Intensive Mesolithic Exploitation of Coastal Resources? Evidence from a Shell Deposit on the Isle of Portland (Southern England) for the Impact of Human Foraging on Populations of Intertidal Rocky Shore Molluscs

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Recent research has indicated the importance of marine foods in the diet of some late Mesolithic (*c.* 5000–4000 cal BC) populations in western Europe, but little is known of the role of such resources in the earlier Mesolithic. Analysis of assemblages of marine molluscs from the shell midden of Culverwell, Isle of Portland, showed changes in the absolute abundance of the three dominant species, as well as changes of mean shell size and age-class frequencies in the species *Monodonta lineata* (da Costa), through the midden. It is suggested that these changes result from the impact of human foraging on the populations of these molluscs, and that rocky-shore intertidal molluscs were exploited intensively and frequently (possibly annually) from the site in the earlier Mesolithic (*c.* 6000–5200 cal BC).   © 2001 Academic Press

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Introduction

There has been much recent discussion of the role of marine resources, including shellfish, in Mesolithic subsistence strategies in northwestern Europe. Seasonality evidence from late Mesolithic shell midden sites on Oronsay (southern Hebrides) suggests year-round exploitation of marine resources on the island (Mellars & Wilkinson, 1980). The stable isotope composition of human bones from sites on Oronsay led Richards & Mellars (1998) to infer that marine foods were a major component of the human diet. A compelling case could be made for coastal sedentism on Oronsay in the late Mesolithic. On a broader geographical scale, stable isotope evidence from late Mesolithic human remains from a range of sites along the Atlantic coast of Europe suggests that marine foods were a significant part of the diet of those individuals studied (Richards & Hedges, 1999*a*), in marked contrast to Neolithic individuals who had fully terrestrial diets (Richards & Hedges, 1999*b*). The late Mesolithic individuals analysed were probably eating mostly fish, with marine molluscs constituting a relatively minor part of the food intake. Was this a continuation of pre-existing food exploitation patterns in the earlier Mesolithic, or did it represent a significant shift in environmental and resource exploitation associated with factors specific to the later Mesolithic, or even to the Mesolithic-to-

Neolithic transition? Calibrated AMS dates on human bone from two sites on Oronsay (Richards & Sheridan, 2000) suggest that occupation there might overlap with the occurrence of the earliest Neolithic in Britain. Mithen (2000) showed that the late Mesolithic chronology of the Oronsay sites (Switsur & Mellars, 1987) fits into a chronological gap identified in a series of radiocarbon dates from other Mesolithic sites in the southern Hebrides. He suggested that this episode of specialized marine exploitation inferred from the Oronsay evidence could have been a short-term departure from the "normal" mixed terrestrial-marine subsistence economy, which lasted throughout the Mesolithic and into the Neolithic (Mithen, 2000: 303).

What contribution marine resources made to earlier Mesolithic subsistence economies is difficult to assess because although late Mesolithic coastal sites (including shell middens) are relatively frequent in western Europe, the rise in relative sea-levels in the early- to mid-Holocene made earlier Mesolithic shell middens quite rare. A combination of rising sea levels and crustal down warping, submerging significant areas of coastline, has made southern Britain particularly deficient in stratified coastal Mesolithic sites, both early and late, but a notable exception to this is the well-stratified site of Culverwell on the Isle of Portland (Palmer, 1999). In this paper we analyse the assemblages of marine molluscs from Culverwell and suggest that human exploitation of shellfish resources at this site was both frequent and intensive.
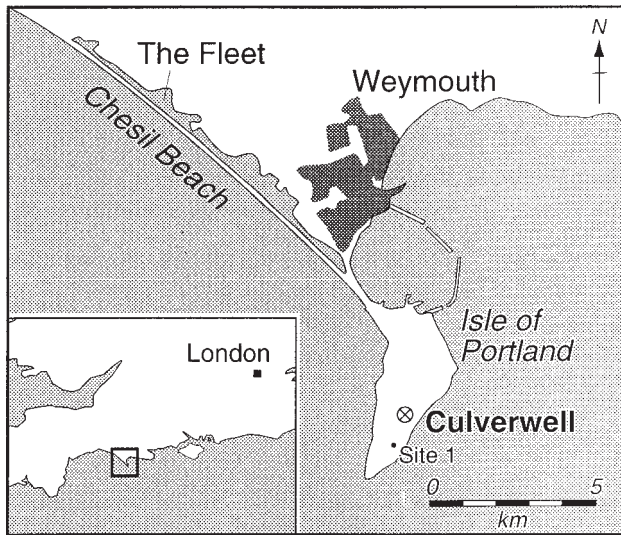
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Figure 1. The Isle of Portland and the Mesolithic sites of Culverwell and Site 1.
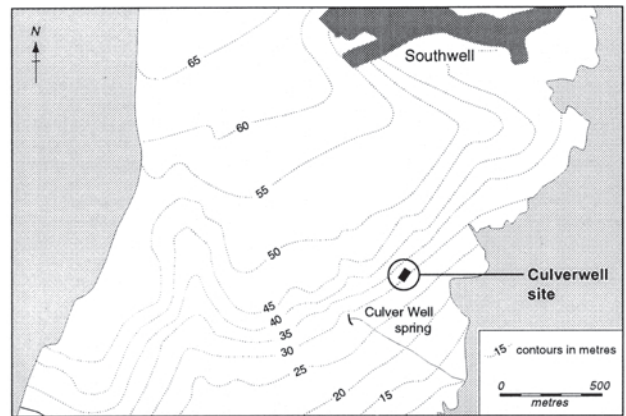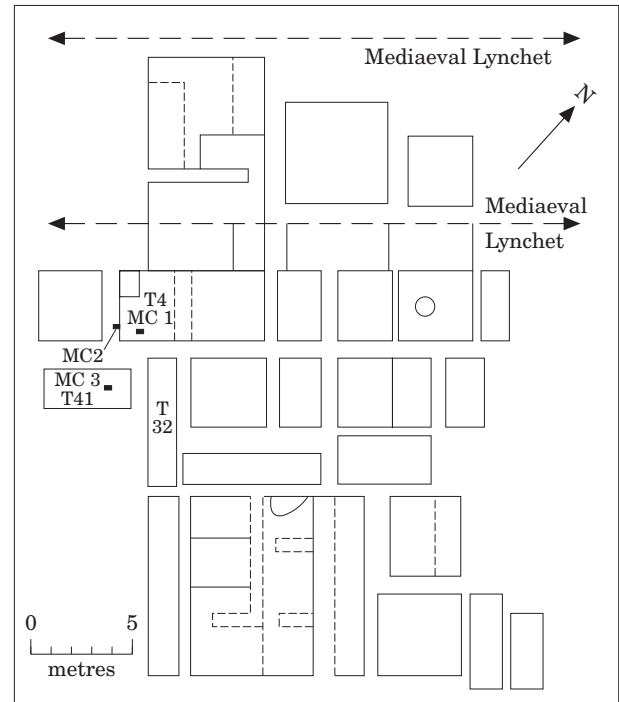

Figure 2. Location map of the Culverwell site.

Figure 3. Schematic plan of the site of Culverwell showing the layout of the excavation trenches and especially trenches 4, 32 and 41 along with the mollusc sampling columns (MC1-3).

