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The changing exploitation of oysters (*Ostrea edulis* L. 1758) in late medieval and early modern England: a case study from Dudley Castle, West Midlands

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Abstract

Analysis of over 4,000 complete left oyster valves from later medieval and post-medieval Dudley Castle reveals the changing role of this perishable luxury over a 700-year period. Throughout the occupation, it seems that oysters were used as ingredients rather than served raw in the shell. A greater reliance on oyster consumption is apparent in the later 14th century, perhaps reflecting a shift towards a more diverse diet amongst the aristocracy in the wake of the Black Death. An increased preference for mussels and whelks is also attested in the Tudor and early modern periods, reflecting changing perceptions of these foods.

Overall, it is likely that natural beds were exploited throughout the time that oysters were being brought to Dudley Castle; however, the evidence demonstrates a shift from limited exploitation of natural inter-tidal sources in the 11th century towards the dredging of sub-littoral beds in later periods, with some possible translocation of oyster stock. Changes in the shape, size and appearance of the oyster shells suggest the source locales from which the oysters derived changed through time. A notable shift occurred in the 14th century, which could reflect changes in supply brought about by altered tenancy at Dudley Castle and/or disruptions to trade brought about by the Black Death. Future biochemical analyses are recommended to provide greater clarity on the origin of those sources.

Keywords

European flat oyster, late medieval, early modern, castle, marine molluscs

Word count

7223

Introduction

The European flat oyster (*Ostrea edulis* L. 1758) is a native shellfish, occupying habitats from the lower shore down to about 80 metres depth on sandy and muddy substrates around the British Isles (Allcock et al. 2017: 557). British oysters were celebrated in the Roman empire (Stott 2004, 39) and endured as a luxury food throughout the medieval and early modern periods, eventually reaching the status of popular proto-fast food in the middle of the nineteenth century when improvements in transport made it possible to transport oysters inland in bulk (Yonge 1960).

The shells of oysters are frequently recovered from historic-period archaeological sites in Britain. As well as contributing to an understanding of changing dietary habits, careful analysis of size, shape and macroscopic surface features provides information on the environment in which they grew. In turn, this information can be used to track the changing management of oyster beds and aid in the reconstruction of regional trade networks. In this paper, we present the analysis of over 4000 complete left oyster valves from Dudley Castle, West Midlands, dating from the 11th to the mid-18th century. The significance of this assemblage rests not only its size and chronological span, but in the fact that it fills a recognised gap in our understanding of post-medieval oyster exploitation in England (Winder 2017: 245) and in the provisioning of elite sites with marine molluscs (Campbell 2015: 186). The size of this assemblage, and the lengthy chronology it covers, coupled with recovery through systematic sampling, allow broad inferences to be made about the management of oyster stocks in Britain in the past. This has been highlighted as an area in of further research (Fulford et al. 1997: 221; Murphy 2001: 27). Our aims are to establish:

- 1) the dietary importance of oysters, relative to other marine molluscs and terrestrial fauna, at a land-locked elite site;
- 2) the source(s) of the oysters that were supplied the site;
- 3) how oyster bed management changed over 700 years.

The latter is achieved by comparing the results of macroscopic examination of the oyster shells against the models of intensifying oyster exploitation proposed by Winder (2017: 247-250) (Table 1), and provides the first application of these to archaeological material.

Model	Characteristics of oyster assemblage
1: exploitation of natural populations in the inter-tidal zone on the sea shore, estuaries or creeks	Small quantities of shell; wide size and age range; high proportion of irregularly-shaped and clumped shells.
2: dredging in-shore shallow sub-littoral natural beds	Average size larger than in model 1, but possibly narrower; high proportion of irregularly-shaped and clumped shells.
3: dredging deeper off-shore sub-littoral oyster beds	As model 2, but different shape of shell; different range of associated molluscs; reduced intensity of epibiont damage.
4: deliberate management of oyster beds	Restricted size and age range; infrequent clumping and irregular sized shells; increased infestation damage in nutrient-rich water.
5: full-scale cultivation and marketing	Restricted size and age range; infrequent clumping and irregular sized shells; increased infestation damage in nutrient-rich water.

Table 1: models of oyster exploitation (after Winder 2017, 247-250).

Materials

Dudley Castle is situated in the West Midlands, England, 15 km north-west of Birmingham (Fig. 1). Excavations within the keep and the confines of the inner bailey were carried out at the site between 1983 and 1993 after growing concern that modern pollution and natural weathering had left many of the sandstone structures of the castle in danger of collapse (Boland 1984). Although the project was essentially a rescue excavation, it also sought to enhance the monument's tourist potential and provide long-term employment through the Manpower Services Commission Community Programme (Boland 1984, 1). Ten phases of activity were identified during the excavations stretching from the 11th to the mid-18th century (Table 1): this phasing was established following archaeological confirmation of historically-attested periods of building activity and was verified by ceramic spot-dating (Thomas 2005a, 6). While the primary site archive remains unpublished, selected aspects of the archaeology have appeared in print (Gaimster et al. 1997; Moffett 1992). Of particular relevance, the faunal assemblage has been subjected to detailed scrutiny and has shed important light on changing dietary habits, agricultural practices, hunting techniques and

human perceptions of animals (Fisher and Thomas 2012; Hamilton and Thomas 2012; Thomas 2005a, 2005b, 2006, 2007a, 2007b, 2008; Thomas and Locock 2000).

In this paper we present the first analysis of the marine mollusc assemblage from Dudley Castle. While oysters form the focus of the present study, other marine molluscs were recovered including, in diminishing order of abundance (Table 3): mussels (*Mytilus cf edulis* L., 1758); common whelks (*Buccinum undatum* L., 1758); common European limpets (*Patella vulgata* L., 1758); and a small number of other edible bivalves, such as cockles (*Cerastoderma* sp.). Oysters far outnumbered other molluscan taxa: notwithstanding a relative increase in mussels in Phase 7 (1397-1533) and whelks in phase 8 (1533-1647), oysters represented more than 80% of the marine mollusc assemblage throughout the occupation of the site.

Phase	Date
1	pre-1071
2	1071-1100
3	1100-1175
4	1175-1262
5	1262-1321
6	1321-1397
7	1397-1533
8	1533-1647
9	1647-1750

Table 2 – designated phases of activity at Dudley Castle (after Thomas 2005).

	Oyster		Mussel		Whelk		Limpet		Other bivalve	
	n	%	n	%	n	%	n	%	n	%
pre-1071-1100	383	93.87	24	5.88	0	0.00	1	0.25	0	0.00
1262-1321	208	83.87	32	12.90	1	0.40	0	0.00	7	2.82
1321-1397	6512	93.98	381	5.50	19	0.27	16	0.23	1	0.01
1397-1533	1991	76.28	575	22.03	36	1.38	1	0.04	7	0.27
1533-1647	1980	79.81	356	14.35	135	5.44	0	0.00	10	0.40
1647-1750	1102	98.48	16	1.43	1	0.09	0	0.00	0	0.00
TOTAL	12176		1384		192		18		25	

Table 3 – number and relative abundance of marine mollusc fragments at Dudley Castle.

