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Back cover (l–r): Dupotetia dupotetiana on shrubby vegetation, Moulouya valley, Morocco; adult mussels attached to rocks at Fistral bay, Cornwall; Bronze Age burial from Ban Non Wat (Central Thailand).

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Prof Les Allen, BSc, DSc, PhD, ARCS, DIC, CPhys, FInstP, FOSA,
1935–2016

To my father, an amateur archaeologist, who nurtured, encouraged and fostered my own interest, and then career in archaeology, ensuring that I continued to publish and attempt to maintain high academic standards. I’m only sorry that I didn’t finish this in time for you to see.

The
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Founded in 1876, the Conchological Society of Great Britain and Ireland is one of the oldest existing societies devoted to the study of molluscs and their conservation. The Society achieves this through meetings, workshops, publications and distribution recording schemes. It publishes its academic journal, the *Journal of Conchology*, twice yearly and *Mollusc World*, a colourful magazine three times a year. These both form part of the annual subscription. Occasional identification guides as well as *Special Publications* in the format of the *Journal* are issued.

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Further information can be found on its website (www.conchsoc.org) or by contacting them at secretary@conchsoc.org.

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Allen Environmental Archaeology has been operating for 10 years, with Mike, a leading geoarchaeologist and environmental archaeologist with over 35 years of experience, specialising in land snails, soils, sediments, hillwash and co-ordinating palaeo-environmental programmes. Mike has undertaken land snail analysis across southern England, for over 35 years including working in Stonehenge, Avebury, Dorchester Environs, Cranborne Chase, and the South Downs National park, and in the past has specialised in the examination of colluvial deposits.

Allen Environmental Archaeology co-ordinates environmental archaeology sampling, processing, analysis and publications programmes for a number of projects and archaeological organisations, providing a one-stop shop for many field archaeologists. Mike has a long publication record, as well as being series editor for the Prehistoric Society Research Papers, and Oxbow's Studying Scientific Archaeology Series and on the editorial board of Oxbow's Insights Series.

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14. Oysters in archaeology

Jessica Winder

This chapter provides an overview of the way in which simple methods for studying the macroscopic features of oyster shells, excavated from relatively recent historical deposits in the UK, were developed during the late 20th century. It also shows how the resulting data have been used to make spatial and temporal distinctions between samples and enabled discussion about oyster trade and collection practices. The chapter tentatively suggests the application of advanced techniques for identification of chemical and protein composition in archaeological oyster shells in order to improve our understanding of the exploitation of oysters in the past. Successful employment of these newer methods could perhaps facilitate interdisciplinary research into wider issues such as oyster population identification, effects of global climate change, and the impact of industrialisation on coastal water quality, by providing baseline data for the investigations.

Background to research

Shells of the European flat oyster or British Native oyster *Ostrea edulis* L. (Figs 14.1 & 14.2) record and reflect to an extraordinary degree the chemical, physical, and biological environment in which they grew. Few other edible bivalve molluscs equal this species for variability in shell shape and structure, and for the range of evidence related to epibiont organisms that use the shell as a habitat. The most useful aspect for study of variation in the archaeologically-derived European flat oyster material, is the extent to which shell size, shape and other features are modified not only by factors in the growth environment but also by the effects of human activities associated with its collection, its use as food, and its disposal. Readily observable features in oyster shells from archaeological excavations can provide important evidence for their source location and manner of exploitation. However, this potential is accompanied by methodological and epistemological challenges for the investigator.

The methods were first developed when a surge of urban redevelopment in 1970s Britain, with its accompanying archaeological surveys and excavations, unearthed large quantities of historical oyster and other marine mollusc shell food remains.

Archaeologists asked how useful this material might be for site interpretation. Would it be possible to say where the oysters had come from? Were they from natural wild populations, farmed or cultivated? What was their significance in the diet and economy of the local and regional economy? Importantly, conscious of the enormous numbers of shells to be processed and funding limitations, could these questions be answered using simple, cost-effective, and easy-to-learn methods?

In the 1970s and 80s, there was already a great deal of interest in archaeological shell deposits, including oyster shells, but research had mainly focused on large early period middens in Britain such as those on Oronsay (Mellars 1987). Work was also being undertaken on shells from Palaeolithic, Mesolithic, Neolithic, post-glacial and Quaternary sites in Australia, Japan, the Americas, and continental Europe, on topics such as midden distributions along prehistoric coastlines, shellfish gathering patterns

