ARCHAEOLOGY AND THE ELECTRON MICROSCOPE. EGGSHELL AND NEURAL NETWORK ANALYSIS OF IMAGES IN THE NEOLITHIC

Anne EASTHAM* and Iolo Ap GWYNN**

Summary

This paper explores the relationship between the bird bone remains and the eggshell recovered from midden material in the Neolithic village of Skara Brae, Mainland, Orkney, and attempts to show the implications for the dietary economics of its inhabitants. The information gained from Skara Brae makes it possible to make comparisons with other contemporary sites and to outline some of the changes in bird exploitation apparent in bone collections from later prehistoric and recent sites down to the 17th century.

Crucial to this study has been the development of a neural network computer image analysis programme and database for the identification of the fossil eggshell from Scanning Electron Micrographs, carried out with the collaboration of the Institute of Biological Sciences, The University of Wales, Aberystwyth. Up to the present this has shown positive recognition of eggs from 17 different species of birds. Results which confirm the bone data, showing that these early farmers exploited a greater variety of avifauna than their successors in the Highlands and Islands in historic times.

Résumé

Archéologie et microscopie électronique. Analyse électronique d'images du réseau neural et de coquilles d'œufs du Néolithique.

Cet article étudie la relation entre les ossements d'oiseaux et les coquilles d'œufs découverts dans un dépotoir du village Néolithique de Skara Brae (Mainland, Îles Orcades) et tente de mettre en évidence les conséquences sur l'économie alimentaire de ses habitants. Les renseignements collectés à Skara Brae permettent de faire des comparaisons avec d'autres sites contemporains et de mettre l'accent sur certains changements dans l'exploitation des oiseaux observés dans les collections d'ossements de sites de l'époque préhistorique récente et jusqu'au XVII^e siècle.

Cette étude n'aurait pu être possible sans le développement d'un programme informatique d'analyse d'images et d'une base de données sur le réseau neural, dans le but d'identifier les coquilles fossilisées, enregistrées sur les Micrographes Électroniques à Balayage, avec la collaboration de l'Institut des Sciences Biologiques de l'Université du Pays de Galles, Aberystwyth. Jusqu'à présent, des critères d'identification ont été mis au point pour 17 espèces différentes d'oiseaux. Ces résultats viennent confirmer les données fournies par les ossements, prouvant que ces agriculteurs des temps passés exploitaient une plus grande variété de l'avifaune que leurs successeurs historiques dans les Highlands et les îles.

Zusammenfassung

Archäologie und Elektronenmikroskop. Die Verwendung neuraler Netzwerke bei der Analyse neolithischer Eischalen.

Die Abhandlung befaßt sich mit den Überresten der Vogelknochen und Eischalen aus dem Abfallmaterial des neolithischen Dorfes von Skara Brae auf der Insel Mainland (Orkney Inseln). Es wird versucht, ihre Bedeutung für die Ernährung der Bevölkerung zu ermitteln. Die in Skara Brae gewonnenen Daten erlauben Vergleiche mit anderen zeitgleichen Siedlungen. Gleichzeitig können Veränderungen in der Nutzung von Vögeln, die sich in den Knocheninventaren prähistorischer und neuzeitlicher Siedlungen (bis ins 17. Jh.) zeigen, umrissen werden.

Entscheidend für diese Studie war die Entwicklung eines Neuralen Netzwerkes und einer Datenbank zur Identifikation fossiler Eischalen anhand elektronenmikroskopischer Aufnahmen, was in Zusammenarbeit mit dem "Institute of Biological Sciences" der Universität von Wales, Aberyswyth, durchgeführt wurde. Bis heute konnten die Eischalen von 13 Vogelarten unterschieden werden. Die Ergebnisse decken sich mit denen der Knochenauswertung und zeigen, daß die frühen Bauern ein größeres Spektrum der Avifauna nutzten, als ihre Nachfolger in historischer Zeit.

Key Words

Skara Brae, Scanning Electron Microscope, Neural network computer image analysis, Avifauna, Ultrastructure.

Mots clés

Skara Brae, Microscope électronique à balayage, Analyse électronique d'images du réseau neural, Avifaune, Ultrastructure.

Schlüsselworte

Skara Brae, Elektronenmikroskop, Bildanalyse, Neurale Netzwerke, Avifauna, Ultrastruktur.

* *Dolau, Dwrbach, Scleddau, Fishguard, Dyfed, United Kingdom.*

* **Institute of Biological sciences, The University of Wales, Aberystwyth, United Kingdom.*

It all began, like so many things, with an egg. More precisely, with 2,000 fragments of eggshell recovered during excavations of Skara Brae, a Neolithic village on Orkney. The date range for the earliest part of the settlement, calibrated to 2 standard deviations, is between 3506 BC and 2800 BC (Birmingham 636, 637, 638 and 639) and for the later phase from 2800 BC to 1900 BC (Birmingham 433, 434, 435 and 436). It was clear that these fragments were not produced by the domestic fowl, which was introduced much later in pre-Roman times, so what kind of eggs did the Neolithic Orcadians go to work on?