Figure 1 – the location of Dudley Castle [image not included in this version of the article]

Methods

Hand-collected oysters from nine phases of occupation (Table 1) were recorded using the variables set out in Table 4. To avoid double-counting, only left-valve oyster shells were subjected to quantitative analysis: these were preferred because the left valve rests on the seabed and better reflects the nature of the environment in which they grew (Campbell 2013: 16).

Variable	Values	Reason
Valve side	Left, right	Minimum number determination.
Valve shape	Round, elongate, broad, irregular	Oyster shape is influenced by environment: round shells form in slow tidal currents with soft muddy beds; elongate oysters form in deeper, off-shore environments where there are fast tidal currents; irregular shells occur when the oyster forms on a rough or uneven surface (Campbell 2010; Winder 1992).
Size	Maximum height (Hmax) and maximum length (Lmax) taken to the nearest mm	Oyster size is linked to age and growth rate, both of which are influenced by the environment, such as position with respect to the shoreline, salinity, food availability, temperature, water depth and management practices (Campbell 2008; Winder 1997: 194).
Appearance	Chalky deposits (present/absence)	Chalky deposits may develop in estuarine areas where there is rapid salinity change (Yonge 1960, 23; Winder 1992).
Epibiont activity	<i>Polydora hoplura</i> Claparède 1870, <i>Polydora ciliata</i> Johnston 1838, <i>Cliona celata</i> Grant 1826, Bryozoa, bore holes (made by a variety of organisms, such as predatory gastropods, sea urchins and starfish), barnacles (Cirripedia), sand tubes (Sabellidae), calcareous tubes (Serpulidae)	Traces of epibiont activity can reveal the regional locale of the bed(s) and reveal specifics concerning the local environment: distinguishing intertidal, littoral or shallow sub-littoral beds; identifying whether the substrate was hard or soft; and establishing the degree of salinity.
Chambering	Present/absent	Chambering in the left valve occurs when oysters are subjected to fluctuating pressure: mainly in tidal zones and estuarine environments (Yonge 1960, 23; Winder 1992).
Clumping	Present/absent	Valves with additional oysters growing on the shell are

		indicative of a habitat in a natural bed, where no or limited cultivation was involved.
Prising	Present/absent	Prising marks indicate where the shell was opened to remove the oyster. These take the form of V or W-shaped notches on the edge of the shell (Thomas 1978: 158 & Fig 5.3.1)

Table 4 – methods used in the analysis of *Ostrea edulis* shells from Dudley Castle.

The statistical significance of temporal differences in oyster shell measurements was determined using the non-parametric Mann-Whitney U test, in recognition of the fact that sample sizes were unequal and the data for some phases were not normally distributed. The non-parametric Fligner-Killeen test was employed to assess homogeneity of variance based on ranks. Changes in shell shape were analysed using a Chi-squared test. The presence of epibiont infestation by phase was investigated using detrended correspondence analysis. All statistical tests were calculated using PAST (PALaeontological STatistics) (Hammer et al. 2001).

Results

A total of 12,177 oyster shell fragments were identified (Table 5). The distribution of fragments by phase was uneven, with the majority dating from the late 14th century until the mid-18th century, reflecting the intensity of occupation of the site and the nature of the archaeological deposits. In phase 5 (1262-1321), for example, a kitchen annexe was constructed on the side of the motte and the moat seems to have formed a convenient locus for the disposal of food waste thereafter.

Phase	L valve	R valve	L fragments	R fragments	Total
1 (pre-1071)	2	4	1	0	7
2 (1071-1100)	19	176	108	73	376
3 (1100-1175)		1			1
5 (1262-1321)	56	81	38	33	208
6 (1321-1397)	2177	2877	904	554	6512
7 (1397-1533)	731	813	211	236	1991
8 (1533-1647)	621	761	315	283	1980
9 (1647-1750)	436	570	40	56	1102
Total	4042	5283	1617	1235	12177

Table 5 – distribution of oyster shell fragments by phase

The oyster shell assemblage comprised 4042 complete left valves, 5282 complete right valves, 1617 fragments of left valves and 1235 fragments of right valves. The mean number of complete left valves in contexts containing oyster was 22.9 (SD = 93.1) and the median was 3. For right valves, the mean was 27.5 (SD = 118) and the median was 3.

The greatest number of oyster shells was recovered from Phase 6 (1321-1397), which contained 2177 complete left valves and 2877 complete right valves. The oysters were concentrated in a small number of contexts, largely in the area to the north and east of the keep, which included the kitchen annexe. Notably rich contexts included <6384>, a Phase 6 clay loam and rubble layer (909 complete left valves (CL), 1240 complete right (CR)); <6417>, the Phase 6 fill of a rectangular pit (708 CL, 903 CR); <6466>, another fill of the same pit (340 CL, 431 CR); and <7148>, a Phase 9 dump of brown, mortary loam in the area of the Great Hall cellar (299 CL, 499 CR).

At Ludgershall Castle in Wiltshire, Winder (2000) suggested that post-preparation separation of left and right valves might explain why some contexts contained more right than left valves, and high proportion of damaged or epibiont infested left valves relative to intact, uninfested left valves. This does not appear to be the case at Dudley Castle. A Mann-Whitney U test shows that the difference in median numbers of left and right valves per context for the total assemblage is not statistically significant ($U=16728$; $p = 0.54$). Higher numbers of right valves are to be expected in oyster assemblages, due to differences in the structure of the shell. Right valves are more robust, with more compact layering, whereas left valves are prone to breakage (Law and Winder 2009).

Assessing the relative contribution of oyster to the diet is challenging in the absence of volumetric data of sediment by phase; however, the frequency of complete left valves can be expressed as a percentage of the total number of hand-collected animal bones (Thomas 2005). This crude analysis (Figure 2) suggests that oysters were consumed relatively more frequently in the late 14th century and in the mid-17th to mid-18th century.

No examples of prising were observed in left valves prior to the 14th century; thereafter the incidence of such marks was low but increased, peaking (at 3.7%) in the final phase of occupation (1647-1750).