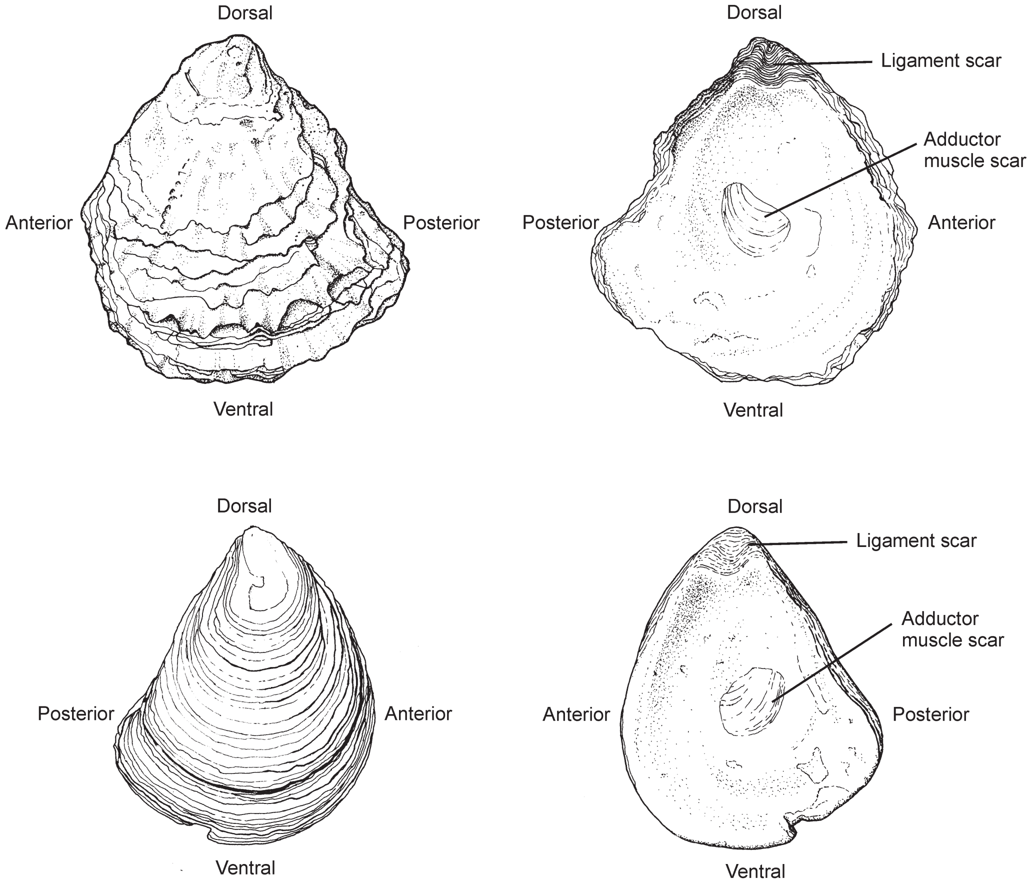

*Figure 14.1 The two valves of the oyster (*Ostrea edulis *L.) showing major features and shell orientation with left valve top and right valve below (illustration: Abby George)*

and subsistence strategies, and seasonality of collection using shell growth line and oxygen isotope analysis. Significant contributors to the research included Bailey (1975; 1978; 1983; Bailey & Parkington 1988); Deith (1983a; 1983b; 1985a; 1985b; 1988); Koike (1979; 1981); Meehan (1982); Mellars (1978; 1987); Shackleton (1983; 1988); and Troels-Smith (1967); and at a later stage Milner with other authors (eg, 2001; 2002; 2009; 2013; Milner & Barrett 2012; Milner & Woodman 2002; Milner *et al.* 2007; Demarchi *et al.* 2011; 2013; Gutierrez-Zugasti *et al.* 2011; Surge & Milner 2003). However, the species of oyster under consideration by these authors were often different from the European flat oyster that was being excavated from English urban sites, and the questions being asked of the material and the strategies for investigation such as those outlined in Cherry *et al.* (1978) were not always applicable or pertinent to the newly-recovered historic pit and stratum oyster shells. Claassen (1998) gives an excellent comprehensive account of the kind of questions that were and are still being asked of archaeological shell material elsewhere. These include enquiries into the taphonomy of the shells and shell assemblages, sampling methods and quantification, palaeo-environmental reconstruction, season of death, and shells as artefacts.

The exception to this general research trend was the work of Kent (1988) in *Making Dead Oysters Talk: techniques for analysing oysters from archaeological sites*, a research project in Maryland, USA, which was being undertaken at much the same time as work along similar lines had started in Britain with the examination of urban deposits of oyster and other marine shells from Saxon sites in Southampton (Winder 1980).

In Britain, the oyster shells and other marine molluscs were generally being excavated from smaller deposits, often in urban and rural, inland as well as coastal locations, and dating from only the last 2000 years. The questions being asked of the material were directed specifically at within-site interpretation and an understanding of aspects of diet, trade and economy on the local and regional scale. Methods were devised to account for these differences in aims and the limited available resources.

Preliminary investigations of the literature indicated that oyster fishermen and oyster connoisseurs could reputedly tell where an oyster had come from merely by its appearance and taste, showing that characters existed by which those from different locations could be distinguished – at least in the fresh undamaged oysters. Lucilius the Roman poet said ‘When I but see the oyster’s shell, I look and recognise the river, marsh or mud where it was first raised’. What might those characters be? Yonge (1960) gives an invaluable account of the structure, biology and natural history of the oyster (*Ostrea edulis* Linnaeus), including the types of marine organism that infest and encrust the shells, as a starting point for understanding what could be the most useful shell characteristics to seek in the archaeological shells.

One question for the archaeomalacologist was whether any useful distinguishing characters still remained in archaeological shells since many features present in fresh specimens would not survive in long-buried samples. The fleshy parts of the mollusc itself and also soft parts of epibiont organisms such as marine worms, barnacles, sea squirts and algae would readily decompose. Breakage, wear and weathering – before, during, and after burial – may have damaged the shell, smoothing the surface sculpturing, obscuring growth lines, removing foliation, along with the destruction of adherent sessile barnacle plates, and chalky or sand-grain tubes of polychaete worms. Shells fade, delaminate, and disintegrate with time. Diligence is often needed to observe and record the features accurately when the condition of the excavated shell is poor.