This study is part of more extensive project of excavation in 1972-3 and 1977 undertaken to provide a better context for the material exposed by Gordon Childe in 1928-30 and to recover evidence for the economic basis of the settlement. The work has been jointly funded and instituted by the National Museum of Scotland and Historic Scotland and the context of the problem was this. The early settlers at Skara Brae were farmers, in that they both reared animals and cultivated crops yet they also exploited the wild fauna, mammalian, avian, fish and invertebrates from the land, the sea and the fresh water lochs in the vicinity of the settlement.

Like their contemporaries in the Highlands and Islands of Scotland, the inhabitants of Skara Brae hunted many species of seabirds as they nested along the cliffs, waders as they gathered in groups along the shore of the Bay of Skail or nested in the marshland and fields around and the waterfowl gathered on the Loch of Skail or wintering in the bay. Amongst the bone remains recovered during excavations there were 41 species of birds most of them edible. A number of them were seasonal or passage migrants. Amongst these were many of the water and wildfowl, nine species in all, some of whom are only seasonal residents or on passage, while others remain to breed. Not strictly migratory, the large group of seabirds, which include the fulmar, gannet and shearwater, cormorant and shag, a number of different species of gull and of the auk family, only settle on land to breed. Another well represented group of birds included the eleven species of wader, all characteristically feeders within the tidal zones or amongst the dunes, marshland and machair between the loch and the sea. The site also attracted its share of predators and scavengers: bones of buzzard and falcons and a probable barn owl, as well as a range of corvids and some remains of blackbird, redwing and skylark give further indication as to the habitat locations around the settlement. A breakdown of the relationship between avian habitat and behaviour is presented in table 1.

The bird remains found in the middens at Skara Brae equate well with the pattern of avian exploitation on other Neolithic sites on Orkney and in the Western Isles. Here a similar range of species were taken and in roughly similar proportions as were hunted as food birds at Knap of Howar, Papa Westray, Orkney (Bramwell, 1984). Though at Knap of Howar a larger number of great auk bones were recovered, probably because of local cliff formations, which indicates the antiquity of the colony of *Alca impennis* on Papa Westray. A comparison between the two sites is given in table 2. The Neolithic remains are very similar in range to those from the Neolithic site at Newark bay (Brothwell *et al.*, 1981). The avian remains from such burial mounds of the same period, as Isbister, (Bramwell, 1983) and The Knowe of Ramsay, Rousay (Platt, 1936) differ somewhat from those at the settlement sites and the inclusion of several specimens of *Haliaetus albicilla*, the white tailed eagle at Isbister are thought to have had cultural rather than economic implications. Since this species was also found in a chambered tomb Knowe of Ramsey the cultural concept may have some validity.

Later changes in the pattern of seabird exploitation were overviewed and analysed by Serjeantson (1988). Settlements dating from Pictish and Roman times, through to Norse, mediaeval and later times appear to have developed a strong bias towards the culling of gannet, a practice which still persists in some parts of the Western Isles. The archaeological evidence was supported by ethnographic evidence gathered by 16th and 18th century visitors to these parts (Munro, 1549; Martin, 1716 and 1740), who put great emphasis on the exploitation of gannets, gulls, fulmars and auks, the great auk in particular. Nevertheless, despite these and other accounts of seasonal exploitation of seabirds in Scottish island communities, the suggestion that they used seabirds exclusively may prove to be deceptive. After all the early writers were perfectly accustomed to markets in all parts of Britain being well stocked with every species of wildfowl, game bird and wader, lark and thrush, whereas a subsistence economy based on the sea and towering cliffs and the dangers endured by the islanders in obtaining and their strange manner of storing their daily meat and eggs was fascinating to these early anthropologists.

With these records for the culling of birds and the collection of eggs in mind, the next objective in the archaeozoological programme had to be to find a way to identify the shell fragments, in order in the end to discover the relationship between them and the hunted carcases and eventually to relate this data to modern ornithological observation.

There is a considerable bibliography of work done on the ultrastructure of avian eggshell. Some of the pioneer work in Britain was carried out by Dr C. Tyler at Reading during the 1960's (Tyler, 1969; Tyler and Fowler, 1978) and

Table 1: Skara Brae: habitat zones of bird species. S = summer resident; W = winter resident; R = resident throughout year; Br = breeding location; F = feeding location; (1): *Sula bassana* now *Morus bassanus*; (2): *Alca impennis* now *Pinguinus impennis*.