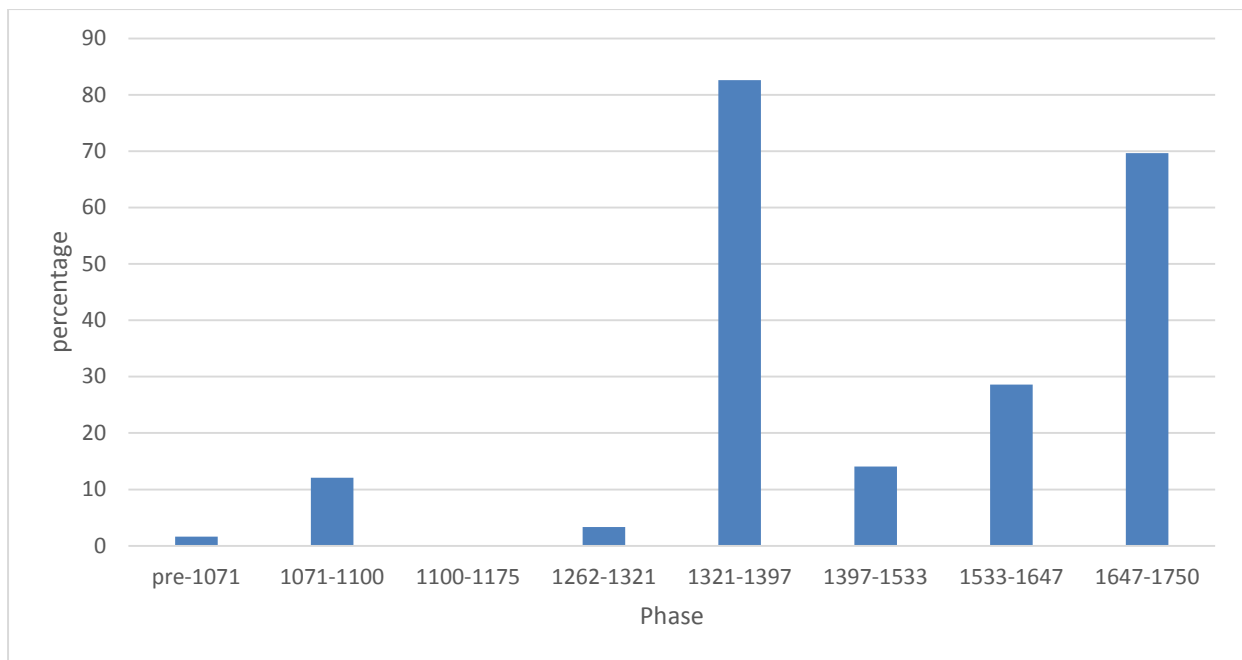


Figure 2 – relative abundance of complete left valves relative to animal bone remains (Thomas 2005) by phase

The mean, range, standard deviation and coefficient of variation of maximum height and length of left oyster valves are presented in Table 6. The data in phases 5-9 were unimodally distributed with the peak typically in the region of 50-60mm for Hmax and the number of shells decreasing with increasing size (i.e. left-skewed) for phases 6-9: the data for earlier phases exhibited a right skew, but the sample sizes were somewhat smaller. This pattern suggests that the shells represent whole populations, with no preferential sorting. Only 9.6% of oysters had a Hmax above 70mm, the modern legal landing size (Campbell 2010, 180), but this increased steadily over time (Figure 3). Small oysters' (i.e. less than 37mm: Campbell 2015: 183) were a persistent presence contributing 2-5% of the oyster assemblage by phase.

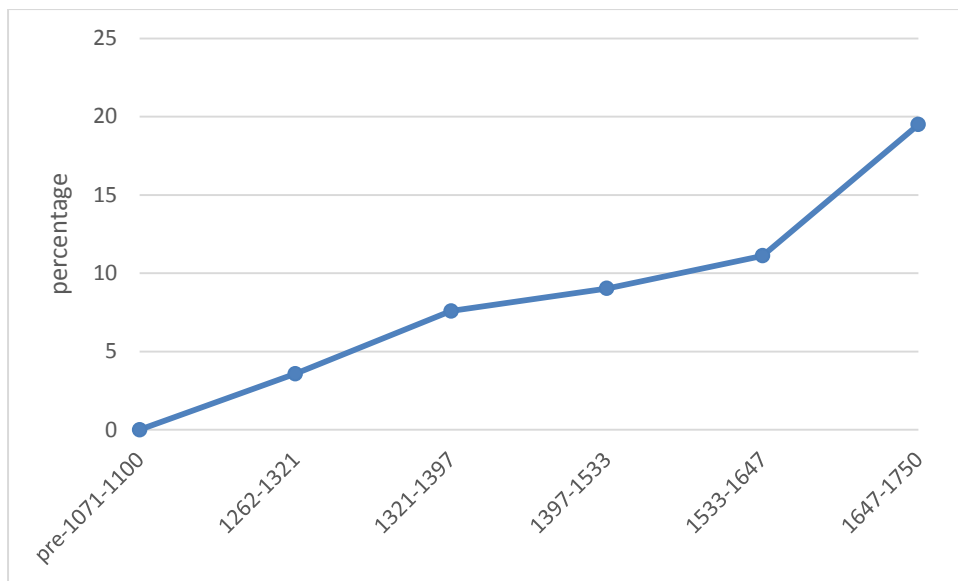


Figure 3 – the relative frequency of oysters over 70mm (the modern legal landing size) by phase.

Figures 4 and 5 provide further evidence of the general increase in oyster size through time, although only three statistical differences were detected between consecutive phases (Tables 8 and 9): (1) late 11th-century shells were generally smaller than more recent shells; (2) the oysters from phase 8 (1533-1647) were smaller in length than the oysters in the preceding two phases; and (3) the shells in the final phase of occupation (1647-1750) were significantly larger in both dimensions than in all preceding phases. Measures of relative dispersal (Table 6) indicate that lengths became progressively more variable over time and that the widest range of oyster heights and lengths was observed in the last two phases of occupation. There was a statistically-significant increase in coefficients of variation (CV) for maximum heights and lengths in consecutive phases from Phase 6 (1321-1397) onwards (Table 7). The fact that the CVs were considerably higher than ten testifies to heterogeneity within the samples in terms of age and possibly intra-taxonomic differences reflective of multiple sources (Simpson et al. 2003, 91).

		pre-1071-1100	1262-1321	1321-1397	1397-1533	1533-1647	1647-1750
	N	21	56	2177	731	621	436
Hmax	Min	27	32	19	20	17	25
	Max	63	81	85	88	117	100
	Mean	51.05	54.25	56.16	55.91	55.58	59.33
	SD	9.51	8.60	9.06	9.92	12.57	11.73
	CV	18.62	15.85	16.13	17.74	22.62	19.77
Lmax	Min	27	25	18	15	16	20
	Max	55	69	86	89	91	93
	Mean	44.00	47.95	49.31	49.05	47.56	52.70
	SD	7.66	8.48	8.83	9.67	11.35	12.04
	CV	17.41	17.68	17.91	19.72	23.87	22.84

Table 6: summary statistics for the oyster shell measurements from Dudley Castle.

	pre-1071-1100	1262-1321	1321-1397	1397-1533	1533-1647	1647-1750
pre-1071-1100		0.8260	0.7721	0.8196	0.2650	0.3037
1262-1321	0.2563		0.8252	0.4410	0.2741	0.0421
1321-1397	0.2560	0.9206		0.0015	0.0000	0.0000
1397-1533	0.5559	0.4905	0.0042		0.0000	0.0003
1533-1647	0.5933	0.0214	0.0000	0.0000		0.6481
1647-1750	0.8700	0.0664	0.0000	0.0096	0.0732	

Table 7 –Two-tailed Fligner-Kileen test for homogeneity of group variances: Hmax is represented in the upper register; Lmax is represented in the lower register. Shaded boxes indicate statistical significance ($p < 0.05$).

