CARISBROOKE CASTLE, ISLE OF WIGHT
THE MARINE SHELL FROM THE 2006 AND 2008/9 EVALUATIONS

ENVIRONMENTAL STUDIES REPORT

Greg Campbell

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

Carisbrooke Castle, Isle of Wight

The Marine Shell from the 2006 and 2008/9 Evaluations

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SUMMARY

The 2006 and 2008-09 English Heritage evaluation at Carisbrooke Castle (Project 4992) produced marine shells in similar numbers to substantial excavations in inland towns, and the largest class of anthropogenic material from the investigation. The shellfish were almost entirely from unconsolidated sea-beds characteristic of the northern coast of Wight.

Oysters dominated throughout, cockles were common, mussels and whelks rare. These came from a wide variety of sources, with the sources and the nature of what was acceptable altering subtly but significantly over time. The shellfish discarded in the more public parts of the castle may have differed substantially from those prepared in the kitchens and discarded near them.

The shellfish were supplied commercially, cleaned and sorted before shipping to the castle. This differs from nearby medieval urban centres, where oysters were supplied sorted and cleaned, but cockles and periwinkles were harvested by each household and sorted and cleaned at home.

Some novel techniques were employed: this would appear to be the first use of correspondence analysis with oysters. It would also appear to be the first archaeological instance of whelks being harvested by dredging and for whelks being harvested during oystering.

CONTRIBUTORS

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ARCHIVE LOCATION

Isle of Wight Council Museum Service

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Front cover: Layer of oysters (context 7333) in trench 6 looking east

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INTRODUCTION AND QUANTIFICATION

The 2006 and 2008-09 evaluation trenches in the Privy Garden at Carisbrooke Castle, Isle of Wight, produced 2380 shells or identifiable fragments of individual shells from 58 stratified contexts, including those from the sorting of nine soil samples. This is similar in number to substantial excavations in inland towns (e.g.: Campbell 2011), and the largest class of anthropogenic material from the project.

The intact shells or pieces diagnostic of individual shells (umbones of bivalves, apices and apertures of gastropods) were extracted and identified to genus, or species where possible, by comparison with standard reference works (Hayward and Ryland, 1990 and 1995) or the author's own reference collection. Scientific nomenclature of the types of shell recovered followed Hayward and Ryland (1995); common names (if any) were taken from Hayward *et al.* (1996), and habitat preferences for each type were taken from these works. For each type of shell in each deposit, every intact shell and diagnostic fragment was counted. For most types of bivalves the left and right valves were identified and counted separately.

Types of shellfish recovered

Consumed shellfish

Types of shellfish that are commonly eaten today made up almost all the shells. The numbers of these principal types of consumed shells, and their percentage of the total identified from stratified contexts, are presented for the assemblage in Table 1. Oysters were the most common shell (59% of the assemblage), and were found in every phase from Phase 3 onwards. Some shells were very similar in form to the Portuguese oyster (*Crassostrea angulata*) (Tebble 1966, 54), but these and all other oyster shells were found to be flat or common oysters (*Ostrea edulis*). These well-known native British shells colonize a wide range of stable sea-beds in inter-tidal and shallow waters, forming dense masses and eventually reefs if not broken up by harvesting (usually by dredging). Preservation was adequate, with 30-50% of the valves intact enough to measure in a given context; no clear traces of how the oysters were opened were observed. Oyster tops (right, upper, flatter valves) were slightly more numerous than bases (left, lower, cupped valves) overall, which is unusual for oysters (Law and Winder 2009), but the difference was not statistically significant ($\chi^2_{[1]}$: 0.484; *P* (same number): 0.49). Also, there were no substantial differences in valve numbers in any one deposit. Therefore there was no evidence that oysters were served 'on the half-shell' (in the left valve, right valve removed).

Cockles were also a common shell (32% of the assemblage), especially in Phases 4 and 5. Most were common cockles (*Cerastoderma edule*), but deposits rich in cockles included a substantial minority of lagoon cockles (*C. glaucum*). These well-known shells live in inter-

tidal and shallow waters near shore just below the surface of muddy and sandy beds, sometimes in vast numbers (hundreds per square metre). Common cockles prefer fully marine conditions, while lagoon cockles tolerate more brackish water and muddier beds, such as harbours and estuaries, but their ranges overlap. Both species are harvested easily by raking or digging, which is usually followed by sieving (Hancock 1967b). Preservation was adequate, with 40-50% being measurable. While they were almost always found in deposits along with other shells, they were the most numerous shells in four deposits. For both species, left and right valves were found in roughly equal numbers.

Table 1: marine shells from Carisbrooke Castle, 2006 and 2008-9

	phase	shell-bearing cxts	% shell-bearing cxts in phase	No. Shells	% shells in phase	oysters	cockle	mussels	whelks	others
3	11th Cent.	1	1.7	27	*1.1*	27				
4a	12th Cent.	6	10.3	62	*2.6*	59		2		1
4b	13th-15th C.	8	13.8	928	*39.0*	381	214	73	12	47
4	12th-15th C.	13	22.4	219	*9.2*	218				1
5	16th-18th C.	20	34.5	1100	*46.2*	468	522	21	66	26
6	early 19th C	3	5.2	12	*0.5*	9	2		1	
7	late 19th C.	2	3.4	3	*0.1*	3				
8	20th Cent.	5	8.6	29	*1.2*	12	14		2	1
	all	58		2380		1398	753	96	81	76
	% of all shells					*59*	*32*	*4*	*3*	*3*

Mussels and whelks were much less commonly consumed (less than a hundred shells, and restricted to Phases 4 and 5). All the mussels were native common mussels (*Mytilus edulis*, which colonizes a wide range of stable marine surfaces, sometimes forming dense masses), with no examples of the warm-water Provençal mussel (of Atlantic Iberian and southwestern French coasts). Preservation was typically poor for this fragile shell, with about a dozen measurable; left and right mussel valves were not counted separately. The whelks (*Buccinum undatum*, highly mobile carnivore-scavengers of deeper near-shore waters that sometimes venture into the inter-tidal, delicacies fished by dredging but mainly by potting) were much better preserved, with about three-quarters worth measuring. Both mussels and whelks were found in deposits with other shells, although most of the whelks were found together in the Phase 5 midden 7325.

Only two other types of shells were consumed, and then only rarely. The four carpet-shells (*Tapes decussatus*, shallow burrowers of near-shore beds of muddy gravel and sand) are seldom eaten in Britain today, but are the *palourdes* of modern French cuisine (Quéro and Vayne 1992, 58), and were the highly prized 'butter-fish' of Victorian Hampshire (Davidson 1999, 139). The single crab dactylus ('thumb-claw') from Phase 5 midden 7325 (not identified to species) showed the occupants of the castle then ate crab, but very rarely.

Incidentals

Shells of inedible molluscs that often live on or amongst the consumed types, or of edible shells too small to have been eaten, were found only in very small numbers, even in the fine residues of soil samples: most of the catches of edible shells were cleaned of these before they were brought to the castle. These incidental shells would have been removed and discarded during final cleaning of the shells before cooking ('kitchen waste'). Phase 4b midden 7333 contained a small number of species of marine sand (four carpet-shell hinges wave-eroded to coarse sand-size (too small to identify to species), three valves of the tiny cockle *Parvicardium exiguum*, a single valve of rayed trough-shell *Mactra stultorum*, and a single needle-whelk *Bittium reticulatum*), showing some marine sand was brought to the castle with the edible shells or their packaging. The single mud-snail (probably *Hydrobia ulvae*) from Phase 5 midden 8000 showed a little marine mud clung to some edible shells all the way from the coast to the castle.

Most incidental shells were saddle-oysters (42 upper valves of *Anomia ephippium*) or oyster spat (18 small valves of one- or two-year-old oysters); these often attach to shells of larger oysters, and were found in deposits with larger oysters (the majority of both saddle-oysters and spat came from the soil sample of Phase 4b midden 7333), so they were probably the few missed during the initial oyster-sorting and cleaning prior to shipping to Carisbrooke. The single sting-winkle (*Ocenebra erinacea*, a mobile shallow-water predator), from Phase 5 midden 7325, can live amongst oysters preying on organisms fouling their shells, so it was also overlooked during oyster-cleaning. Periwinkles (*Littorina littorea*, common grazers on inter-tidal and shallow-water weedy rocks and stable muds), while often consumed (and easily harvested by hand-picking), were very rare (only four were found) and too small to eat, so they may have been collected incidentally with other shells.

Shellfish use and its change through time

For each phase, the number of shells, the percentage this represented of all identified shells from stratified contexts, the number of shell-bearing contexts, and the percentage this represented of all stratified shell-bearing contexts, is presented in Table 1. Shellfish were being consumed in small quantities as early as late Phase 3 (context 7344, the final in-filling of one of the ring-work ditches, produced a few oysters), and possibly earlier in the phase (these earlier deposits tended to be less fully excavated because they were deeper and less at risk).

Shellfish were most commonly eaten during the medieval period (Phase 4, which had the greatest proportion of shell-bearing deposits), especially the later medieval (Phase 4b): this phase had the greatest proportion of the shells (nearly two of every five shells) and the widest range of types of shell (all except for the sting-winkle and mud-snail). Shellfish consumption diminished in the early post-medieval (Phase 5), with fewer shells and a narrower range of types discarded in fewer deposits. Cockles and whelks were more favoured than in medieval times (whelks were considerably more numerous, and cockles were the main shells in some deposits). Since shellfish in their shell (un-preserved) are

generally thought safe to eat only if alive just before eating or cooking, and cockles and whelks may survive less well out of water than oysters, it may be that transport of bulky heavy goods such as shellfish to Carisbrooke was more efficient in post-medieval times. In later phases, shellfish were discarded much less commonly in this part of the site, although consumption did not cease completely (a few shells were discarded into a small number of deposits in Phases 6, 7 and 8).

Throughout these phases, the shellfish (both consumed and incidental types) were dominated by species of unconsolidated sea-beds of mud, sand and gravel, characteristic of the northern coasts of Wight (the Medina estuary and the Solent beyond). There are few or no marine molluscs of solid rocky shores (limpets, toothed top-shells, larger periwinkles) common elsewhere on the island.

Distribution

Of course, shells were not evenly distributed through the excavated deposits. Only 58 deposits contained any shells, and 23 of those contained only one or two; half contained six shells or less. Over three-quarters of the assemblage (1798 identifiable shells) came from the six richest deposits, all recognised as middens during excavation. These were a sequence of successive Phase 4b middens (8016, later 7353, then 7333), the Phase 4 midden 322, and two Phase 5 middens 8000 and 7325 (which might have included material redeposited from 8000). These samples were the only ones which had enough well-preserved shellfish to make useful further inferences about the sources of shellfish exploited, and the means of exploitation. The results of further detailed analysis of the interpretable groups of whelks, oysters and cockles from these deposits are presented below.

THE WHELKS

Introduction

Phase 5 midden 7325 was rich in shells or fragments of common whelk (*Buccinum undatum*); the remains of at least 59 individuals were hand-retrieved. Preservation was quite good: the four dimensions often measured on whelks (shell height, shell width, aperture height and aperture width) (Fig. 1) were measurable or accurately estimable in 32 shells; damage to the lip of the aperture in a further 16 meant only the shell height could be measured. This damage had not affected smaller shells more than larger: the 32 intact shells and the 16 more broken shells were not statistically different in average shell height (Mann-Whitney $U_{[31,15]}$: 208.5; *P* (same medians): 0.30) or shell height distribution (Kolmogorov-Smirnov test: $D_{[32,16]}$: 0.281; *P* (same distributions): 0.31). Therefore the dimensions in the 32 intact shells were a reliable sample of all the whelks.

Size

Usually shell height (H in Fig. 1) is used to measure whelk size (e.g: Hancock 1967a, 3). The intact and more-broken whelks combined had shell heights which ranged from 37.7 - 79.0mm and averaged 51.4 ± 9.1mm; half were less than, and half more than, 49mm high. The distribution of heights (Fig. 2) was truncated for small sizes (only one was less than 40mm high) and highly positively skewed (skewness statistic was 1.41, and 15% were over 60mm high). Whelks less than 40mm were really not acceptable for harvest; this is not very different from the modern minimum legal size for whelks, at 45mm (EU 1998, 29). Most whelks were about 50mm, and whelks larger than this were preferred. The size distribution was similar to that for modern southern English whelks: those potted off Deal in Kent in 2006 ranged from 31 – 89mm, averaging 54.3mm (Shelmerdine *et al*. 2006, 2).
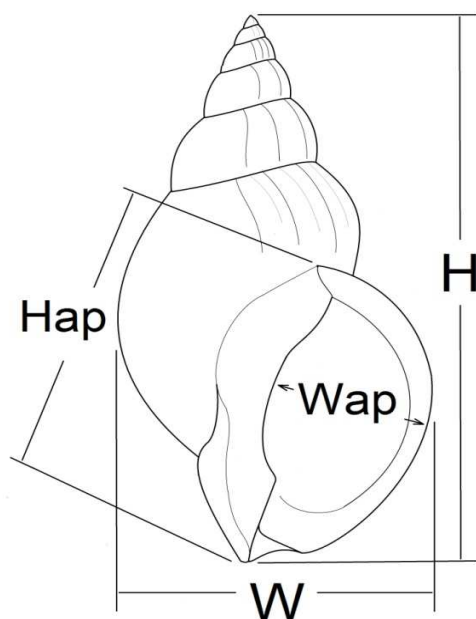
*Figure 1: Measurements on whelks (*Buccinum undatum*) from Carisbrooke.*

Damage

Most of the whelks had unusual features on the lip of the aperture or (less commonly) to the outside of the last whorl (Fig. 3). Damage could be slight (Fig. 3b.): a check in growth was marked by an abrupt step along the entire aperture, with the inner nacreous lining just visible on the surface (ten whelks; in four short growth-spurts separated two or three growth-check bands). More common was moderate damage (Fig. 3c.): the lip bore one or two cracks over 5mm long, or a chip over 3mm (15 whelks). Damage could also be severe (Fig. 3d): numerous cracks had propagated into the body-whorl, and large fragments of the lip or outer whorl had been detached, and in some cases re-cemented into the shell by the living animal (11 whelks). Traces on the spire showed a whelk had survived moderate or severe damage once in 11 whelks, twice or three times for seven, and four times once; one unfortunate whelk had survived five episodes.