It is frequently possible to identify former epibiont associations on oyster shells by examining the damage they render or the remnant encrusting material. For example, the holes left by mud-tube bearing marine worms, predatory gastropods and boring sponges can be distinguished from each other (eg, Boekschoten 1966; Carriker & Yochelson 1968); whilst attached organisms like calcareous tube worms and acorn barnacles leave recognisable attachment scars or basal plates.

Notably, whilst many excavated shells are worn and relatively featureless, some can remain surprisingly fresh in their appearance and even retain pigmentation or fragments of ligament and periostracum, to the extent that they could easily be mistaken for freshly-dead shells. In some special circumstances oyster shells survive well with minimal damage and preservation of the proteinaceous structures of the ligament and the conchyolin framework that supports the largely inorganic shell. This usually happens in waterlogged deposits. Examples include shells from the extensive late Saxon and early Conquest-period midden found by the old Town Cellars on the edge of Poole Harbour in Dorset (Horsey & Winder 1991; Winder 1992a) and medieval shells recovered from a well in North West Cambridge excavations.

Not all samples of examined oyster shell are suitable for analysis. Whereas shell samples from a site can all be recorded in a basic way by making species identifications and counts, facilitation of viable statistical comparisons between samples require that detailed records be taken only from shells in contexts that are securely dated or phased and (as far as can be ascertained unbiased), and with samples comprising larger numbers of near-intact shells. Correct identification, quantification, and understanding of the significance of the varying shell features, allied with knowledge of the limitations of extrapolation and interpretation from the archaeological data, allow the questions posed to be addressed.

Methods

The methods devised for recording these features are described in Winder (1992b) and later with numerous accompanying illustrations in Winder (2011) – both supplying detailed instructions for the initial processing and recording methods for macroscopic characteristics in archaeological oyster shells. Standardisation of recording methods is vital, especially when samples recorded by different individuals are being compared. The methods involved quantified recording of objective characters such as numbers, ratios of left to right shell valves, (Figs 14.1 and 14.2), measurements (Fig. 14.3), and details of epibiont infestation in the oyster shells (eg, damage caused by forms of worms and sponges, see Figures 14.4 and 14.5 respectively). Quantified recording of subjective characters noted relative shell thickness, presence of chambering, shape, colour, degree of wear, clumping, attached spat, degree of distortion and man-made marks (eg, Fig. 14.6). A combination of the measurable and objective, together with some subjective

Figure 14.2 Typical oyster right (upper) and left (lower) valves, showing inner and outer views

and descriptive characters, can be used in analyses. Records of up to 25 features are suggested. For accurate recording of these kinds of features great care needs to be taken with handling and washing the shells, as this could potentially physically damage shells and destroy evidence.

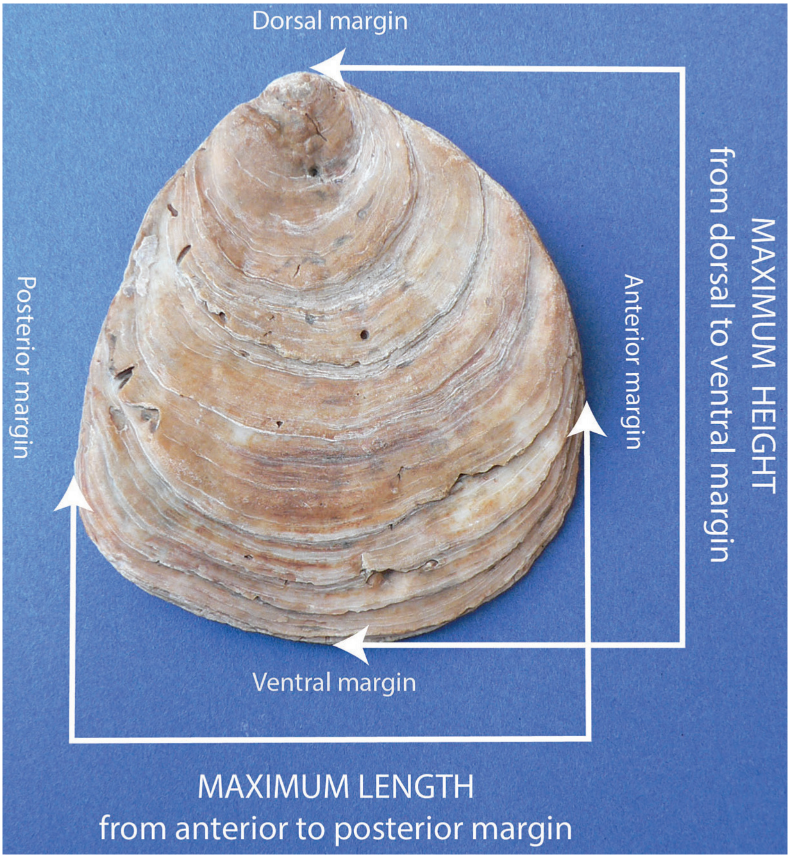

Figure 14.3. Photograph of right oyster valve (exterior view) showing measurable dimensions. Note that height is the measurement from the beak or umbo to the ventral margin – but this measurement has commonly been called the width in many archaeological analyses, see Endnote

Outcomes

The information gathered from the oyster shells is expressed as a mean frequency of occurrence of each characteristic in the whole sample. These frequencies give each sample a unique description. Statistical analysis of both objective and subjective sample characteristics are used to make spatial intra-site and inter-site comparisons of samples from a local context and feature level, to a wider geographical level; and also to make temporal comparisons both within a site on a phase-by-phase level and across broad historical time or occupation periods.