Portland and the Culverwell Site

Mesolithic sites on the Isle of Portland have been protected from rising sea levels because high cliffs line the coast. Palmer (1989, 254) states that there are some 30 Mesolithic sites on Portland, of which "at least three contain very substantial evidence for habitation in the form of shell midden deposits and massive quantities of artefacts". Two of these sites, Site 1 at the Old Lower Lighthouse and Culverwell (Figure 1) have been excavated and published (Palmer, 1971, 1999), but the location of the majority of these sites has not been published. From our own observations, based on field walking in various parts of Portland, most are probably only surface scatters of struck stone artefacts. The shallow shell-bearing Mesolithic deposits at Site 1 were subject only to limited excavation and environmental sampling (Palmer, 1971), but the large site of Culverwell has been extensively excavated over many short seasons of field work since 1967. It is located in the southern part of the Isle of Portland, close to the Culver Well Spring (from which it is named), at 30 m above sea level and some 200 m from the present-day cliffs (Figures 1 & 2).

The Mesolithic deposits at Culverwell are on the lower part of a steep slope whose profile has been modified by a series of Mediaeval strip lynchets (Figures 2 & 3). Small excavations to the northeast and southwest of the main excavated area (Figure 3) produced scant evidence for human activity, suggesting that the area excavated covers the main area of Mesolithic activity at this locality (although work in the fields upslope might extend the known area of the site). Most of the trenches excavated lie to the southeast of the lowest lynchet (Figure 3), where the Mesolithic deposits are close to the surface of the field. In consequence, most of the excavations are shallow

and often less than half a metre in depth. It is possible that the Mesolithic deposits have been truncated or disturbed by Mediaeval and later farming, and some of the marine shell and artefacts could have been re-deposited from upslope. Palmer (1999) has described the features excavated at the site, including the post-holes of supposed structures, an extensive "floor" of flat limestone slabs, a number of "hearths", a pit cut into the limestone bedrock, and an extensive shell midden. These features led Palmer (1989, 1990, 1999) to suggest that the site was occupied all-year-round. The midden deposit contains abundant shells of marine molluscs, mixed up with struck stone (mainly of locally

Table 1. Sample details from Mollusc columns 1, 2 and 3

Sample	Layer	Column 1	Layer	Column 2	Layer	Column 3
1	6	0–7 cm	6	0–7 cm	6	0–5 cm
2	6	7–12 cm	6	7–12 cm	6	5–10 cm
3	6	12–17 cm	6	12–17 cm	6	10–15 cm
4	7	17–20 cm	6	17–20 cm	6	15–19 cm
5	8	20–25·5 cm	6	20–24 cm	7	19–25·5 cm
6	8	25·5–31 cm	7	24–29 cm	8	25·5–30·5 cm
7	8	31–37 cm	8	29–34 cm	8	30·5–36·5 cm
8	9	37–42 cm	8	34–39 cm	8	36·5–42·5 cm
9	9–12	42–47 cm	8	39–44 cm	9	42·5–48 cm
10	—	—	8	44–49 cm	12	48–55 cm
11	—	—	9	49–54 cm	—	—
12	—	—	12	54–59 cm	—	—
13	—	—	12	59–64 cm	—	—

available chert), non-struck stone artefacts (Stewart, 1999), and huge quantities of fragmented burnt Purbeck chert, limestone and small quantities of sandstone (Stewart, 1999, 67).

English Heritage permitted excavations to continue into the mid-1980s, after when the full site report was to be prepared and published. One of us (KDT) was consulted in 1988 when, during cleaning-up operations in trench 4 (T4 in Figure 3), a "deep midden" deposit was found under what had been supposed to be natural deposits. Systematic environmental work began at the site in 1989, when a column of contiguous samples (MC1, Figure 3) was taken through this "deep midden". Another column of samples (MC2, Figure 2) was taken in 1991. The so-called "deep midden" was clearly in a small gully or depression, but the form and extent of it could not be determined without further excavation. In 1995 English Heritage gave permission for a small (2 × 4 m) trench to be excavated to investigate this new feature. The authors excavated this trench (T41, Figure 3) and took another column of samples (MC3, Figure 3) for laboratory analysis, along with two short columns (MC4 & MC5) through layer 8 only. Details of the samples are given in Table 1 and by Thomas & Mannino (1999), who also describe the laboratory procedures (including sieving down to 2 mm). It must be emphasised that the following discussion is based almost entirely on the "deep midden" in trenches 4 and 41 and in part of trench 32 (T32, Figure 3). These are the only areas of the site of which we have direct knowledge and the only areas that have been subject to systematic environmental analysis.

The extent and stratigraphy of the "deep midden"

Resistivity and magnetometry surveys at the site failed to clarify the location and extent of the unexcavated parts of the depression containing the deep midden (Gale, 1999). The excavation in trench 41 showed that the densest concentration of midden materials was in layer 8, which was constrained to a shallow depression, some 4·5 to 5 m wide, in the limestone bedrock and

extending into part of trench 32 (Figure 4). The limited and incomplete excavation in trench 4 showed that the midden sloped steeply upwards in the northern part of the trench, suggesting a termination of the limestone depression. The southern extent of the depression, and therefore of the midden, beyond trench 41 remains unknown. In trench 32 the dark midden deposits abut an outcrop of limestone rock (Figure 4), the strata of which are both contorted and tilted at a high angle to the dip of the underlying bedrock. It is likely that this is a relict cryoturbation feature, within which the midden materials were deposited.

Shell midden deposits have long been acknowledged to be highly complex in terms of their depositional histories and stratigraphy, with lateral variation in deposits even over small areas (e.g. Stein, 1992; Claassen, 1998). Even deposits close together and with similar colour, texture and inclusions, may represent quite distinct episodes in the development of the site (as noted below for the chronology of the deposits in trenches 4 and 41). The layers identified in the stratigraphy at Culverwell were clearly separable, based on matrix colour and texture (mainly variations in the amounts of clay) and abundance and type of inclusions (stones, struck stone, burnt stone, finely-comminuted charcoal and ash, marine shell, etc.)

The stratigraphy of trench 41 (Figures 4 & 5) consists of two groups of deposits. Layers 1 to 6 are outside the limestone depression and occur extensively across the site. They lie virtually horizontally in a northeast to southwest direction (Figure 4) and slope gently down from the northwest to the southeast, following the slope of the hillside (Figure 5). In our view they are all likely to be colluvial in origin and are not considered further in this paper. Only layer 6 contains marine shells in any significant quantity and it was probably eroded from a midden deposit upslope at some time in the past. The deposits in layers 7 to 13 are contained within the limestone depression.