Figure 2: distribution of shell heights for whelks from Phase 5 midden 7325.
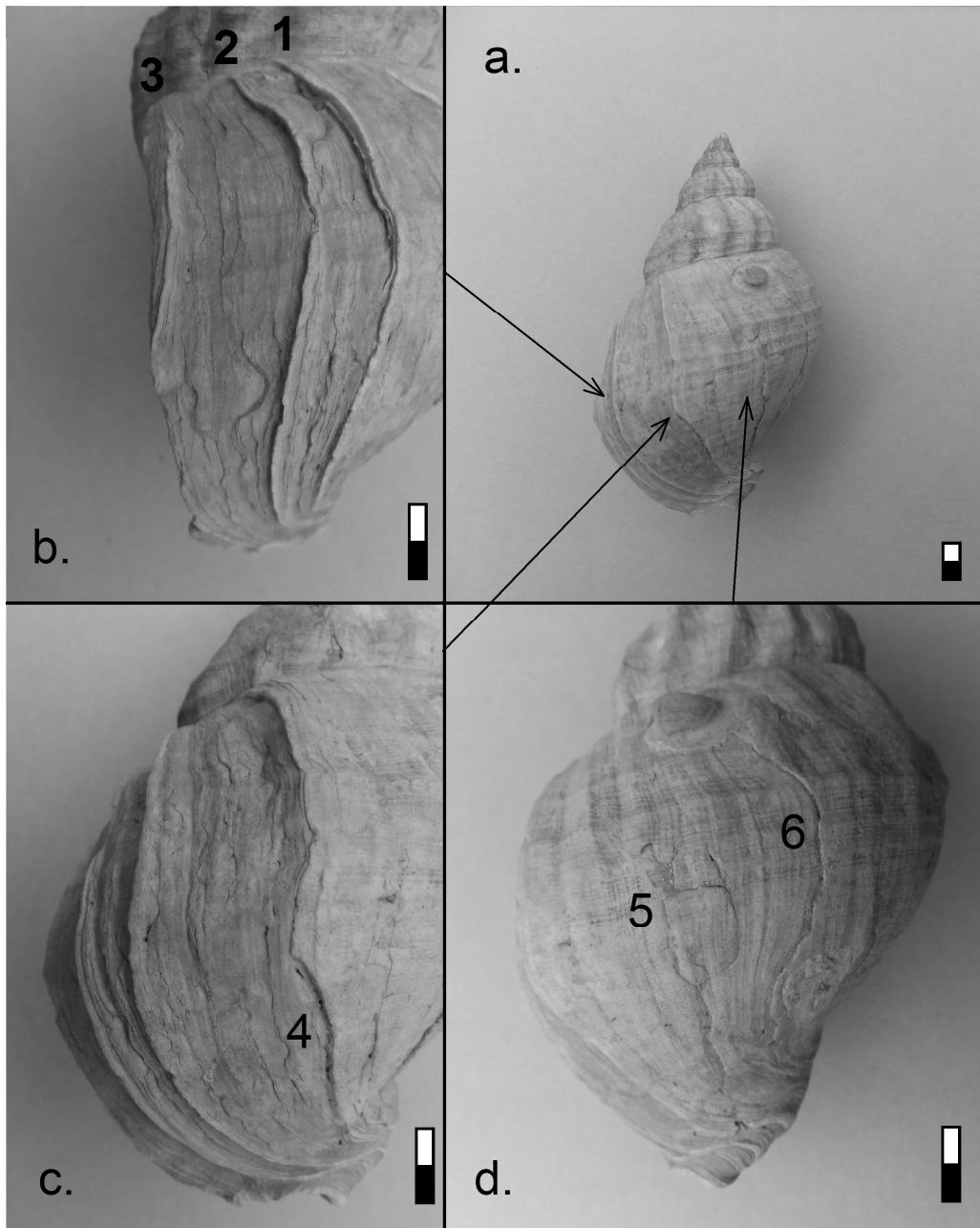
*Figure 3: (a.): a single whelk (*Buccinum undatum *L.) from Phase 5 midden 7325 at Carisbrooke, showing all three types of damage caused by dredging. (b.): three successive episodes (1-3) of slight damage to shell lip. (c.): moderate damage to shell-lip, preceding damage shown in (a.); fragment of shell-lip lost (4). (d.): severe damage on back of body-whorl, preceding damage shown in (c.); fragments re-cemented to shell by living animal (5, 6). Scale bar: 10mm.*

While the slight damage could be caused by infection, attack by a predator, or some other trauma, it and the moderate and severe damage is very like that documented for whelks harvested by dredging (Mensink *et al*. 2000, 55). Repaired shell damage is characteristic of whelks in an intensive dredge-fishery (Cadée *et al*. 1995, 338; Mensink *et al*. 2000, 56).

Shape

An organism's shape varies with size; the stresses and strains on its body from physical forces vary as its weight, volume and surface area change as it grows, so the body and its parts must adjust to compensate (Gould 1966, 588; McMahon 1975). Usually, the relationship between any two dimensions (*x*, *y*) of an organism (the allometry of those dimensions) is exponential ($y = A x^b$) (Huxley 1932: 4-6). The multiplicative term (A) is the allometric coefficient, and the exponential term (b) is the allometric exponent (White and Gould 1965: 5). Relationships between dimensions are said to show 'isometry' if the exponent (b) is exactly one (the ratio of two dimensions is constant), 'positive allometry' if (b) is more than one (*y* is growing faster than *x*), and 'negative allometry' if less than one (Gould 1966: 594). Marine molluscs, living an aquatic life, are inevitably subjected to fluid dynamics effects, which vary with size (Vogel 1994, 87), and therefore marine molluscs usually grew allometrically (Seed 1980), whether modern (Gaspar *et al*. 2002) or archaeological (Reitz *et al*. 1987).

The exponential relationship becomes linear if the dimensions are transformed to their logarithms (log *y* = log A + b log *x*) (Huxley 1932: 4-6). The techniques of linear regression can then be used to fit a straight line to the data, and find the slope and intercept for the formula of that line; for log-transformed dimensions, the slope is the allometric exponent, b, and the intercept is logarithm of the coefficient, log A. The variability of the data around that fitted line is used to calculate Pearson's correlation statistic (*R*), a quantity which characterises how closely the line fits the data; a value of one shows the data all lie exactly on the fitted line; the nearer to zero, the poorer the fit (Sokal and Rohlf 1995, 452-521). The variability of the data around the line can also be used to estimate the standard errors for the slope (b) and intercept (log A). A standard error is simply a standard deviation of a statistic (Sokal and Rohlf 1995, 137), and it can be used in the common statistical tests which use standard deviations to determine the probability that the estimated value of the statistic might be some other value, such as the *t*-test (Sokal and Rohlf 1995, 223). It is possible to use a *t*-test with the estimate and the standard error of the fitted slope, b, to determine the probability that b is exactly one (whether the *x* - *y* relationship is isometric, and the ratio *x/y* remains constant for all sizes).

The most commonly used technique for fitting a straight line, ordinary least-squares (o.l.s.), is specifically designed for prediction, not for fitting a line as closely as possible to the data (Sokal and Rohlf 1995, 453); the latter requires what are called Model II regressions in biometry (Sokal and Rohlf 1995, 457). Amongst the common Model II regressions (see Warton *et al*. 2006 for a review), the reduced major-axis (r.m.a.) technique makes the

fewest assumptions about measurement errors and distributions (Sokal and Rohlf 1995, 544), and is the most commonly used (Hammer and Harper 2006, 54).

The four dimensions measured in the 32 intact whelks were transformed to their common (base-10) logarithms, and the allometric relationship of the other three dimensions (W, Hap, Wap) with shell height (H), and the relationship of aperture height (Hap) with aperture width (Wap), were found using linear regression with r.m.a. fitting, using Version 1.90 of the palaeontological statistical program PAST (Hammer *et al.* 2009). The resulting values for coefficient logarithm (log A), allometric exponent (b), their standard errors, the quality of fit to the line (Pearson's *R*), and the probability that the relationship was isometric (b = one), are shown in Table 2. The relationship of shell width with shell height was negatively allometric (the exponent was significantly less than one); the whelks tended to become relatively more narrow as they grew. This was confirmed by the ratio H/W, sometimes used to characterise shell shape (Magnúsdóttir 2010, 18; Thomas and Himmelman 1988, 227): this averaged 1.65 ± 0.06, but tended to increase with shell height in a statistically significant manner (R: 0.45; *P* (R = 0): 0.0098).

Table 2: allometric relationships in the whelks from midden 7325

main dim'n	H	H	H	Hap
second dim'n	W	Hap	Wap	Wap
log A	-0.093	-0.209	-0.517	-0.308
std. err.	0.051	0.060	0.096	0.073
b	0.928	0.988	0.989	1.001
std. err.	0.031	0.036	0.058	0.050
Pearson's *R*	0.984	0.980	0.947	0.961
P (b = 1):	0.025	0.74	0.94	0.99

Both aperture height and aperture width were slightly negatively allometric (although not statistically significantly), and to the same extent (their exponents were almost identical), suggesting the aperture maintained the same relative shape regardless of size. Indeed, the aperture height-width allometry was isometric (the exponent was indistinguishable from one). The consistent aperture shape was confirmed by the ratio Hap/Wap: this averaged 2.03 ± 0.10, and had no relationship with shell height (R: 0.098; *P* (R = 0): 0.59).

These whelks had very consistent relationships between shape and size: all four allometric relationships were well-characterised by the straight line, and values of R were all close to

one. Whelk shape is very variable, even within single large embayments (Magnúsdóttir 2010, 25-26), so the consistent size-shape relationships show all these whelks were harvested from a very similar habitat, probably the same bit of sea-bed. Ratios were within the ranges found elsewhere (Magnúsdóttir 2010, 18; Thomas and Himmelman 1988, 227). The Hap/Wap ratio seemed somewhat high, indicating narrow apertures, perhaps to thwart being eaten by crabs (Thomas and Himmelman 1988). Keeping a foot in proportion with size as it increased suggests a need to remain attached, while making the shell narrower with size suggests a need for streamlining, so these whelks probably lived in fast or turbulent tidal flows, such as those in the Solent (Velegrakis 2000, 33).

Infestation

Some of the whelks bore traces of organisms attached to their shells. Of the 48 shells intact or complete enough to measure shell height, one had been bored by the bristle-worm *P. ciliata*, two had bryozoan mats, one had a sand-worm tube, one had an *Anomia* byssus, and four had oyster spat. Like oysters, the large solid shells of whelks are regularly infested by other marine organisms (Hancock 1967a, 4) and all these organisms had also infested oysters in the same deposit. The oyster spat infestation was unusual, since oysters tend somewhat to settle amongst other oysters (Bayne 1969), and would be expected to avoid one of their predators.

Discussion

It is quite likely that these whelks were harvested incidentally during oyster-dredging. The size distribution was similar to that for modern southern English whelks. Their damage pattern is characteristic of dredging, and some were dredged repeatedly. It is usual in Britain to harvest whelks using baited pots (Hancock 1967a), since damage from dredging eventually decimates the stock (Cadée *et al.* 1995). The very consistent size-shape relationships suggest they were all dredged from a similar habitat, probably in fast tidal flows. The whelks were infested in a similar manner as the oysters, and the infestation included oyster spat, which tend to prefer other oysters. This would appear to be the first archaeological instance of whelk-dredging being diagnosed via shell damage, and the first archaeological evidence for whelk harvesting being incidental to oystering.

THE OYSTERS

Introduction

The oyster's base valve (the left, cupped valve) lies on the sea-bed, and therefore reflects the nature of that bed. The valve tends to take a particular shape for particular beds: in reefs, it is usually irregular (Winder 1992, 196) or acutely triangular, flat- sided and long-hinged (Gruet 1998); on sheltered mud in harbours and bays, it is usually round, thin-shelled and small-hinged; it tends to become gradually more oval, larger-hinged and thicker-shelled with increasing depth and distance off-shore (Campbell 2010; Winder 1992, 197). Assigning the bases in oyster-rich deposits to these shapes can help reconstruct the intensity of oyster harvesting and the likely setting for those beds (e.g.: Campbell 2009, 7-8). The base can also be infested by a wide range of organisms which attach to or burrow into the outer surface, and these organisms have slightly differing habitats and distributions along the coast (Winder 1992, 197), so recording the presence of the various infestations can be used to assign the oysters to typical habitat or region (e.g.: Winder and Gerber-Parfitt 2003).