Species	Season	Sea Cliffs	Inter- tidal	Open Sea	Inland Water	Marsh & Grass	Hedge & Wood
Gavia stellata	S			R & F			
Gavia immer	W			R & F			
Podiceps cristatus	W			R & F			
Fulmarus glacialis	S &W	R & Br		R & F			
Puffinus puffinus	S	R & Br					
Sula bassana (1)	S &W	R & Br					
Phalocrocorax carbo	S &W	R & Br					
Phalocrocorax aristotelis	S &W	R & Br					
Cygnus cygnus	W				R & F	R & F	
Anser anser	S? &W				resting	R, F, Br	
Tadorna tadorna	S		feeding		resting	breeding	
Anas penelope	S &W			R & F	resting	breeding	
Anas crecca	S &W				feeding	breeding	
Anas acuta	S				feeding		
Aythya fuligula	S &W				feeding	breeding	breeding
Mergus serrator	S & W				feeding		
Buteo sp cf. *lagopus*	rare					rare	rare
Buteo buteo	S &W	breeding				R	R & Br
Falco peregrinus	S &W					R	R & Br
Falco tinnunculus	S &WS		feeding		R & Br	R	R & Br
Fulica atra	&W		feeding				
Haematopus ostralegus	S &W		feeding			breeding	
Calidris alpina	S &W		feeding			breeding	
Charadrius hiaticula	S &W		feeding			breeding	
Pluvialis apricaria	S &W		feeding			breeding	
Tringa sp.	S &W		feeding			breeding	
Tringa totanus	S &W					breeding R	
Scolopax rusticola	S? &W		feeding			& Br	
Gallinago gallinago	S &W					R & Br	
Numenius arquata	S &W	breeding		resting		R & Br	
Larus argentatus	S &W	breeding		resting			
Larus marinus	S &W	breeding		resting			
Larus fuscus	S &W	breeding		resting			
Larus canus	S &W	breeding		resting			
Rissa tridactyla	S &W	low rocks		resting			
Alca impennis (2)	?	breeding		resting			
Uria aalge	S &W	breeding		resting			
Alca torda	S &W	breeding				breeding	
Cepphus grylle	S &W	breeding				feeding	breeding
Fratercula arctica	S &W	breeding				R, F, Br	
Strigid. sp. cf. *Tyto alba*	S &W						R & Br
Alauda arvensis	S &W					R & F	R & F
Turdus merula	W					R & F	R, F, Br
Turdus iliacus	S &W					R & F	
Sturnus vulgaris	S &W	breeding				feeding	R & Br
Corvus frugilegus	S &W	breeding					
Corvus monedula.	S &W						
Corvus corone	S &W						

Table 2: Bird bone on two Neolithic settlements in Orkney. Eggshell at Skara Brae starred in final column.

Knap of Howar number of bones	Bird species represented		Skara Brae number of bones	Eggs
	Red throated diver	*Gavia stellata*	1	
1	Great Northern diver	*Gavia immer*	1	
3	Black throated diver	*Gavia arctica*		
1	Little grebe	*Podiceps tachybaptus*		
	Great crested grebe	*Podiceps cristatus*	1	
17	Fulmar	*Fulmarus glacialis*	9	*
1	Manx shearwater	*Puffinus puffinus*	4	*
24	Gannet	*Sula basanus*	20	*
9	Cormorant	*Phalocrorax carbo*	1	*
14	Shag	*P. aristotelis*	1	
3	Whooper swan	*Cygnus cygnus*	2	
12	Grey lag goose	*Anser anser*	5	
1	Shelduck	*Tadorna tadorna*		*
	Wigeon	*Anas penelope*	1	
	Teal	*Anas crecca*	5	*
	Pintail	*Anas acuta*	2	*
	Tufted duck	*Aythya fuligula*	2	
3	Eider	*Somateria mollissima*		
1	Velvet scoter	*Melanitta fusca*		
1	Buzzard	*Buteo buteo*	3	
	Peregrine	*Falco peregrinus*	1	
	Kestrel	*Falco tinnunculus*	1	
1	Spotted crake	*Porzana porzana*		
1	Corncrake	*Crex crex*		
	Coot	*Fulica atra*	2	
1	Oystercatcher	*Haematopus ostralegus*	3	
	Ringed plover	*Charadrius hiaticula*	1	
	Golden plover	*Pluvialis apricaria*	4	*
1	Grey plover	*Pluvialis squaterola*		
	Dunlin	*Calidris alpina*	1	
2	Snipe	*Gallinag gallinago*	2	
	Woodcock	*Scolopax rusticola*	2	
1	Redshank	*Tringa totanus*	1	
4	Turnstone	*Arenaria interpres*		
2	Curlew	*Numenius arquata*	2	
5	Great skua	*Stercorarius skua*		
6	Less. black backed gull	*Larus fuscus*	1	*
2	Common gull	*Larus canus*		*
	Herring gull	*Larus argentatus*	3	
17	Grt. Black backed gull	*Larus marinus*	1	*
	Kittewake	*Rissa tridactyla*	4	
1	Sandwich tern	*Sterna sandvicensis*	3	
36	Guillemot	*Uria aalge*	1	*
9	Razorbill	*Alca torda*	7	*
35	Great auk	*Alca impennis*	5	
4	Black guillemot	*Cepphus grylle*	1	*
3	Puffin	*Fratercula arctica*	8	*
	Barn owl	*Tyto alba*	1	
2	Skylark	*Alauda arvensis*	7	
	Blackbird	*Turdus merula*	6	
	Redwing	*Turdus iliacus*	5	
1	Starling	*Sturnus vulgaris*	2	
1	Raven	*Corvus corax*		
	Jackdaw	*Corvus monedula*	1	
	Hooded crow	*Corvus corone*	5	