Layer 7 has a clay-rich matrix supporting abundant stones, some struck lithic materials and abundant, but often crushed, marine shells. A few tiny fragments of
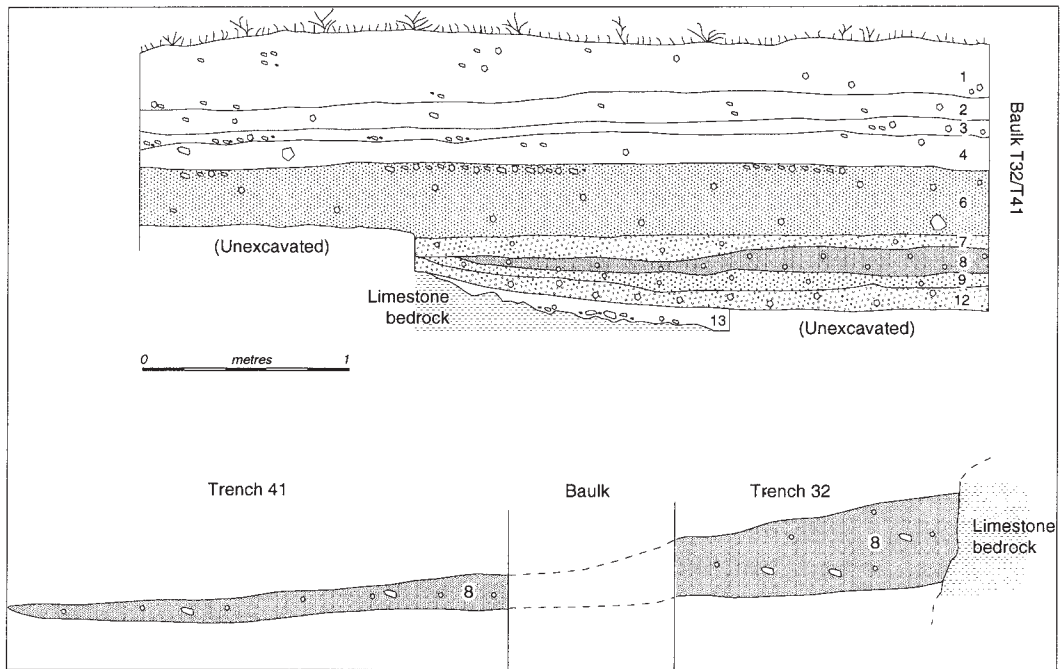
Figure 4. Southwest to northeast section through the shell midden deposits in trench 41 (upper) and variation in the thickness of layer 8 across trenches 32 and 41 (lower). Darker shading indicates higher densities of shells, stone and comminuted charcoal.
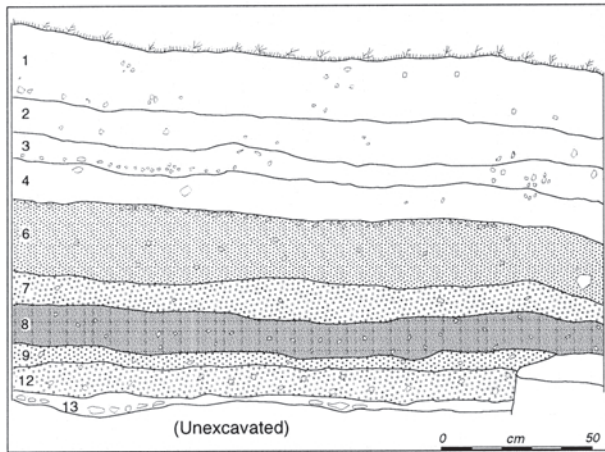

Figure 5. Northwest to southeast section through the shell midden deposits in trench 41. Shading conventions as for Figure 4.

(probably) prehistoric pottery were found. It is not clear if layer 7 is *in situ* or if it is colluvial in origin. Layer 8 lenses out in thickness across trench 41, away from the limestone rock in trench 32 (Figure 4); it is also thicker in parts of trench 4. It was probably deposited as a series of dumps from the northern and eastern side of the depression. Layer 8 is dark brown, almost black, in colour and has abundant finely comminuted charcoal, fragments of burnt stone, chert flakes and cores, and shells of marine molluscs, suggesting a range of intensive human activities at the site during its formation. Layers 9 to 13 are also restricted to the gully, but unlike layer 8 they extend across the full width of the feature. Layer 9 has abundant marine shell but less charcoal and burnt stone. Layer 12 is not rich in marine shell, although those within it are generally well preserved, and has fewer artefacts and less burnt stone than layer 9. Layer 13 is pale yellow

Table 2. Radiocarbon determinations and calibrations for the Culverwell "deep midden" (see text for explanation)

Trench/ layer no.	Laboratory code	Radiocarbon age (years BP ± 1 S.E.)	Calibrated age* (years BC; 95·4% confidence)	Calibrated age** (years BC; 95·4% confidence)
T41/L7	AA-28213	6800 ± 60	5440–5240	5480–5260
T41/L8a	AA-28214	6730 ± 55	5360–5200	5470–5080
T41/L8b	AA-28215	6410 ± 55	5060–4800	5040–4730
T41/L9	AA-28216	7145 ± 70	5760–5500	5740–5480
T41/L12	AA-28217	7285 ± 60	5900–5640	5890–5640
T41/L13	AA-28218	7525 ± 60	6080–5880	6160–5840
T4/L9-12	AA-28219	6525 ± 60	5220–4920	5260–4850
T4/L12	AA-28220	6855 ± 75	5500–5240	5610–5290

*Calibration based on the "marine curve" of Stuiver, Pearson & Braziunas, (1986).
**Calibration based on correction for marine effect (Harkness, 1983) and INTCAL98 (Stuiver et al., 1998).

Table 3. List of shellfish taxa recovered from the Culverwell Shell Midden

MOLLUSCA	GASTROPODA		
Family Patellidae	*Patella* species	Limpets	A;T
Family Trochidae	*Monodonta lineata* (da Costa)	Thick top shell	A;T
	Gibbula umbilicalis (da Costa)	Purple top shell	F;T
	Calliostoma zizyphinum (Linnaeus)	Painted top shell	R
Family Littorinidae	*Littorina littorea* (Linnaeus)	Edible periwinkle	A;T
	Littorina obtusata (Linnaeus)	Flat periwinkle	F;T
	Littorina saxatilis (Olivi)	Rough periwinkle	R
Family Eratoidae	*Trivia monacha* (da Costa)	European cowrie	R
Family Muricidae	*Nucella lapillus* (Linnaeus)	Dog whelk	F;T
	Ocenebra erinacea (Linnaeus)	Sting winkle	I
Family Buccinidae	*Buccinum undatum* Linnaeus	Whelk	I
Family Rissoidae	*Rissoa* sp.	(No common name)	R
Family Cerithiidae	*Bittium reticulatum* (da Costa)	Needle whelk	I
Family Nassariidae	*Hinia reticulata* (Linnaeus)	Netted dog whelk	I
	Hinia incrassata (Ström)	Thick-lipped dog whelk	I
MOLLUSCA	BIVALVIA		
Family Arcidae	*Arca tetragona* Poli	Ark shell	R
Family Mytilidae	*Mytilus edulis* Linnaeus	Common mussel	I
Family Ostreidae	*Ostrea edulis* Linnaeus	Common European oyster	R
Family Pectinidae	*Pecten maximus* (Linnaeus)	Great scallop	I
Family Cardiidae	*Cerastoderma edule* (Linnaeus)	Common edible cockle	F;T
Family Veneridae	*Tapes decussata* (Linnaeus)	Carpet-shell	F;T
CRUSTACEA	DECAPODA		
Family Cancridae	*Cancer pagurus* Linnaeus	Common edible crab	F;T

A—abundant; F—frequent; I—infrequent; R—rare; T—throughout.

and clay rich; it lies on the weathered limestone bedrock and contains few marine shells but has numerous chert flakes, including large core-preparation flakes in "pristine" condition, suggesting the possibility that knapping might have taken place near the edge of the depression. The clarity of the boundaries between the layers suggests that they represent a sequence of discrete events, with little mixing between them during, or subsequent to, their deposition.

Chronostratigraphy of the "deep midden"

Carbonates from the shells of the intertidal gastropod *Monodonta lineata* (da Costa) were used to generate AMS radiocarbon dates (Table 2). A study of the mineralogy (by SEM and X-ray diffraction) of *M. lineata* shells from the site showed that the inner aragonitic layers were unaltered and had probably not undergone post-depositional isotopic exchange (Mannino, 2000). Details of the sampling and sample preparation methods used are provided by Thomas & Mannino (1999, 104). The radiocarbon determinations were calibrated using Stuiver's "marine curve" (Stuiver, Pearson & Braziunas, 1986). They were also corrected for the marine effect by subtracting the correction value proposed by Harkness (1983) of 405 ± 40 years, before being calibrated using the INTCAL98 programme (Stuiver *et al.*, 1998). The original radiocarbon determinations are in Table 2, along with the 95·4% confidence ranges of the two calibrations. The calibrations given here supersede those in Thomas & Mannino (1999, 105).