Shapes

Each of the 427 bases in the six shell-rich deposits were classified as having oval, reef, round, or irregular shape, or too broken to determine (indet.), and the oyster bases of each shape counted for each deposit. The number of bases, and the percentages of each shape in each deposit, are presented in Table 3. Many of the bases were too damaged to be shaped (39% of these bases), and this was reasonably consistent for all these samples (as little as 29%, to as much as half).   Of the bases which could be shaped, oval oysters were the most common (about one in three of these bases), but varied from as much as half the bases (contexts 7353 and 8000) to as few as one in eight (context 7333). The remaining bases were round, reef-type and irregularly-shaped in equal numbers overall, but these also varied substantially between contexts. While the round oysters had shell length and shell height about equal, only one had the small hinge and thin, frilly-edged shell typical of sheltered bay muds; most had the larger hinges and thicker shells typical of oysters outside bays but near the shore (cf. Fig. 7c in Campbell 2010).

Table 3: Percentages of oyster bases with characteristic shapes,
and main infestation types

cxt	all	322	8016	7353	7333	8000	7325
No. Bases	427	41	88	64	108	39	87
Phase		4	4b	4b	4b	5	5
oval	34.7	41	34	50	15	49	39
irregular	10.1	5	5	6	15	3	18
reef	8.4	7	7	8	16	0	6
round	7.5	12	14	6	3	3	8
indet.	39.3	34	41	30	52	46	29
clean	29.0	39	31	11	15	13	22
P. hoplura	41.7	39	15	55	35	74	51
P. ciliata	4.9	5	2	19	1	3	3
whelk-drill	13.8	10	2	19	23		18
oyster cultch	9.8	2	5	11	5	5	7
Anomia cultch	8.9		6	3	10	3	16
Anomia byssus	7.0			16	6	8	13
spat	3.3	2	2	9	0	5	3
bryozoan mats	3.0		3	6		5	2
Cliona boring	2.6	5		2	2	3	2

It is often useful to compare and contrast several different samples according to their content, but this is difficult when that content is divided amongst several different categories. The statistical technique of correspondence analysis (CA) was developed to separate samples from each other according to the relative difference of their content in several categories, and produce a graphical plot of the results. The plots can include the position of each category, and samples of similar content tend to correspond with the category which makes them similar (Hammer and Harper 2006, 224-226). Baxter and Cool (2010) give an accessible introduction using archaeological ceramics; Beh (2004) gives the mathematical basis. The technique does not determine whether samples are statistically significantly different; the researcher must determine the causes of any patterning.

The oyster shape counts were subjected to correspondence analysis. The results of the analysis are plotted in Figure 4. This distinguished deposits rich in reef and irregular bases

(7325, 7333), those dominated by oval bases (7353, 8000), and those with mainly oval but considerable numbers of round bases (322, 8016). The variation in indeterminate bases was not a factor: no deposit showed high correspondence with oysters of indeterminate shape, and repeating the analysis without those indeterminates produced the same pattern.

Infestation

The bases from the six shell-rich deposits were examined for traces of infesting or adhering organisms, and each shell with one or more of each trace was counted (the method employed by Winder 1992). The percentages of bases in each deposit with the main types of infestation are also shown in Table 3. Some 29% of the 427 bases were clean of any traces, but infestation varied substantially between deposits (from as little as 11% clean to as much as 39%).

The most common infestation was the burrows of the bristle-worm *Polydora hoplura*, a widely-distributed burrower into limestone crevices and shells, especially in southwest England (Hayward and Ryland 1990, 230), which varied between deposits from as little as 15% of the bases to three-quarters of the bases. Only one in 20 bore burrows of *P. ciliata*, of similar habitat but smaller and more generally distributed (Hayward and Ryland 1990, 229); infestation varied from negligible to one in five valves. Holes bored by predatory gastropods such as whelks or sting-winkles were quite common (14% of the bases overall, and up to 23% in one deposit). Also fairly common were shells of saddle-oyster (*Anomia ephippium*) attached to or overgrown by the oyster, or the short calcareous plug-like byssus by which this shellfish attaches. Less common were traces of older oyster to which the harvested oyster had attached; empty oyster shell is sometimes used as cultch (returned to the sea-bed by oystermen to provide surfaces for oyster spat to settle), so this was recorded as 'oyster-cultch'. About 3% of the bases had been bored by the encrusting sponge *Cliona celata*, or had juvenile oysters (spat) or patches of bryozoan sea-mats attached. The intensity of these moderately common or moderately rare infestations also varied between deposits. Rarer still were bases which had grown from mussel shells (10 in all, five from 8016); empty mussels are sometimes also added to beds to aid oyster spat settlement, so this was recorded as 'mussel cultch'. Other minor infestations were sand-worm tubes, (10 in all, six from 7333), keel-worms (*Pomatoceros triqueter*, four in all), and traces of barnacles (five in all); there was a single base which had grown attached to a whelk-shell in deposit 7353.
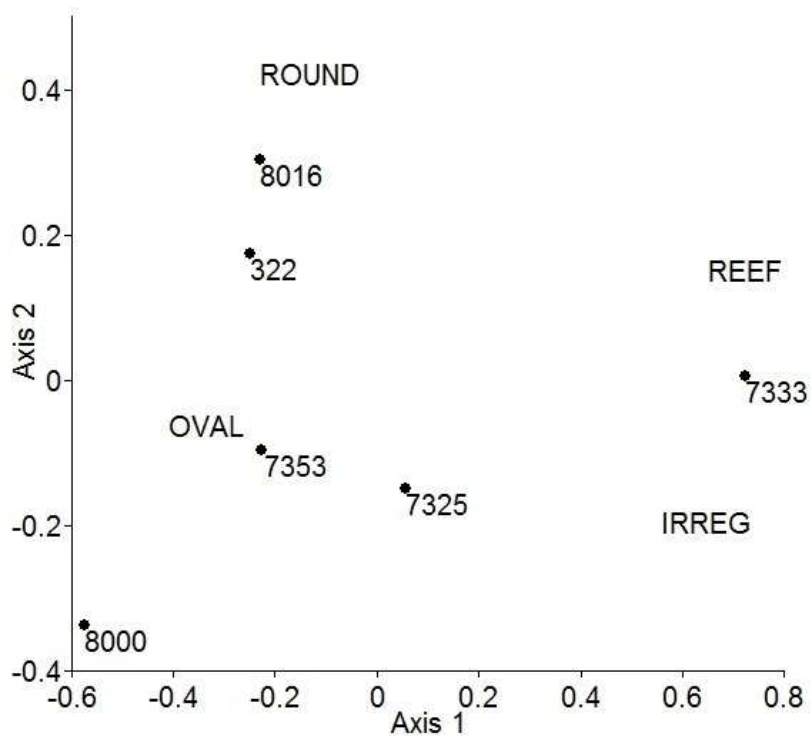
Figure 4: Plot of the results of the correspondence analysis of oyster base shape.
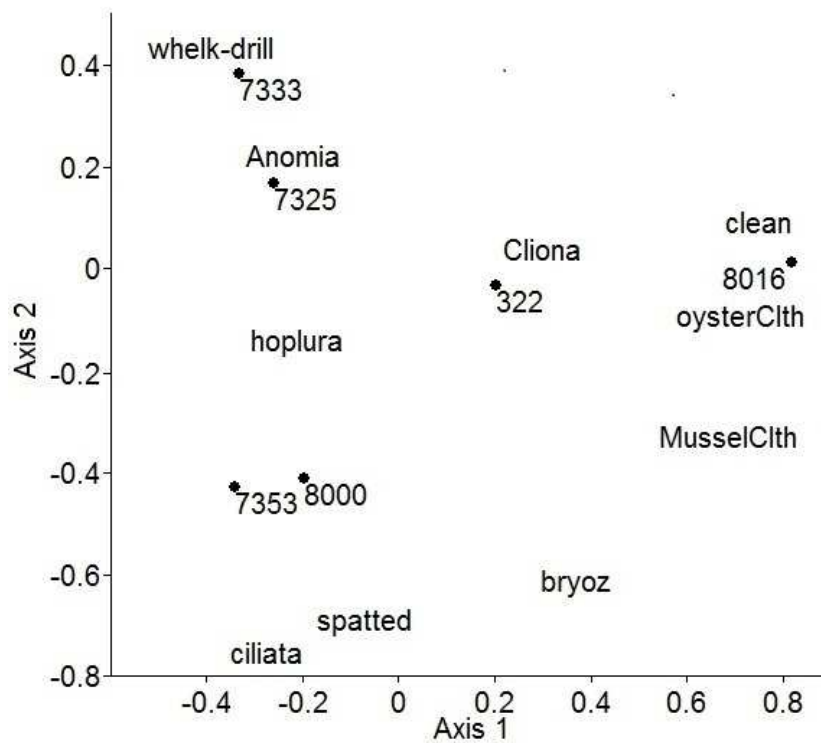

Figure 5: Plot of the results of the correspondence analysis of oyster base infestation

These infestations are all fairly common and widely distributed, with ranges that overlap, so a correspondence analysis (CA) was carried out on the infestation counts to determine any associations. This may be an improvement over the principal component analysis (PCA) technique used to examine infestation patterns by Winder and Gerber-Parfitt (2003), since PCA was designed for measurements of dimensions, while CA was designed for counts in categories (Hammer and Harper 2006, 224). The results of this analysis are plotted in Figure 5. This CA distinguished the same three groups as the shape CA (Fig.4), so these groups are genuine:

- Those deposits rich in oval and round bases (332, 8016) were also relatively rich in clean oysters, with some oyster cultch, mussel cultch or *Cliona*-borings. These deposits were probably rich in oysters from intensively harvested and managed beds. Round oysters are usually from sub-tidal beds just off-shore, oval oysters from deeper water, and *Cliona* only survives sub-tidally; regular dredging tends to keep oysters clean from infestation, and adding cultch is part of conscious management of oyster beds.
- Deposits dominated by oval bases (7353, 8000) were also those richest in bristle-worm borings and spat. These deposits were rich in oysters from unmanaged beds in deeper waters. Oval oysters are found in deeper-water beds, and the bristle-worms and spat often settle naturally on oysters.
- Deposits rich in reef-type and irregular bases (7325, 7333) were also those rich in saddle-oyster traces, with only moderate bristle-worm borings. These deposits were probably rich in oysters from reefs; dredging may be breaking up the reefs often enough to reduce the bristle-worm infestation.

Typical Size and Age

The oyster top valve (the right, flatter valve) opens into the surrounding sea-water, and is inset within the base valve and only slightly larger than the area occupied by the living oyster (Stenzel 1971, 990). Its size and shape therefore reflects the living oyster better than the base valve (Campbell 2010, 181). The oyster top valve also shows the annual rings that mark the slowing or halt of growth during the colder part of the year, so counting the number of these rings gives the age of the oyster. Results are not absolute, since annual rings are not always clear in oysters (Richardson *et al.* 1993, 493) and can be eroded or broken off in archaeological oysters.

Table 4: Percentages of oysters of identifiable shapes in the shell-rich middens

cxt		all	322	8016	7353	7333	8000	7325
Phase			4	4b	4b	4b	5	5
No. Bases		259	27	52	45	52	21	62
oval		57.1	63	58	71	31	90	55
irregular		16.6	7	8	9	31	5	26
reef		13.9	11	12	11	33	0	8
round		12.4	19	23	9	6	5	11
No. Tops		152	14	28	22	25	26	37
oval		65.8	50	72	72	40	52	89
	fast			36	27	16	18	32
	slow			36	45	24	34	57
irregular		5.3	22		5	12	4	
reef		11.2	14	17	14	8	16	3
	fast			13	9	4	12	3
	slow			4	5	4	4	0
round		18.4	14	11	9	40	28	8
	near-sh.			7	5	36	14	5
	rounded			4	4	4	14	3

There were two drawbacks to using the oyster tops in this way. The size and shape of the top valve does not correspond exactly with the base, because the top valves are slightly inset within the bases. Secondly, at Carisbrooke the top valves were far less well-preserved than the bases. In the six shell-rich midden deposits (for which the bases were analysed for shape and infestation, above), 60% of the bases were intact enough to assign

to shape (259 of the 427 bases), but only 38% of the top valves were intact enough to measure valve height and width (155 of the 410 tops). These two drawbacks mean the tops are only a guide to bases of the same approximate shape. For the oyster valves of identifiable shapes, the numbers of base valves, top valves, and percentage of the valves of each shape in each shell-rich midden (and for the identifiable oyster valves overall) are shown in Table 4. The numbers of valves recovered from each context are small, so percentages are approximate (especially so for the top valves, recovered in even smaller numbers). While tops and bases were recovered in roughly the same proportions for valves of oval and reef shape, irregular forms were under-represented in the top valves, and round forms were over-represented in the top valves. It is likely that irregular tops were classified as round in the initial shape-sorting.

Deposit 322 contained only 14 intact tops, too few for statistical analysis. Therefore the height and length of the 141 intact top valves from the five other shell-rich midden deposits (contexts 7325, 7333, 7353, 8000 and 8016) was measured to the nearest millimetre. The summary statistics for top valve height and age for the oysters from oyster-rich middens in Phase 4b (in stratigraphic order: context 8016, 7353 and 7333) and Phase 5 (contexts 8000 and 7325) are shown in Table 5. The oysters in the Phase 4b middens were harvested at similar typical sizes (Kruskal-Wallis (K-W) test; H: 3.19; *P* (same median heights): 0.20) and typical ages (K-W test; H: 4.58; *P* (same median ages): 0.10). The oysters from the Phase 5 middens were harvested at similar typical sizes (K-W test; H: 0.030; *P* (same median heights): 0.86) and typical ages (K-W test; H: 0.033; *P* (same median ages): 0.86). When oysters in the same phase were combined and compared, the oysters from Phase 4b were harvested when significantly larger (Mann-Whitney test; $U_{[76,65]}$: 1768; *P* (same median heights): 0.0033) and older (Mann-Whitney $U_{[76,60]}$: 1610; *P* (same median ages): 0.0027). Oysters were being harvested in a similar manner within a phase, but this manner differed between phases.