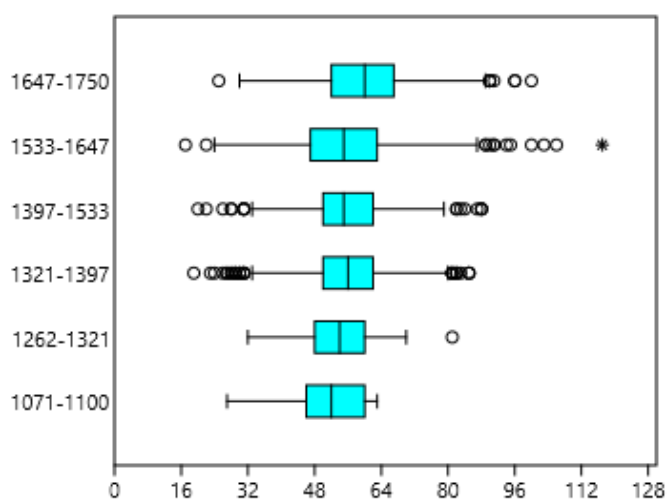


Figure 4 – Maximum height of oyster shells by phase

	pre-1071-1100	1262-1321	1321-1397	1397-1533	1533-1647	1647-1750
pre-1071-1100		500.5	16700	5858	5283	2700
1262-1321	0.3191		53030	18460	16510	8695
1321-1397	0.0332	0.0958		775600	637700	391300
1397-1533	0.0640	0.2193	0.3049		218800	129300
1533-1647	0.1388	0.5307	0.0309	0.2535		108700
1647-1750	0.0015	0.0004	0.0000	0.0000	0.0000	

Table 8 – Mann-Whitney pairwise comparison of maximum height by phase: U-values in the upper register; *p*-values in the lower register. Shaded boxes indicate statistical significance ($p < 0.05$).

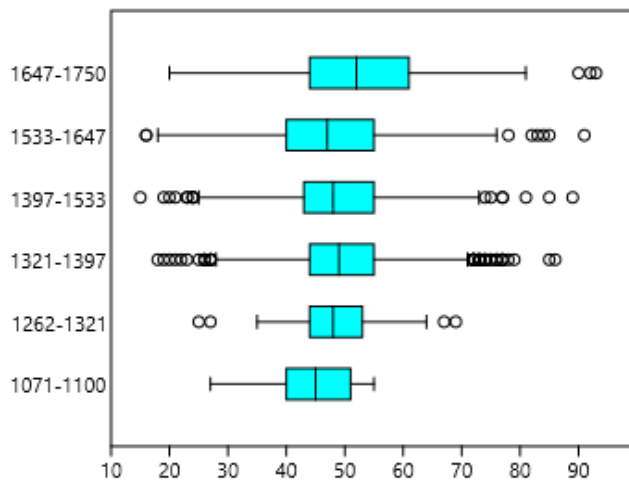


Figure 5 – Maximum length of oyster shells by phase

	pre-1071-1100	1262-1321	1321-1397	1397-1533	1533-1647	1647-1750
pre-1071-1100		434.5	15500	5369	5442	2503
1262-1321	0.0797		56800	19430	16350	9083
1321-1397	0.0105	0.3874		783600	596100	384700
1397-1533	0.0187	0.5262	0.5361		204300	128000
1533-1647	0.1970	0.4599	0.0000	0.0015		99900
1647-1750	0.0004	0.0018	0.0000	0.0000	0.0000	

Table 9 – Mann-Whitney pairwise comparison of maximum length by phase: U-values in the upper register; *p*-values in the lower register. Shaded boxes indicate statistical significance ($p < 0.05$).

Figure 6 presents the visual analysis of shape in the Dudley Castle oysters by phase. Irregular shells were recorded infrequently, while round shells (exhibiting a similar height and length) consistently comprised two-thirds of the dataset in each phase. Chronological differences are statistically significant ($\chi^2=25.67$, $df=10$, $p=0.004$) and probably driven by the gradual increase in the frequency of elongate shells relative to round shells from the 11th until the 14th century. The highest frequency of elongate shells was recovered in phase 8 (1533-1647) and this probably explains the statistically-significant difference observed in length measurements in this phase (Table 9).

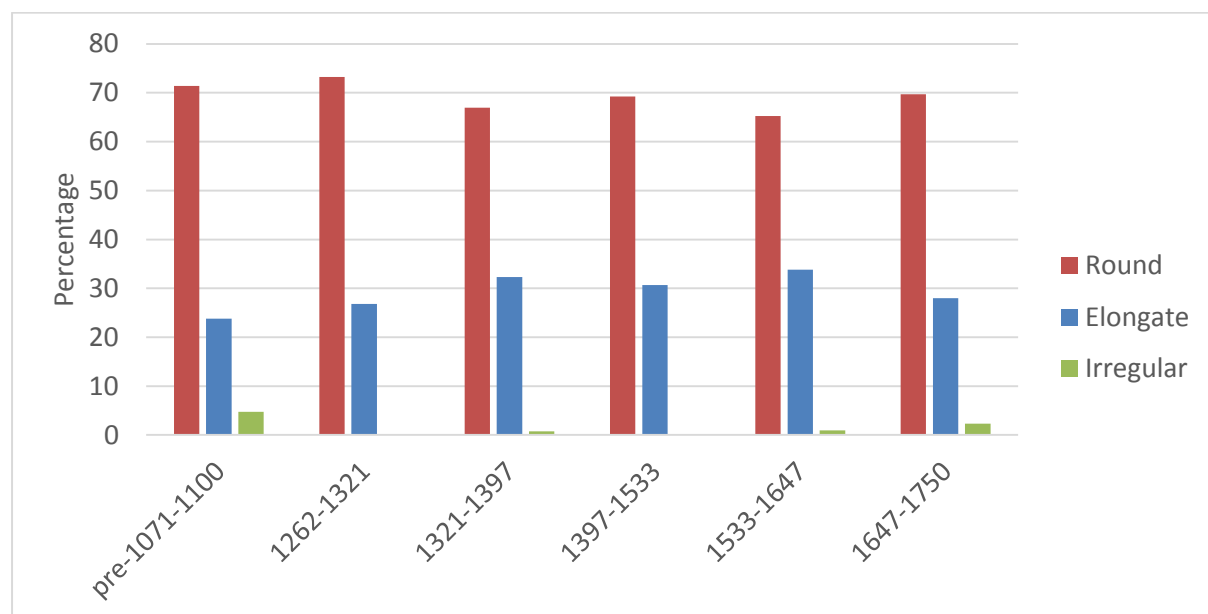


Figure 6 – shape of left valve oysters by phase

Chambering was generally infrequent at Dudley Castle (Figure 6), although there was a notable increase in frequency in the final phase of occupation (1647-1750), more than double the percentage observed in previous phases. Chalky deposits were more common than chambering but followed the same pattern, potentially supporting a shared causality (Table 4).

