boiled cod, and abdominal vertebrae proved to be the best represented bones. The preferential loss of vertebrae from the caudal region should be considered when methods of fish processing are discussed, as the preparation of stockfish, for example, involves the removal of the head and front (abdominal) part of the spine while leaving bones of the shoulder and caudal region in the dried or salted body, which is then exported. It is clear that absence of vertebrae from the caudal region cannot alone be cited as good evidence for the exportation of stockfish.

## CONCLUSIONS

The aims of this paper have been broadly to enable a better understanding of variability within archaeologically recovered fish bone assemblages and to document the effects of different cooking methods on bone survival. Additionally, it was hoped that it would prove possible to distinguish by physical appearance, quantitative analysis or chemical means an assemblage in which a representative sample of bones have survived from an assemblage where a large majority of bones have decomposed.

Not surprisingly, bone diagenesis has been shown to be an extremely complicated subject. Even after just seven years, rates of bone decomposition were dramatically different within the soil environments used in this study and appear not to be solely dictated by soil pH and drainage. It has been argued elsewhere (Nicholson, forthcoming b) that microbiological considerations may be of paramount importance, and the build up of humic material within the bones buried in a compost heap may explain their excellent condition.

This study has also demonstrated that some methods of cooking (baking) may have little effect on bone survival (at least in the short-medium term), while other methods (boiling) may dramatically reduce bone survival. The accelerated loss of cooked fish bone (particularly boiled bone) has obvious application to archaeology, as it may be assumed that most fish captured by humans were destined in one way or another for cooking, and that in many instances entire fish would have been cooked.

While some patterns of skeletal element loss appeared to be generally predictable, for example that among the Gadidae caudal vertebrae are likely to decompose more rapidly than abdominal vertebrae, other trends were less obvious. The numbers of individuals used in this study were insufficient to allow the construction of an «index» whereby diagenetically altered assemblages may be recognised by changes in skeletal element representation frequencies, but this must be a priority for future investigation.

It did not prove possible to characterise any but the poorest preserved assemblages by chemical means. Under the conditions of testing, the rate of breakdown of collagen in fish bone after burial was extremely variable, and difficult to predict either from the apparent condition of the recovered bones or from the type of burial environment. Loss of collagen, and changes to the composition of the «collagen» fraction sometimes did, but in many cases did not, reflect the apparent condition of the skeleton and the amount of bone loss which had taken place. Neither C/N ratios, C and N concentrations, nor «collagen» concentration proved to be a sensitive indicator of preservational state.

Contrary to common preconception, it has been shown that, despite their small bones, herring may be represented even in soils where many bones from much larger-boned individuals (such as Gadidae) have decomposed. The vulnerability of fish bone in comparison to other animal bone was confirmed by this study, a finding which warrants more consideration in archaeozoological discussions as it has direct bearing upon the methods by which bones are quantified and taxa compared. The use of relative abundance quantification techniques currently favoured - notably MNI, NISP and Meat Weights constructed from the above or from bone weights - are inappropriate or meaningless unless the pattern of bone loss is understood. This study has demonstrated that bone loss between taxa frequently does not follow easily defined rules, for example based on bone size or bone density, and based on easily measured parameters of the soil en-

vironment, such as pH and drainage. Consequently, it would seem reasonable to suggest that we may never be able to accurately establish the relative abundance of different taxa in an originally buried assemblage. In almost every archaeological circumstance it may be better to accept this fact, and therefore to abandon direct numerical comparisons in favour of an estimate of the frequency with which a species occurs in the contexts or samples under investigation. This use of relative frequency as an abundance measure has a tradition in zoology, and has been occasionally advocated and discussed in the archaeozoological literature, for example O'Connor (1985), and, specifically for fish bone, Wheeler & Jones (1989, 152-3). Given the weight of evidence indicating the vulnerability of fish bone, and its very diverse size, structure and composition, it is remarkable that the measure has so far found little support among archaeoichthyologists.

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