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Mesolithic shellfish exploitation in SW Italy: seasonal evidence from the oxygen isotopic composition of *Osilinus turbinatus* shells

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ABSTRACT

Oxygen isotope analyses were carried out on the topshell *Osilinus turbinatus* from archaeological sites with the aim to investigate the temporal exploitation patterns by Mesolithic groups inhabiting coastal caves in SW Italy. In order to assess the present day *O. turbinatus* intra-annual $\delta^{18}O$ variability, living specimens were collected monthly at Marina di Camerota (SW Italian peninsula). Their shell-edges were analysed and the seasonal results were compared with archaeozoological material. Our findings show that Mesolithic *O. turbinatus* exploitation was carried out almost exclusively during the colder and intermediary seasons (e.g. autumn, winter, spring), with very sporadic harvesting during the warmer seasons. Results suggest a possible regional exploitation pattern of *O. turbinatus* by Mesolithic groups inhabiting this region.

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1. Introduction

The Mesolithic subsistence system along the SW Italian peninsula and Sicily (from ca. 10 to 7 ka BP; Martini, 1993; Lo Vetro and Martini, in press) involved a broad spectrum of terrestrial and marine resources, including large mammals, birds, fish and molluscs (e.g. Mussi, 2001). Among fauna remains shellfish are a very common archaeozoological constituent. The most frequent species belongs to the genera *Patella* and *Osilinus*, both living in the intertidal rock shores. On overall, shellfish remains rarely forms many abundant accumulations in archaeological sites and are often associated to mammals, fish and land snail shell remains (Bonuccelli, 1971; Durante and Settepassi, 1972; Cassoli and Tagliacozzo, 1982; Compagnoni, 1991; Tagliacozzo, 1993; Wilkens, 1993; Martini et al., 2007a,b; Colonese, in press). The low productivity of the intertidal zones of the Mediterranean Sea (e.g. Bailey and Flemming, 2008; Fa, 2008), suggests shellfish played only a minor role in the diet of Mesolithic groups from these regions (e.g. Bailey and Milner, 2002/3; Guixé et al., 2006; Fa, 2008). Therefore probably shellfish were gathered by SW Italian Mesolithic hunter-gatherers as only part of their diet which was probably governed by the availability and exploitation of primary sources, such as larger mammals (e.g. Martini, 1993). Nevertheless, some Mesolithic sites have intriguingly provided very abundant shellfish whereas other faunal (e.g. mammals) and artefact remains were extremely poor (e.g. Cala Mancina; Colonese, in press). This would indicate that in some circumstances intertidal molluscs might have played a most important position in the diet.

Although qualitative and/or quantitative data on shellfish exploitation are available for the Mesolithic sites of these regions (e.g. Martini et al., 2007a), comprehensive information about their temporal exploitation patterns is scarce (Mannino et al., 2007) and emphasize the necessity of more regional data. A proven approach to investigate temporal patterns of prehistoric shellfish exploitation is the analysis of the oxygen isotopic ratio ($\delta^{18}O$) of the latest growth increment of mollusc shells (e.g. Kennett and Voorhies, 1996; Quitmyer et al., 1997; Mannino et al., 2003, 2007; Jones et al., 2008). This is based on the fact that the $\delta^{18}O$ of aquatic biogenic carbonate, such as the aragonitic and calcitic shells secreted by molluscs, is controlled by the $\delta^{18}O$ composition of the ambient

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water and by the temperature at which the carbonate secretion takes place (e.g. Wefer and Berger, 1991). Therefore, by establishing the seasonal variations of the molluscs shells $\delta^{18}O$ relative to the seawater temperature, the season in which the molluscs were harvested can be estimated.

This paper investigates the temporal pattern of *Osilinus turbinatus* (von Born, 1778) exploitation by Mesolithic groups inhabiting the coastal areas of SW Italy. The main objective is to establish if the abundant *O. turbinatus* remains from selected Mesolithic coastal sites are associated with seasonal or all-year-round intertidal exploitation. To this means we analysed the $\delta^{18}O$ composition of this topshell from both living and Mesolithic specimens. *O. turbinatus* was selected because it was one of the most exploited intertidal species in SW Italy since the Late Glacial (e.g. Compagnoni, 1991; Colonese and Wilkens, 2005). Other species are also abundant (e.g. *Patella caerulea*; Wilkens 1993; Colonese, in press) and may occur together to *O. turbinatus* in intertidal rock shore environments, therefore it is probable that the gathering periods of *O. turbinatus* might be the same of the other intertidal species.

1.1. Archaeological and environmental setting

SW Italy, including Sicily, has a typical Mediterranean climate, with warm to hot dry summers and mild wet winters (Lionello et al., 2006). Mean annual temperature in the coastal zone is ca. 16 °C and annual amount of precipitation ranges from 600 to 1000 mm. The area has numerous coastal caves (e.g. Grotta della Serratura; Grotta dell'Uzzo, Grotta di Cala Mancina, Grotta d'Oriente, Grotta delle Uccerie), which were intensively inhabited during prehistoric times (Fig. 1). During the Early–Middle Holocene (from ca. 10 to 7 ka BP) these regions were occupied by Mesolithic human groups referred to as different lithic facies (Martini and Tozzi, 1996; Aranguren and Revedin, 1998; Lo Vetro and Martini, in press), resulting from the evolution of the different local Late Epigravettian traditions, sometimes combined with external Mesolithic influxes (e.g. Sauveterrian). Archaeological records from coastal sites of these regions testify to the ability of Mesolithic groups to exploit a broad spectrum of terrestrial and marine resources. Among the terrestrial fauna, larger mammals constituted