Size comparisons within a site are made using parametric two-sample tests and also non-parametric Kolmogorov-Smirnov or Mann-Whitney U-tests. Infestation frequencies can be simply collated and compared visually with both archaeological material and modern marine invertebrate distributions of nearby coastal localities. Some examples of first attempts to collate and analyse oyster shell data are published in Winder (1980; 1985; 1991; 1992a; 1992b; 1993a; 1993b; 1994a; 1994b; 1997a; 1997b; 2000a; 2000b; Winder & Reidy 1996), and Wyles and Winder (2000).

Winder (1992b) brought together much of this reported material (from 1980 to 1992) and used the substantial database of over 30,000 oyster shells from 60 archaeological sites (together with other marine molluscs) to demonstrate distinctions in size and infestation between oysters from the south coast of England in Poole Bay and Harbour, the Solent and Southampton Water, and the Thames estuary and East Anglian coastline. Comparisons of size for broadly defined historical periods revealed interesting variations in mean sizes between the Roman, Saxon, medieval, post medieval and modern oyster shells. This appeared to indicate statistically significant temporal differences in the average size of oyster shells. Roman shells were largest but size decreased progressively through successive periods until a recovery to almost Roman dimensions in the modern period. In addition to clear ideas about movements and transport of oysters between different localities in the past, and of site specific information about oyster usage, in brief terms, the following picture emerged about oyster exploitation in Britain.

No oyster shells were, at that time, recovered from Iron Age sites. Specimens found at Owslebury in Hampshire are now believed to be incorrectly assigned to that period. Roman sites throughout the UK were renowned for the massive quantities of oysters, but, contrary to assertions in the literature, no physical or documentary evidence was found at that time to indicate that the Romans introduced oyster cultivation as such to Britain. The cultivation techniques used in Italy between AD 0–400, would have been impractical and unnecessary in Britain. Although prehistoric oyster middens have been found in the Scottish isles, oysters appear to have been a largely unexploited resource in the period immediately prior to the Roman invasion of Britain. The claim that oysters were transported around Britain alive in tanks of water during the Roman occupation (Frere 1967) seems also to be highly unlikely and immensely impractical. Since oysters will remain fresh for up to 10 days if kept cool and closely-packed, oysters could have been simply tightly-packed into baskets, barrels, or even British-made pots for transport. Black burnished-ware pottery manufactured on the shore of Poole Harbour, Dorset, was sent as far afield as Hadrian's Wall (Cox & Hearne 1991) and it would have been easy to fill them with fresh oysters from the adjacent beds before dispatch. The large average oyster size for the period may reflect an abundance of mature specimens, a preference for eating larger oyster meats than we select today, as well as a rapid growth rate.

Saxon sites also produced lots of oysters but these were mostly near the coast or within easy reach of the coast by river. Deterioration of the roads at the end of the Roman period and poorer organisation meant that oysters could not be sent far. Average size was found to be slightly but significantly smaller than those from Roman sites. To date there is still no evidence for farming or cultivation of oysters in that period.

By the medieval period, oysters were far more widely distributed across the country. They were also noticeably smaller. Their size tended not to be a selection of immature specimens but rather of prevalence of slower growth rate, possibly attributable to temperature changes but also maybe directly resulting from oyster relaying and storage activities. Documentary records exist for the ownership of oyster beds and oyster fishing rights at this time together with evidence for re-laying stock for fattening. Intertidally re-laid oysters cease to grow shell whilst periodically out of water and therefore achieve smaller sizes. Simultaneously they learn to keep the valves tight shut when exposed to the air, preventing desiccation, which means they stay fresh when being transported over greater distances. The increasing numbers of oysters found on coastal sites reflects their easy availability and indicates that they were a staple of the diet there. The smaller numbers of oysters found at inland sites suggests that the cost of transporting oysters made them an occasional and luxury item away from the coast.

Not many oyster specimens of post-medieval date were available for the study, so conclusions are few. The examined shells were smaller than in earlier periods. The Modern period was taken as including the 19th century onwards which saw the advent of railways and with them an efficient countrywide distribution of increasingly cheap oysters. It was a boom time for oystermen fishing the natural and re-laid beds, with shoreline holding pits to store the catches and ensure constant availability for marketing in season. Oyster stocks eventually became depleted by overfishing. All attempts to increase oyster stocks by cultivation and introduction of foreign species failed. Rare physical evidence of this type of cultivation experimentation at the Sinah Circle (Fig. 14.7), has been recorded in Langstone Harbour (Adams *et al.* 2000). The final blow to the incredibly successful oyster industry of the 19th and early 20th centuries came with massive extinctions of beds in the 1920s – thought to result from extreme cold weather and disease.

A few natural beds of oysters survived. Oysters became a luxury item on the menu again. A second catastrophe in the form of *Bonamia* disease devastated remaining stocks in the 1970s. Modern technology came to the rescue of the British oyster industry by breeding oyster spat of both *Ostrea edulis* and *Crassostrea gigas* in the laboratory so that beds could be restocked. Oyster farming today with its net bags of lab-reared oysters and floating platforms would not be recognised by our predecessors. Their methods were undoubtedly simpler but harder and we still have much to find out about them.