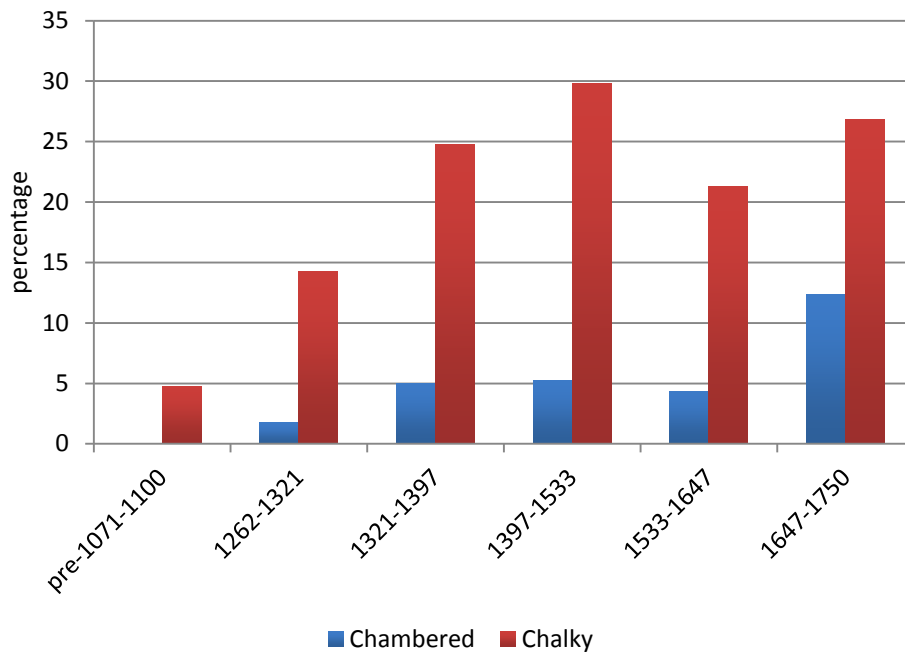


Figure 7 – percentage of left valve oysters exhibiting chambering and chalkiness by phase

Clumping was typically observed in 10-15% of specimens (Figure 8). There were no consistent changes through time; however, a notable increase in proportion of clumped shells was recorded in the final phase of occupation (1647-1750).

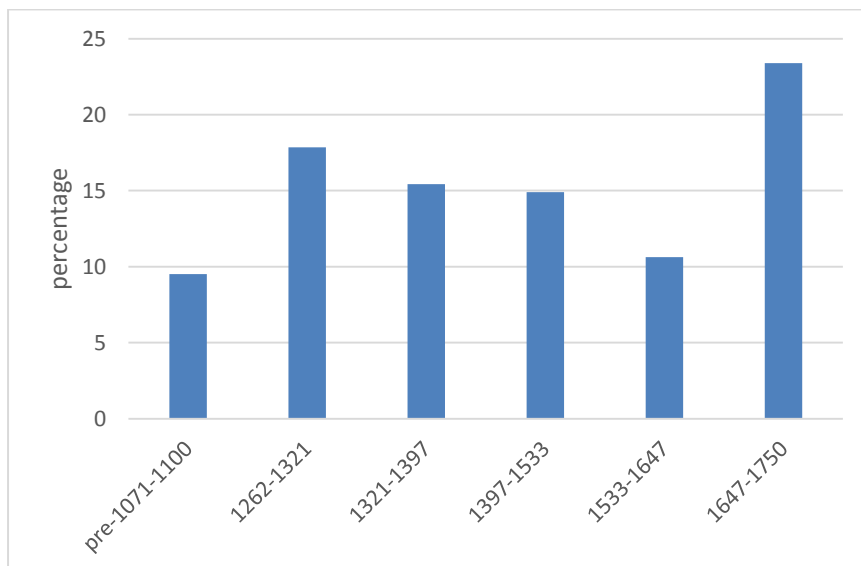


Figure 8 – percentage of clumped oysters by phase

Epibiont activity in the Dudley Castle assemblage is summarised in Table 10. Approximately three-quarters of the oysters were free from infestation and this was broadly consistent

through time, except for the final phase of occupation (1647-1750), where a higher proportion of shells were affected. Much of the damage evidenced in the oyster shells was caused by marine polychaete worms, especially *Polydora ciliata*. This worm prefers hard, sandy or clay substrata in shallow, warm waters (Hancock 1974:21; Knight-Jones et al. 2017, 254). Following a notable decline in relative abundance after phase 5 (1262-1321), an increasing proportion of oysters exhibited *P. ciliata* infestation from the later 14th century until the mid-18th century; the highest frequency occurred in the final phase of occupation (1647-1750). The low abundance of *P. hoplura* may partly reflect the fact that this worm is less widespread than *P. ciliata*. However, it could also testify to the origin of the oysters, since it thrives in warm, still, soft substrata in areas such as estuaries and inlets, especially in south-west England (Hancock 1974:21; Knight-Jones et al. 2017, 254).

L

Context	Phase	MW	ML	LVMD	Polydora ciliata	Polydora hoplura	Cliona celata	Calcareous tubes	Barnacles	Polyzoa	Bore holes	Sand tubes	
					i	ii	iii	iv	v	vi	vii	viii	
7581	1	48	36	48									0
1188	2	61	46	61									0
1196	2	49	49	49									0

Table 10 – number and percentage of epibiont activity by phase.

Other epibionts affected fewer than 10% of oyster shells. The only notable trend was that sand tubes, *Cliona celata*, bryozoa and barnacles were most abundant in the final phase of occupation (1647-1750). In terms of habitats, sand tubes are made and occupied by worms of the family Sabellidae in the wet sand at the lowest shore levels, normally underwater (Winder 1992; Knight-Jones et al. 2017). Some species can be traced to the warmer climates of the southern and western coasts of England, although others are present in all British coasts (Winder 2011; Knight-Jones et al. 2017). *C. celata* is a boring sponge found in sublittoral waters across the British coast, but prevalent in southern and western England in wave-exposed open shores and sheltered estuaries, however it is not tolerant of low salinity so in general it is rare among estuarine oyster stocks (Yonge 1960: 126; Hancock 1974:21; Goodwin et al. 2017: 46-8). It most commonly affects older oysters (Yonge 1960: 126). Bryozoans are colony-forming invertebrates which form a mesh-like layer on the exterior of

the shell and are present in a wide range of coasts. Unfortunately, the bryozoans in the Dudley Castle assemblage were too damaged to permit identification to taxon, which is dependent on skeletal characteristics such as the morphology of the frontal wall and presence or absence of spines (Law 2013).

To identify trends within the distribution of epibionts across phases, the total counts of each type were combined using detrended correspondence analysis (Figure 10). To counter the potential effect of the much higher numbers of shells in later phases, epibiont counts were scaled logarithmically in Base 2. The analysis did not account for much of the variation (c. 7% on Axis 1 (eigenvalue = 0.0735) and c. 2% on Axis 2 (eigenvalue = 0.0215)); however, earlier phases are clearly separated from the last three phases, and from each other. This seems to highlight a diversification of sources of exploitation, especially between 5 (1262-1321) and 6 (1321-1397) and again between 6 (1321-1397) and 7 (1397-1533): the position on the plot of *Polydora hoplura*, most common on south-western shores, is striking in this context. The position of phases 1 and 2, which were combined for this analysis is probably a function of the small sample size.