The six determinations from trench 41 show good stratigraphic ordering with the exception of AA-28215,

from layer 8b, which is anomalously young. The slightly older date of the shell from layer 7, compared with those from layer 8, is consistent with the hypothesis that layer 7 is colluvial, containing reworked material from upslope. The two determinations (AA-28219 and AA-28220) from trench 4 accord with their stratigraphical order, but both are younger than the dates from apparently corresponding stratigraphic layers in trench 41. The single vertical and two lateral radiocarbon "reversals" noted here are not uncommon occurrences in shell middens with complex depositional and post-depositional histories (e.g. Erlandson & Rockwell, 1987).

The radiocarbon dates place the development of the "deep midden" deposits in the early to middle Atlantic period, although two radiocarbon dates from other areas of the Culverwell site (Palmer 1999, 91–93) suggest that human activity at the site might extend back into the late Boreal period. Mesolithic activity at the site spanned a period of rising sea levels (and significant coastal change), with levels rising from around −20 m below present sea level (layer 13) to around −10 m (layer 8), based on the sea-level curve in Brunsden & Goudie (1997, 51).

Biostratigraphy of the "deep midden"

Marine shellfish (Table 3) overwhelmingly dominate the subsistence remains (Thomas & Mannino, 1999). Three rocky-shore gastropod taxa *Littorina littorea*, *Monodonta lineata* and *Patella* (limpet shells were generally poorly preserved and could not be reliably assigned to particular species) predominate, followed by a fourth gastropod species *Nucella lapillus*. Only two bones of fish were recovered and some fragments of mammal

Table 4. Molluscs recovered from MC1 (MN1 values; +=present) with MNI values adjusted to standard volume (2000 cms) for the 3 main taxa MNI values for bivalves based on Umbone counts, for gastropods on apices (except N. lapillus based on siphonal canals)

	Mollusc Column 1					
	S4/L7	S5/L8	S6/L8	S7/L8	S8/L9	S9/L9–L12
Littorina littorea	197	257	316	213	249	103
Patella species	102	134	229	160	217	68
Monodonta lineata	76	179	318	288	246	108
Nucella lapillus	5	7	3	2	—	1
Gibbula umbilicalis	1	2	3	3	2	1
Littorina obtusata	—	—	1	1	1	—
Arca tetragona	—	—	1	—	—	—
Mytilus edulis	1	—	—	—	—	—
Cerastoderma edule	—	—	+	—	—	—
Tapes decussata	+	+	+	+	+	—
Standard MNI values						
Littorina littorea	328	234	287	178	249	103
Patella species	170	122	208	133	217	68
Monodonta lineata	127	163	289	240	246	108

bones and teeth, the only identifiable ones being of wild pig (*Sus scrofa* Linn.). A few charred fragments of hazelnut shells (*Corylus avellana* Linn.) were also found.

Although the shellfish assemblages from the site are dominated by rocky shore intertidal species, species preferring unconsolidated sandy or muddy substrates also occur. They are relatively more abundant in the lower midden deposits (especially layers 12 and 13), suggesting that lower sea levels at this stage might have allowed access to a wider range of shore types. *Cerastoderma* and *Tapes*, however, occur throughout the stratigraphy, implying that people were bringing them in from suitable habitats within the foraging area of the site.

Minimum numbers of individuals (MNI) for each taxon were calculated. The results for the three main columns (MC1, MC2 & MC3) and for the two short columns (MC4 & MC5) are shown in Tables 4 to 7. The MNI values are not directly comparable because the sampling intervals varied according to the thickness of the different layers (Table 1). The MNIs for the three dominant species in the deposits were therefore adjusted to a "standard" sample volume of 2000 cm³ (Tables 4 to 7). Figure 6 shows the variation in the abundance of the three main taxa in the three full columns. There is a trend for progressive increase in abundance through layers 12 and 9 into layer 8. Within layer 8 (which, as noted above, might represent the most intensive phase of human activity) the species peak in abundance and then fall off. This is also apparent in the two short columns from layer 8 (MC4 and MC5, Table 7), with numbers peaking in the lowest samples (samples S13 & S16, respectively) and then, except for *Patella* in column 5, falling off quite dramatically. With the exception of *Monodonta lineata*, this effect is least noticeable in MC1 (trench 4). This column might have been taken where the midden had been subject to some post-depositional disturbance. Despite the complex processes affecting these deposits (their formation, possible post-depositional disturbance, and the time-averaging effect of the sampling intervals), comparable patterns of change in abundance of the three main mollusc taxa are still apparent.

Volume versus time in quantification

Variations in the rate of accumulation of the midden deposits should be considered when interpreting the

Table 5. Molluscs recovered from MC2 (as for Table 4)

	Mollusc Column 2						
	S6/L7	S7/L8	S8/L8	S9/L8	S10/L8	S11/L9	S12/L12	S13/L12
Littorina littorea	72	137	171	311	211	170	31	1
Patella species	28	55	61	104	99	101	21	1
Monodonta lineata	12	30	81	178	154	94	14	7
Nucella lapillus	2	—	1	8	6	4	—	1
Gibbula umbilicalis	1	1	—	1	1	2	1	1
Tapes decussata	+	—	—	+	—	+	—	—
Standard MNI values							
Littorina littorea	72	137	171	311	211	170	31	1
Patella species	28	55	61	104	99	101	21	1
Monodonta lineata	12	30	81	178	154	94	14	7

Table 6. Molluscs recovered from MC3 (as for Table 4)

	Mollusc Column 3					
	S5/L7	S6/L8	S7/L8	S8/L8	S9/L9	S10/L12
Littorina littorea	63	141	410	319	67	23
Patella species	57	54	151	242	147	137
Monodonta lineata	28	37	141	183	60	24
Nucella lapillus	5	12	11	14	2	1
Gibbula umbilicalis	3	4	4	2	2	—
Littorina obtusata	—	—	—	—	1	2
Calliostoma zizyphinum	—	—	—	1	—	—
Tapes decussata	—	—	—	+	+	—
Cerastoderma edule	—	—	—	—	+	+
Standard MNI values						
Littorina littorea	48	141	342	266	61	16
Patella species	44	54	126	202	134	98
Monodonta lineata	22	37	118	153	55	17

Table 7. Molluscs recovered from MC4 & MC5 (as for Table 4)

	Mollusc Column 4			Mollusc Column 5		
	S11	S12	S13	S14	S15	S16
Littorina littorea	42	128	321	92	116	197
Patella species	21	29	103	43	31	64
Monodonta lineata	21	42	128	28	39	96
Nucella lapillus	2	5	13	2	7	2
Gibbula umbilicalis	—	—	—	1	1	4
Littorina obtusata	—	—	—	—	1	—
Standard MNI values						
Littorina littorea	42	107	268	92	97	179
Patella species	21	24	86	43	26	58
Monodonta lineata	21	35	107	28	33	87

changes in abundance noted above. To estimate the length of time elapsed within each layer of the midden, Bayesian calibrations (Buck et al., 1991, Buck, Litton & Smith, 1992) of the radiocarbon determinations were made on-line (Buck, Christen & James, 1999), using various stratigraphic scenarios in each Markov chain Monte Carlo simulation model. Three repeat simulations, using identical parameters, were run to test for convergence (reproducibility) within each stratigraphic scenario (models A to G). The stratigraphic models used were permutations of the following possibilities: that "stratum" 9–12 overlapped with layers 9 and 12, or that it was part of layer 9; that sub-layers 8a and 8b were overlapping, or were just one layer; and that layer 7 was directly (i.e. chronologically as well as physically) abutting layer 8, or was deposited after a time lag. Model G was based only on the radiocarbon determinations from trench 41.