Models of oyster exploitation

The strong database of detailed information about oyster shells enabled the formulation of models in which data recorded from oyster shells could be used to interpret the mode and level of exploitation of this marine resource (Winder 1992b, 281–304). The models identify which types of evidence, from the shells themselves and the context in which they are found, might indicate different types of oyster bed location, and suggest the degree of effort required to take advantage of this natural resource. The models represent a system view considering direct evidence from the oyster shells themselves, all associated data recorded for the natural environment where they were possibly reared, and for the man-made environment in which they were collected, used and discarded (such as other associated marine mollusc species, contextual information, coastal ecosystem data, and historical records) to characterise the whole system from which they were derived and of which they were an integral part. The proposed five

Figure 14.4. Oyster with: top Polydora ciliata *(worm) infestation, and bottom* Cliona celata *(sponge) infestation*

Figure 14.5. Oyster with: top burrow of Polydora hoplura *and, bottom: with blisters caused by* Polydora hoplura

theoretical models illustrate exemplar points in what is really a transitional series from a representation of a simple collection strategy of sporadic hand-collection of oysters from natural intertidal beds; through gradually increasing intensity of effort to a full-scale cultivation, harvesting and marketing scenario.

Each element of data recorded from the oyster shells and the site can potentially contribute to our understanding of the particular type of environment in which the oysters lived, and the level of activity involved in their collection or harvesting. For example, infestation evidence could be used to suggest the locality of the bed, whether the bed was intertidal littoral or shallow sub-littoral, harder or softer substrate, and also the degree of salinity. Size distributions may reflect growth rate, recruitment variability, selection preferences, and survival rates. Certain combinations of shell sample characteristics can be used in an attempt to distinguish between fished and farmed oysters. A natural population might be suggested by a wide range of size and age, irregularity in shell shape, and the presence of attached oysters including spat. Shells from re-laid or cultivated populations might show a narrowing of size and age range, greater regularity in shape, an absence of attached oysters (especially spat), and

Figure 14.6. Oyster with man-made perforations and notches

possibly cultch (deliberately deposited spat-collection material), or an imprint of it, at the heel of the shell. Fluctuating salinity regimes typical of inshore shallow waters where oysters are re-laid can be indicated by chambering of the shell, and by chalky deposits.

At the lowest organisational level of exploitation (Model 1; Fig. 14.8) there would be sporadic collection by hand of oysters from natural populations in the intertidal zone on the sea shore, estuaries or creeks. In this scenario the exploitation level would be low and indicated by small quantities of shell, possibly in isolated pockets or separate layers suggesting short-term periodicity of collection. There might be a wide size and age range from random collection, and a high proportion of irregularly shaped and clumped groups of shells of different ages (indicative of a natural population because distorted shapes result from a competition for growing space when many spat oysters settle on the same object). An example of a Model 1 situation is provided by the 12th–13th century shell midden at Ower Farm on the southern shore of Poole Harbour (Winder 1991) where all the evidence pointed to collection from a small, natural, overcrowded population on a rough substrate including accumulations of empty cockle shells.

Model 2 postulates the introduction of special equipment which enables fishing for oysters by dredging inshore shallow sub-littoral natural beds of oysters. This requires greater expenditure of effort and a more organised approach to collection which is probably conducted on a more regular basis because the equipment makes the resource accessible at all times. The average sizes of the shells might be larger than those recovered from the intertidal zone because growth would not have been interrupted by periodic exposure to air. The size range might possibly be narrower if a dredge net had been used. As in Model 1 a high proportion of shells with irregular shape and groups of oysters clumped together might be expected, as typical of an unmanaged bed. An example of a possible Model 2 situation was seen in samples from Greyhound Yard in Dorchester (Winder 1992b; 1993a) where a study of oyster shells from medieval and Roman contexts indicated that they had originated from 30 miles (48 km) away in the shallower waters of Poole Harbour rather than the deeper water of Poole Bay.

Model 3 is an extension of Model 2 involving the dredging of deeper off-shore sub-littoral oyster beds. Exploiting the deeper waters at this distance from shore