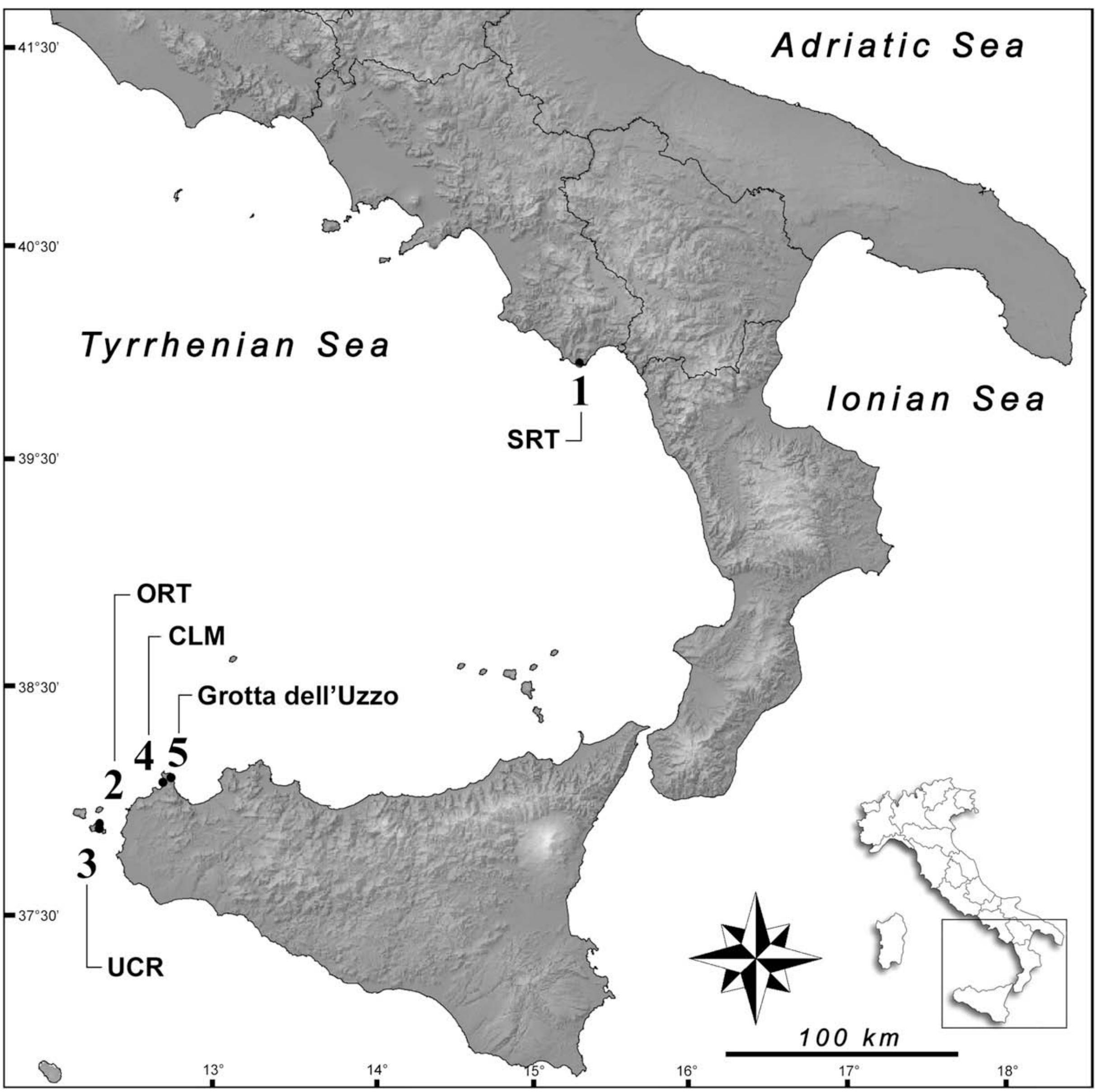

Fig. 1. Southern Italy and map location of SRT at Marina di Camerota (1), ORT (2) and UCR (3) at Favignana island, CLM (4) and Grotta dell'Uzzo (5) in the Capo San Vito.

Table 1
Sites, occupation phases and chronologies (BP).

Mesolithic sites	Layers	^{14}C year BP	Lab. code	^{14}C cal year BP (1σ)
Grotta della Serratura	4	10,000 ± 200	UtC-750	11,235–11,826
	5	9720 ± 60	Bnl-3568	11,095–11,227
	5	9790 ± 170	UtC-751	11,064–11,406
	6	9620 ± 60	Bnl-3569	11,005–11,024
	6	9770 ± 140	UtC-752	11,066–11,351
	7	9870 ± 70	Bnl-3570	11,206–11,346
	7	10,230 ± 130	UtC-753	11,699–12,178
Grotta di Cala Mancina	3C	9332 ± 65	LTL771A	10,485–10,606
Grotta d'Oriente	5A	7040 ± 55	LTL877A	7828–7940
	6C	8608 ± 65	LTL874A	9526–9632
Grotta delle Uccerie	2	7998 ± 80	LTL1514A	8761–9005
	3	8320 ± 85	LTL1515A	9252–9461

Radiocarbon dates were calibrated using CALIB program (Stuiver and Reimer, 1993).

a central position in the subsistence system (e.g. Mussi, 2001), with *Cervus elaphus* and *Sus scrofa* as most hunted species.

Among the marine resources shellfish and fish remains are the most common archaeozoological findings. Shellfish exploitation was mainly limited to species of the intertidal rock shores, with species of the genus *Patella* (e.g. *Patella caerulea*) and *Osilinus* (e.g. *Osilinus turbinatus*) being most common (Bonuccelli, 1971; Cassoli and Tagliacozzo, 1982, 1995; Durante and Settepassi, 1972; Compagnoni, 1991; Tagliacozzo, 1993; Wilkens, 1993; Martini et al., 2007a,b; Colonese, in press). Fish remains consist mainly in sea water species among which appear *Belone belone*, *Epinephelus guaza*, *Epinephelus caninus*, *Mugil* sp., *Dentex dentex*, *Sparus aurata*, etc., followed by sporadic evidence of reptiles and cetaceans (Cassoli and Tagliacozzo, 1982, 1995; Tagliacozzo 1993; Wilkens 1993).

1.2. The Mesolithic sites

Archaeological shells were collected from four Mesolithic sites (Fig. 1, Table 1); one is located in the SW of the Italian peninsula (1 – Grotta della Serratura) and three in NW Sicily (2 – Grotta d'Oriente, 3 – Grotta delle Uccerie, and 4 – Grotta di Cala Mancina). The Mesolithic stratigraphic succession in the caves shows distinct human occupation periods, alternated by sedimentary deposits with no cultural evidence (Martini, 1993; Martini et al., 2007b).

Grotta della Serratura (SRT) is a coastal cave situated 2 m about sea level (a.s.l.) at the foot of Monte Bulgheria, a hilly-mountainous range of the Southern Apennine, in the Cilento–Vallo di Diano Park (Campania). Two different almost contemporaneous Mesolithic facies are present in the cave succession (Martini, 1993). The first Mesolithic occupations span layers 7–6 and are associated with a local Sauveterrian aspect (from ca. 10.3 to 9.6 ka BP; Martini, 1993). Layers 5 and 4 are assigned to the undifferentiated Epipalaeolithic tradition (Martini, 1993). The genera *Patella* and *Osilinus* dominate the shellfish remains.

Grotta d'Oriente (ORT) and Grotta delle Uccerie (UCR) are coastal caves located in Favignana Island, in the Egadi Archipelago (Sicily). These caves open on the slope of the "Montagna Grossa", respectively at ca. 40 and 10 m a.s.l. (Martini et al., 2007b).

At ORT Mesolithic occupation phases are recorded in layers 6 and 5, with distinct episodes (Martini et al., in press; Lo Vetro and Martini, in press). The lithic production of layer 6 is assigned to a local Mesolithic facies in which some local-revised Sauveterrian influences are present (from ca. 9.5 to 8.5 ka BP; Lo Vetro and Martini, in press). Layer 5 provides cultural evidence related to the end of the local Mesolithic and the beginning of the Neolithic in Sicily. In this layer, devoid of pottery remains, lithic industry possesses some characters comparable to the Castelnovian model as detected also in the Early Neolithic levels from Uzzo Cave (Cassoli et al., 1987; Tusa, 1996). The Mesolithic succession provided very scarce large mammal remains, and in layer 5 rare domestic (*Ovis* vel *Capra*) items appears. Shellfish are relatively abundant, with the genera *Patella* and *Osilinus* being most common (Martini et al., in press).

At UCR the Mesolithic cave occupation is recorded in layers 2 and 3, with distinct episodes; nevertheless a cultural definition, in the frame of Mesolithic groups of this region, has yet not been established. However a high frequency of the genera *Patella* and *Osilinus* is recorded (Lo Vetro and Martini, in press).