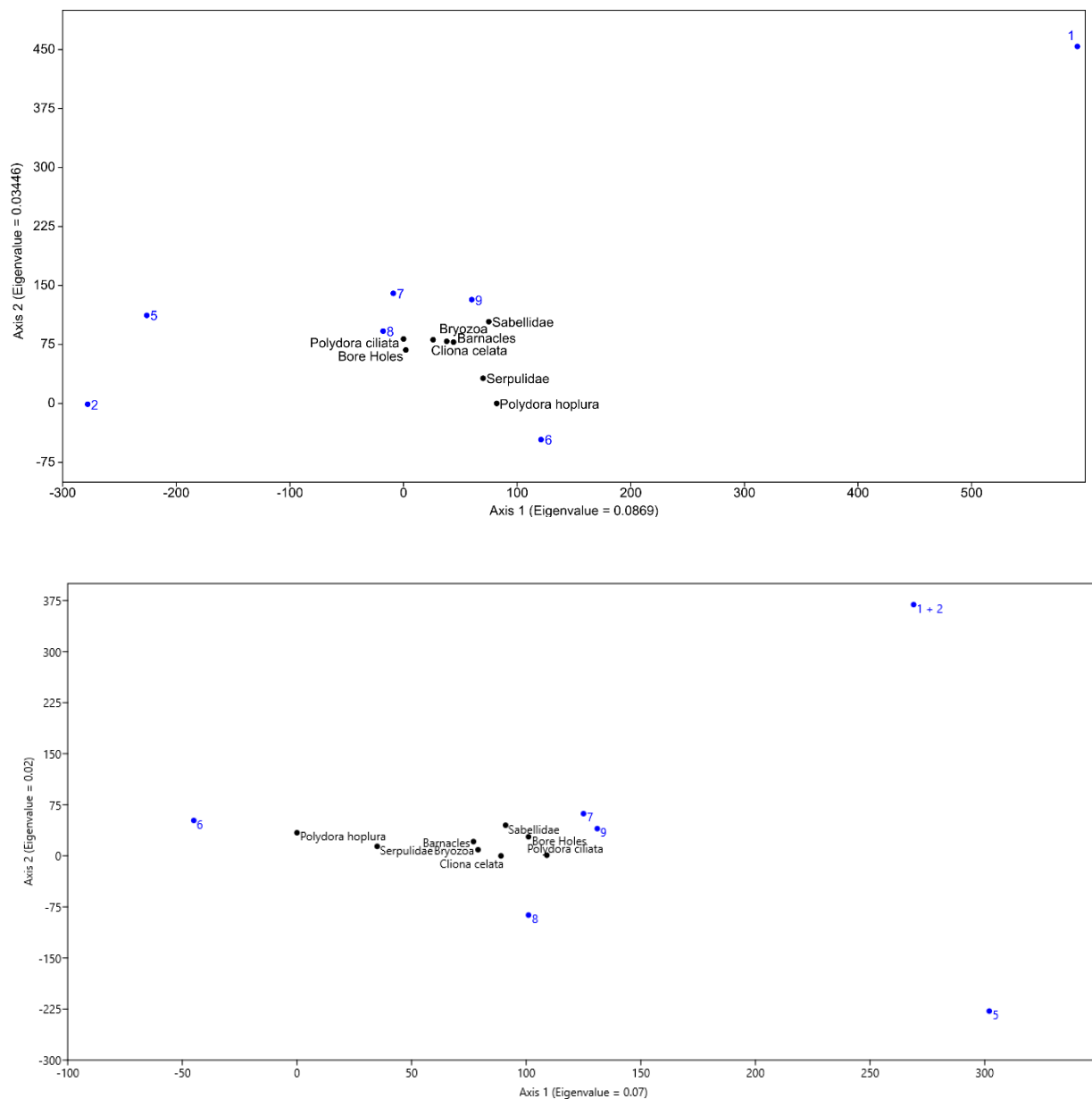


Figure 10 – Detrended correspondence analysis of epibiont evidence per phase, coded into a logarithmic scale (Base 2). Blue dots represent archaeological phases.

Discussion

A summary of the key changes in the Dudley Castle oyster assemblage is provided in Table 11 and forms the basis for the following discussion.

Phase	Characteristics of oyster assemblage
pre-1071-1100	A small assemblage, with the smallest sized oysters. The oysters were relatively more round and irregular. Except for sand tubes and boreholes there was a low frequency of epibionts. The oysters in this phase had the lowest frequency of chambering and showed no evidence of clumping or prising.
1262-1321	The oysters were larger and the shells relatively more elongate, although the majority remained rounded. There were higher frequencies of <i>P. ciliata</i> and barnacles but no bryozoans; <i>P. hoplura</i> first appears. Chambering and clumping increased in frequency.
1321-1397	This phase contained the greatest relative and absolute number of oysters. The shells were consistent in size with phase 5 (1262-1321), although they were relatively more elongate, and a higher proportion were over 70mm. The oysters exhibited the lowest frequency of <i>P. ciliata</i> , <i>C. celata</i> , calcareous tubes and sand tubes; bryozoans appeared for the first time. An increased frequency of chambering was observed.
1397-1533	The relative proportion of oysters declined to 80% due to the presence of mussels. There were no statistically-significant changes in the size or shape of oysters, although the proportion of oysters >70mm continued to increase. An increase in <i>P. ciliata</i> and bryozoa infestation was observed. This phase contained the highest frequency of prising.
1533-1647	The relative proportion of oysters remained below 80% due to the presence of mussels and whelks. Shells were relatively more elongate, and this was reflected in a statistically-significant decrease in Lmax. Oysters >70mm continued to increase. The frequency of <i>P. ciliata</i> and bryozoa infestation increased further.
1647-1750	Shells in this phase were larger than in all preceding phases and relatively rounder. The highest frequency of <i>P. ciliata</i> , <i>C. celata</i> , sand tubes, bryozoans and barnacles were all recorded in this phase, along with the highest frequency of clumping and chambering.

Table 11 – Summary of the key changes in the marine mollusc assemblage at Dudley Castle by phase.

Dietary contribution

The abundance of oyster shells at Dudley Castle demonstrates that they formed an important dietary component throughout the medieval and early modern periods. Because of their limited ‘shelf-life’ and the logistical demands of transporting oysters to an inland site sufficiently quickly to minimise spoiling, they would have been a “perishable luxury” (Campbell 2010, 185). The numerical supremacy of oysters compared with other marine

molluscs (Table 3), reflects the existence of a hierarchy of preferred shellfish apparent in early modern sources (e.g. Moffett 1655). Oysters were always described as the best and mussels were least favoured. Cockles were discussed in more detail during the 17th century and compared favourably against mussels but they were never rated as good or better than oysters. Whelks were discussed less commonly: comments on them were primarily made in the later 17th century but were positive, albeit piling into comparison with oysters.