Note: Some eggshell at Skara Brae appears to have been collected from species other than those gathered for meat. So far red throated merganser, *Mergus serrator* has not been recorded in bone remains at either site but its eggshell has been recognised at Skara Brae.

by Drs S. G. Tullett and R. G. Board and their team at Bath during the 1970's and 1980's (Tullett, 1975; Tullett *et al.*, 1976; Tullett and Board, 1977; Board, 1982) and over the same period by Taylor (1970), Rahn *et al.* (1979) and others in the U.S. The main objective of most of these studies was to demonstrate the way in which eggshell structures of different species are an adaptation to environment. Their work opened up the field of eggshell identification to the archaeozoologist and, amongst others, some determinations have been achieved at the English Heritage laboratory by Carole Keepax (1977, 1981) and by Julie Sidell at the Institute of Archaeology in London. These have been based on cone and pore counts from scanning electron microscope (SEM) micrographs of the inner surface of the shell. Clearly the use of an electron micoscope is essential but the subsequent method of identification seemed to be too criteria based and too prone to subjective error to be entirely satisfactory.

We therefore decided to analyse the SEM images using a computer neural network programme, to create and test a database of known samples which could be used as a reference for the archaeological material. Such a database required eggshell relevant to the ecology of Skara Brae, as many as possible from each species and from different clutches and a variety of breeding areas, to take account of possible phenotype as well as genotype variations. Tenby Museum, The Institute of Terrestrial Ecology at Monk's Wood, the National Museum of Wales at Cardiff and the Wildfowl and Wetland Trust all offered material. Samples were taken from all the 55 Orkney breeding species (Booth, 1990), though it was, later, decided to restrict the neural network study to waterfowl and seabirds, the species already shown to be most commonly exploited for meat by the inhabitants of the site, though within these groups were included some known breeders, even though they had not

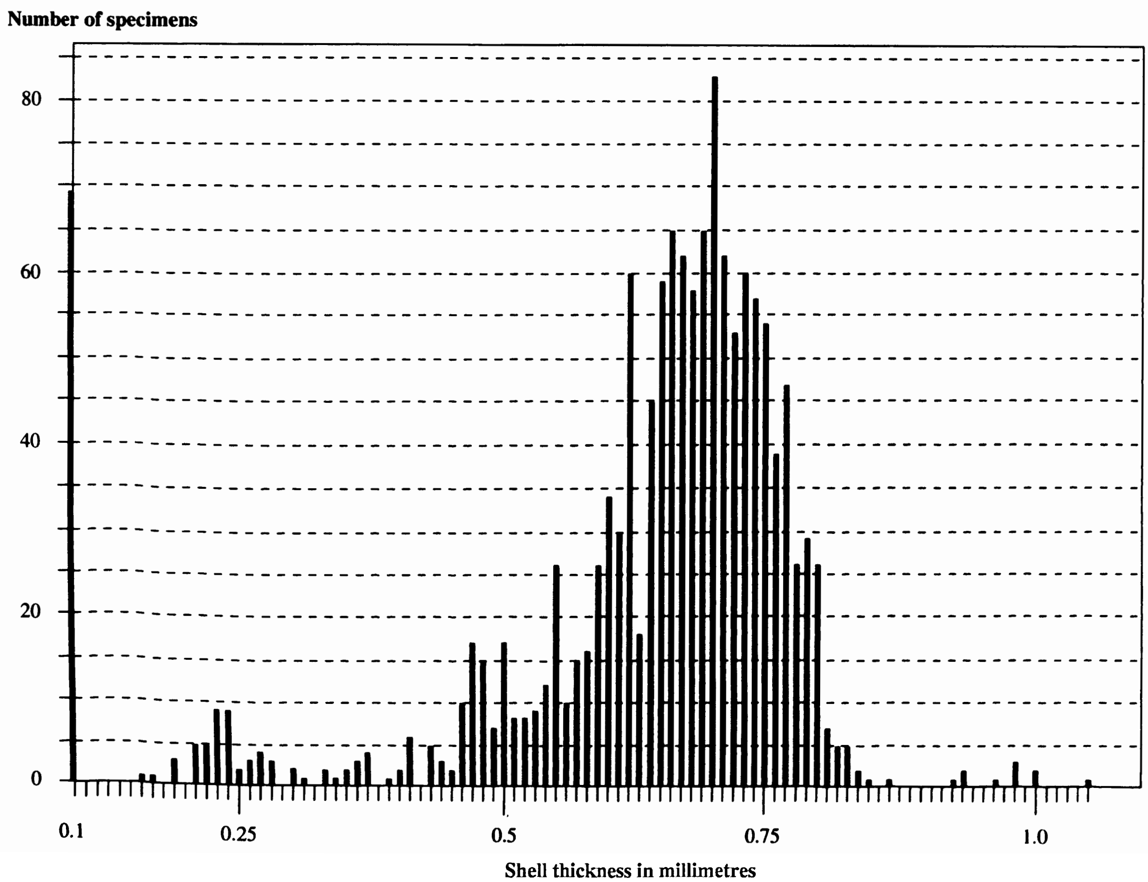

Fig. 1: Skara Brae habitation site. Thickness distribution of sample of 1425 pieces of eggshell recovered.