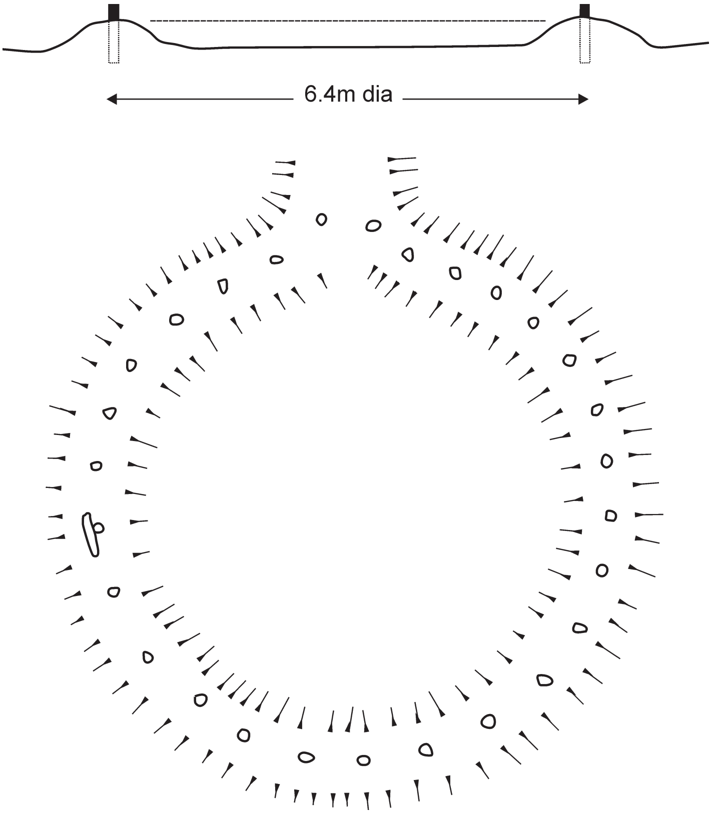

Figure 14.7. Sinah Circle structure from Langstone Harbour (from Allen & Gardiner 2000, fig. 36; illustration: Abby George)

would require more effort than expended in Models 1 and 2, better equipment, and more advanced skills. Many of the characteristics expected in Model 2 would also be found in Model 3. Some differences would be likely as in the lower intensity and type of epibiont damage from relatively nutrient-poor deeper water, a different range of associated molluscs, and possibly the shape of the shells from growing on firmer offshore substrates (Winder 1992a; 1992b). A modern example of the Model 3 type of exploitation is seen in the fishing for wild oysters that takes place in Poole Bay for relaying or for direct sale. Archaeological samples that parallel the size characters and infestation patterns of the natural oysters from Poole Bay, include all of the medieval oysters from Paradise Street, Poole (Winder 1992a; 1992b).

The first three models describe a trend towards the more systematic and expert recovery of oysters growing naturally in the wild. Model 4 illustrates a further intensification of procedures which are designed to increase stocks and availability while improving quality of oyster meat. This model postulates the introduction of deliberate management of oysters stocks, with foresight, planning, and development

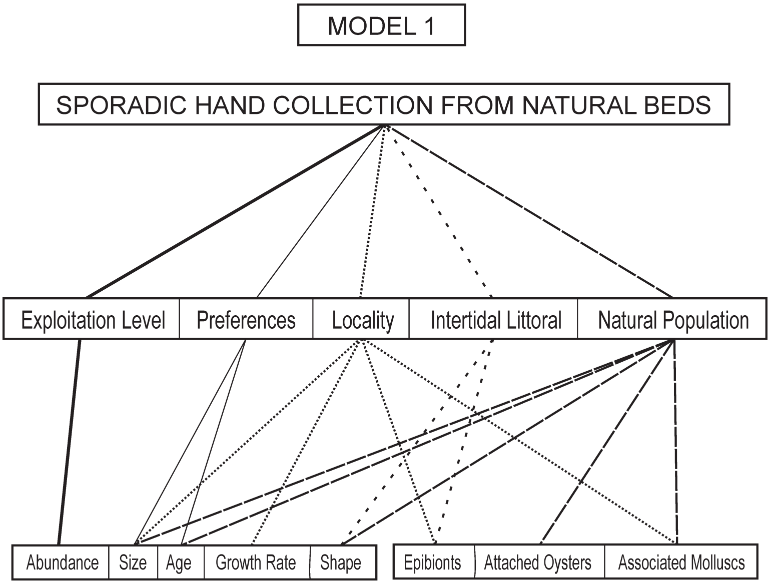

Figure 14.8. Model 1: lowest levels of exploitation of oysters (sporadic hand collection from natural beds) showing the relationship between combinations of recorded shell sample characteristics, shell collection preferences, and features of the source bed

of cropping strategies, implying an understanding of the oyster life-cycle. The scenario proposes dredging and culling immature oysters from natural beds for re-laying on sheltered inshore sub-littoral or intertidal oyster beds for fattening – which is the first stage of oyster farming. Typical features of shell samples would include a restricted size and age range from regularised cropping, grading for market, or stock conservation regulations. Clumping and irregular shape would be less common because of separating individuals and removal of organisms by culling, and infestation damage might increase in the relatively nutrient-rich water. A modern example of Model 4 was found in the re-laid oysters from Wych (*sic*) Channel and South Deep in Poole Harbour of 1987 and the sample from the 1971 Colchester Oyster Feast.

Model 5 involves full-scale cultivation and marketing and represents the maximum amount of effort for maximum gain in terms of food for the local market and surpluses for cash or goods trade. It describes a situation where the oyster populations are managed to the fullest extent from spawning to table. It includes dredging activities and relaying as in other models but goes further, with actual cultivation in which spawning is monitored, spat is collected and nurtured in special conditions, grown on, harvested, stored live, graded and marketed. Model 5 type of activity would be comparable to 19th century methods rather than current ones. Since the mid-20th century oyster cultivation practices in Britain have changed a great deal to take into account vulnerability of the natural stocks to disease and the need for greater control of the beds and productivity resulting in increased use of laboratory cultured spat oysters of non-British species and new techniques of relaying for growing on. The first four models of oyster exploitation could well describe activities that had developed through time in the region where the Horndon-on-the-Hill (Essex) oysters originated. The oysters from the four features under consideration at the Horndon site differed from each other and it was considered possible that these differences could be interpreted as the result of varying fishing practices.