The numbers of imported oysters increased substantially in phase 6 (1321-1397), which is notable as it mirrors other changes in consumption habits evidenced in the animal bone assemblage at Dudley Castle. This includes: a sharp decline in the abundance of domestic pigs (*Sus scrofa domesticus* Erxleben, 1777) relative to other domestic mammals; a shift in the relative abundance of deer away from red deer (*Cervus elaphus* L., 1758) and roe deer (*Capreolus capreolus* L., 1758) and towards fallow deer (*Dama dama* L., 1758); and an increased diversity of wild bird taxa (Thomas 2005). Many of the changes observed reflect social, environmental and economic changes precipitated by the demographic decline associated with the Black Death (Fisher and Thomas 2012; Hamilton and Thomas 2012; Thomas 2005a, 2005b, 2006, 2007a, 2007b, 2008). Of particular relevance, Thomas (2007a) identified diversification of diet amongst the medieval aristocracy in this period, to maintain social boundaries through consumption practices in the face of increased incomes and higher standards of living amongst the peasantry. The greater relative abundance of oysters may provide an additional signal of this trend, supporting evidence for which is provided at Carisbrooke Castle, Isle of Wight (Campbell 2013), and Wigmore Castle, Herefordshire (Campbell 2015), where the numbers of marine molluscs increased in the 13th-15th century and mid-14th-15th centuries respectively.

The fact that the relative abundance of oysters dropped in the 15th-mid-17th centuries at Dudley Castle but then increased in the mid-17th-mid-18th centuries also mirrors the trends observed at Wigmore Castle, where over a quarter of the entire shellfish assemblage from the site was recovered from deposits dating to the period of the English Civil War (Campbell 2015: 177). This pattern could reflect shifting attitudes towards oysters. Butts (1599, i101) advised that oysters gave little nourishment, were somewhat difficult to digest and would increase phlegm in the stomach which would likely create obstructions and illness. Later

authors such as Venner (1620, 81) maintain this position describing oysters as giving “a light, salt, and phlegmatick nourishment” that was “very hurtfull vnto them that be phlegmatick”.

During the mid-17th century warnings about the impact of oysters on the phlegmatic were toned down. Hart (1633, 91) argued that they could be consumed by all ages, sexes and constitutions if corrected with pepper, vinegar, onions and a good claret wine. Authors such as Moffett (1655, 162) openly challenged Galen’s warnings that oysters caused excess phlegm stating that had he sampled English oysters then “no doubt he would have given oysters a better censure”. By the end of the 17th century the caveats around oysters were dropped and they were being recommended as seafood that excelled “for wholesomeness, pleasantness, and easiness of digestion” (Maynwaringe 1683, 67).

A slight decrease in the abundance of oysters relative to mussels occurred from the 15th century until the mid-17th century; while a higher frequency of whelks was recorded in the mid-16th to mid-17th century (Table 3). These trends mirror patterns observed at elite and non-elite sites elsewhere in the country (e.g. Buglass 2010: 129; Campbell 2013: 7; 2015: 177), and likely reflect prevailing attitudes to shellfish. At the start of the 16th century all shellfish, except for oysters, were described by Elyot (1539, i21) as “makynge ylle iuyce” [making ill ice]. A shift in opinions can be detected in the first half of the 17th century, however, when authors such as Cogan (1636, 169) explained that cockles could be “eaten without danger”, whilst Moffett (1655, 159) suggested that some mussels could be eaten safely.

The available evidence suggests that most of the oyster shells were used as ingredients, shucked from their shells, rather than served raw in their liquor within the left valve. If the oysters were served raw, differences in disposal pattern between left and right valves would be expected. The low incidence of prising and the selection of very small oysters and unsightly shells exhibiting widespread epibiont infestation (especially *P. ciliata*), are consistent with this interpretation (Tables 6 and 10). It is unclear whether the preference for shucked oysters reflects medieval and early modern culinary tastes, or an attempt to minimise food poisoning resulting from transportation to a land-locked site. Irrespective, it is worth noting that the *Forme of Cury*, a 14th-century collection of recipes, records numerous recipes for which oysters are shucked from their shells (Pegge 1791, XX.VI.I and

XX.VI.III). This preference for shucked oysters continues in the 17th century: Cogan (1636, 168) advised that oysters were used in “brothes, boyled, or roasted upon coles” and warned that if eaten raw they required “good wine to be drunke after them, to helpe digestion”.

Sourcing the oysters

One of the ambitions of this study was to identify the source of the oysters that were being supplied to Dudley Castle and track how these changed through time. The habitat preferences of epibionts offer some potential; unfortunately, the evidence at Dudley Castle was equivocal. Firstly, the most abundant epibiont (*P. ciliata*) is widely distributed (Hancock 1974: 21) and therefore of limited value in narrowing down the source of the oysters. Secondly, while two of the epibionts more commonly associated with the warmer waters of south-western Britain were not abundant (*P. hoplura* and *C. celata*: Goodwin et al. 2017: 46-8; Hancock 1971: 21; Haywood and Ryland 1990: 229; Knight-Jones et al. 2017: 254), they exhibited opposing trends through time: the relative abundance of *P. hoplura* decreases into the later 14th century before increasing into the mid-18th century, while *C. celata* exhibited the reverse trend (Table 10). Nevertheless, comparisons with frequencies of epibionts at other sites provide some meaningful insights. At Carisbrooke Castle, Isle of Wight, for example, *P. hoplura* infestation was recorded in 41% of left valves, while *P. ciliata* was only present in 5% (Campbell 2013: 17); moreover, *P. hoplura* was typically recorded in frequencies of c. 15%-25% in modern and archaeological oyster samples from Poole, Dorset (Winder 1997: 197), 11-28% at Okehampton Castle, Devon (Backway 1982). At Ludgershall Castle in Wiltshire, however, which was likely provisioned from the Solent or Poole harbour, *P. ciliata* predominated in all sectors of the site, with between 11-18% of shells affected, whereas *P. hoplura* affected between 4-14% of shells (Winder 1983: 7). Taken together, the evidence suggests that the south-west coast of England was an unlikely source of the oysters supplied to Dudley Castle.

When combined using multivariate methods, differences in epibiont manifestation emerge (Figure 10) between phases 5 (1262-1321) and 6 (1321-1397) and again between phases 6 (1321-1397) and 7 (1397-1533). This seems to be primarily driven by a temporary decrease in *P. ciliata* relative to *P. hoplura* and *C. celata* in phase 6 (Figure 9). The changes in the relative abundance of epibionts in phase 6 (1321-1397) might testify to altered supply networks that

arose because of a shift in tenancy at Dudley Castle. In 1322 the de Sutton family inherited the barony of Dudley, after John de Somery died without heir. John de Sutton inherited the estate through marriage; however, many of the manors that belonged to the estate were split between the de Suttons, John de Somery's wife and his second sister (Hemingway 2006: 47). Consequently, the barony of Dudley lost most of its Buckinghamshire manors as well as a number in the West Midlands, particularly in Worcestershire and Warwickshire. This was offset by the acquisition of manors in Cheshire, Rutland, Derbyshire, Bedfordshire, Nottinghamshire, Oxfordshire, Essex and Wales. Alternatively, or perhaps additionally, supply chains might have been affected by depopulation and economic upheaval in the wake of the Black Death (1348-1352); although clearly, this did not affect the number of oysters arriving to the site (Table 3). The fact that the decline in the relative abundance of *P. ciliata* seems to have been temporary (Figure 9) lends some support to this hypothesis, especially given the subsequent continuity of ownership by the de Sutton family until 1533.