Table 3: List of bird species, whose eggshell was used in creating the neural network data training set.

Wildfowl	*Anser anser,* Grey lag goose
	Tadorna tadorna, Shelduck
	Anas crecca, Teal
	A. penelope, Wigeon
	A. acuta, Pintail
	A. clypeata Shoveller
	Aythya fuligula, Tufted duck
	Somateria mollissima, Eider
	Clangula hyemalis, Long tailed duck
	Mergus serrator, Red breasted merganser.
Seabirds	*Fulmarus glacialis,* Fulmar
	Puffinus puffinus, Manx shearwater
	Sula basanus, Gannet
	Larus ridibundus, Black headed gull
	L. argentatus, Herring gull
	L. marinus, Greater black backed gull
	L. fuscus, Lesser black backed gull
	L. canus, Common gull
	Rissa tridactyla, Kittiwake
	Uria aalge, Guillemot
	Alca torda, Razorbill
	Cepphus grylle, Black guillemot
	Fratercula arctica, Puffin
Waders	*Charadrius hiaticula,* Ring plover
	Pluvialis apricaria, Golden plover

been found among the bone remains. Initially, it had been impossible to obtain any sample of eggshell of the now extinct great auk, whose bones were recovered on the site but, since the presentation of this paper in September 1994, in Konstanz, Dr. Christian Érard of the Muséum national d'Histoire naturelle in Paris has given a small piece from a broken egg in the collections which can now be incorporated into the study.

In order to handle the archaeological material in a systematic way, each fragment from all the separate levels of the excavated areas of the site needed to acquire an identity, so that sampling methods could be tested. Each of 1,425 fragments was listed in numerical order according to its age and location on the site and at the same time the thickness of each was measured, using a small bench micrometer with a digital readout. At the time this was merely an attempt to identify approximate thickness clusters, which might prove useful in the sampling and, as a control, all the recent specimens were treated in the same way (fig. 1). Plotted on a histogram the Skara Brae shell showed major peaks between 0.6 and 0.8 mm, whereas the recent samples of most species were thinner. Most species of duck eggs were between 0.2 mm and 0.35 mm, grey lag 0.57; gulls also averaged between 0.2 mm and 0.35 mm according to the size of the species. Auk eggs tended to be a little thicker in proportion to their volume, the guillemot being the most robust at around 0.6 mm. Gannet shells were, surprisingly, thinner, averaging just under 0.5 mm, with fulmar close behind at 0.45 to 0.46 mm. However, as the results will show, in the end shell thickness does not seem to have proved crucial to the archaeological enquiry, although it may in future open up other questions not directly related to it.

The species used so far in the neural network training programme are listed in table 3.

With a range of samples from all the relevant species in hand, the recent eggshell was prepared, prior to making the SEM micrographs which could then be digitised for processing using the neural network software. Each fragment of eggshell was given the standard treatment of boiling in a 5% w/v solution of sodium hydroxide for 5 minutes followed by a hot rinse before drying at room temperature. This seemed to be effective on most samples in removing shell membrane and extraneous organic material. The pieces were then mounted on stubs and coated with gold, in the usual way, for study and photographing under a JEOL 840 SEM working at 10 kv accelerating voltage. A standard working distance of 14 mm was established and two levels of magnification, x 100 and x 800 were initially selected, though once trials with the neural network programme had begun and it was clear which was the optimum, the x 800 micrographs became redundant and were eliminated.

Visual examination of micrographs of recent eggshell at both lesser and greater levels of magnification revealed clear genetic clustering.

Patterns within groups like the *Anas* ducks or the *Alcidae* were recognisable, even to the point of being able to distinguish *Fratercula arctica* as having a quite separate structure from other auks and it is interesting that there is some doubt about the inclusion of the puffin in this group. But when it came to unknown and fossil material, the human eye could not make valid distinctions.

From the moment when the micrographs were scanned into the computer system, using a Scanjet IIP scanner, the whole process of recognition and identification depended on the programme. We had more than seven specimens of each species of waterfowl and seabird selected for the

Figs. 2a, 3a and 4a: Micrographs of recent common gull, greater black backed gull and shelduck eggs.

Figs. 2b, 3b and 4b: Micrographs of eggs of the same species from the fossil material.