The distribution histograms of top valve height for the oyster-rich middens are shown in Figure 6; the age distribution histograms are shown in Figure 7. Very few small oysters (less than 40mm or two years old) were ever harvested in these phases; only oysters over 45mm were really acceptable. In all deposits and both phases, oysters were typically of moderate size (55-65mm and 4-6 years old); since the top valve is smaller than the base, this suggests that most oysters were probably only slightly smaller than the modern minimum legal landing size of 70mm (Southern IFCA 2011). Larger oysters (over 65mm, and 7-10 years old) were less common, but present in both phases; exploitation was not decimating the oyster stock. The size of the smallest acceptable oyster seemed to decrease in the later phase: apart from a single very small oyster in midden 7353, all Phase 4b oysters were over 46mm, and almost all over 50mm, but smaller and younger oysters (three- and four-year-olds, or less than 50mm) were more common in the later phase. Larger oysters were less common in the later phase. These differences in the size and age distribution confirmed the results of the statistical tests: the manner of harvesting differed between these phases. More intensive harvesting in post-medieval times was probably

removing a greater proportion of the larger oysters, forcing the landing of smaller oysters to satisfy demand.

Table 5: oyster top valve height and ages

	cxt	8016	7353	7333	8000	7325
	Phase	4b	4b	4b	5	5
	no.	29	22	25	28	37
top valve height, mm	mean	65.6	60.6	66.4	59.6	58.3
	s.d.	9.6	11.3	11.2	14.4	9.4
	median	66.0	59.5	68	58.5	58.0
	min	47	32	47	37	37
	max	85	80	85	86	83
	skew	-0.02	-0.38	-0.04	0.24	0.39
Age, years	mean	5.4	5.4	6.3	4.9	5.0
	s.d.	1.2	1.6	1.8	1.7	1.5
	median	5	5.5	6	5	5
	min	4	2	3	3	3
	max	10	8	10	9	8
	skew	1.93	-0.10	0.11	0.81	0.78
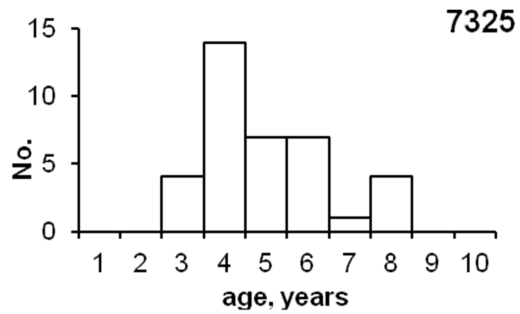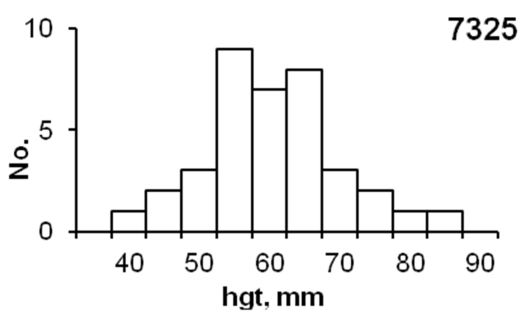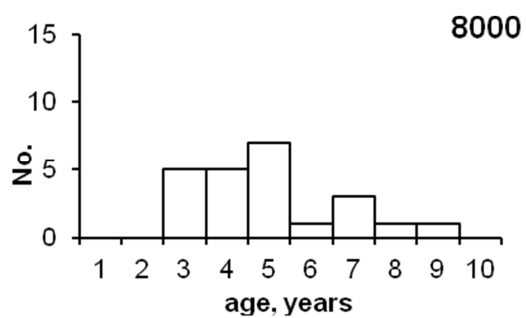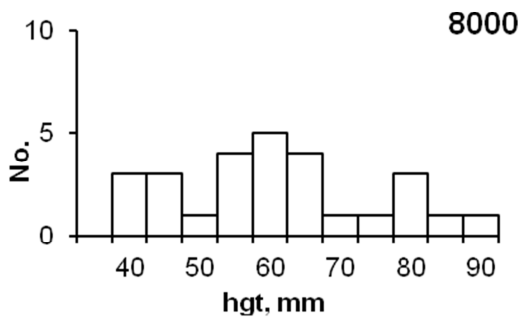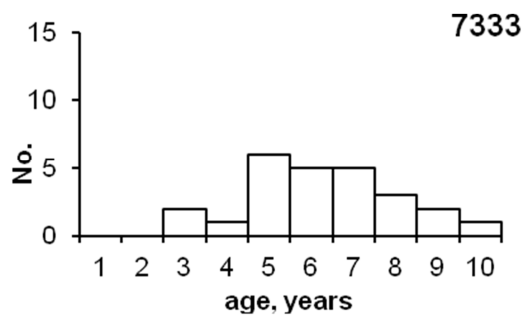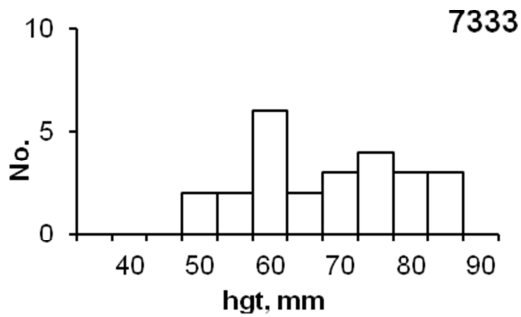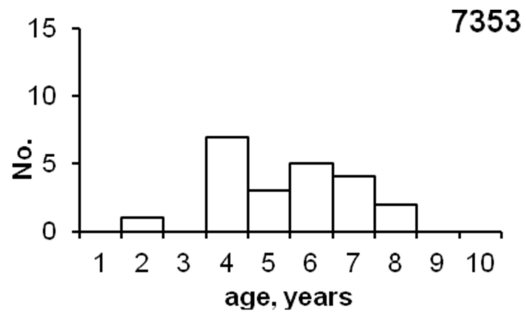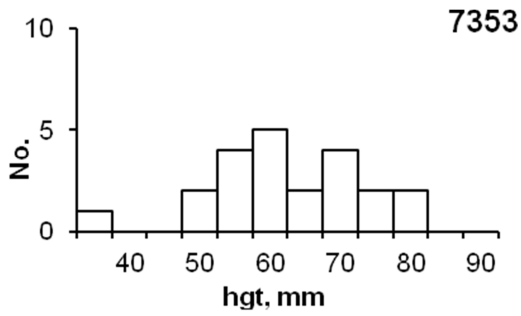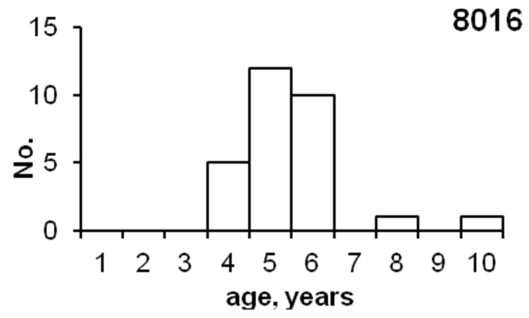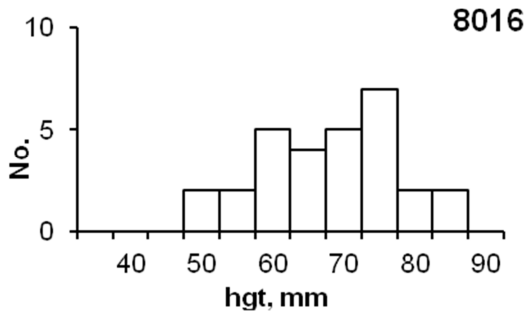
Figure 6: distribution of top-valve heights of oysters from oyster-rich middens of Phase 4b (8016, 7353, 7333) and Phase 5(8000, 7325).

Figure 7: distribution of ages of oysters from oyster-rich middens of Phase 4b (8016, 7353, 7333) and Phase 5 (8000, 77325).

Shape Change with Size

The intact top valves were assigned to the same five shapes as the bases (oval, round, reef, irregular and indeterminate due to breakage). However, the shapes of the top valves do not correspond exactly to the shapes of the bases, because the top valves are not in contact with the seabed and are slightly inset within the bases. Therefore the height and length of the 141 intact top valves from the five oyster-rich midden deposits (contexts 7325, 7333, 7353, 8000 and 8016) were measured to the nearest millimetre. This difference between top and base valve shape, along with the poor preservation of top valves (see *Typical Size and Age* above) meant shape and growth-rate patterns in the tops were a guide to bases of the same shape overall, but not to specific deposits.

Like most other living things (Gould 1966) and most other marine molluscs (Seed 1980) such as the whelks from context 7325 (see above), oysters grow allometrically (they change shape as they change size) in an exponential manner ($y = A x^b$) which is converted to a linear relationship ($\log y = \log A + b \log x$) if the dimensions are log-transformed (Huxley 1932, 4-6). This allometry tends to differ between habitats. Therefore the shape change with size was analysed in the same manner as for the Carisbrooke Castle whelks. The top valve height-length allometry was characterised using linear regression with reduced-major-axis fitting to the common log-transformed measurements: this estimated the value and the standard error for the logarithm of the allometric coefficient (log A) and for the allometric exponent (b) (a fuller explanation is given in the analysis of the whelks, above). To determine whether oysters of different shapes or from different deposits had different size-shape relationships, a one-way analysis of covariance (ancova) was employed (Sokal and Rohlf 1995, 499-513).

The estimates of the logarithm of the allometric coefficient (log A), the allometric exponent (b), their standard errors, a measure of the goodness of fit to the straight line (Pearson's *R*, one indicating all data sit on the fitted line, and zero that the data is randomly scattered), and the probability of isometry (that the exponent (b) is exactly one, and the dimensions remained in the same proportions throughout life) are shown in Table 6. A straight line characterised all the top-valve height-length relationships well (*R* was always near one). While reef-form tops always remained narrow (length never approaching height), in both reef and oval forms length was growing faster than height, and at a similar rate (the allometric exponents were similar). Growth-rate analysis revealed a slow-growing and fast-growing group (see *Growth Rate* below), but these were harvested from quite similar habitats, since the height-length relationship (Figure 10a) was not statistically different between the slow- and fast-growing (ancova: $F_{[1,92]}$: 0.060; *P* (same allometry): 0.81), or between oval oysters from different deposits (ancova: $F_{[4,89]}$: 0.486; *P* : 0.75). A single trend characterised all the reef-shaped top valves (Fig. 8b).

Table 6: oyster top valve height - length allometry

shape	cxt	No.	log A	std.err.	b	std. err.	R	P (b = 1)
	slow	57	-0.385	0.093	1.185	0.054	0.940	0.0012
oval	fast	38	-0.483	0.145	1.235	0.082	0.918	0.0066
	all	95	-0.357	0.065	1.168	0.037	0.953	1.5×10^{-5}
reef		15	-0.478	0.171	1.192	0.098	0.955	0.071
near-shore		18	-0.063	0.059	1.021	0.035	0.990	0.53
round		8	-1.148	0.098	1.102	0.066	0.989	0.17
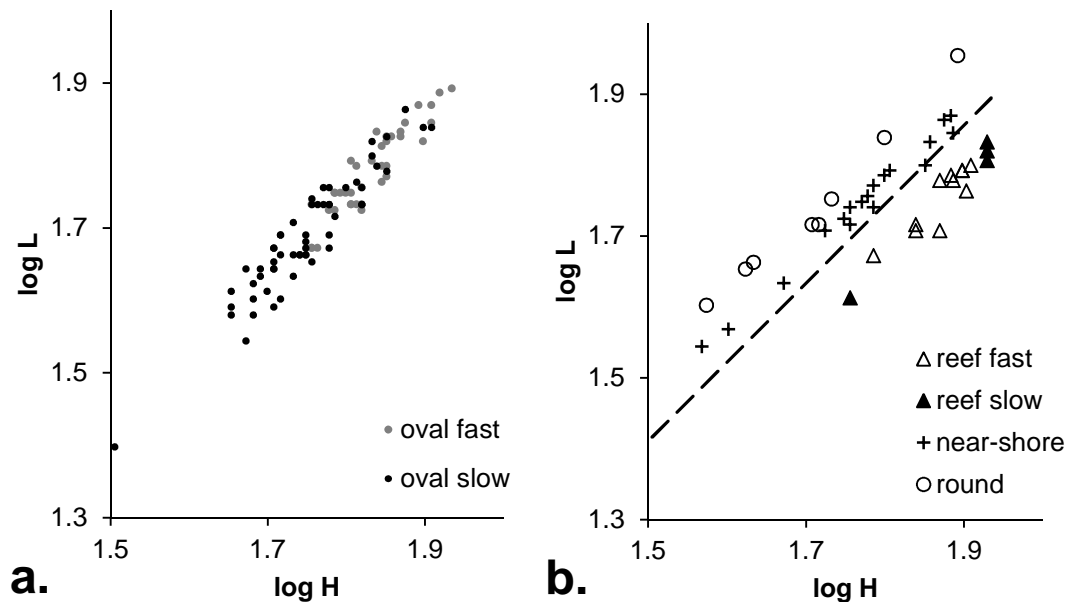
Figure 8: top-valve height-length allometry for oysters of designated shapes from Carisbrooke. (a): two types of oval oyster. (b.): round, near-shore, and both types of reef oyster. Dashed line: regression-fitted straight line for all oval oysters in (a.).