Grotta di Cala Mancina (CLM) is located on Capo San Vito, Sicily. It consists of a small cave-rockshelter opening ca. 8 m a.s.l. Mesolithic cave occupations are shown in layers 2 and 3. According to the lithic assemblages, Mesolithic evidence of CLM are ascribed to

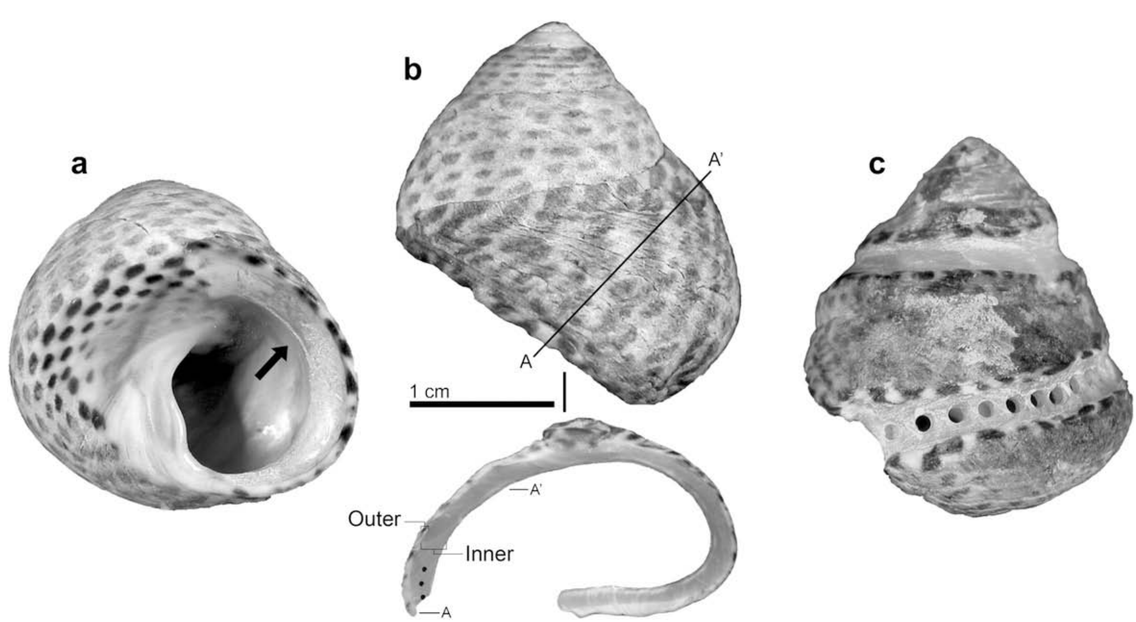

Fig. 2. (a) Shell-edge carbonate sampling in the inner shell layer of modern and (b) Mesolithic *Osilinus turbinatus*, and (c) sequential inner carbonate samples in Mesolithic shells from SRT (L5).

a local Epigravettian tradition (from ca. 9.5 to 8.5 year BP; Lo Vetro and Martini, in press) and again the genera *Patella* and *Osilinus* are dominant (Colonese, in press).

2. Materials and methods

The topshell *Osilinus turbinatus* is a common species living in the lower intertidal rocky shore along the Italian peninsula and islands (Torelli, 1982; Schifano, 1983; Schifano and Censi, 1983; Benedetti-Cecchi et al., 2003). It inhabits the biotope exposed to high wave energy with low salinity oscillations (Torelli, 1982; Schifano and Censi, 1983; Mannino et al., 2008). Regional studies have attested that *O. turbinatus* grows generally throughout the year (Regis, 1972; Schifano, 1983; Valli et al., 2003; Mannino et al., 2008). However growth rates exhibit strong variability in SW Italy, mostly related to seasonal environmental conditions and age (e.g. Schifano and Censi, 1983; Mannino et al., 2008). In NW Sicily maximum growths are recorded during autumn–winter, whereas minimum growths are observed in spring–summer, providing a mean annual growth rate ranging from ca. 17 to 19 mm. Elevate mortality have been observed in summer months probably due to the higher temperatures. As is already observed in other species (e.g. Schöne et al., 2007 and references therein), shell growth rate decrease with ontogenetic age (Mannino et al., 2008).

Table 2
Monthly $\delta^{18}O$ values (mean and standard deviation) of living *Osilinus turbinatus* collected monthly at Marina di Camerota.

	$\delta^{18}Os$‰ (V-PDB)	Mean $\delta^{18}Os$‰	SD	Measured SST (°C)	MFSTEP SST (°C)	SD	Calculated SST (°C)	MFSTEP SSS (PSU)
2004								
March	+2.2			14.0	14.0	0.3	15.1	37.8
April	+1.7	+1.7	0	15.7	15.4	0.3	17.3	37.7
April	+1.7			15.7	15.4		17.3	37.7
May	+1.6	+1.4	0.2	18.2	17.4	1.1	17.7	37.7
May	+1.4			18.2	17.4		18.6	37.7
May	+1.3			18.2	17.4		19.0	37.7
June	+0.9	+0.9	0.2	21.5	22.0	1.6	20.7	37.9
June	+0.7			21.5	22.0		21.6	37.9
June	+0.6			21.5	22.0		22.0	37.9
June	+1.1			21.5	22.0		19.9	37.9
June	+0.9			21.5	22.0		20.7	37.9
June	+0.9			21.5	22.0		20.7	37.9
June	+1.2			21.5	22.0		19.4	37.9
July	+0.3	+0.2	0.1	25.8	25.8	0.5	23.3	37.9
July	+0.1			25.8	25.8		24.2	37.9
August	+0.2	+0.1	0.1	26.5	26.5	0.4	23.8	37.9
August	−0.1			26.5	26.5		25.1	37.9
August	+0.0			26.5	26.5		24.6	37.9
September	+0.6	+0.5	0.1	24.5	25.1	1.1	22.0	37.9
September	+0.5			24.5	25.1		22.5	37.9
September	+0.3			24.5	25.1		23.3	37.9
September	+0.6			24.5	25.1		22.0	37.9
October	+0.8	+0.9	0.2	22.5	22.6	0.6	21.2	37.9
October	+1.1			22.5	22.6		19.9	37.9
October	+0.7			22.5	22.6		21.6	37.9
November	+0.9	+0.7	0.3	22.5	20.1	1.2	20.7	37.8
November	+0.6			22.5	20.1		22.0	37.8
November	+1.0			22.5	20.1		20.3	37.8
November	+0.4			22.5	20.1		22.9	37.8
November	+0.4			22.5	20.1		22.9	37.8
November	+0.6			22.5	20.1		22.0	37.8
November	+1.1			22.5	20.1		19.9	37.8
November	+0.8			22.5	20.1		21.2	37.8
November	+0.8			22.5	20.1		21.2	37.8
December	+1.3	+1.5	0.2	18.0	17.3	0.7	19.0	37.7
December	+1.7			18.0	17.3		17.3	37.7
December	+1.8			18.0	17.3		16.8	37.7
December	+1.6			18.0	17.3		17.7	37.7
December	+1.7			18.0	17.3		17.3	37.7
December	+1.3			18.0	17.3		19.0	37.7
December	+1.4			18.0	17.3		18.6	37.7
2005								
January	+1.8	+1.9	0.2	15.0	15.0	0.5	16.8	37.6
January	+1.8			15.0	15.0		16.8	37.6
January	+2.1			15.0	15.0		15.5	37.6
January	+2.2			15.0	15.0		15.1	37.6
January	+1.8			15.0	15.0		16.8	37.6
January	+1.9			15.0	15.0		16.4	37.6
February	+2.1			14.0	13.5	0.3	15.5	37.7
March	+1.8			14.0	13.9	0.7	16.8	37.7
Max.	+2.2			26.5	26.5		25.1	37.9
Min	−0.1			14.0	13.5		15.1	37.6
Mean	+1.1			20.3	19.8		19.8	37.8
σ	0.6			3.8	3.9		2.7	0.1
Range	2.3			12.5	13.0		10.0	0.3

Local SST from field measurements (measured SST) and from MFSTEP program (MFSTEP SST), including standard deviation (SD). The MFSTEP program also provides local monthly SSS. Also reported calculated SST using Grossman and Ku's (1983) equations on shell-edge $\delta^{18}O$ values.

