The Mediterranean coral Cladocora caespitosa: a proxy for past climate fluctuations?

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Abstract

Sclerochronology was applied to recent, Holocene and Pleistocene samples of Cladocora caespitosa. Late Pliocene samples were recrystallised and thus unsuitable for sclerochronology. Quaternary samples showed a clear, alternating banding pattern as in the living coral, confirming a marked seasonality of past climate. The computed mean annual growth rates ranged from 2.1 to 6.9 mm year \(^{-1}\), with highest growth rates during the warmer phase (isotope stage 5e) of the first climate cycle. It is hypothesised that the largest fossil banks of C. caespitosa grew in a coastal environment with considerable alluvial inputs and warmer temperatures than today.

Keywords: Paleoclimatic reconstruction; Cladocora caespitosa; Coral; Mediterranean; Sclerochronology

1. Introduction

Cladocora caespitosa (L.) is the main native zooxanthellate and constructional coral of the Mediterranean Sea, abundant both in the geological past and in recent times. Large fossil Cladocora formations were found as old as Late Pliocene, when this coral formed true reefs both in the eastern and western Mediterranean Sea (Aguirre and Jiménez, 1998; Dornbos and Wilson, 1999). Large fossils banks of C. caespitosa are also known from the Early Pleistocene (Bernasconi et al., 1997), from the Middle and Late Pleistocene and from the Holocene (for a review, see Peirano et al., 1998).

Today, C. caespitosa is a major carbonate producer among Mediterranean organisms (Peirano et al., 2001). It occurs on shallow bottoms (4–10 m) forming ‘beds’ of numerous, distinct, hemispherical colonies. From 10 m down to 40 m of water depth, the
coral becomes more rare. But, where present, it can form build-ups rising up to 1 m above the surrounding seafloor and covers several square metres in surface area.

Recent *C. caespitosa* growth has been studied by sclerochronology, i.e., the study of seasonal growth marks in the skeleton. X-radiographs of these skeletons show a clear banding pattern, indicating that the coral deposits two bands per year: a high-density band during the cold and rainy winter season (November–March) and a low-density band in the warm and dry summer season (July–September). No differences in banding were found between colonies collected from shallow and those from deeper water. Timing of band formation proved to be correlated with monthly sea temperature and irradiance levels (Peirano et al., 1999).

Sclerochronology has been largely used in the tropics to assess the response of corals to environmental changes and to provide a proxy for seawater temperature of past centuries (Hudson, 1981; Lough and Barnes, 1997). Here, we present preliminary data on the sclerochronology of fossil *C. caespitosa*. The present work aims to study the presence and preservation of the annual banding pattern in fossil Cladocora skeletons. In case of positive results, we want to compare annual growth rates of recent and fossil samples with climate parameters.

2. Material and methods

Recent coral skeletons were samples isolated from the Ligurian Sea (NLS). Fossil samples come from Tuscany (PV), Sardinia (C1 and C2), Calabria (LB95), Apulia (TaSV, TaSR and TaST) and SE Spain (AL).

NLS samples were collected in 1994–1997 in the Ligurian Sea at 4–30 m of depth from Bocca di Magra to Bonassola (La Spezia) (Peirano et al., 1999). Sclerochronology allowed measuring annual growth rates of 114 colonies back to 1930.

All the Holocene and Pleistocene samples were single colonies; they were dated by the Th/U method and attributed to ancient shorelines and isotopic stages following Hearty et al. (1986).

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Fig. 1. Positive X-ray images of skeletons (corallites) of *C. caespitosa* from Holocene (NLS) and Pleistocene (TAST, LB95) samples. Dark bands are high-density zones (HD) and white bands are low-density zones (LD). Reference bar is 5 mm.
Samples PV from Piana della Versilia (Massaciucoli lake, Pisa) were extracted from a lagunal silt-clay layer in a borehole at 68.8 m of depth. They were dated 129.2 ± 15 ky BP.

Sample C1 was extracted from fossil deposits of Iletta Island at the center of S. Gilla Lagoon (Cagliari, Sardinia), where *C. caespitosa* is abundant and embedded in a littoral sandy matrix. It was dated 149 ± 10 ky BP, and attributed to the isotopic stage 5e (Euthyrrenian). Sample C2 was collected from the bay-mouth bar, named La Playa that locks the lagoon. It was dated 7 ± 1 ky BP corresponding to the Holocene climatic optimum. Its living depth was probably 0.5–1 m (Ulzega and Hearty, 1986).