Oyster management strategies

While the regional source(s) of the Dudley Castle oysters remains elusive, changes to the size, shape and appearance of the shells can be used to cast light on the environment of the beds and changing management patterns over time. The predominance of round oysters throughout all phases of occupation suggest that they primarily formed in low-energy environments where there were soft, muddy beds (Campbell 2010: 183-4), such as in harbours and bays. Intriguingly, Moffett (1655, 161) described the best oysters as those that were "thick, little and round sheld".

The gradual increase in bryozoa over time hints at increased exploitation of harbour habitats over time: in a survey of modern oysters from the area of Poole in Dorset, Winder (1997) found that bryozoans were more prevalent on shells collected from the harbour than the bay. Law (2013) suggests that this may be due to the wider availability of hard substrates on which the colonies can settle in the harbour area. The increased relative abundance of elongated shells, peaking in the mid-16th-mid-17th century, might also testify to increased exploitation of higher-energy environments, but these remained a minority (Campbell 2010: 184; Winder 1992: 196-7).

The increase in chambering in Phase 9 (1647-1750) might be suggestive of the oysters having been moved in life. In 1677, Bishop Thomas Sprat (1677, 308-9) reported that oysters in the Colchester area would be transplanted from the offshore grounds where they were raised to beds in river channels to mature, and that some would be moved to special pits in high in the tidal range of saltmarshes, which were “overflowed only at Spring tides”. This latter group were known as green oysters, on account of the distinctive algal mat that developed on their shells. The effect of this kind of management was to alter the taste of the oyster meat, specifically rendering it less salty (Sprat 1677: 309). This kind of practice might be expected to induce physiological changes in the shells such as chambering. Unfortunately, the evidence here seems equivocal: Phase 9 is also associated with some of the highest incidences of boring by *Cliona celata*, which is unlikely to flourish among green oyster pits away from higher salinity waters. In fact, at the level of records of individual left valves, with three exceptions the two phenomena (chambering and *Cliona* boring) are mutually exclusive in Phase 9. A likely scenario then is that Phase 9 oysters were supplied from a range of sources.

When the evidence summarised in Table 11 is considered against Winder’s (2017) models of intensifying oyster bed management several trends emerge. The broad range of measurements, continued presence of ‘small oysters’ (Campbell 2015: 183), low frequency of epibiont damage (except for *P. ciliata* infestation: Table 10) and the persistence of clumping indicate that natural beds were exploited throughout the 700-year occupation. There is certainly no evidence for the deliberate management of oyster beds and full-scale marketing and cultivation until the seventeenth century (Table 1: models 4 and 5).

In the 11th century, the low quantities of oyster shell, their relatively small size and the highest frequency of irregular shells, suggest exploitation of “natural inter-tidal beds” (Table 1: model 1). A clear change in oyster management occurred in phase 5 (1262-1321), indicative of “dredging inshore shallow sub-littoral natural beds of oysters” (model 2). This is supported by the larger size of the shells, reflecting the fact that their growth was not “interrupted by periodic exposure to air” (Winder 2017: 247), and a lower coefficient of variation for Hmax, potentially indicating the use of a dredge net.

While there may have been shifts in the loci of supply in phase 6 (1321-1397) judging by the different patterns of *Polydora* sp. infestation, continuity in size and shape suggest that management practices were similar until the first half of the 16th century. It merits observation that the composition of the animal bone assemblage in terms of taxonomic representation, size of domestic animals and exploitation patterns, was also broadly consistent between phases 6 (1321-1397) and 7 (1397-1533) (Thomas 2005), suggesting stability of provisioning arrangements at the site.

There are hints that some deeper off-shore sub-littoral oyster beds were exploited in phase 8 (1533-1647) (i.e. model 3: Table 1), evidenced by an increased proportion of other molluscan taxa (mussels and whelks) and elongated oyster shells. However, there is no reduction in intensity of epibiont damage, which might be expected if more oysters derived from nutrient-poor deeper water (Winder 2017: 248).

Profound differences were apparent in the oyster assemblage in the final phase of occupation (1647-1750). The whelks and mussels disappear, the oyster shells are significantly larger (but also more variable in size) and the frequency of clumping, chambering and epibionts is higher than in all previous phases. There is evidence suggestive of the exploitation of inshore shallow sub-littoral oyster beds, although perhaps without the use of a dredge net (Winder 2017: 247), and perhaps also for translocation of oysters to creeks or pits in saltmarsh. The fact that more shells over 70mm were recovered in this phase suggest that the intensity of exploitation did not compromise the sustainability of the oyster beds and/or that the same beds were not being repeatedly harvested.

Conclusions

Analysis of over 4,000 complete left oyster valves from later medieval and post-medieval Dudley Castle reveals the changing role of this perishable luxury on a high-status, inland site. Throughout the occupation, it seems that oysters were used as ingredients rather than served raw in the shell. A greater reliance on oyster consumption is apparent in the later 14th century, perhaps reflecting a shift towards a more diverse diet amongst the aristocracy in the wake of the Black Death. An increased preference for mussels and whelks is evidenced for the late medieval and Tudor period. The fact that these trends are mirrored at other sites and in contemporary written sources, are indicative of changing dietary fashions.

Overall, it is likely that natural beds were exploited throughout the medieval and early modern periods at Dudley Castle. Natural populations are implied by a wide range of sizes and age, irregularity in shell shape, and the presence of attached oysters including spat, whereas shells from re-laid or cultivated populations tend to show a narrowing of size range, greater regularity in shape, an absence of attached oysters (especially spat), and possibly cultch (deliberately deposited spat-collection material, or an imprint of it, at the heel of the shell (Winder 2017, 246-7).

A shift in harvesting strategy occurred between the 11th and 13th century, from sporadic collection of oysters from the intertidal zone (model 1) to the dredging of inshore sub-littoral oyster beds (model 2). There are hints towards the exploitation of deeper shore beds in the mid-16th-mid-17th century (model 3), but this did not continue into the 17th and 18th century. There is no evidence to suggest that the sustainability of the beds was affected by the intensity of exploitation, however oyster beds were afforded legal protection at this time (Spratt 1677: 309).

Changes in the shape, size and appearance of the oyster shells suggest the source locales from which the oysters derived changed through time. A notable shift occurred in the 14th century, which could reflect changes in supply brought about by altered tenancy at Dudley Castle and/or disruptions to trade brought about by the Black Death.

While the size and chronological precision of the *Ostrea edulis* assemblage from Dudley Castle has made it possible to identify broad trends in oyster exploitation using macroscopic methods, details concerning the precise origin of the oyster beds remain frustratingly elusive. Advances in sclerochronological and sclerochemical methods provide hope for refined deductions concerning the origin and exploitation of oysters at Dudley Castle in the future. For example, analysis of stable carbon and oxygen isotope ratios could potentially distinguish if estuarine or fully marine shells were present (Reimer 2004), while other chemical signatures in the shells (Thomas 2015a, 2015b) might make it possible to source locales more specifically, rather than just 'estuarine' or 'fully marine'. The season of procurement and consumption could also be determined using the methods of Milner (2001). Such research must be underpinned by macroscopic analysis however, which we

offer as the first step forward to a greater understanding of medieval and early modern oyster exploitation in England.

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