Table 8 shows the likely elapsed time between the late and early boundary dates computed for each layer, based on the 95% posterior probabilities for the particular parameters used. Layers 13 and 7 could not be included because no earlier or later chronological markers were available for them. Figure 7 gives examples of the probability plots for selected runs in models A, D and G. With the exception of model G, all the models are in good accord. They show that the differences between the early and late boundary dates for layers 12 and 9 are approximately equal and much wider than for layer 8. In model G, layers 8 and 9 have roughly the same duration, with layer 12 being less. It appears likely that layer 8 was deposited over a time span not longer than for layer 9 and probably not longer than for layer 12. The greater density of shells in layer 8 cannot therefore be explained by a longer time of accumulation.

Taphonomic factors

Differences in preservation and recovery of the three species could account for the patterns in abundance through the midden. *L. littorea* has the most robust shell and most of its MNI is contributed by the >4 mm sieve fraction. *M. lineata* and *Patella* are less robust. For *M. lineata*, the >2 mm sieve fraction makes the largest contribution to its MNI, while for *Patella* there are approximately equal proportions in the >4 mm and >2 mm fractions. If shell preservation alone were responsible for the observed patterns of change in
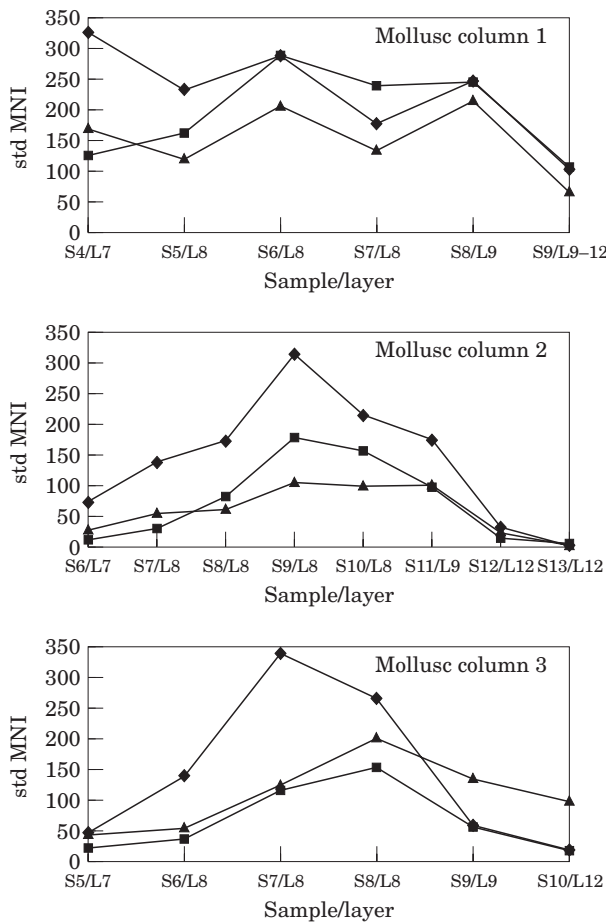
Figure 6. Changes in abundance of the three main mollusc taxa through the sample columns (based on MNI values adjusted to standard sample volume, as discussed in the text). —◆—, *Littorina littorea*; —▲—, *Patella* spp.; —■—, *Monodonta lineata*.

Environmental change

A range of environmental factors, ranging from climatic shifts to local shore changes resulting from rising sea levels, might "explain" the changing patterns of abundance through the midden deposits. Without going into all of the possibilities, environmental change *per se* as an explanation of the observed patterns is unlikely for a number of reasons. *Monodonta lineata* is a southern species near the northern edge of its range at Portland (e.g. Preece, 1993; Hawthorne, 1994), while *Littorina littorea* has a broader distribution, extending north to the White Sea (Reid, 1996), and the limpets (depending on the exact species present) have a modern distribution which either approximately coincides with that of *M. lineata*, or extends much further north (Fretter & Graham, 1976). The patterns of decline seen in Figure 6 show that *M. lineata* was not affected to a greater degree than the other two taxa, so climate change is an unlikely explanation. If rising sea levels had led to shores similar to those found today near the site, *Monodonta* and *Littorina* should decline, but *Patella* (the dominant large gastropod on today's shores) should have been unaffected. If rising sea levels had produced shores with greater exposure to wave action, *Patella* should have been less affected than the other two taxa and might even have increased in abundance. Evidence from the variation in shell morphology of *Nucella lapillus* from the midden (Mannino & Thomas, in preparation *a*) suggests that they were gathered from shores that were relatively sheltered (Andrews *et al.*, 1985). Although environmental changes might have had a role, they cannot alone explain the patterns observed.

Role of human exploitation

The shells in the midden were deposited as a consequence of initial human selection and collection on the shore, transport to the site for processing, and subsequent deposition of the "waste" shells. Although the shells of some of the smaller species of molluscs might have been collected for ornamental purposes (beads, etc.), those of the larger species considered here appear

abundance, *L. littorea* should show relatively least change compared with the other two taxa. Figure 6 shows that there is only very weak conformation to this prediction and that on its own, differential destruction or recovery cannot account for the observed patterns.

Table 8. *Bayesian analysis of the elapsed time (in years) between the late and early boundary dates computed for each layer, based on the 95% region of the highest posterior density of the posterior probability distributions of the particular parameters used for each layer (Buck et al., 1999). Three simulations were run within each stratigraphic model (A–G) analysed (see text for explanation)*

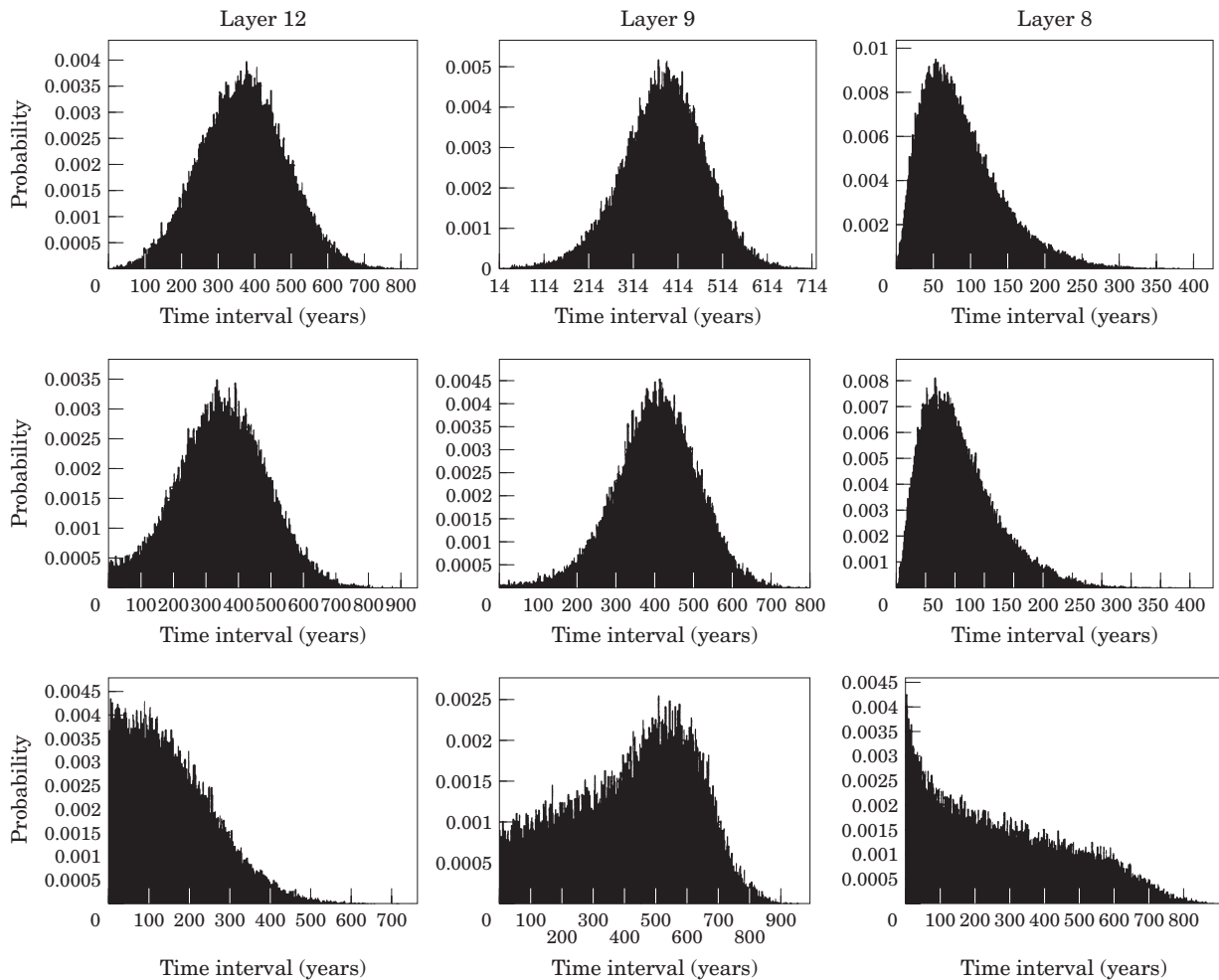| Layer	Model A	Model B	Model C	Model D	Model E	Model F	Model G
L8	7–190	10–220	9–200	10–230	1–150	1–150	1–610
	8–190	10–220	8–190	12–230	1–160	1–150	1–610
	9–190	11–230	9–200	10–220	1–150	1–150	1–620
L9	200–560	200–600	220–560	200–600	250–620	240–580	32–700
	210–550	200–590	210–550	200–600	260–610	230–580	51–700
	210–550	200–600	210–550	210–600	250–620	220–580	59–710
L12	150–570	98–600	150–560	81–590	87–590	150–580	1–340
	150–570	110–590	150–570	100–600	100–580	140–590	1–340
	160–570	96–590	150–580	95–590	91–580	140–580	1–350