Previous studies have found strong correlations between intra-annual shell $\delta^{18}O$ and the sea surface temperatures (SST) of coastal areas of NW Sicily (Schifano and Censi, 1983; Mannino et al., 2008), thus emphasizing their potential suitability for the study of seasonal shellfish exploitation in prehistoric sites (Mannino et al., 2007). Since the intra-annual pattern of shell $\delta^{18}O$ is not available for the SW Italian peninsula (e.g. where SRT is located) living specimens of *O. turbinatus* were collected monthly from March 2004 to March 2005 on the intertidal rocky shore in front of SRT (Marina di Camerota). These modern shells were used to assess the present intra-annual $\delta^{18}O$ trend for comparison with prehistoric specimens.

During each collection period, surface sea water temperature was measured. Mean monthly sea surface salinity (SSS) for this area was obtained from the European Project "Mediterranean ocean forecasting system: toward environmental predictions (MFSTEP)" (http://www.bo.ingv.it/mfstep). The same website offers the SST range for the studied period. Specimens were killed at the moment of collection by immersion in H_2O_2.

Complete and well preserved prehistoric shells were selected from Mesolithic layers 4, 5, 6, 7 from SRT, layer 3C from CLM, layers 6C and 5A from ORT and layer 2C from UCR. All these levels coincide with periods of human occupation. *O. turbinatus* exhibits a notable variability in growth rate, therefore estimation of animal age (i.e. younger and older individuals) according to shell size can be only approximate. Adult specimens may be represented by shells ranging from 15 to 38 mm of diameter (e.g. Poppe and Goto, 1991), and shell growth checks might not provide reliable markers of ontogenic age (Mannino et al., 2008). Since medium shells provide sufficient calcium carbonate relative to the last growth year to be sampled for seasonal studies (Mannino et al., 2007), medium shells of almost similar size were selected (20–24 mm width).

Both modern and archaeological specimens were immersed in 30% of H_2O_2 for 48 h, rinsed with de-ionised water, cleaned in an ultrasonic bath and dried in an oven at 35 °C for 24 h. *O. turbinatus* secretes an entire inner aragonite shell (Schifano and Censi, 1983; Mannino et al., 2008). The shell structure was investigated using X-ray diffraction (XRD) and scanning electron microscopy (SEM). Internal aragonitic structures for all specimens were intact; no recrystallization to calcite was found.

To ensure comparable results with other studies, sample procedures follow Mannino et al. (2007, 2008) for *O. turbinatus* from the Sicilian coast. A single carbonate sample of the inner nacreous layer was taken from the ultimate growth increment (shell-edge) of modern specimens by using a manual microdrill with a 0.5 mm bit (Fig. 2a) and the powder was collected for isotope analyses. Archaeological shells were sectioned along the last whorl and three inner carbonate samples were obtained from the shell-edge in the inner layer using the same microdrill bit at 1.0 mm intervals (Fig. 2b). A Mesolithic shell from layer 5 of SRT (L5, 23 mm width) was sampled continuously along its growth spiral for $\delta^{18}O$ analysis at intervals of about 1 mm (Fig. 2c) to evaluate the intra-annual shell $\delta^{18}O$ variability and to compare with $\delta^{18}O$ values of archaeological shells used to estimate the seasons of collection.

Previous works have observed that *O. turbinatus* reduces its shell secretion during hotter and cooler SST in NW Sicily (Schifano and Censi, 1983; Mannino et al., 2008). Reduction and interruption, of shell secretion increase the time-averaging of $\delta^{18}O$ in shell carbonate samples (Goodwin et al., 2003). As consequence shell $\delta^{18}O$ values might underestimate and overestimate SSTs of hottest and coldest months respectively. We have checked this pattern in modern shells from Marina di Camerota through the comparisons of monthly measured SSTs with calculated SSTs using the Grossman and Ku (1986) equation's for biogenic aragonite on shell-edge $\delta^{18}O$ values:

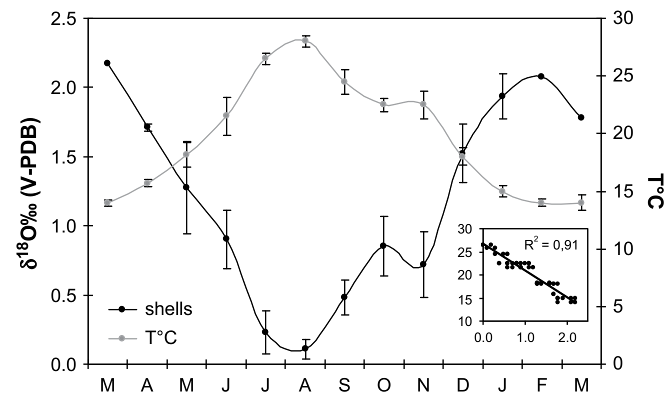

Fig. 3. Intra-annual variations of mean monthly $\delta^{18}O$ values of living *Osilinus turbinatus* and monthly SST from Marina di Camerota at the time of shell collections. Monthly SST vs $\delta^{18}O$ provide a determination coefficient (R^2) of 0.91.

$$SST\ (^\circ C) = 20.6 - 4.34 * \left(\text{shell } \delta^{18}O - \left(\text{seawater } \delta^{18}O - 0.27‰\right)\right)$$

Here the equation was rewritten so that $\delta^{18}O$ values of seawater are referenced to the V-PDB scale (Dettman et al., 1999).

$\delta^{18}O$ analyses were performed at the VU University Amsterdam using a Finnigan MAT 252 mass spectrometer equipped with an automated preparation line (Kiel II type). The reliability of a routinely analyzed carbonate standard (NBS 19) is more than 0.09‰ for both $\delta^{18}O$ (1σ) and $\delta^{13}C$. The oxygen isotope composition is expressed using the δ (‰) V-PDB standard (Vienna Pee Dee Belemnite) notation.

3. Results

3.1. Intra-annual $\delta^{18}O$ variation of modern *Osilinus turbinatus*

Mean intra-annual water temperature measured at the time of shell collection (March 2004–March 2005) was 20.3 ± 3.8 °C, with an intra-annual range of 12.5 °C. According to MFSTEP data, mean

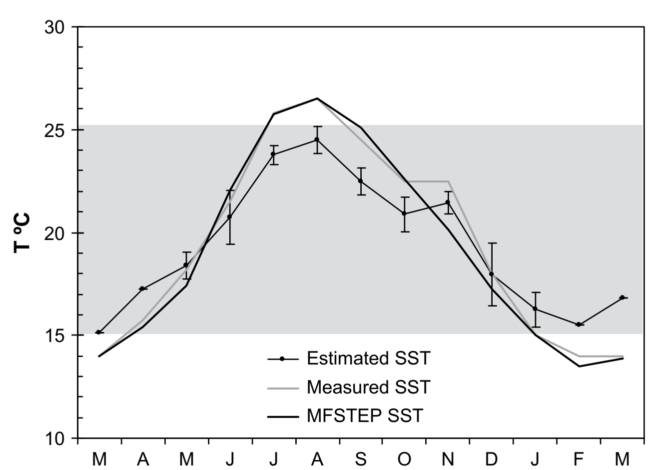

Fig. 4. Variations over 13 months of calculated temperature from shell-edge $\delta^{18}O$ values at Marina di Camerota and comparisons with measured SSTs at the moment of shell collections and from MFSTEP. The grey band encloses the intra-annual temperature range of *O. turbinatus* at Marina di Camerota (ca. 10 °C).