Oyster shape

Differences in oyster shell shape in relation to habitat can contribute to the identification of the source oyster beds for archaeological material. Shape was first investigated in British material by Winder (1992a) who correlated shape in archaeological shells of late Saxon, medieval, and post medieval date from Poole in Dorset, England, with modern shells from known locations – firm cleaner substrate in deep water within Poole Bay and softer muddy substrate in shallower water of Poole Harbour – thus indicating the oyster source and suggesting transfer of stock for historical shell deposits. This work has since been advanced by Campbell (2010) who developed a more effective means of calculating shape in oysters from Roman Winchester and in living populations of oyster from across the Solent (Hampshire). Campbell found shell shape varied between harbours, near-shore and deeper water, probably in response to differing bed currents. Archaeological shells changed abruptly during growth from a range of shapes to a single shape arguing for oyster management in late Roman England.

Principal Component Analysis

Experimentally from 1998 onwards a meta-analysis by Principal Component Analysis (PCA) was used to compare the sum total of all recorded characteristics in oyster shell samples from sites at Elms Farm and Great Wakering in Essex, and the Royal Opera House in London (Winder & Gerber-Parfitt 2003), for example, compared with all other oyster shell material gathered to that date. This way of presenting the data gave a unique virtual 'fingerprint' identity to each sample and was an attempt to address concerns that comparisons of not only size but also infestation and other characters in oysters needed a statistical base. However, it was found that PCA based on only the epibiont infestation and encrustation characteristics (which closely relate to the natural conditions in which the oyster was growing – such as the depth of water, the substrate and the geographical location), proved most useful in differentiating oysters from different regions.

PCA of infestation in Roman oyster samples demonstrated segregation mainly into one group with similar characteristics from east coast sites in Essex and Suffolk, and another from south coast sites in Dorset, Hampshire and Wiltshire. Oysters from The Shires excavation in Leicester (Monckton 1999) and from Pudding Lane in London (Winder 1985) were included in the grouping of samples known to have originated in

East Anglia thus indicating that oysters at the two inland sites were obtained from that part of the coast. The same marked differentiation can be seen in PCAs for other periods as well. The organisms that seem primarily to account for this regional differentiation of oysters from the south coast compared with the east coast of England are polychaete worms of the *Polydora* genus. These worms leave characteristic burrows in the shells. *Polydora ciliata* (Johnston) seems to be ubiquitous (Fig. 14.4) while the larger species *Polydora hoplura* Claparède (Fig. 14.5) appears to be restricted to southern waters. PCA seems a promising approach for pinpointing the source of oyster samples.

Caution about interpretations

It is important to reflect, albeit briefly, upon the nature of the data being used, and the particular constraints that can arise when using archaeological material rather than recent samples over which there would be a greater level of control in selection. There are many challenges to working with archaeological oyster shells. It is important to know the exact nature of the sample being selected for study to avoid biases – to know how representative are the examined samples of the potentially available pool of archaeological oyster material. For example, in the case of the extensive Saxo-Norman oyster heaps on Poole waterfront (Horsey & Winder 1991; Winder 1992a), and the nearby 12th century middens at Ower (Winder 1991) on the southern shore of the Poole Harbour, neither are likely to have been permanent habitation sites. The shells excavated from these sites are thought to result from processing of the meats prior to marketing, with the shells being discarded on the spot, so the shells in the middens would probably represent the entirety of the catches.

On sites such as Elms Farm in Essex near to the head of the Blackwater estuary, famed for its oyster beds, the smaller numbers of shells remaining on site from Roman and early Saxon phases may well indicate that the majority of the catch was being marketed in the shell. Oyster shells are very bulky and can present a disposal problem when fishing for and eating oysters is an important part of community life; so an alternative possibility to consider is that the shells may have been recycled. They can, for example, be returned to the sea bed as cultch on which oyster spat can settle; used to fertilise (lime) the fields; used in the manufacture of lime; crushed for chicken feed, shell-tempered pottery, medicines and cosmetics; used as hardcore, for paths and yard surfaces; and used as mortar for stone work.

Another question might be how representative are the shells from an individual site of the original incoming samples to that site – both in quality and quantity? Moorgate and Coleman Street excavations in London uncovered two 11th–12th century domestic rubbish pits with strikingly different oyster shells in each. One contained poor quality oysters of very small and very large size, while the other had all the better quality shells of the optimal mid-size range. It is easy to see how erroneous conclusions could have been drawn if the specimens from only one pit had been selected for analysis.

Has there been an excavation bias with only the larger or intact shells being retained? We need to know the criteria for retrieval. And subsequently, what was the rationale for selecting samples for analysis? How much reliance can be placed on comparisons of archaeological oyster shells with samples of modern material from known locations? Comparisons of this sort would be very informative. However, there have been substantial losses of natural oyster beds in Britain, plus coastline and sea-level changes, and possible contamination of native oyster beds by interbreeding with imported oysters from home and abroad.

Finally, the taphonomic history of the shells, soil conditions and disposal methods will affect the chemical and mechanical wear on the shells. There is randomness to shell survival and recovery as well as to the process of shells being made available for study. All of these factors have to be considered and they place constraints on the interpretations based on the shells. Additionally, there can never be enough samples. Only with this awareness can the data from oyster shells be analysed.