Figure 7. Bayesian analysis of radiocarbon determinations. Examples of data plots of the likely elapsed time, in years, between the late and early boundary dates computed for each layer, based on the 95% region of the highest posterior density of the posterior probability distributions of the particular parameters used for each layer (Buck, Christen & James, 1999). Three alternative models are shown: top row, model A; middle row, model D; lower row, model G (see text).

to have been collected for consumption. Large numbers of shells of both *Monodonta* and *Littorina* in the midden are intact, suggesting that they were subject to heat (possibly boiling in water) to extract the enclosed animals. Limpets are easily extracted from their shells but are more difficult to collect than the other two taxa. It is probable that all three taxa were collected at the same time during forays to the shore, although limpets might have been preferred because of significantly higher meat yields (Mannino, 2000) and lower energy costs of processing. A study by Bird & Bliege Bird (1997) of shellfish gathering strategies by the Meriam of Torres Strait showed that the shells of species with high processing costs tended to be relatively over-represented at home bases than species with low processing costs, which were either processed or consumed in the field. It is difficult to see how such choices could have caused the patterns of change in abundance of the taxa in the Culverwell midden.

The patterns of species abundance might reflect a shift away from molluscs towards alternative food resources, although there is no evidence from the midden for such alternative resources.

Another possibility is that there was a reduction in human occupation and activity at the site during the formation of layer 8, leading to a fall off in the numbers of molluscs exploited for food. This explanation is not consistent with the continued high densities of artefacts, fragmentary burnt stones and finely comminuted charcoal throughout the deposits of layer 8, as noted by Stewart (1999).

A final possibility is that continued, or intensified, human foraging (especially during layer 8) might have had a depleting effect on the available intertidal resources.

Impact of human predation on intertidal gastropods
Changes in the abundance of marine molluscs through midden deposits, especially when accompanied by

reduced mean shell size, have often been interpreted as the consequence of human predation (e.g. Botkin, 1980; Koike, 1986; Lightfoot & Cerrato, 1988; Spenneman, 1989). Studies of the effects of modern human exploitation on shellfish populations have shown that targeted species can become depleted (e.g. Branch, 1975; Okera, 1976; Castilla & Durán, 1985) and also that predation by people can have a broader impact on the composition of intertidal communities (e.g. Hockey & Bosman, 1986; various papers in Siegfried, 1994; Lindberg, Estes & Warheit, 1998). Ecological studies by Lasiak (1991a, 1991b, 1993) of exploited and non-exploited populations of intertidal molluscs have highlighted problems of inferring over-exploitation by human foragers, and the attendant problems of making such inferences from archaeological evidence (Lasiak, 1992). She showed that inter-annual fluctuations in biological and ecological factors, such as recruitment and natural mortality, could account for differences between exploited and non-exploited populations. Lasiak's observations were, however, made over only a few years and any long-term effects of human predation might have been masked by short-term fluctuations. Archaeological samples are time-averaged, the main advantage of which is the filtering out of short-term "noise", revealing long-term "signals" (Olszewski, 1999).

Claassen (1986, 1998) has taken a stance against the idea that past human predation could have had an impact on populations of molluscs, although she concedes that rocky-shore intertidal molluscs could potentially be affected. Claassen rightly points out that both changes in abundance and the mean size of shells could result from environmental change. She suggests (1986, 130) a possible criterion for over-exploitation: that there should be a reduction in the mean age of shells through a sequence of deposits, preferably without a change in mean shell size within each age group.

This hypothesis can be investigated in *M. lineata* from the Culverwell site, because this species can be aged by counting the growth lines (varices) on well-preserved shells. These varices have been shown to be annual (Williamson & Kendall, 1981). It is likely that human foragers would have collected shellfish on the basis of their size rather than age. Size is not independent of age, as is shown in Figure 8 for a modern population of *M. lineata* and for an assemblage from the Culverwell site. The younger age classes (up to 3 or 4 varices) show significant inter-age size differences, but between older age groups the size distinctions are less. Not all size (and, therefore, age) classes would be equally visible on the shore. Very small young shells (less than two years old) would be difficult to detect and also would have very low meat yields. Human gathering would have tended to select for larger (higher meat-yielding) shells, and therefore larger and older shells would be expected to dominate the midden samples.

The age structures of the assemblages from the main layers of the midden are shown in Figure 9, for
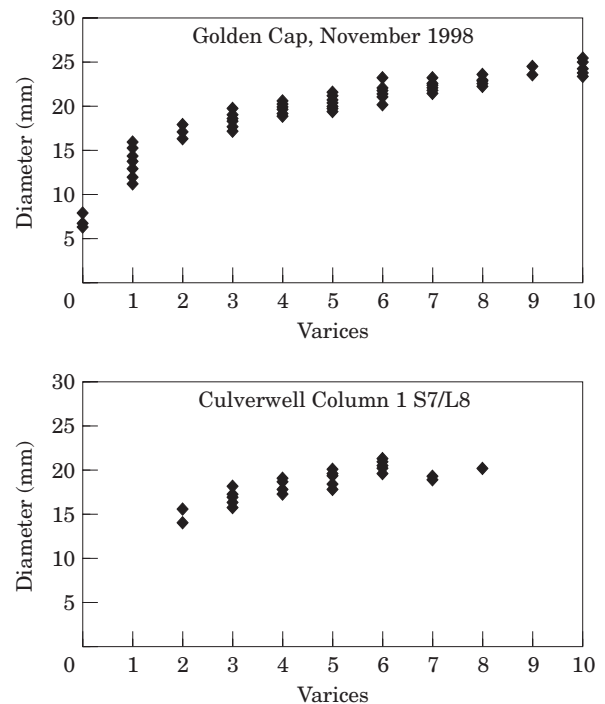