Samples LB95, from Grotta del Prete (S. Nicola di Arcella, Scalea) were isolated from a *Cladocora*-bearing biocalcarenites dated 329 ± 196 – 64 ky BP. They were referred to the sea level highstand 9. Living depth of coral banks was ≤ 4.5 m (Carobene et al., 1986; Carobene and Dai Pra, 1991).

Samples from Apulia were collected near Taranto and extracted from a sandy matrix. TaSV (S. Vito Cape; 104 ± 2 ky BP) and TaPR (Ponte Romano; 108 ± 1.5 ky BP) were referred to isotopic stage 5c, TaST (S. Teresiola; 125 ± 8 ky BP) to stage 5e.

The most ancient sample analysed (AL) was attributed to Late Pliocene on the basis of planktonic foraminifer assemblages (Aguirre and Jiménez, 1998; Aguirre and Sánchez-Almazo, 1998). It came from the Almería-Nijar basin (Spain) where *Cladocora* formed banks covering a surface area of up to 3000 m². Skeletons were recrystallised and embedded in a cemented silty clay. The corals probably lived at 20–30 m of water depth.

From each sample, corallites were separated, cleared of epibionts and immersed in a 1:1 peroxide solution to remove organic remains and then dried at 70 °C. To measure growth rates the corallites were X-rayed. Positive images from X-ray films were analysed with the public domain NIH-Image programme for Macintosh. According to Peirano et al. (1999), mean growth rates were computed averaging the measurements of distances between two successive HD density peaks (= 1 year of growth). Differences between mean growth rates were analysed through one-way ANOVA. Homoscedasticity of variances was achieved through logarithmic transformations of variables.

### Table 1

<table>
<thead>
<tr>
<th>Sample</th>
<th>Age (ky)</th>
<th>Isotopic stage</th>
<th>Number of measurements</th>
<th>Mean growth rates (mm year⁻¹)</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td>7 ± 1</td>
<td>1</td>
<td>27</td>
<td>4.11</td>
<td>1.25</td>
</tr>
<tr>
<td>TaSV</td>
<td>104 ± 2</td>
<td>5c</td>
<td>47</td>
<td>2.13</td>
<td>0.89</td>
</tr>
<tr>
<td>TaPR</td>
<td>108 ± 1.5</td>
<td>5c</td>
<td>81</td>
<td>3.62</td>
<td>1.78</td>
</tr>
<tr>
<td>TaST</td>
<td>125 ± 8</td>
<td>5e</td>
<td>170</td>
<td>6.94</td>
<td>2.14</td>
</tr>
<tr>
<td>PV</td>
<td>129 ± 15</td>
<td>5e</td>
<td>7</td>
<td>6.25</td>
<td>2.96</td>
</tr>
<tr>
<td>C1</td>
<td>149 ± 10</td>
<td>5e</td>
<td>4</td>
<td>2.57</td>
<td>0.73</td>
</tr>
<tr>
<td>LB95</td>
<td>329 + 196</td>
<td>9</td>
<td>98</td>
<td>2.55</td>
<td>0.80</td>
</tr>
</tbody>
</table>

From each sample, corallites were separated, cleared of epibionts and immersed in a 1:1 peroxide solution to remove organic remains and then dried at 70 °C. To measure growth rates the corallites were X-rayed. Positive images from X-ray films were analysed with the public domain NIH-Image programme for Macintosh. According to Peirano et al. (1999), mean growth rates were computed averaging the measurements of distances between two successive HD density peaks (= 1 year of growth). Differences between mean growth rates were analysed through one-way ANOVA. Homoscedasticity of variances was achieved through logarithmic transformations of variables.

![Fig. 2](image-url)  
Fig. 2. Mean growth rates (▲) and standard deviations (bars) of recent (NLS) and fossil samples of *C. caespitosa*. Continuous line indicates Shackleton’s (2000) δ18 O atm isotopic curve; in brackets, isotopic stages.
3. Results

All the skeletons from the Quaternary showed a clear banding pattern (Fig. 1). Corallites of the Pliocene from Spain (AL), recrystallised, did not show growth bands. Mean annual growth rates of Quaternary samples ranged from 2.1 to 6.9 mm year\(^{-1}\) (Table 1).