Figure 2a

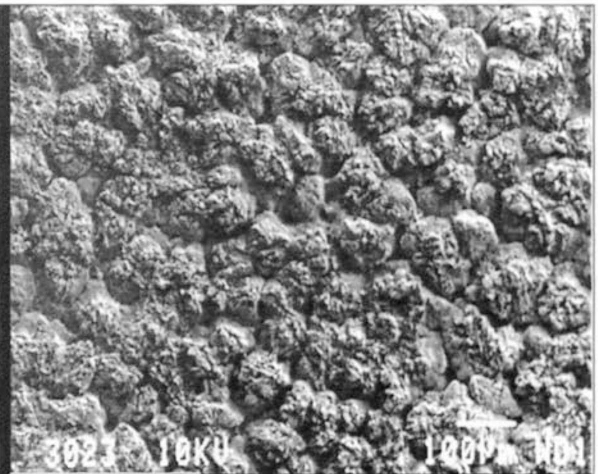

Figure 2b

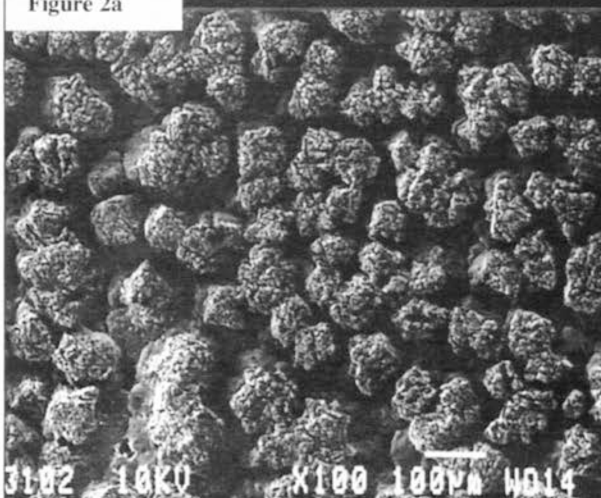

Figure 3a

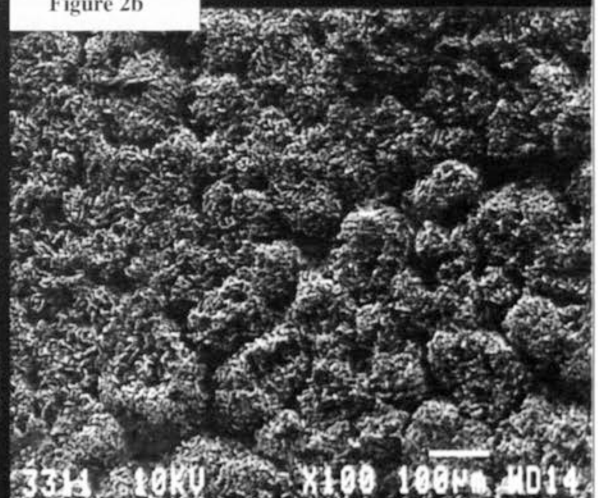

Figure 3b

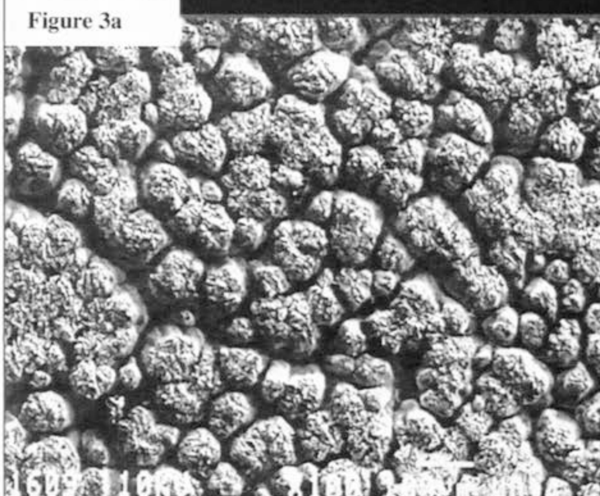

Figure 4a

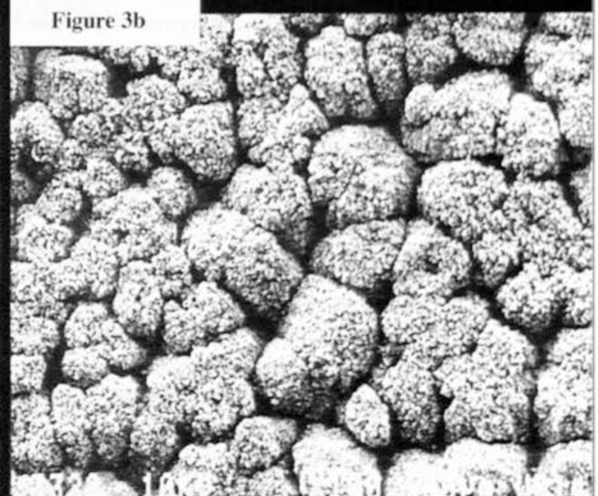

Figure 4b

study. The basic programme from Finland, called a Learning Vector Quantitization or Kohonen network (LVQ - PAK version 2.1, Helsinki University of Technology, Laboratory of Computer and Information Science, Espoo, Finland) was designed initially to measure language density therefore a certain amount of pre-processing of the data from contoured images of eggshells was necessary before the network could handle the information. By taking 10 strips of 300 x 20 pixels from each 300 x 200 micrograph, a considerable amount of training material - 2500 images in all - was made available for training the network program. Each image was pre-processed, using locally written software in QBASIC, to convert it to a set of 44 different parameters based on pixel density and distribution on both horizontal and vertical axes.