Figure 8. Relationships between shell size (diameter) and age (varix counts) in a modern population at Golden Cap, Dorset (upper) and an archaeological assemblage from the Culverwell site (lower).

columns MC1 and MC2 and trench 41. [Note: all intact chells of *M. lineata* encountered during excavation of trench 41 were collected and it is the age structures of these samples, plus the small numbers of relatively intact shells from column MC3, that are shown in Figure 9]. The mean sizes and mean ages of these assemblages are shown in Table 9a. The assemblages of intact shells from MC1 and MC2 were sufficiently large to analyse separately the sub-samples within layer 8. The age-frequency histograms for these are in Figure 10 and mean sizes and ages are in Table 9b, Taking these data sets together, the following results are apparent:

(1) As expected, the assemblages are biased away from youngest age classes (i.e. shells too small to collect and with very low meat yields);

(2) The lowest assemblages in MC1 and MC2 have irregular age distributions, suggesting either bias in collection or fluctuations in recruitment to the shore. The assemblages from layers 8 and 9 (taking into account biases in the younger age cohorts) have age structures more similar to those of age-stable populations. This might suggest that collecting of shellfish had become more intensive, resulting in assemblages that, for the older age classes, more closely reflect the age structures of the shore populations from which they were derived;

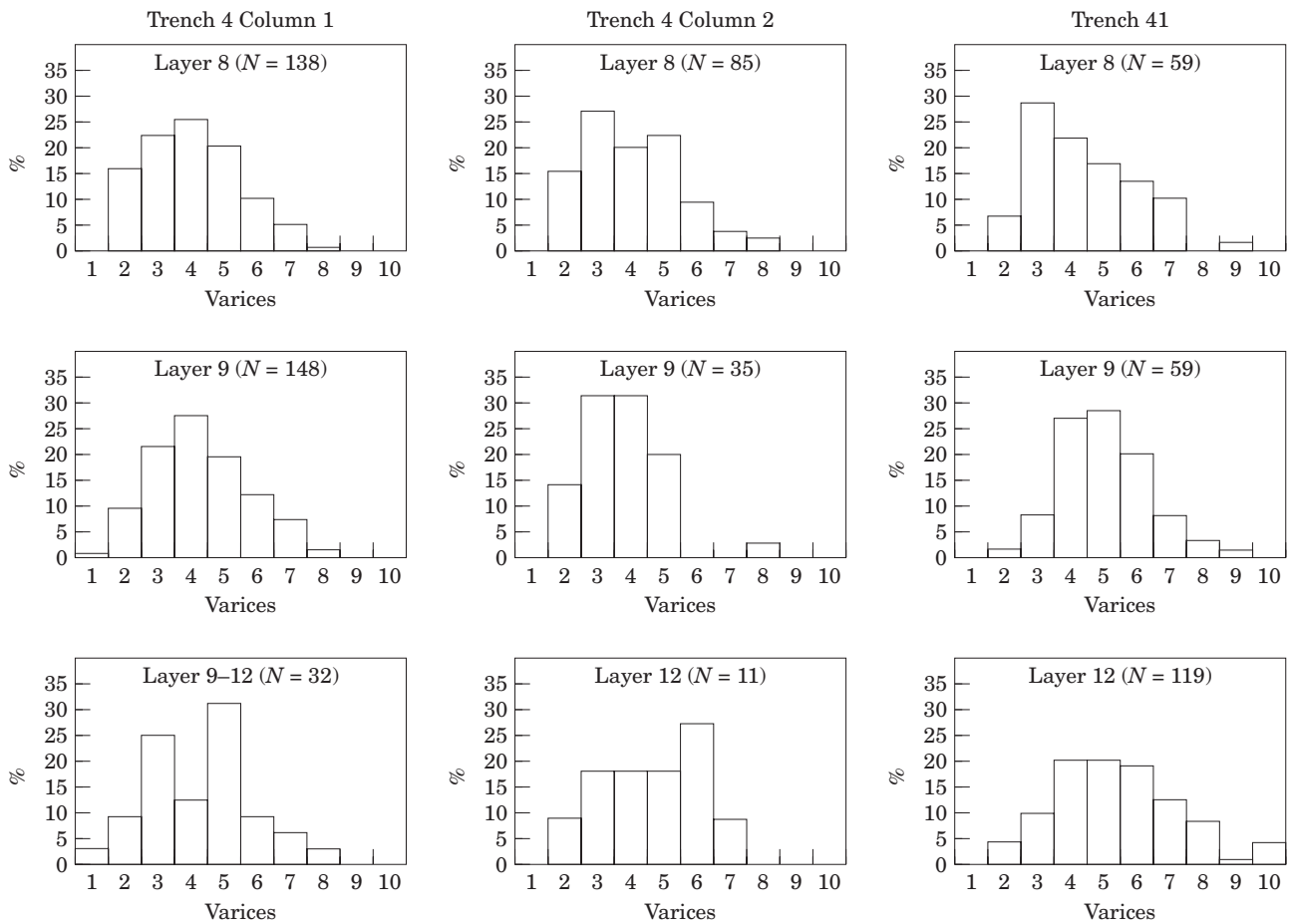(3) In every case there is an overall reduction in mean shell size through the depositional sequence,

Figure 9. Age profiles (based on varix counts) of *Monodonta lineata* through the midden samples of mollusc columns 1 and 2 and trench 41 (*N*=number of countable shells in each sample).

but this is only statistically significant between samples 7 and 6 of MC1 (*P*=0·0325, Mann-Whitney U test);

(4) In every case there is an overall reduction in mean age, with those between layers 9 and 8 and layers 12 and 8 of trench 41 being statistically

Table 9. (a) Mean shell sizes (diameters in mm) and mean ages (based on varix counts) of M. lineata *from MC1, MC2 and trench 41. Figures in brackets are sample sizes. (Samples for mean size are smaller because size is measured from the point of maximum curvature of the aperture in undamaged specimens). (b) As for 9(a) but including the sub-samples within layer 8 from MC1 & MC2*

(a)

| | Trench 4 Column 1 | | | Trench 4 Column 2 | | | Trench 41 | |
Layer	Mean size	Mean varices	Layer	Mean size	Mean varices	Layer	Mean size	Mean varices
L8	17·70 (56)	4·0 (138)	L8	17·90 (37)	4·0 (85)	8	19·00 (12)	4·4 (59)
L9	18·41 (82)	4·3 (148)	L9	18·70 (11)	3·7 (35)	9	18·91 (21)	5·1 (59)
L9–12	17·67 (20)	4·3 (32)	L12	19·16 (7)	4·6 (11)	12	19·82 (38)	5·4 (120)

(b)