Summing up and future work

The elementary nature of the preliminary analyses reflects an original requirement to develop methods for the study of *Ostrea edulis* shells that were easy to learn and to replicate on a wider scale by on-site non-specialists constrained by limited time, funding and expertise. The advantages of the devised methods are their simplicity and ease of application. The drawbacks are their labour intensiveness, lack of consistency in recording between individuals, and paucity of suitable modern comparative material. Despite these difficulties, the methods have provided a means of addressing questions about the use of oysters and disposal of their shells, of distinguishing farmed from natural wild oysters, and suggesting source locations of oyster beds, by using records of multiple macroscopic characteristics to make spatial and temporal comparisons and statistically identify clusters of associated samples. However, it seems time to consider whether the questions originally posed could now be addressed more effectively with alternative techniques; and whether a different set of questions could be addressed.

It seems likely that oyster shells, as with many other species of marine mollusc from archaeological or historic deposits, may still contain protein which is potentially recoverable from within and between the crystals of the shell matrix as well as in any surviving ligament. Archaeological *O. edulis* shells often retain colour banding caused by organic pigments and occasionally remnants of hinge ligaments; and closed system pigment proteins have been extracted from fossil brachiopod shell crystals (eg, Comfort 1951; Bouniol 1982; Curry 1991; 1999; Fox 1996; and Evans *et al.* 2009). A number of researchers have also studied shell ligaments showing open system presence of amino acids in various species including the Pearl Oyster *Pinctada maxima* (eg, Zhang 2007 and De Paula & Silveira 2009). If proteins can survive in ancient mollusc shells, this may allow the calculation of time-since-death by amino acid racemisation in *O. edulis* as well as by radiocarbon dating.

Radiocarbon dating has already been applied to historical deposits of *O. edulis* shells by Horsey and Winder (1991; 1992) and Reimer (2014) but radiocarbon dating gives wide time margins and calculating the appropriate carbon reservoir correction can be a problem (Chapters 21 & 22 by Fernandes & Dreves, & Douka) Amino acid racemisation (AAR) for dating shells from archaeological deposits is increasingly used, providing shorter time-scale assessments that can be used in conjunction with radiocarbon dating. A substantial body of published work would serve as the basis for any similar studies in *O. edulis*. It is also possible, as the work of Demarchi *et al.* (2011) has shown, that AAR use can even detect exposure of shells to heat from fires, which may allow the identification of cooking.

Of even greater interest is the field of proteomics using closed or open system protein lacking genetic material, which has the potential to allow the problem of distinguishing between oysters from different populations and localities to be addressed. The ability to derive unique amino acid profiles (that might be termed protein 'fingerprinting') using pattern recognition methods on bulk amino acid composition of stable intra-crystalline proteins preserved in biominerals has been demonstrated by Demarchi *et al.* (2014).

The further tool for future archaeological oyster shell study might be trace element analysis. This could lead to the identification of source oyster beds by enabling comparison of the chemical constituents of shells from different geographical locations, whilst also contributing to knowledge of heavy metal accumulation in coastal sediments and waters that have accompanied increasing industrialisation and pollution. The techniques for this have been developed in a variety of marine shell species from archaeological deposits and recent specimens including oysters (eg, Claassen & Sigmann 1993, Markwitz *et al.* 2003). Significantly Medakovic *et al.* (2006) showed that the malformed chambers present in the inner nacreous layers of the *O. edulis* exposed to TBT pollution in the marine environment contained tin. Chambers are one of the macroscopic features routinely recorded by the earlier methodology, and the contents of them could be an important source of information about past environments. Methods that might be applicable to trace element analysis of *O. edulis* shells have been developed by Schone (2008), Bougeois *et al.* (2014), Pourang *et al.* (2014), Ferella *et al.* (1973), Boyden *et al.* (1981), and Zacherl *et al.* (2009).

The main achievement from applying simple macroscopic character recording and basic statistical analysis to archaeological oyster shells has been that the resulting detailed information provides a unique descriptive identifier for each sample that can then be used to compare and contrast samples in space and time, and make distinctions between groups of samples, leading to the development of theoretical models of oyster exploitation. Assiduously applied and further developed, the methodology remains a useful tool for understanding how this marine resource has been utilised over at least the last two thousand years in Britain. The use of rapidly developing efficient technologies for amino acid racemisation dating, proteomics studies, and trace element analysis, to investigate deeper structural and constituent aspects of ancient *Ostrea edulis* shells, could potentially augment the existing foundational database by more directly and objectively addressing questions regarding point of origin; and also supplying baseline information for investigations into oyster population and evolutionary studies, effects of climate change and ocean acidification, and the monitoring of pollution and contamination by metals in an increasingly industrialised world.

Endnote

The axis of an oyster shell that runs from the dorsal to the ventral margin is known as the height dimension in biological terminology. However, the height has frequently but incorrectly been called width in much archaeological research and this is in common usage in many archaeological reports. The difference in nomenclature does not affect the integrity of the analyses undertaken because the so-called width measurement is the same as for height.

It is clear to archaeo-zoologists that the two names refer to the same dimension/measurement.

Caveat: a problem arises, however, where some early career analysts of archaeological data have confused and transposed the terms length and width when referring to bivalve dimensions. This has resulted in incompatibilities between assemblage datasets, between the associated analyses, and between the reporting of those analyses. Where such reports have been published this gives particular cause for concern.

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