The 'round' oysters separated into two groups (Fig. 8b). In most, length and height grew roughly in concert throughout life; these were probably harvested from near-shore beds in the open sea (Campbell 2010). A smaller number of unambiguously round oysters (in which length exceeded height) were probably the tops for the irregularly shaped bases, which went unrecognised in the sorting. The near-shore oyster beds were distinct from the beds in deeper water that produced the oval oysters: while the height-length relationships were similar and overlapped, they were statistically significantly different (ancova: $F_{[1,110]}$: 24.9; P : 2.3×10^{-6}).

Growth rate

The oyster top valve shows the rings that mark the slowing or halt of growth during the colder part of the year, so measuring these annual growth-rings shows each oyster's year-on-year growth. The typical growth rate can vary between habitats, so it can be used to assign archaeological oysters to different types of sea-bed (e.g.: Campbell 2011, 11). Results are not absolute, since annual growth rings are not always clear in oysters (Richardson *et al.* 1993, 493) and can be eroded or broken off in archaeological oysters. Since growth rate is reconstructed from tops, growth rate suffers the same drawbacks as reconstructing age, size and allometry (see above): shapes of tops and bases do not correspond exactly, and at Carisbrooke the tops are more poorly preserved than the bases. Therefore growth-rate patterns are a guide to the various shapes of oysters overall, but not for specific deposits.

The oyster top valves of rounded near-shore shape had consistent growth patterns, as did the round oyster tops. The round oyster tops were harvested young (a mean age of four years, and always less than five, while the near-shore and other oysters were allowed to grow to greater average ages; if these did represent oysters of irregular shape, these were probably harvested attached to older oysters.

However, the oval oysters could be separated into two groups with different growth-rates, because they had distinctly different sizes at the same age. A faster-growing group had top-valve heights over 55m when four years old, 60mm when five, and 63mm when six; a group of slow-growers did not achieve these sizes at all those ages. The valve heights for the very young slow- and fast-growing oval oysters overlapped, but the faster-growers were bigger on average (mean top valve height: 47.0 ± 7.9mm) than the slow-growers (40.1 ± 6.6mm) by a statistically significant amount (Mann-Whitney test; $U_{[54,38]}$: 510; *P* (same medians): 4.2×10^{-5}). Even when only two years old, the faster-growers were on average (mean top valve height: 33.4 ± 6.1mm) out-growing the slow-growers (28.3 ± 6.0mm) by a statistically significant amount (Mann-Whitney test; $U_{[54,38]}$: 544; *P* (same medians): 0.00016).

 The difference in average size between the two groups was not due to a difference in age at harvest: the two groups were being harvested at similar intensities, since their typical ages at harvest were not significantly different (Mann-Whitney test; $U_{[55,38]}$: 918; *P* (same medians): 0.31), and neither were the distribution of ages at harvest (Kolmogorov-Smirnov test; D: 0.10; *P* (same distribution): 0.97). The type of sea-beds supporting the two groups was also similar, since size-shape allometry was not significantly different (see *Shape Change with Size* above). The faster-growing group probably grew faster because the surrounding sea-water was somewhat less turbid or richer in nutrients. The growth-rate difference between the two groups does not seem to have been observed by the harvesters, since the age-profile showed the intensity of harvesting was similar.

The reef oysters could also be separated into two groups: the fast-growing group that was over 24mm in top-valve height when two years old, over 45mm when three, and over 57 mm when four; and a slower-growing group that were smaller than these sizes at those ages. The growth-rate tended to fall off in the older fast-growing reef oysters, but remained more consistent in the older slow-growing forms. As a result the sizes of the two groups overlapped when five years old, and were quite similar in six- and seven-year-olds. The difference in growth rate also suggests two broad types of reef were available for harvest; since growth-rate is inhibited by high turbidity and low nutrient content, the slower-growing reef oysters, like the slower-growing oval oysters, probably lived in poorer-quality water. All the faster-growing reef forms were harvested before they were eight years old, while the slower-growing forms were left to grow for eight years or more, suggesting the harvesters knew some oyster reefs grew more slowly than others, and harvested the more productive reefs more often.
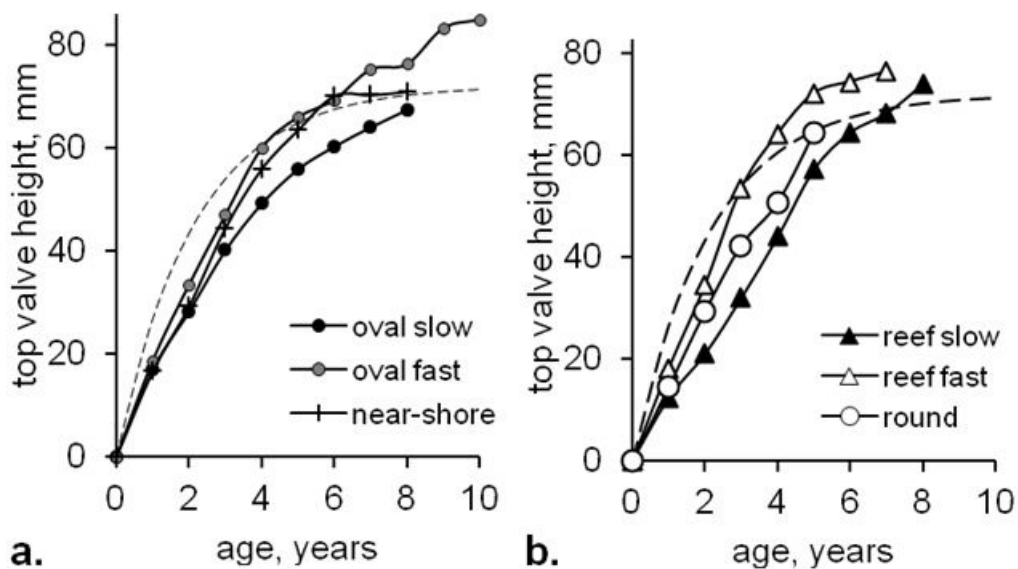
Figure 9: growth curves (top-valve height v. age) for oysters from Carisbrooke. (a.): oval and near-shore oysters. (b.): reef and round bay oysters. Dashed line: growth curve for Solent oysters from Bramble Bank, taken from Richardson et al. (1993).

Like most molluscs, oysters grow throughout life, but the amount by which an oyster grows its shell each year tends to slow with age (Richardson *et al.* 1993, 498), approaching an upper size limit over time in a manner which differs between habitats (Seed 1980, 33). Therefore a typical plot of average oyster size with age tends to trace out a flattening curve (Richardson *et al.* 1993). The average top-valve height at various ages is shown for near-shore rounded oysters, and the fast- and slow-growing oval oysters in Figure 9a, and for the round (probably irregular) oysters, and the fast- and slow-

growing reef oysters in Figure 9b. Almost all closely approximate the expected pattern of diminishing increase in size with age; the probably irregular oysters were harvested before growth-rate began to drop off significantly. Most of the oysters grew in a manner similar to those from the modern Solent (dashed line in Fig. 10) at Bramble Bank (Richardson *et al.* 1993), but the Carisbrooke oysters tended to grow more slowly in earlier years than modern oysters. The slow-growing reef oysters were particularly slow-growing when young, and the slow-growing oval oysters grew the most slowly of all (distinctly more slowly than modern oysters).

Table 4, which compares the shape composition of base and top valves for the shell-rich deposits, also sub-divides the oval and reef-shaped tops into the percentages that are fast- and slow-growing, and percentage of round tops that are near-shore and rounded (probably irregular). These percentages are very approximate (moving even one shell to a different category would seriously alter the percentages); only broad inferences can be drawn. Both fast- and slow-growing oysters were being harvested during Phases 4b and 5, with the possibility that fast-growing oysters were favoured in the earlier times. Both fast- and slow-growing reefs were being harvested for oysters in these phases, with fast-growing reefs favoured throughout.

Discussion

The variety of typical shapes, allometries, age ranges, and growth-rates of these oysters, taken together, show oysters were being procured from several different sources. Near-shore oysters (of round, large-hinged shape) tended to be from managed beds (from deposits rich in clean oysters, and rich in cultch) were quite fast-growing (like modern Solent oysters). Deeper-water oysters (oval and large-hinged) tended to be from un-managed beds (from deposits with little cultch, and rich in bristle-worms and spat) from waters of both good and poorer quality for growing oysters (quite poor for the slower-growing deep-water oysters, which grew distinctly slower than modern Solent oysters), but on similar bottoms (the shape-size relationships were the same). Oysters from reefs (with long, narrow, and faceted bases), which tended to be more infested with saddle-oysters than the other sources, were also harvested from good- and poorer-quality waters (although the growth-rate suggests the slower-growing reefs were in better-quality waters than the slow-growing deep-water oysters). Unlike the deep-water oysters (which were harvested at similar ages), the harvesters knew the quality of reef oysters differed; the slow-growing reef oysters were left to grow longer. Irregularly-shaped oysters were probably harvested principally from reefs: they tended to be found in deposits relatively rich in reef oysters, had similar types of infestation, and were harvested young, probably because most had attached to older oysters.

Deposit 8016, the earliest midden in Phase 4b, was well-supplied by deep-water oysters principally from un-managed beds (from both good-quality and poorer-quality waters), but with considerable numbers of near-shore oysters and oysters from managed beds. Both the shape and infestation correspondence analyses showed Phase 4 midden 322 had very similar oysters to those in midden 8016; it seems likely that these deposits formed at a similar, early date.

The oysters in subsequent Phase 4b midden 7353 were supplied principally from deep-water and un-managed beds, perhaps with a good proportion from poorer-quality waters (slow-growing oval oysters were nearly as common as fast-growing forms); near-shore beds and reefs supplied fewer oysters. The later Phase 4b midden 7333 was more richly supplied by oysters from reefs. Throughout Phase 4b, what constituted acceptable oysters to be used at Carisbrooke remained effectively unaltered; the average age, average size, and minimum size remained consistent for all three middens. The average size was smaller than the present minimum landing size for oysters, but there was no evidence of over-fishing (the wide range of sources was wide, the sizes were consistent over time, and the numbers of large and aged oysters remained fairly high).

In the two middens from Phase 5 (deposit 8000 was earlier than deposit 7325), the typical sizes and ages were statistically indistinguishable, so the concept of what constituted acceptable oysters was very similar throughout this phase. This concept was different from that in Phase 4b; oysters that were smaller, younger, and of a smaller minimum size had become acceptable in the later phase. These smaller sizes, younger ages, and lower numbers of aged oysters in the later phase, suggested oysters may have begun to be over-fished in the later phase.

The two Phase 5 middens were distinct. The later midden (deposit 7325) may have had some re-deposited oysters from the earlier (8000). However, the shape and infestation levels were sufficiently different that the middens were separated in both correspondence analyses. Deep-water un-managed beds were the main source of oysters in the earlier midden, but reefs were a significant source in the later midden. Also, the earlier midden was the only one in this excavation in which oyster tops were better preserved than bases, the near-universal state elsewhere. Why taphonomic processes at Carisbrooke should differ so from those at other sites is not clear; an explanation might be framed using the ceramic or vertebrate remains.

THE COCKLES

Introduction

There were three shell-rich middens that produced cockles intact enough to be measured and assigned to species in enough numbers for statistical comparison: Phase 4b midden 7353, and the two Phase 5 middens 8000 and 7325. These cockles were identified to species using the criteria of Hayward and Ryland (1995). About half the shells were too broken to identify or measure. Phase 4b midden 7353 was quite rich in cockles: it produced 64 measurable common cockles (*Cerastoderma edule*) and 43 lagoon cockles (*C. glaucum*). The earlier Phase 5 midden (deposit 8000) was even richer (129 measurable commons and 15 lagoons); later consumption of cockles may have fallen (Phase 5 midden 7325 produced only 14 common and six lagoon cockles worth measuring).

Cockle populations can be distinguished if shell size, shape and age can be compared. The age of each measurable cockle in each cockle-rich midden was determined by counting the number of annual growth-rings and the outer edge. Shell height, H, and shell length, L (Fig. 10), were measured to ± 0.1mm with vernier calipers. Height was used as a size, as recommended by Jones and Baxter (1987); shell length was used with height as a measure of shape.
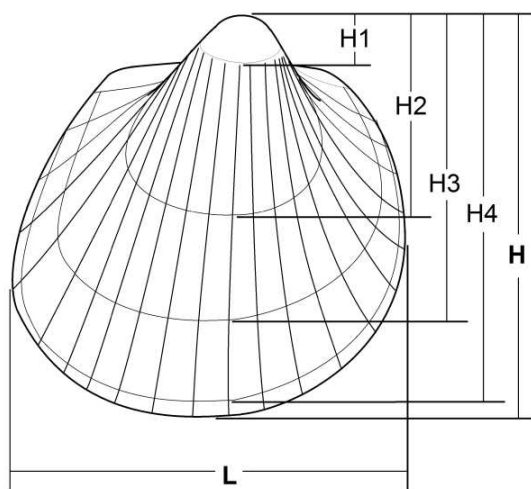
Figure 10: measurements taken on cockles from Carisbrooke. H: shell height; L: shell length; H1 – H4: heights at previous ages, preserved by annual rings.

Cockle-Shell Sizes and Ages

The basic statistics for the ages and sizes for all the cockles (*C. edule* and *C. glaucum* combined) from the three cockle-rich middens are shown in Table 7. The two species are superficially almost indistinguishable, even when clean; biologists only realised recently the typically Mediterranean *C. glaucum* was also an Atlantic native (Høpner-Petersen 1958). It is unlikely that the harvesters, dealing with masses of muddy cockles, knew they

were harvesting two different species. Only looking at sizes and ages of both species together from a deposit shows what constituted a typical cockle and the smallest acceptable cockle in the past. Cockles were harvested at very similar sizes and ages to supply the cockles in the Phase 4b midden 7353, and later for the Phase 5 midden 8000: mean size and age, and median size and age were very similar. Later, cockles were typically harvested when considerably larger and older: the later Phase 5 midden 7325 had cockles with considerably larger average sizes and ages.