Table 3
Range and quartile boundaries based on sequential $\delta^{18}O$ values of Mesolithic shells from Marina di Camerota (Grotta della Serratura) and NW Sicily (Mannino et al., 2007).

References	Minimum value	25% quartile	50% quartile	75% quartile	Maximum value	Range	^{14}C year BP
(Mannino et al., 2007)	−0.5‰	+0.2‰	+0.9‰	+1.6‰	+2.3‰	2.8‰	7173 ± 37
(Mannino et al., 2007)	−1.1‰	−0.2‰	+0.8‰	+1.7‰	+2.6‰	3.7‰	8745 ± 55
(Mannino et al., 2007)	−0.1‰	+0.7‰	+1.4‰	+2.2‰	+2.9‰	3.0‰	9855 ± 70 9720 ± 60
L5	−0.3‰	+0.3‰	+0.9‰	+1.8‰	+2.7‰	3.0‰	9720 ± 60 9790 ± 170

annual SSS for the intertidal zone was 37.8 ± 0.1 PSU with an annual range of 0.3 PSU. Monthly $\delta^{18}O$ of surface seawater exhibit very small oscillations in these regions (e.g. mean seawater $\delta^{18}O = +1.2 \pm 0.02$‰; Mannino et al., 2008), suggesting that oscillations in shell $\delta^{18}O$ are controlled mainly by temperature. Monthly $\delta^{18}O$ values are reported in Table 2. The intra-annual mean $\delta^{18}O$ value is +1.1 ± 0.6‰ with an intra-annual range of 2.3‰. Intra-annual $\delta^{18}O$ values exhibit a clear seasonal fluctuation, with highest $\delta^{18}O$ values corresponding to lowest SST conditions (winter and early spring), reaching their maximum values in March 2004 (+2.2‰), January 2005 (+2.2‰) and February 2005 (+2.2‰). Lowest $\delta^{18}O$ values are recorded during the highest water temperatures (summer), reaching a minimum in July 2004 (+0.1‰) and August 2004 (−0.1‰) (Fig. 3). $\delta^{18}O$ are quite variable (e.g. 0.7‰ in November) and could arise from intra-specific variability in growth rate, which can be pronounced in seasons with greatest growth. Furthermore different microenvironmental conditions of the lower intertidal cliff may also be involved in $\delta^{18}O$ variability. For instance, different food quality and quantity (Schöne et al., 2007) or different individual time of aerial exposure during low tide (Schifano and Censi, 1983; Goodwin et al., 2001), local variations in $\delta^{18}O$ of water (Mannino et al., 2008). This emphasizes the need of measuring multiple specimens to improve seasonal discrimination of $\delta^{18}O$ values. The correlation of determination (R^2) between SST measured at the time of shell collection and the $\delta^{18}O$ values is 0.91, which is compatible with values found by Mannino et al. (2007, 2008) (from 0.78 to 0.98) and Schifano and Censi (1983) (0.87) in Sicilian populations. Our study therefore agrees with previous studies which show that seasonal $\delta^{18}O$ values of *O. turbinatus* from Marina di Camerota are primarily controlled by changes in SST.

Calculated temperatures from shell-edge $\delta^{18}O$ values (using seawater $\delta^{18}O = +1.2$‰) show a strong relation with measured SSTs ($R^2 = 0.97$), provided a very close mean annual temperature (19.8 ± 3.8 °C). Shell-edge $\delta^{18}O$ of *O. turbinatus* track clearly fluctuations in SSTs ranging from 15 to 25 °C, which seems to represent the optimal range of this species at Marina di Camerota. Nevertheless $\delta^{18}O$ temperatures are underestimated at measured SSTs ranging from 21 to 25 °C (mean offset from −0.1 to −0.8 °C), and not provide temperature over 25 °C in summer (mean offset of −2 °C compared to measured SSTs) (Fig. 4). It confirms that temperatures over 25 °C represent an important limit for *O. turbinatus* in SW Italy (Mannino et al., 2008). More variable is the animal response to lower temperatures. Indeed, $\delta^{18}O$ temperatures are higher than measured SSTs in winter and the beginning of spring, and not provide temperature under 15 °C (mean offsets from +1.1 to +2.8 °C). This pattern is also reported by Schifano and Censi (1983) in populations from NW Sicily and from Tuscan coast, but not by Mannino et al. (2008). Comparisons of calculated temperatures with mean monthly SSTs from MFSTEP show a similar pattern ($R^2 = 0.95$). To some extent our results agree with patterns observed by Mannino et al. (2008) in NW Sicily, suggesting lower growth rates at hottest temperature and interruption of growth at temperature over 25 °C. However our results also suggest lower growth rate during cooler temperature, and no shell secretion at temperature under 15 °C, in agreement with other regional studies (Schifano and Censi, 1983; and references therein).

As is observed previously (Schifano and Censi, 1983; Mannino et al., 2008), combined results evidence complex behavioural and physiological adaptation by *O. turbinatus* in relations to local environmental conditions. The main implications for seasonal studies concern the lower temporal resolution of shell-edge $\delta^{18}O$ values relative to coldest and hottest months. To circumvent this issue seasonal determination of archaeological shell-edge $\delta^{18}O$ values can be performed by grouping them into quartile, which

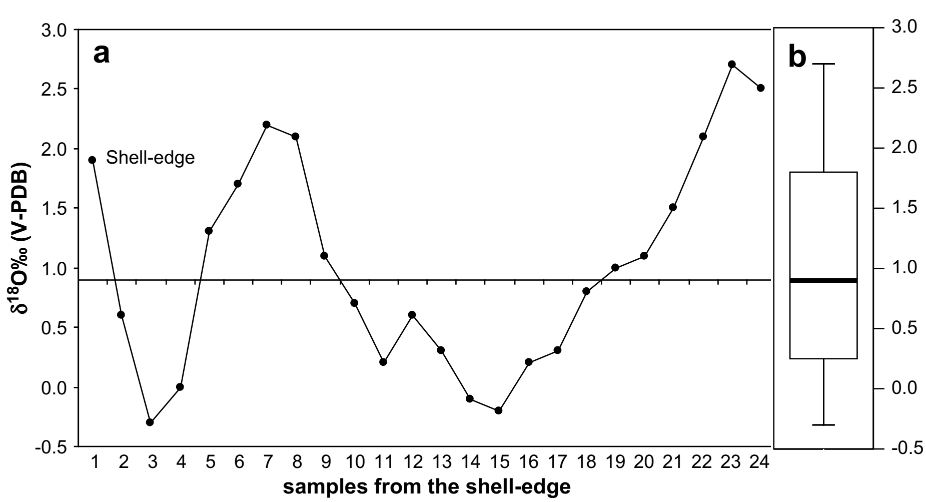

Fig. 5. (a) Sequential $\delta^{18}O$ values of Mesolithic shell (L5) from SRT and (b) graphic description of quartile $\delta^{18}O$ distribution used to estimate the intra-annual range and seasonal isotopic boundaries for Mesolithic shells.