Once the training had been done the original data could be scrambled, in a test exercise, and applied to the trained network for re-identification. Results from these trials looked hopeful, with an accuracy of more than 70%. After that it became a question of testing and modifying the training of the network, until acceptable levels of accuracy were reached.

It was now time to apply the imaging data to the micrographs of the fossil material. Ninety-six specimens from the Skara Brae were selected in two ways. One sample was selected to cover the range of shell thickness and the second to represent the different archaeological levels from phases I and II of the occupation stages of the site as evidenced from a single excavation trench I.

The early trials on this sample have been encouraging. By giving it 10 chances at identifying each specimen, the computer has been able to present the results in terms of scores out of 10, which gives a percentage component to the results. At less that 30% no recognition has been achieved, over 30% is regarded as positive and successive re-runs usually confirm it. Examples of positive identification are shown in figures 2, 3, and 4. Inevitably, some images are doubtful, either because of the effects of abrasion, chemical activity in the soil, or the breakdown of the cone structure during incubation. But most of the results are positive and show that quite a wide variety of birds eggs were sought by the villagers of Skara Brae.

So far the findings indicate that the seabirds predominate: eggs from gannets, fulmars and shearwaters, along with greater and lesser black backed and common gulls and the eggs of common and black guillemot, razorbill and puffin were all collected by the inhabitants of Skara Brae. Nevertheless there are, besides these, eggs of wildfowl, shelduck, teal, pintail duck and red breasted merganser (fig. 4) and this perhaps is the less predictable outcome, on the basis of the ethnographic evidence (tab. 3). Up to the present less than 100 out of the total of 1,425 measured fragments have been processed and still fewer submitted to neural network processing. Even so the sample already identified appears to have been selected on a sufficiently random basis to be fairly representative of the whole collection. Cost and the fact that the eggshell is not easily retrievable after preparation for the SEM restricts the number of samples which can be examined by this method. The use of lower accelerating voltages in the SEM would enable uncoated specimens to be examined and thus make more available to study.

The seabirds from the fossil collection, whose eggs have been identified, all nest either in ledges along the cliffs or in burrows along the cliff tops and the wildfowl make their nests in hollows and vegetation, usually back from the shore and sometimes in dunes and heather close to inland waters, so that as more eggshell samples are identified by the programme, it is becoming possible to gain a clearer idea of the catchement area around the village within which the people gathered eggs during the Spring and early Summer months.

There is a broad relationship between those avian species which were exploited for meat and oil and those whose eggs were collected. Where there is some small disparity, this may partly be explained by archaeological factors, because though a particular species may feature amongst the eggshell, like the shelduck, the razorbill or the merganser, yet their bones do not appear in the midden remains from the areas of the site already excavated. This is reasonable, as it is unlikely that eggs and meat were gathered simultaneously. Owen (1603) and Lockley (1941) record the regular cropping of both heron chicks and gull's eggs in Pembrokeshire, West Wales, throughout the season so that the adult birds extended their laying period. Seasonal movements also played a part in the availability of individual species. Many of the seabirds disperse to marine or inshore waters at the end of the breeding season and wildfowl migrate to other feeding grounds after the young are fledged, to moult and then on to Winter quarters.

One species, which is abundant along the shores of these islands at the present day but is totally absent from the bone collections at Skara Brae and poorly represented at Saevar Howe and the Isbister tomb, is the eider duck, *Somateria mollissima*. However, at the time of writing a sample of eggshell has just been identified as eider, with a 40% weighting. Ericson (1987) in his study of the eider in Southern Scandinavia found that although environmental conditions favourable to it had existed in that region since Preboreal or even Late Glacial times, its bones were not recovered in any quantity until the Viking period 800 - 975 AD. Ericson was considering the osteological record rather than eggs, yet his findings suggest that eider numbers have increased only relatively recently and the small numbers recovered from Neolithic and later prehistoric sites in Scotland may be an accurate reflection of its population ecology.

In conclusion, this study has produced a number of results, which have on-going implications for work in biological and computer sciences as well as for archaeozoology.

At Skara Brae the inhabitants appear to have enjoyed as much variety of birds eggs in their diet as the number of species which they killed for meat.