Table 7: cockle valve heights and ages

|	cxt	7353			8000			7325		
	species	all	*edule*	*glauc.*	all	*edule*	*glauc.*	all	*edule*	*glauc.*
	no.	107	64	43	144	129	15	20	14	6
Height mm	mean	23.5	24.9	21.4	23.0	23.2	21.2	26.0	26.2	25.8
	s.d.	5.3	5.7	3.8	3.5	3.5	2.8	4.1	4.7	2.7
	median	21.6	22.7	20.5	22.3	22.4	20.8	25.5	25.6	24.9
	min	16.2	16.2	16.4	17	18	17	19.4	19.4	22.9
	max	40	40	37	37	37	26.5	35	35	30.5
	skew	1.22	0.74	2.62	1.54	1.62	0.52	0.91	0.81	1.23
Age, years	mean	3.4	4.0	2.7	3.4	3.4	3.0	4.5	4.4	4.7
	s.d.	1.4	1.4	0.9	1.1	1.1	1.3	1.5	1.3	1.9
	median	3	4	2	3	3	3	4	4	4.5
	min	2	2	2	2	2	2	2	2	3
	max	7	7	6	7	7	6	8	6	8
	skew	0.78	0.43	1.56	0.98	1.01	1.26	0.55	-0.09	1.28
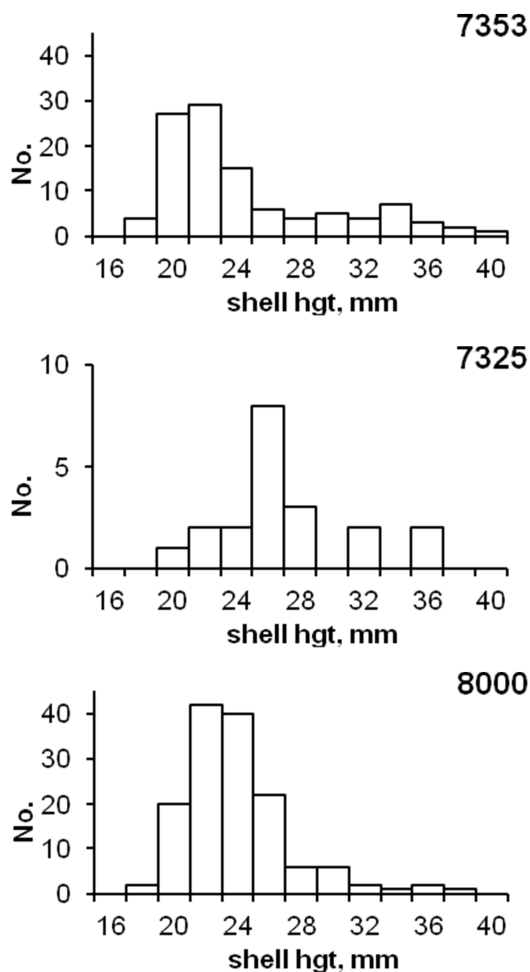
Figure 11: distribution of cockle shell heights from cockle-rich middens, of Phase 4b (7353) and Phase 5 (8000, 7325).

In both deposit 7353 and 8000, a range of sea-beds were being exploited: lagoon cockles were being harvested, unwittingly, from beds where they typically had smaller average sizes and ages than common cockles. Later, both cockles appeared to come from a similar range of beds: deposit 7325 had lagoon and common cockles of similar average sizes and ages.

The distributions of shell height for all cockles from each cockle-rich midden are shown as histograms in Figure11. Quite small cockles were acceptable in the supply: in the two earlier middens (7353 and 8000), the minimum acceptable size was about 18mm; only a tiny fraction (small enough to be considered accidental inclusions) had smaller shell heights. The minimum acceptable size may have increased later: the smallest shell in midden 7325 was 19.4mm.

Despite these small sizes, the cockles did not appear to be dangerously over-exploited: average ages and age ranges were somewhat greater than most natural populations. Cockles can begin breeding in their first year if large (over 15mm), and only a few live more than three years; a ten-year-old is extremely venerable (Seed and Brown 1975). The sources of lagoon cockles may have been more intensively harvested in Phase 4b: these cockles from midden 7325, while numerous, were rather younger than the common cockles.

Growth Rate

Cockles have clear annual growth-rings, preserving their sizes at previous ages, so these growth-rings can be used to reconstruct the pattern of growth in a cockle over its lifetime (Hancock 1967b). Interpretation is not unequivocal, since annual rings can be lost through erosion or confused with disturbance rings (Richardson *et al.* 1980, 981). The growth-rate or pattern (the relationship of average growth-ring height with age in a cockle population) is consistent for similar habitats, and differs between habitats, and is used to understand cockle habitats, both modern (Jones and Baxter 1987) and ancient (e.g.: Campbell 2009). Therefore the height of each successive annual ring (Fig.10.) in each measurable cockle in the three cockle-rich middens was measured to ± 1mm with vernier

calipers, and plotted against age for each midden for each species of cockle. Different populations were distinguished by checking whether cockles forming a cluster of similar sizes at one age also formed a distinct grouping at another (usually younger) age.

Common Cockles (*Cerastoderma edule*):

Two different populations could still be distinguished in the small number of common cockles in Phase 5 midden 7325, because the cockles formed two distinct groups at each age (Fig. 12). A faster-growing population (Fig. 13), 7325(a), had shells 29 - 30.5mm high when four years old, 23 - 35mm when five, and 34.5mm when six; a slower-growing population, 7325(b), were 21.2 - 26.2mm when four, 23 - 26mm when five, and 25.5 – 26.7mm when six.

The same process distinguished three populations in the earlier Phase 5 midden 8000 (Fig. 13): a fast-growing population, 8000(c); a population of moderate growth-rate, 8000(d), similar to 7325(a); and a very slow-growing group, 8000(e), which were 17 – 21.6mm when four years old, 19 – 23.5mm when five, and 22 – 25.6mm when six.

The Phase 4b midden 7353 contained three populations (Fig. 13): a very fast-growing group, 7353(f), similar in growth to 8000(c); a fast-growing group, 7353(g), similar in growth to 7325(a) and 8000(d); and a slow-growing group, 7353(h), similar in growth to 7325(b).

All populations showed growth typical of molluscs, which tends to diminish with age in a manner which differs between habitats (Seed 1980). Growth rates broadly typical of cockles (from the Menai Strait, Wales) (Sanchez-Salazar et al. 1987) are included in Figure 13, for both low- and high-tide populations.

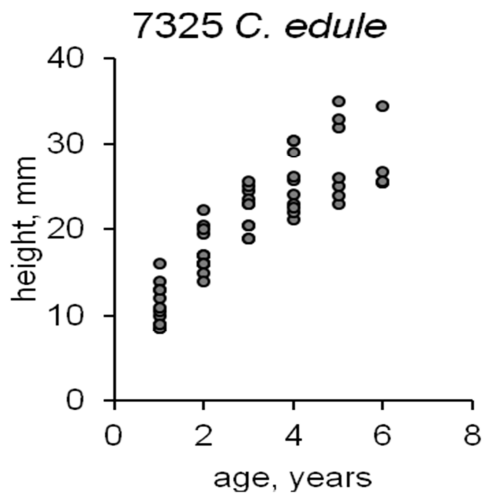*Figure 12: heights of annual rings (mm) at a known age (number of rings from umbo) for common cockles (C. edule) from Phase 5 midden 7325*
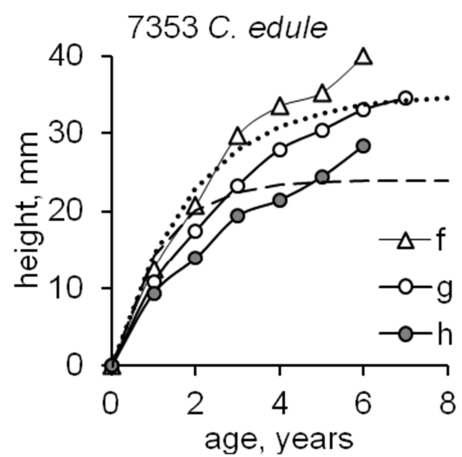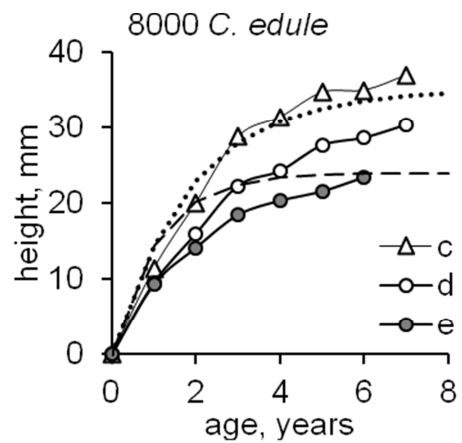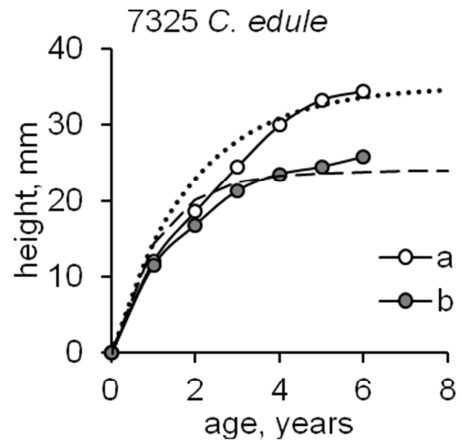

Figure 13: growth rates (average valve height at known ages) for common cockles (C. edule) from the cockle-rich middens at Carisbrooke. Dotted line: high-tide cockles, light dashed line: low-tide cockles, Menai Str. (from Sanchez-Salazar et al., 1987).

Lagoon cockles (*C. glaucum*):

The late cockle-rich midden, Phase 5 deposit 7325, contained only one population of lagoon cockles: the largest cockle, at eight years old (with a shell height of 30.3mm) was the smallest three-year-old (at 18mm). Their growth pattern (Fig. 14) was similar to that in population 7325(a), and they may have been harvested at the same time. The earlier Phase 5 midden, deposit 8000, also contained one population of lagoon cockles, which had a growth pattern (Fig. 14) similar to the very slow-growing common cockle population 8000(e) (shown in Fig.13). The Phase 4b midden 7353 had two lagoon cockle populations; a faster-growing group, 7353(i), similar in growth to common cockle population 7353(f); and a more numerous slow-growing group, 7353(j), similar in growth to common cockle population 7353(h).

Figure 14: growth rates (average valve height at known ages) for lagoon cockles (C. glaucum) *from the cockle-rich middens at Carisbrooke. Dotted line: low-tide cockles, Light dashed line: high-tide cockles, Menai Str. (from Sanchez-Salazar* et al*., 1987).*

Discussion:

The populations fell into four groups, with comparable growth-rates in each group. Cockle growth-rate varies principally due to the time the cockles are covered by the tide, and able to feed; low-tide cockles grow quickly and become large, while high-tide cockles grow the most slowly and remain smallest on average (e.g.: Barnes 1973, 428). Therefore varying growth-rates in the cockles can be used to assign them broadly to tidal position.

The group of fast-growing cockles, populations 8000(c), 7353(f) and 7353(i) (the fast-growing lagoon cockles), were probably harvested from low-tide; while these tended to be the largest cockles in a midden, they also tended to make up relatively few of the cockles in any deposit, since their beds are covered by the tide most of the day, and least available for harvesting. The fast-growing common and lagoon cockles from the Phase 4b midden (populations 7353(f) and (i)) had similar growth patterns, and were probably harvested together.

Moderately fast-growing cockles, populations 7353(g), 8000(d), 7325(a) and the lagoon cockles from 7325, were likely harvested from beds around mid-tide. The lagoon cockles
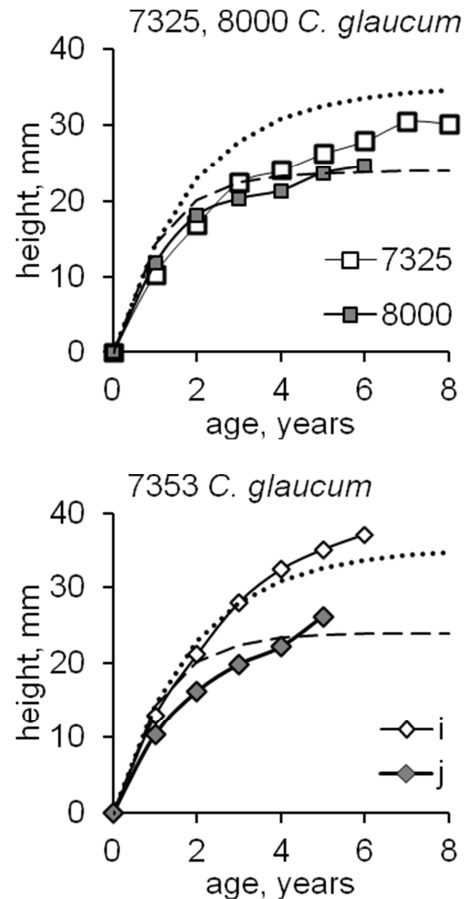
in late midden 7325 may have been harvested along with common cockles 7325(a). Slow-growing cockles (populations 7353(h), 7353(j), 7325(b), the slow-growing lagoon cockles in the Phase 4b midden) were harvested from the high mid-tide. The very slow-growing cockles (common cockles 8000(e), and all the lagoon cockles from midden 8000) were probably gathered from high-tide.