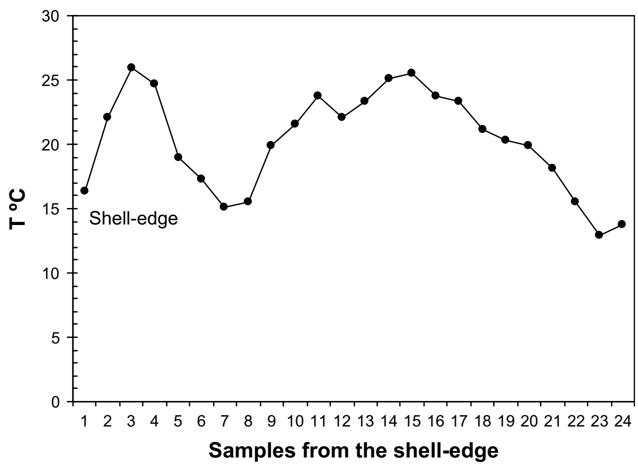

Fig. 6. Calculated temperature from sequential shell $\delta^{18}O$ values of L5 representing two years of growth.

allows for seasonal discrimination without subjective attributions of $\delta^{18}O$ values to specific month or seasons (Mannino et al., 2007).

Given the quasi-sinusoidal pattern of intra-annual shell-edge $\delta^{18}O$ values of *O. turbinatus* (warmer (summer), colder (winter) and intermediary (autumn–spring) SST conditions), the $\delta^{18}O$ data set can be organized seasonally by grouping it into quartiles. Quartile data distribution places data set values into four groups of equal parts consistent with 1/4th of the total. Lowest $\delta^{18}O$ values, corresponding to the warmer months are thus grouped in the lower quartile, which is consistent with the lowest 25% of total data set ($\delta^{18}O \leq 0.6‰$). Highest $\delta^{18}O$ values, related to colder months are clustered into the upper quartile ($\delta^{18}O \geq 1.7‰$). Intermediate $\delta^{18}O$ values (spring and autumn), are grouped into the interquartile range (>25% and <75%), consistent with the 50% of the $\delta^{18}O$ data set.

3.2. Seasonal exploitation of Osilinus turbinatus in Mesolithic sites

Based on the modern observations, the harvesting season of archaeological shells can be determined by comparing their $\delta^{18}O$ values with one of the three quartiles (upper, lower, and interquartile). Since intra-annual $\delta^{18}O$ oscillations of modern shells can differ from those of Mesolithic specimens (e.g. due to different temperature, salinity and seawater $\delta^{18}O$), the intra-annual $\delta^{18}O$ pattern of Mesolithic shells were determined using the sequential $\delta^{18}O$ values of archaeological shells as proposed by Mannino et al. (2007). Intra-annual $\delta^{18}O$ oscillation for shells from Mesolithic sites of NW Sicily are known (Mannino et al., 2007), but no data are available for the Mesolithic frequentations of SRT. Therefore an archaeological shell from layer 5 of SRT (L5) was sampled sequentially to assess its intra-annual $\delta^{18}O$ pattern. The resulting ontogenic $\delta^{18}O$ oscillations are used here to establish seasonal quartiles (warmer, colder and intermediary) as a reference for the Mesolithic shells from SRT (Table 3). The $\delta^{18}O$ trend of L5 represent 2 years of growth and exhibits a quasi-sinusoidal pattern ranging from $-0.3‰$ to $+2.7‰$; the total $\delta^{18}O$ range (3‰) is higher than for modern specimens (2.2‰). Considering the 1 mm interval between samples of 1.0 mm diameter, the $\delta^{18}O$ trend indicate an appreciable ontogenic reduction of growth rate during the last year (ca. 13 mm) compared to the previous one (ca. 32 mm) (Figs. 5a,b).

$\delta^{18}O$ values of L5 suggest that this shell experienced a higher temperature oscillation compared to the intra-annual trend observed in modern counterparts. In order to calculate the palaeotemperature of shell secretion seawater $\delta^{18}O$ must be known. According to Kallel et al. (1997) and Emeis et al. (2000), the SSS in the central Mediterranean basin and in the southern Tyrrhenian Sea at ca. 9.7 ka BP (layer 5) was substantially similar to nowadays (ca. 38–39 PSU). Therefore using the modern Mediterranean seawater $\delta^{18}O$/SSS relationship (0.25‰/S‰; Pierre, 1999) for the onset of the Holocene, and assuming no intra-annual changes in SSS in this coastal areas, a seawater $\delta^{18}O$ value of ca. $+1.2‰$ can be reasonably estimated to ca. 9.7 ka BP. Using the Grossman and Ku (1983) equations, the $\delta^{18}O$ trend provides SSTs ranging from 25.9 to 12.9 °C, whose are respectively higher and lower than SSTs recorded by modern shell at Marina di Camerota (Fig. 6). Previous studies have obtained $\delta^{18}O$ temperatures lower than those calculated at Marina di Camerota using modern shells (e.g. 12 °C; Mannino et al., 2008) but $\delta^{18}O$ temperature over 25 °C has not been recorded in moderns populations from SW Italy. Therefore our