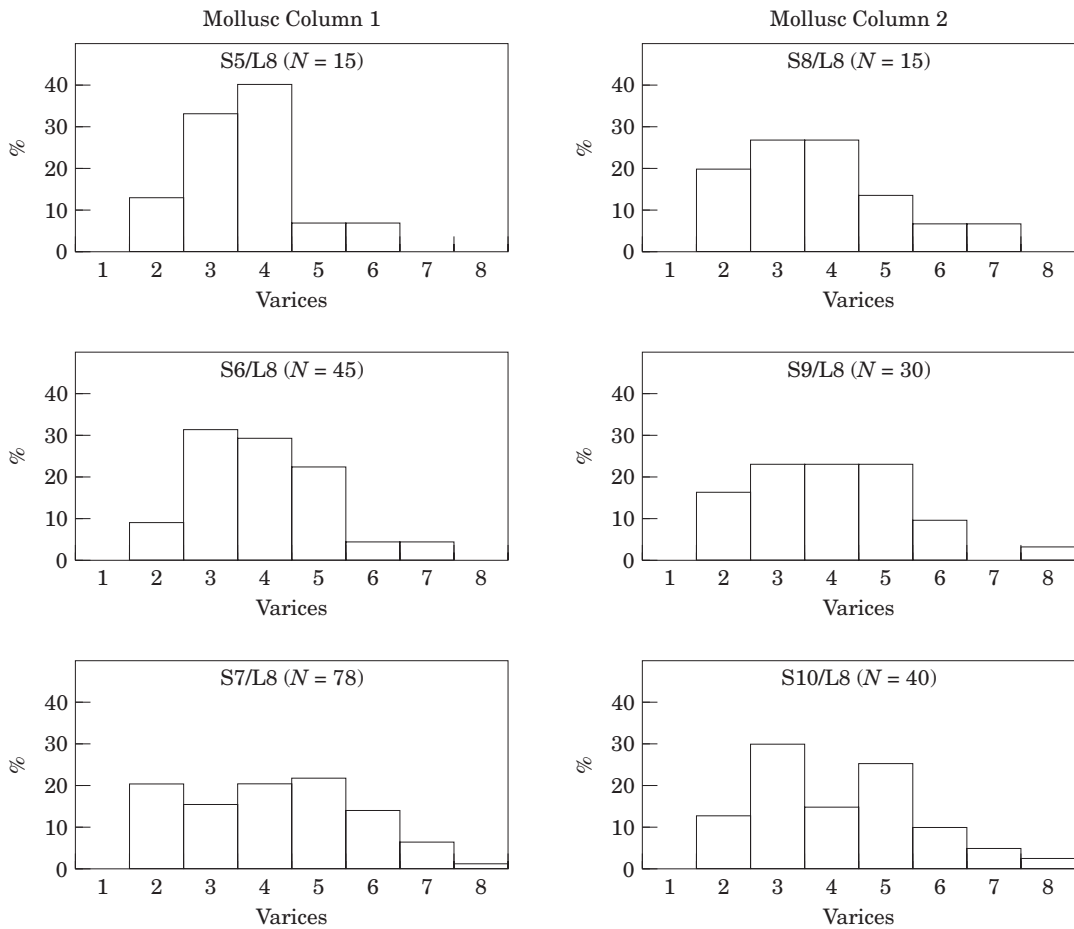| | Trench 4 Column 1 | | | Trench 4 Column 2 | |
Sample/ layer	Mean size	Mean varices	Sample/ layer	Mean size	Mean varices
S5/L8	16·73 (4)	3·6 (15)	S8/L8	17·67 (3)	3·8 (15)
S6/L8	17·01 (19)	4·0 (45)	S9/L8	17·60 (12)	4·0 (30)
S7/L8	18·15 (33)	4·2 (78)	S10/L8	18·08 (22)	4·2 (40)

Mollusc Column 1

Mollusc Column 2

Figure 10. Age profiles of *M. lineata* in the sub-samples of layer 8, mollusc columns 1 and 2 (*N*=number of countable shells). Sample S7 from column 2 has been omitted because of small numbers of sufficiently intact specimens.

significant ($P=0.0130$ and $P=0.0004$, respectively, Mann-Whitney U test).

Environmental change cannot explain these results. Ecological studies on populations of *M. lineata* have shown that mean shell size and population density are negatively correlated (Kendall, 1987; Mannino & Thomas, in prep.*b*) and that populations in less favourable environments invariably have higher proportions of older individuals (Mannino & Thomas, in prep.*b*). Had the fall-off in abundance through the midden been the result of environmental change on the local shores, both mean size and age should have increased, rather than decreased.

If rising sea levels (rising, as suggested above, from -20 to -10 m below present mean sea level during the life of the midden) had produced shores with narrower intertidal zones, then a combination of human predation and environmental change could account for the results. Such shores might have supported lower populations of the species considered here, which might have *caused* the increased pressures of human exploitation interpreted from the later assemblages in the midden. Unfortunately, we have no direct evidence relating to shore morphologies during

the period of the midden. The gently shelving submerged rocky ledges around the present coast suggest, however, that the width of the intertidal zone at a mean sea-level of -10 m would probably not have differed significantly from that at a mean sea-level of -20 m.

It has been suggested that layer 8 represents an intensified phase of occupation and of shellfish collection. Despite the effects of time-averaging and possible post-depositional disturbance (both of which would blur trends), the age histograms of *M. lineata* through layer 8, MC1 (Figure 10), show a progressive shift in the dominant age classes towards the younger age ranges. There is a marked reduction in the 5, 6, 7 and 8 varix classes. For MC2 (Figure 10) the pattern is less clear-cut, but there are broadly similar trends. The reduction in varix classes 8–10, inclusive, can also be seen in the assemblages from layer 8 in trench 41 (Figure 9). Studies of 24 modern populations of *M. lineata* across the geographical range of the species (Mannino, 2000; Mannino & Thomas, in prep.*b*) have shown that age classes of 7, 8 and usually more varices are consistently represented, and that low-density populations in less favourable environments actually have relatively higher proportions of older age

categories. Environmental factors are unlikely, therefore, to lie behind the trends in layer 8 of the midden.

To summarize: the results presented here suggest that changes in the abundance of the three main species during the later phases of occupation of the Culverwell midden reflect the impact of increased levels of human predation on nearby shores. In particular, changes in the age and size distributions of assemblages of *M. lineata* from the midden have been interpreted as the consequence of intensive and frequent exploitation, causing a marked reduction of recruitment into older age cohorts. Recruitment from the plankton to the shore populations of the species must have been continuous through the period, but selective predation against larger (older), higher meat-yielding, specimens led to a marked decline in their abundance in the shore populations.

Discussion

Shell midden deposits are highly complex phenomena with many factors influencing both their formation and their post-depositional history. It is essential that such deposits be approached with critical caution, and to be understood through a consideration of alternative hypotheses, as we hope to have shown here for the Culverwell Mesolithic shell midden. Despite these complexities and uncertainties, evidence from this shell midden has been interpreted as showing that during the period of most intense occupation, human foraging in the littoral zone had a significant impact on shellfish resources, causing at least three species to decline in abundance. For *Monodonta lineata*, it seems that exploitation of this species changed the age structures of the populations on the exploited shores. Stenotopic rocky shore molluscs that recruit only once a year, such as those taxa discussed here, might be especially vulnerable in areas of sufficiently intensive harvesting.

The failure of animals to grow on into older age categories (7 or 8 years, or older) probably indicates that human predation must have been both intense and frequent. With so many variables unknown, it is difficult to calculate how frequent these episodes of predation were, but it is likely that they were annual (otherwise, in these time-averaged assemblages, we might have expected to find some older age classes). The preliminary results of oxygen isotope analysis of the shells of *M. lineata* from the Culverwell site (Mannino, 2000; Mannino, Spiro & Thomas, in prep.) indicate that they were collected in the late autumn to winter period. Taken together, these results suggest a marked seasonal pattern to shellfish exploitation at Culverwell, with exploitation sufficiently intense to reduce their populations on local shores and sufficiently frequent to prevent recruitment, by shell growth, into older age classes.

As noted in the Introduction, recent work has shown that marine resources, including shellfish, were an important component of human diets in the later Mesolithic. Evidence from the Culverwell shell midden suggests that intertidal species of shellfish were intensively exploited for food by earlier Mesolithic populations. It is likely that this was seasonal, probably as part of an annual cycle. It is not known if this annual cycle was exclusively coastal, or if (as seems likely) other environments were also exploited.

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