Cockle-Shell allometry

Cockles live buried within the sea-bed, and must re-bury themselves in that bed to survive, if washed out by waves or dug out by predators. The ease of re-burial differs between beds (soft mud is easiest, coarse gravel most difficult), so shells of different species have similar shapes if they live buried in similar beds (Stanley 1970, 59). Lagoon cockles tend to be more spherical than common cockles because *C. glaucum* live in soft lagoon muds, and *C. edule* live in more gravelly wave- and tide-washed sediments (Mariani *et al*. 2002, 488). Therefore the shape of the shell and its change with size (its allometry) should be very similar for cockles from similar beds. To help determine which of the cockle populations recognised in growth-rate analysis were being harvested from similar beds, their typical shell height-length allometries were compared, using the same methods outlined for oysters, above. The estimates of the logarithm of the allometric coefficient (log A), the allometric exponent (b), their standard errors, a measure of the goodness of fit to the straight line (Pearson's *R*, one indicating a perfect fit), and the probability of isometry (that the exponent (b) is exactly one, and the ratio H/L was constant for all sizes in the group) are shown in Table 8. A straight line characterised all the height-length relationships well (*R* was always near one).

Table 8: cockle shell height - length allometry

common cockles (*C. edule*)

cxt	ppln.	No.	log A	std.err.	b	std. err.	R	P (b = 1)
7325	a, b	14	0.099	0.059	0.945	0.045	0.986	0.25
8000	c,d	85	-0.017	0.038	1.031	0.027	0.970	0.26
8000	e	26	0.084	0.052	0.951	0.065	0.964	0.35
7353	all	53	0.073	0.033	0.972	0.025	0.984	0.26

lagoon cockles (*C. glaucum*)

cxt	ppln.	No.	log A	std.err.	b	std. err.	R	P (b = 1)
7325 & 7353	(all) i,j	49	0.008	0.040	1.012	0.031	0.979	0.54
8000	all	15	0.061	0.081	0.973	0.066	0.970	0.68

Common Cockles (*Cerastoderma edule*):
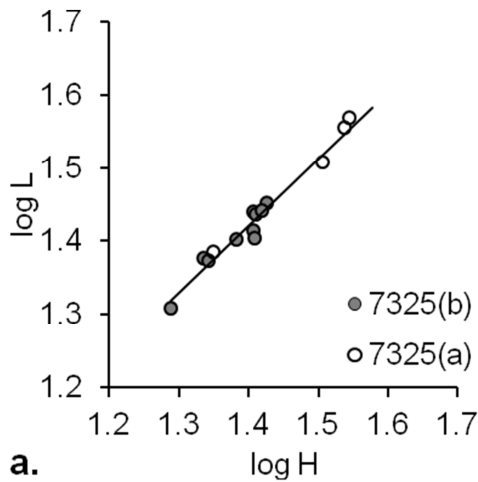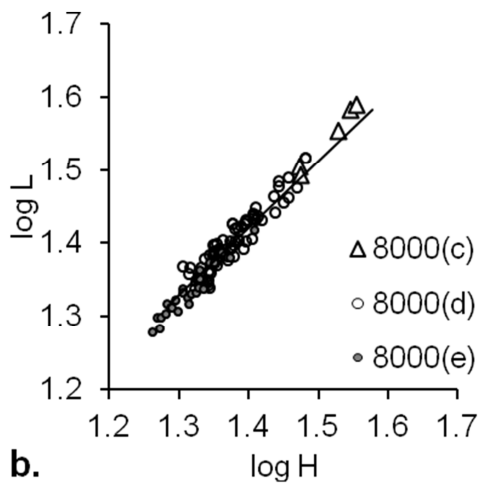
*Figure 15: height- length allometry for common cockles (*C. edule*) from cockle-rich middens at Carisbrooke. (a.): midden 7325; (b.): midden 8000; (c.): midden 7353. Heavy solid line (b & c): regression line for population 7325(b). Light solid line: regression line for all* C. edule *in 7353.*

The two populations in Phase 5 midden 7325 were likely harvested from sea-beds of similar composition. The height-length allometry of the faster-growing population, 7325(a), fitted closely to the height-length allometry of the slower-growing population (Fig. 15), and the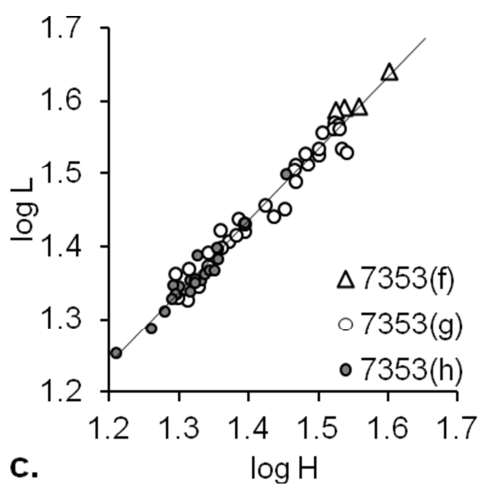 allometric relationship was not statistically significantly different (ancova; $F_{[1,11]}$: 0.77; *P*: 0.40). Table 8 reports the regression-fitted quantities for these two populations combined.

In the earlier Phase 5 midden 8000, the faster-growing population, 8000(c) and moderate-fast population, 8000(d) were harvested from similar beds: the height-length allometry (Fig. 15) was not significantly different (ancova: $F_{[1,82]}$: 1.45; *P*: 0.23). Table 8 reports the regression-fitted quantities for these two populations combined. The slow-growing population, 8000(e), was harvested from elsewhere: its allometry (Fig. 15) was significantly different from 8000(d) (ancova: $F_{[1,102]}$: 6.97; *P*: 0.0096). The cockles in populations 8000(c and d) were harvested from beds like those harvested for midden 7325: the height-length allometry (Fig. 15) was almost indistinguishable (ancova: $F_{[1,96]}$: 0.62; *P*: 0.43).

In the Phase 4b midden 7353, the three populations were harvested from very similar beds: the height-length allometry (Fig. 15) was not significantly different (ancova: $F_{[2,60]}$: 2.54; *P*: 0.087). The regression for these populations combined is reported in Table 8. These beds were not like those harvested for later populations: the height-length allometry was significantly different from populations 8000(c and d) (ancova: $F_{[1,135]}$: 9.74; *P*: 0.0022), from population 8000(e) (ancova: $F_{[1,76]}$: 25.9; *P*: 2.6 × 10^{-6}), and the common cockles in 7325 (ancova: $F_{[1,64]}$: 5.37; *P*: 0.024).

Lagoon cockles (*C. glaucum*):

The lagoon cockles were harvested from two types of bed. The height-length allometry (Fig. 16) was statistically significantly different across the lagoon cockle populations (ancova: $F_{[2,59]}$: 2.82; *P* : 0.047). The populations with the most similar values for allometric exponent and coefficient (without the lagoon cockles from midden 8000) did not have significantly different allometries. The regression-fitted values for allometry for these three lagoon-cockle populations combined are reported in Table 8. The beds harvested for these three similar lagoon-cockle populations were like those harvested for the common cockles in Phase 4b midden 7353: the height-length allometry for the lagoon cockle populations and these early common cockles were not statistically different (ancova: $F_{[3,97]}$: 2.13; *P* : 0.41).

The regression-fitted values for the distinct lagoon cockle population, from midden 8000, are also shown in Table 8. The beds harvested for these were like those harvested for the common cockles in the same midden; their allometries (compare Fig. 16 with Fig. 15) were not significantly different (ancova: $F_{[1,38]}$: 3.15; *P* : 0.084).
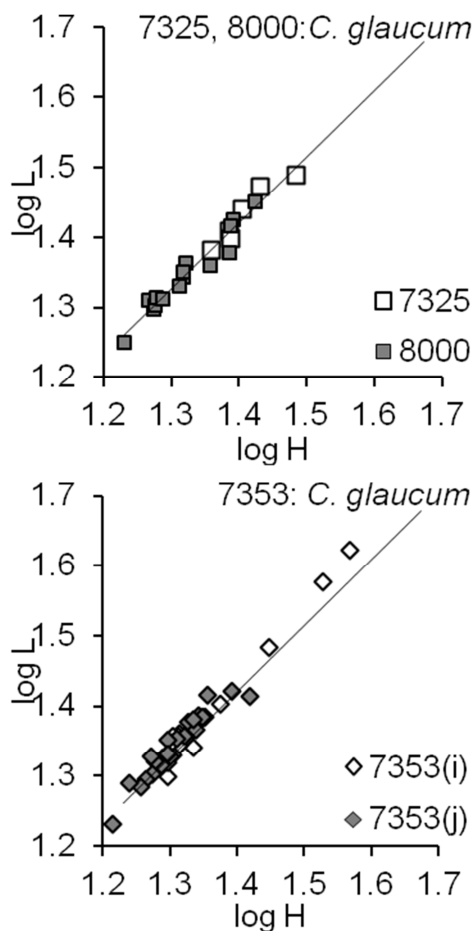

Figure 16: height- length allometry for lagoon cockles (C. glaucum) from cockle-rich middens at Carisbrooke. Light solid line: regression line for all lagoon cockles in 8000.

Types of sea-bed:

There were three different types of height-length allometry in the cockles. The Phase 4b common cockles (all those in midden 7353), the Phase 4b lagoon cockles (from the same midden), and the latest lagoon cockles (those from midden 7325) had similar allometries. Most Phase 5 common cockles (those in populations 7325(a), 7325(b), 8000(c), 8000(d)) had similar allometries. Only the small, slow-growing common cockles in Phase 5 (population 8000(e)) had similar allometry to the lagoon cockles from the same midden.

There were broadly three different types of sea-bed exploited for cockle-harvesting. Using cockle allometry to infer sea-bed type will require further research, but a rough idea can be at least suggested from the shell shapes. All of the fitted allometric relationships were isometric; none of the values for the allometric exponent (b) were statistically

significantly different from one (the values for *P* (b=1) in Table 8 are all far greater than 0.05, or odds of one in 20). Therefore the ratio of length to height for each individual cockle did not vary significantly during its lifetime. Shell shape tends to vary in known ways with sediment type: rounder shells are easily buried, and tend to be found in soft muddy sediments, while shells tend to become increasingly oval with increasing coarse content (sand and gravel) in the sea-bed (Stanley 1970). The average ratio within each allometric group can therefore be used to compare the relative coarse content of the cockles' sea-bed.
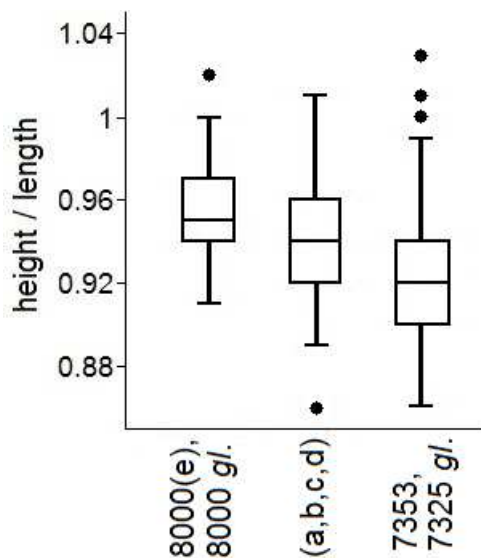

Figure 17: box-plot of height-length ratio for the three types of cockle allometry in the cockle-rich middens at Carisbrooke. The box encloses the middle 50%; the horizontal bar marks the median; the T-extensions mark the extent of the middle 95%; outliers are shown as dots.

The distribution of the ratio of height to length, H/L (HLR) for the cockles in the three types of allometry are shown as box-plots in Figure 17. The most rounded cockles were the slow-growing Phase 5 common cockles (population 8000(e)) and the lagoon cockles from the same midden: these 41 cockles had an average HLR of 0.953 ± 0.025. These most round cockles were likely harvested from quite muddy beds. The other common cockles from Phase 5 (populations 7325(a), 7325(b), 8000(c) and 8000(d)) were more elongated: these 99 cockles had an HLR averaging 0.943 ± 0.030. These cockles were harvested from less muddy beds. The cockles with the third type of allometry (all cockles in midden 7353, and the lagoon cockles from midden 7325) were the most elongated, with an average HLR of 0.924 ± 0.032. These 113 most elongate cockles came from the least muddy beds, despite the preference of lagoon cockles for stable conditions, which are usually muddy. The three types of bed were likely quite different, because the shells were quite different in shape: the HLR values for the three allometry types were very significantly different (Kruskal-Wallis test; H: 35.4; *P* (same medians): 2.1×10^{-8}).

Conclusions

Table 9 shows the cockle populations separated by species and growth pattern from other cockles in the same deposit, in their four positions in the tidal range determined from their relative growth-rates, and classified by sea-bed type determined from their

height-length allometries. This classification is only a broad guide. Annual ring heights can be lost or confused with disturbance rings, growth rate can be affected by cockle density and other factors, and the relationship between sediment and shape change with size has not been researched in detail. The relatively small number of cockles means that lightly-exploited populations will have gone un-recognised, 'lumped in' with larger groups. Nevertheless it is clear that several different sources were harvested to supply the castle with its cockles, and these sources and how they were used varied over time.