Notwithstanding the low number of fossil corals analysed and the fact that samples came only from one colony per site, mean growth rates were in good accordance with Shackleton’s (2000) isotopic reconstruction of climate cycles (Fig. 2). In particular, samples C2, TaPR, TaSV and PV showed a positive trend of mean growth rates that is consistent with warm phases of the first climatic cycle. On the contrary, C1 and LB95 did not fit with previous samples and exhibited lower growth rates than expected. Holocene (C2) and recent (NLS) samples were consistent with the temperature profiles from the Greenland ice sheet (Dahl-Jensen et al., 1998). Annual mean growth rates (2.5 ± 0.91 mm year\(^{-1}\)) of recent *C. caespitosa* (NLS) were significantly different from TaPR, TaST, C2 and PV (Table 1). Highest growth rates were found in TaST (6.94 ± 2.14 mm year\(^{-1}\)).

To test the possible relationship of past coral growth with climate, growth rates of recent *C. caespitosa* collected in the Ligurian Sea were compared to the 150-year record of air temperature (ISTAT, 1986–2000), which is strongly and positively correlated with seawater temperature (Astraldi et al., 1995). Notwithstanding the variability in the amplitude of oscillations, due to the differences in the numbers of corals analysed per year, the growth of *C. caespitosa* was in good agreement with climatic data (Fig. 3). Two synchronous, parallel cycles were recognised: a sinusoidal long-term cycle of 90 years, and a shorter cycle of about 7 years. The overall, positive trend is in agreement with the global warming, and the warmer climatic phase in the 1930s is consistent with the temperature profiles from Greenland ice sheet GRIP (Dahl-Jensen et al., 1998). The five-order polynomial regression indicated a coral growth increase of 0.7–1.6 mm year\(^{-1}\) in relation to a rise in air temperature of 0.7–1 °C. If this relationship is applied to the fossil coral samples, then the TaST corals should have grown in a climatic phase characterised by a mean annual air temperature 3.2 °C higher than today. This is in the range of temperatures reported by Cita et al. (1977) and Zazo (1999) for past Mediterranean climates.

![Fig. 3. Interannual variations of mean growth rates of the coral C. caespitosa (upper graph) compared to air temperature records of Liguria (NW Mediterranean) since 1866 (lower graph). Curves are the multi-annual trends generated by a five-order polynomial regression.](image)
4. Discussion and conclusions

An identical banding pattern in fossil and recent *C. caespitosa* indicates that also the past Mediterranean climate was characterised by a marked seasonality, with cold winters and warm summers. However, fossil corals formed larger and higher banks than those of today, hence the environmental conditions of past Mediterranean Sea, in terms of both temperature and water quality should not have been exactly the same. The descriptions of fossil coral banks, their stratigraphic sequences and their sedimentological features often report their presence in sites exposed to fine sediments and alluvial inputs (Aguirre, 1998). Fornos et al. (1996) suggested that *C. caespitosa* banks developed mainly during maximum flooding conditions at the end of transgressive phases, and massive input of sediments is supported by Peizhen et al. (2001) who showed that in the Pliocene–Pleistocene erosional processes were the highest since 80 Myr.

Such a turbid environment is consistent with the observation of recent coral ‘beds’ and banks, often found in coastal waters exposed to important terrestri al inputs. Here *C. caespitosa* competes successfully with soft, frondose algae thanks to its capability of combining autotrophy and heterotrophy (Peirano et al., 1998, 1999). In the Pliocene and Early Pleistocene, the presence of extensive ‘beds’ of Ostrea spp. (Bernasconi et al., 1997; Aguirre and Jiménez, 1998; Dornbos and Wilson, 1999), forming the basement of or being intercalated in coral banks, confirms the assumption of turbid waters, where suspension and filter feeding organisms were favoured.

Late Pleistocene *C. caespitosa* banks differed from older banks in the presence of *Striobombus bubonius*, which characterised the isotopic stage 5e (our samples C1, TaST). This gastropod, a Senegalese species, is an indicator of a warmer climate phase. This coincides with higher *C. caespitosa* growth rates (Fig. 1).

In conclusion, we can hypothesise that major fossil reefs of *C. caespitosa* grew in coastal waters characterised by a marked seasonality, with alluvial inputs of fine sediments, higher turbidity and higher temperature than today. Such results, although preliminary, suggest that *C. caespitosa* could be a reference species for future work on changing Mediterranean climate, allowing the study of climate cycles at short (annual), medium (decadal) and long (millennia) terms.

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References