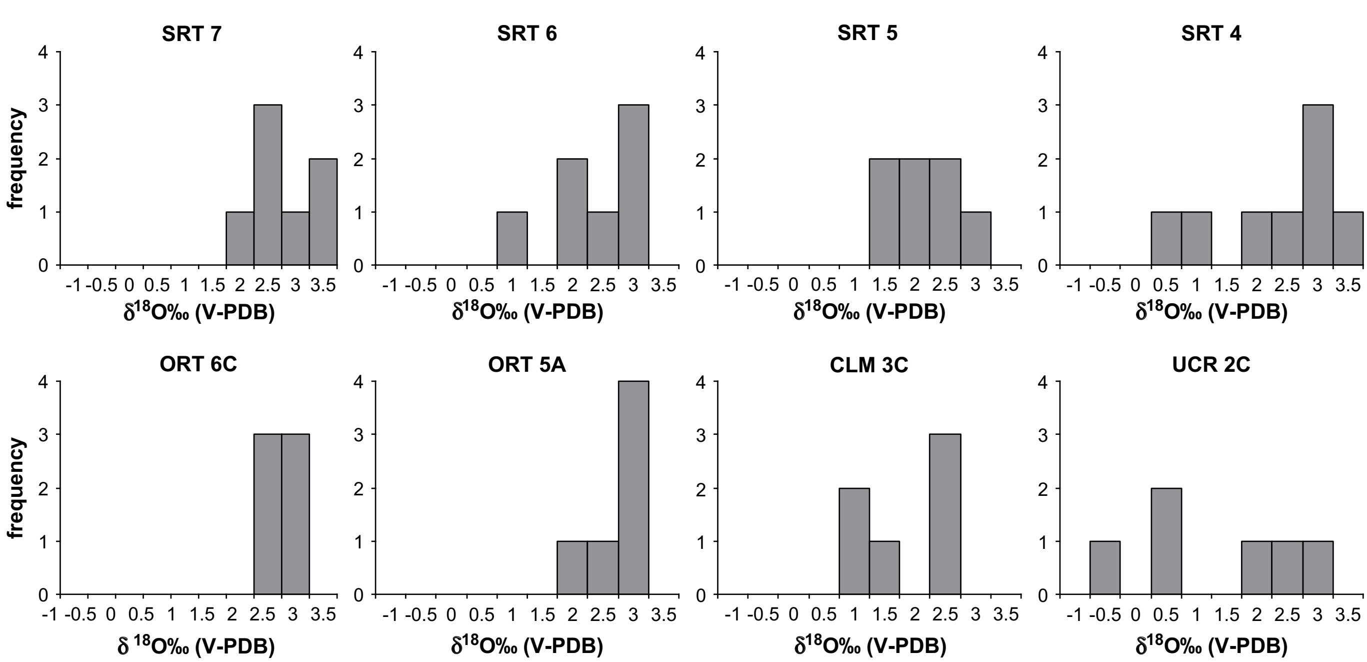

Fig. 7. Frequency distribution of $\delta^{18}O$ values of Mesolithic shells from occupations episodes of SRT, ORT, CLM and UCR.

Table 4
Results of sequential shell-edge oxygen isotopic composition of *Osilinus turbinatus* from Mesolithic frequentation of coastal caves of SW Italy.

Stratigraphic layers	δ^{18}Os‰ (V-PDB)			Shell size (mm)
	1st sample (shell-edge)	2nd sample	3rd sample	
SRT 7	+1.9	+1.2	+0.8	20.5
	+2.3	+1.9	+1.3	21
	+2.4	+1.1	+1.0	20
	+2.4	+2.2	+1.4	20.5
	+2.6	+2.3	+1.7	23.5
	+3.1	+2.2	+2.0	23
	+3.2	+2.1	+1.9	20.5
SRT 6	+2.9	+2.2	+1.6	20.5
	+3.0	+3.3	+2.8	21
	+2.6	+3.1	+2.7	21
	+2.4	+2.7	+3.2	20
	+1.9	+2.4	+2.9	20
	+1.7	+2.3	+1.9	20
	+0.9	+2.5	+3.1	20
SRT 5	+1.1	−0.2	+0.5	20
	+1.3	−0.6	+0.5	20
	+1.6	+1.0	+0.8	22.5
	+1.9*	+0.6	−0.3	23
	+2.2	+1.3	+0.8	24
	+2.4	+2.4	+1.6	23
	+2.6	+0.9	+0.3	20
SRT 4	+2.7	+1.4	+1.0	24
	+3.1	+2.9	+1.8	23
	+2.8	+2.3	+1.8	24
	+2.7	+3.0	+2.6	24
	+2.5	+2.8	+2.9	21
	+1.9	+2.0	+2.6	20
	+0.9	+1.2	+1.7	21.5
	+0.2	−0.8	+0.1	22
ORT 6C	+2.7	+1.4	+0.8	20.5
	+2.4	+1.8	+1.2	23
	+2.4	+1.6	+1.2	21
	+2.4	+1.8	+1.2	20
	+2.8	+1.9	+0.7	22
	+2.8	+2.6	+2.7	20
ORT 5A	+2.7	+2.1	+1.8	21.5
	+2.2	+2.4	+1.7	24
	+2.8	+2.1	+1.9	21
	+2.8	+2.7	+1.4	20
	+2.6	+2.7	+1.8	21.5
	+1.9	+1.9	+0.6	21.5
CLM 3C	+0.7	+1.6	+1.8	23.5
	+2.3	+2.2	+1.4	20
	+1.3	+1.1	+0.8	24
	+2.3	+1.5	+0.9	20
	+0.7	+0.0	+1.2	23.5
	+2.4	+2.2	+2.5	22
UCR 2C	+2.4	+1.9	+0.8	21.5
	+2.7	+2.0	+2.1	20.5
	−0.6	0.0	+0.1	22
	+0.5	+0.8	+1.2	20.5
	+0.4	+0.2	+1.9	22.5
	+2.0	+2.2	+1.7	21

*Shell sampled sequentially (L5).

results seem to suggest a fairly higher tolerance to hottest temperature (i.e. over 25 °C) by Early Holocene populations compared to modern ones in the area.

Fig. 7 and Table 4 shows the frequency distribution of δ^{18}O values from Mesolithic shells from SRT, ORT, CLM, UCR. Their quartile δ^{18}O distribution is indicated in Figs. 8b,c, using the data from L5 and Mannino et al. (2007) as lower and upper quartiles boundaries.

The SRT shells exhibit different δ^{18}O distributions according to the Mesolithic group exploitation (Fig. 8b). The whole set of δ^{18}O values from layer 7 (SRT 7) falls into the upper 25% of data, is consistent with an exclusive *O. turbinatus* exploitation during cold months, and can thus be ascribed to late autumn–winter harvest (mean +2.4‰ ± 0.4). The narrow isotopic range (1.3‰) also denotes a short-term interval of this topshell exploitation during this frequentation. δ^{18}O values from layer 6 (SRT 6) vary from the upper (e.g. +1.7 to +3‰) to the interquartile range (0.9‰), and display a quite large isotopic range (2.1‰). This δ^{18}O distribution indicates a winter early–spring exploitation (mean +2.2‰ ± 0.7). δ^{18}O values from layer 5 (SRT 5) also vary from the upper (e.g. from +1.8 to +2.6‰) to the interquartile range (e.g. from +1.1 to +1.6‰). The δ^{18}O distribution shows a fairly narrow range (1.5‰) denoting, similar to SRT 7, autumn–winter exploitation (mean +1.8‰ ± 0.5). Almost all δ^{18}O values from layer 4 (SRT 4) fall into the upper quartile (e.g. from +1.9 to +3.1‰), however δ^{18}O values related to the interquartile (+0.9‰) and lower quartile range (+0.2‰) are also present. The large isotopic range (2.6‰) and distribution suggest that *O. turbinatus* was exploited mainly during the winter season (mean +2.1‰ ± 1), with some specimens collected also during spring and late summer.

At ORT δ^{18}O values from both layer 6C (mean +2.6‰ ± 0.2) and 5A (mean +2.5‰ ± 0.3), fall exclusively into the upper quartile reported by Mannino et al. (2007) for Mesolithic shells of Grotta dell'Uzzo with quite similar radiocarbon dates, respectively 8745 ± 55 and 7171 ± 37 BP (Fig. 8c). The results are indicative of a winter exploitation. Their narrow isotopic range (respectively 0.4 and 0.9‰) indicates a very short-term interval of *O. turbinatus* exploitation during this Mesolithic frequentation.

The shells from the Mesolithic frequentation of layer 3C of CLM provide δ^{18}O values spanning the interquartile range (e.g. +1.3 and +0.7‰) to the upper quartile (e.g. +2.3 and +2.4‰), with similar proportions (Fig. 8c). The distribution of δ^{18}O values, coupled to its fairly large δ^{18}O range (1.7‰), indicates that *O. turbinatus* was exploited from winter to early spring (mean +1.6‰ ± 0.8).