Table 9: tidal height and sea-bed type for the cockle populations
at Carisbrooke

tidal height	sea bed		
	very muddy	less muddy	least muddy
high tide	8000 *edule*: (e) 8000: *glauc.*		
high middle		7325 *edule*: (b)	7353 *edule*: (h) 7353 *glauc.*: (j)
middle		7325 *edule*: (a) 8000 *edule*: (d)	7325: *glauc.* 7353 *edule*: (g)
low tide		8000 *edule*: (c)	7353 *edule*: (f) 7353 *glauc.*: (i)

Phase 4b midden 7353 was rich in cockles, harvested when over 18mm and two years old, and usually a little less than an inch long and three years old (Table 7). These were quite small cockles; the average is much smaller than the modern minimum landing size in the region of 15/16'' (23.8mm) (Hancock 1967b, 138; Southern IFCA 2011). The very small proportion of under-sized cockles is consistent with the cockles being sieved, rather than selected for size by hand (Hancock 1967b, 139). More common cockles than lagoon cockles were harvested, but the shell shape analysis showed most cockles, including the lagoon cockles (which tend to prefer stable, soft, muddy sea-beds) were from beds relatively low in mud. Perhaps the local sea-beds that were most free from wave- and tide-washing at the time may have been the least muddy. Lagoon cockle populations in unexpected conditions have been found in the Southampton Water: bed stability was more important than sediment type (Barnes 1973, 420). Growth pattern analysis showed that cockles were harvested in small quantities from low-tide, mid-tide and high middle-shore levels within these least-muddy beds. Both common and lagoon cockles were harvested around low tide in small numbers (fast-growing lagoon cockles of population (i) and common cockles of population (f) were probably harvested together), common cockles alone from the mid-tide, in considerable numbers (population (g)), and both common and lagoon cockles from the high mid-tide, in some quantity (populations (h) and (j) were likely harvested together). The lagoon cockles were considerably smaller

on average, probably because they grew quite poorly in coarser beds on the high mid-tidal.

Cockles continued to be eaten in considerable numbers later in the occupation of the castle: Phase 5 midden 8000 was even richer in cockles than the Phase 4b midden 7353. The notion of the smallest acceptable and typical cockle had not changed over time; the minimum and average sizes and ages hardly differed from those in the Phase 4b midden. Sieving the catch seems to have continued, using the same size mesh as the earlier phase. Shape analysis and growth pattern showed harvesting had shifted to muddier beds in the low and middle tide (populations (c) and (d)) and to the muddiest beds near high tide (the slow-growing common cockles of population (e) and the deposit's lagoon cockles were likely harvested together). This led to the inadvertently harvesting considerably more common cockles than in Phase 4b. The few lagoon cockles were again considerably smaller than the common cockles, because only slow-growing lagoon cockles from high-tide beds were harvested.

Cockle consumption may have begun to decline later in Phase 5: the otherwise shell-rich midden produced only a few dozen cockles. This decline in consumption was accompanied by greater discrimination in what was acceptable in a cockle: the minimum and average sizes were the same for both cockle species, and bigger than in the earlier two middens. The much broader range of smaller sizes suggests the catch might have been selected by hand and eye during harvest, rather than sieved. Moderately muddy beds at mid-tide and high mid-tide were harvested for common cockles (populations (a) and (b)), and the mid-tidal of the least muddy beds for lagoon cockles.

CHANGE OVER TIME

Phase 3 (11th Century AD)

Shellfish were being consumed at least in small quantities as early as late Phase 3. Few early deposits were excavated in this project, so the role of shellfish in the diet during the early use of the castle cannot be determined. This role is likely to have been quite sophisticated: in Southampton, the Norman Conquest did little to alter the extant Saxon consumption of a wide range of shellfish, procured and managed in complex ways (Campbell 2010, 15).

Phase 4 (12th-15th Centuries AD)

Shellfish were most commonly eaten at the castle in later medieval times (Phase 4), especially the 13th – 15th Centuries (Phase 4b had the greatest proportion of the shells and the widest range of types). The bulk of the shells were discarded in middens of kitchen waste.

The shellfish in midden 8016, the earliest midden in Phase 4b, were almost exclusively oysters. These oysters, along with those from the other middens, were assigned to classes of different shape, characteristic of beds near shore (rounded, large-hinged), in deeper water (oval-large-hinged), or reefs (flat-faced and narrow-hinged, or irregular). A correspondence analysis of the shapes showed the middens could be grouped, each group with a similar balance of sources supplying oysters. The oysters were also examined for traces of infesting organisms; a correspondence analysis on the infestation grouped the middens in the same way as the shape correspondence analysis. Some middens rich in near-shore (round) oysters had infestation characteristic of managed beds (quite clean, with mussel and oyster shell used as cultch, which were also perforated by sponges). Other middens dominated by deep-water (oval) oysters had infestation expected in un-managed beds (quite infested, mainly with bristle-worm tubes and juvenile oyster spat). Middens rich in reef or irregular oysters were also quite infested, especially with saddle-oyster traces but fewer bristle-worms. An analysis of the height-length allometry confirmed the distinctness of the broad shape classes. An analysis of the growth-rates showed most oysters had adequate conditions for growth (not very different from modern Solent oysters). Some deep-water oysters grew in good conditions of growth, others in poorer beds; reef oysters also had both good and poor conditions.

These analyses showed that most oysters in midden 8016 were from un-managed beds in deep water, some in good conditions for oyster growth, and some in poor conditions. However, a considerable part of the supply was of near-shore oysters and oysters from managed beds. This is not early for management; some oyster beds supplying Southampton were managed from the later Saxon period (Campbell 2009, 15).

Phase 4 midden 322 had very similar oysters to those in midden 8016; it seems likely that 322 was also deposited early in Phase 4b.

The oysters in subsequent Phase 4b midden 7353 were supplied principally from deep-water and un-managed beds, perhaps with a good proportion from poorer-quality waters (slow-growing oval oysters were nearly as common as fast-growing forms); near-shore beds and reefs supplied few oysters.

Midden 7353 was also quite rich in cockles. Quite small cockles were acceptable, considerably smaller than what is legal now. Only a tiny number were less than 18mm, so small a fraction that this minimum acceptable size was probably maintained by sieving during harvest. The analysis of shell shape initially used height-length allometry, which confirmed that height-length ratios could be compared. This showed most cockles in this midden, including the lagoon cockles (which tend to prefer stable, soft, muddy sea-beds), were from beds relatively low in mud. The analysis of growth rate distinguished several cockle populations. Both common and lagoon cockles were harvested around low tide in small numbers, common cockles alone from the middle shore, in considerable numbers, and both common and lagoon cockles from the high middle shore, in some quantity. The lagoon cockles were considerably smaller on average, probably because they grew quite poorly in the coarser beds on the high middle shore.

The later Phase 4b midden 7333 had oysters from deep water and near-shore beds, but was more rich in oysters from reefs than most other middens. Two broad sorts of reefs were harvested throughout, one fast-growing, the other in poorer growth conditions; the difference in this quality of growth was recognised by the oystermen, and the very slow-growing reefs were harvested less often. Midden 7333 also contained most of the mussels from the excavation, and most of the incidental shells of marine sand and mud, so the mussels may have been collected from sandy beds, rather than the expected rocky shores.

Throughout Phase 4b, what constituted acceptable oysters to be used at Carisbrooke remained effectively unaltered.   Only oysters over 45mm were really acceptable. Average oysters were typically of moderate size (55-65mm and 4-6 years old), but larger, older oysters were available in some numbers, so over-exploitation was not decimating the oyster stock.

Phase 5 (16th-18th Centuries AD)

Shellfish consumption diminished in the earlier post-medieval (Phase 5), with fewer shells of fewer types in fewer deposits. Cockles and whelks were more favoured than in medieval times, perhaps bulk transport times to Carisbrooke had improved. The bulk of the shells continued to be discarded in middens of kitchen waste.

In midden 8000, deep-water un-managed beds were the main source of oysters; the management of oyster beds may have diminished. The concept of what constituted acceptable oysters had also altered from the previous phase. Typical oysters remained of moderate size (55-65mm and 4-6 years old) but oysters that were smaller, younger, and of a smaller minimum size had become acceptable; oysters may have begun to be over-fished.

The midden also had abundant cockles, which continued to be quite small (mean size and age, and median size and age were very similar to Phase 4b). As in Phase 4b, the minimum acceptable size was about 18mm, probably maintained by sieving. Shape analysis and growth pattern showed harvesting had shifted to muddier beds on the low and middle shore (which gathered only common cockles), with a few common and lagoon cockles from the muddiest beds near high tide. Only slow-growing lagoon cockles from high-shore beds were harvested, so the lagoon cockles were considerably smaller than the common cockles.

For midden 7325, deep-water beds continued as the main source of oysters, without much evidence of management of the beds; but reefs became a significant source. Acceptable and typical sizes of oysters had not changed from the earlier midden 8000, suggesting oysters continued to be somewhat over-fished.

This midden produced few cockles; later consumption of cockles may have fallen. This decline was accompanied by greater discrimination in what was acceptable: the minimum and average sizes increased to almost modern legal size, and the minimum size might have been selected by hand-selection, not sieving. Shape and growth-pattern analysis showed most common cockles came from moderately muddy beds (middle and high-middle shore) while most lagoon cockles from the least muddy beds (on the middle shore).

Whelks were abundant in this midden. It is quite likely that these whelks were harvested incidentally during oyster-dredging. The whelks were infested in a similar manner as oysters, and the infestation included oyster spat, which tend to prefer other oysters, so the whelks were living among or near the oysters. The damage pattern is characteristic of dredging (unusual in Britain, since it is unsustainable); some were dredged repeatedly. The very consistent size-shape relationships suggest they were all dredged from a similar habitat, in fast tidal flows (the main source of the oysters in the midden).

Midden 8000 was distinct from later midden 7325, despite the possibility that material from the earlier midden was redeposited in the later. Correspondence analysis showed their oysters differed in shape and in infestation. The density of cockles differed between the middens, and the cockles differed in size, age, and proportion of species. Cockle allometry and growth-rate analyses showed some were being harvested from different beds.

Later Phases

In Phases 6-8 (19th and 20th Centuries AD), shellfish were discarded much less commonly in this part of the site, although consumption did not cease completely (a few shells were discarded into a small number of deposits in Phases 6, 7 and 8).

CONCLUSIONS

Throughout these phases, types of shellfish that are commonly eaten today made up almost all the shells. Oysters dominated throughout, cockles were common (especially in Phase 4 and 5), mussels and whelks eaten occasionally, and periwinkles not at all. A wide variety of sources supplied the shellfish, with the sources and the concept of what was acceptable for a type of shellfish altering subtly but significantly over time, even within a phase. This differs from the previous shellfish excavated from the site, which were almost entirely oysters, harvested from the same type of sea-bed throughout the occupation of the castle (Wyles and Winder 2000, 188). The shellfish discarded in the more public parts of the castle may have differed substantially from those prepared in the kitchens and discarded near them. It is more likely that the recent excavations recovered a more representative sample; how the shellfish were recovered between 1921 and 1996 was not documented, and intact shells were suspiciously common (Wyles and Winder 2000, 185). Oyster top valves were more badly preserved than bases at Carisbrooke, the reverse of the situation almost everywhere else (Law and Winder 2009). The oysters at Carisbrooke must have been treated quite differently in the kitchen or in the ground from the usual way; identifying this difference requires some further consideration.

The rarity of incidental types of shellfish showed the catches were supplied commercially, cleaned and sorted before shipping to the castle. This differs from medieval and early post-medieval Southampton (Campbell 2010, 15): oysters were dredged and supplied sorted and cleaned as at Carisbrooke, but cockles and periwinkles were harvested by each household and sorted and cleaned at home.

The shellfish (both consumed and incidental types) were dominated by species of unconsolidated sea-beds of mud, sand and gravel, characteristic of the northern seas of Wight (the Medina estuary and the Solent beyond). There are few or no marine molluscs of solid rocky shores (limpets, toothed top-shells, larger periwinkles) that are common in the island's southern coasts. When looking for supplies of fresh shellfish, the occupants of Carisbrooke throughout its history were distinctly 'north-facing'.

Some novel techniques were employed in this analysis, and some novel conclusions drawn. This would appear to be the first use of correspondence analysis on oyster shape, and on oyster infestation. It may be the first use of correspondence analysis on consumed shellfish. It would also appear to be the first archaeological instance of whelks being harvested by dredging, the first archaeological instance of whelk-dredging being diagnosed via shell damage, and the first archaeological evidence for whelks being harvested during oystering.

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In midden 8000, deep-water un-managed beds were the main source of oysters; the management of oyster beds may have diminished. The concept of what constituted acceptable oysters had also altered from the previous phase. Typical oysters remained of moderate size (55-65mm and 4-6 years old) but oysters that were smaller, younger, and of a smaller minimum size had become acceptable; oysters may have begun to be over-fished.

The midden also had abundant cockles, which continued to be quite small (mean size and age, and median size and age were very similar to Phase 4b). As in Phase 4b, the minimum acceptable size was about 18mm, probably maintained by sieving. Shape analysis and growth pattern showed harvesting had shifted to muddier beds on the low and middle shore (which gathered only common cockles), with a few common and lagoon cockles from the muddiest beds near high tide. Only slow-growing lagoon cockles from high-shore beds were harvested, so the lagoon cockles were considerably smaller than the common cockles.

For midden 7325, deep-water beds continued as the main source of oysters, without much evidence of management of the beds; but reefs became a significant source. Acceptable and typical sizes of oysters had not changed from the earlier midden 8000, suggesting oysters continued to be somewhat over-fished.

This midden produced few cockles; later consumption of cockles may have fallen. This decline was accompanied by greater discrimination in what was acceptable: the minimum and average sizes increased to almost modern legal size, and the minimum size might have been selected by hand-selection, not sieving. Shape and growth-pattern analysis showed most common cockles came from moderately muddy beds (middle and high-middle shore) while most lagoon cockles from the least muddy beds (on the middle shore).

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