The process of identification has demonstrated the use of neural network analysis of images as a tool in identifying structures too complex for the human eye. The technique of creating a database avian eggshell ultrastructure is complex and time consuming but it is not ephemeral and the present programme of 25 species forms the beginnings of a reference library of material to which further units may be added at any time. Archaeologically the present results are interesting, but the technique is a tool which can be applied to other orders of cell structure, where closely related patterns have to be isolated.

In addition, there are problems posed by eggshell samples themselves, which open up new fields for research. The apparent differences in the thickness bias of the fossil as against the recent samples are an example. The specific nature of this is not yet fully quantified, though it is becoming clearer as more of the Skara Brae samples are processed. The impression is that for at least some of the species already identified there is a difference in eggshell thickness of at least one third. As this non-conformity becomes clearer, a reason must be sought. Questions about whether thickness is related to a timescale, geography or climate change arise. There are a number of possibilities for this ecological adaptation, which may turn out to have little to do with any trendy explanations for wildlife change but it is a fascinating phenomenon and tempting to explore.

Acknowledgements

Our thanks are due to the College Research Fund of the University of Wales, Aberystwyth, who provided a grant which enabled the purchase of the hardware needed to digitise and process the micrographs; to Tenby Museum, The National Museum of Wales, the Monk's Wood laboratories of the Institute of Terrestrial Ecology, the Wildfowl and Wetlands Trust, Slimbridge and Dr N. Sparks of The Scottish College of Agriculture, who gave samples of eggshell; to Dr R.G.Board, who gave much initial advice and encouragement and to the National Museum of Scotland and Historic Scotland who instituted this research study.

Bibliography

BOARD R. G., 1982.– Properties of avian eggshell and their adaptive value. *Biological Revue,* 57 : 1-28.

BOOTH C., 1990.– *Orkney Bird Report.* Rendell Stromness.

BRAMWELL D., 1983.– The bird bones. *In* : J. Hedges ed., *Isbister : a chambered tomb in Orkney.* Oxford : B.A.R. Brit. Ser. 115, pp. 159-70.

BRAMWELL D., 1984.– Bird bones from Knap of Howar, Orkney. *In* : A. Ritchie ed., *Excavation of a Neolithic Farmstead, Papa Westray. Proc. Soc. Antiq. Scot.,* 113 : 100-102 [1983].

BROTHWELL D., BRAMWELL D. and COWLES G., 1981.– The relevance of birds from coastal and island sites. *In* : D. Brothwell and G. Dimble eds., *Environmental aspects of coasts and islands.* Oxford : B.A.R. Inter. ser., 94, pp. 195-206.

KEEPAX C., 1977.– *The identification of avian eggshell from archaeological sites and the potential use of the SEM.* London : Ancient Monuments Laboratory Report 2415.

KEEPAX C., 1981.– Avian eggshell from archaeological sites. *Journal of Archaeological Science,* 8 : 315-335.

LOCKLEY R. M., 1941.– *The way to an island.* London : Dent.

MARTIN M., 1716.– *A description of the Western Islands of Scotland.* Reprinted from the Philosophical Proceedings of the Royal Society 1697.

MARTIN M., 1740.– *A voyage to St Kilda.* London : Griffith.

MUNRO D., 1549.– *Munro's Western Isles of Scotland and the genealogies of the clans.* R. W. Munro ed. 1961.

OWEN G., 1603.– *A description of Penbrokshire.* London : Cymmrodorion Soc. 1891.

PLATT M. I., 1936.– Report on the animal bones found in the Chambered Cairn, Knowe of Ramsey, Rousay, Orkney. *Pro. Antiq. Scot.,* 70 : 415-419.

RAHN H., AR A. and PAGANELLI C. V., 1979.– How birds breathe. *In* : *Birds.* Extracts from Scientific American Pub. Freeman and Co 1980, pp. 208-17.

SERJEANTSON D., 1988.– Seabird exploitation in Scotland. *Archaeozoologia,* 2 (1-2) : 209-224.

TAYLOR T. G., 1970.– How an eggshell is made. *In* : *Birds.* Extracts from Scientific American, Pub. Freeman and Co. 1980, pp. 201-207.

TULLETT S. G., 1975.– The regulation of avian eggshell porosity. *Jour. Zool.,* 177 : 339-348.

TULLETT S. G., BOARD R. G., LOVE G., PERROTT H. R. and SCOTT V. D., 1976.– Vaterite deposition during eggshell formation in the cormorant, gannet and shag and in shell-less eggs of domestic fowl. *Acta Zool.,* 57 : 79-87.

TULLETT S. G. and BOARD R. G., 1977.– Determinants of eggshell porosity. *Jour. Zool.,* 183 : 203-211.

TYLER C., 1969.– Avian egg shells : their structure and characteristics. *Int. review of General and Experimental Zoology,* 4 : 81-129.

TYLER C. and FOWLER S., 1978.– The distribution of organic cores, cones, cone junctions and pores in the egg shells of wild birds. *Jour. Zool.,* 186 : 1-14.