At UCR δ^{18}O values from layer 2C vary from the interquartile (e.g. +0.4 and +0.5‰) to the upper quartile range (e.g. +2 and +2.7‰), but one shell provides δ^{18}O values (−0.6‰) compatible to the lower quartile data distribution (Fig. 8c). The distribution of δ^{18}O values exhibits a large isotopic range (3.3‰) suggesting harvesting in different seasons (mean +1.2‰ ± 1.3). However the δ^{18}O distribution appears bimodal, with two main data sets separated by 1.6‰, a value very close to the interval of the interquartile range found by Mannino et al. (2007) in Mesolithic shells with a quite similar radiocarbon date at Grotta dell'Uzzo (1.9‰). This range is also significantly higher than those observed in living specimens collected monthly at Marina di Camerota (1.0‰). This would indicate that *O. turbinatus* was collected in two different and distinct intervals: winter and late spring–summer.

4. Discussion and conclusions

Our results show a rather variable seasonal pattern of *O. turbinatus* exploitation along the Mesolithic coastal sites of SW Italy. In general the δ^{18}O values suggest exploitation from one (even short episodes) to several seasons, but never throughout the year. Cold or intermediate seasons are preferred, with sporadic specimens collected during summer.

At ORT *O. turbinatus* was gathered in very short episodes during winter, while at CLM Mesolithic groups collected it from winter to early spring. This narrow period of *O. turbinatus* exploitation coincides with scarcity of larger mammal faunal and artefacts remains recorded in both caves (Martini et al., in press; Colonese, in press). Data thus suggest a sporadic occupation of these caves by Mesolithic groups. Furthermore, as suggested for ORT, no significant seasonal change of *O. turbinatus* exploitation is recorded among Mesolithic and Mesolithic–Neolithic transitions. At UCR *O. turbinatus* was collected in two different periods, e.g. in winter and in late spring–summer, the longest temporal topshell exploitation among these sites.

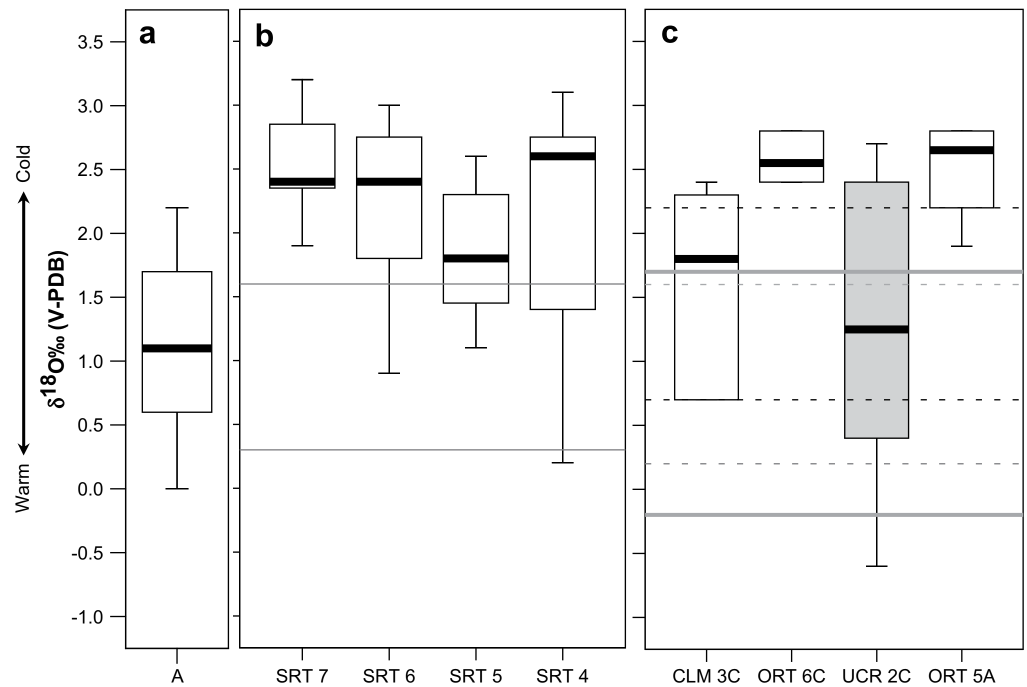

Fig. 8. $\delta^{18}O$ distribution of Mesolithic shells compared with upper and lower quartile boundary of reference. (a) $\delta^{18}O$ distribution of living specimens collected monthly at Marina di Camerota; (b) upper and lower quartile boundaries (L5) and $\delta^{18}O$ distribution of Mesolithic shells from Grotta della Serratura; and (c) upper and lower quartile boundaries (Mannino et al., 2007) and $\delta^{18}O$ distribution of Mesolithic shells of Sicilian sites. Grey line: reference for $\delta^{18}O$ of UCR 2C; grey dotted line: reference for $\delta^{18}O$ of ORT 5A; black dotted line: reference for $\delta^{18}O$ of CLM 3C and ORT 6C.

During the Mesolithic frequentations of SRT, the exploitation of *O. turbinatus* occurred in similar seasons, but with a more temporally confined exploitation during Sauveterrian, than during undifferentiated Epipalaeolithic occupations. Seasonal data of fish remains (Wilkens, 1993) indicate that Sauveterrian groups captured fish during autumn and spring, whereas the undifferentiated Epipalaeolithic people exploited them in spring and winter. Findings at SRT show an almost exclusive occurrence of *O. turbinatus* exploitation during the colder or intermediary seasons, while the warmer months are scarcely recorded. The longer seasonal *O. turbinatus* collection period recorded in layer 4 could indicate a different use of the cave. This hypothesis is supported by quantitative data of fauna and artefacts remain. In general, large mammals (Hellemans et al., 1993), artefacts (Martini, 1993) and shellfish (Wilkens, 1993) are more abundant in the undifferentiated Epipalaeolithic layers compared to Sauveterrian counterparts. This would indicate a more stable, or intense, cave frequentation during this Mesolithic occupation.

Results presented above agree with seasonal patterns of Mesolithic *O. turbinatus* exploitation recorded at Grotta dell'Uzzo, in NW Sicily (Mannino et al., 2007). In the early Mesolithic phase of Grotta dell'Uzzo *O. turbinatus* exploitation did occur mainly during the winter, with some specimens collected also in the early spring. In late Mesolithic layers molluscs are present from all seasons, associated with a significant increase of faunal remains and human activity in the cave (Tagliacozzo, 1993), suggesting a phase of greater stability of its occupation (Tusa, 1996). However during the successive phase, Mesolithic–Neolithic transition and Neolithic, *O. turbinatus* exploitation returns to strictly seasonal, occurring during autumn and winter (Mannino et al., 2007). Combined results are indicative of a regional exploitation pattern of *O. turbinatus* by Mesolithic groups inhabiting this region. Unfortunately available data do not allow us to propose explanations for these temporal patterns, predominantly associated with cold or intermediary seasons. Nevertheless temporal and spatial Mesolithic exploitation of coastal resources may have been governed by the seasonal availability of some crucial dietary sources, among which large mammals (Barker, 1981) and involved short-term use of caves. Indeed the spatial behaviour of several large mammals, such as *Cervus elaphus*, is characterized by seasonal migrations induced by seasonal climatic conditions (Barker, 1981; Luccarini et al., 2006). Migratory and stationary *Cervus elaphus* are known to display periodic movements throughout the year, with migrations towards distant areas located at higher altitudes during the summer (e.g. Luccarini et al., 2006). Such faunal migratory patterns could have influenced seasonal hunter-gatherer mobility (Barker, 1981; Pellegrini et al., 2008) and a return to coastal resource exploitation during colder or intermediary seasons, when larger mammal faunals were more frequent at low altitudes.

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