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Biomass, Carbonate Standing Stock and Production of the Mediterranean Coral *Cladocora caespitosa* (L.)

Andrea **Peirano**, La Spezia, Carla **Morri**, Genova, C. Nike **Bianchi** and
Riccardo **Rodolfo-Metalpa**, La Spezia

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Summary

The Mediterranean coral *Cladocora caespitosa* often occurs in large beds, i.e. populations of hemispherical colonies with stock densities varying between 1.9 and 4 colonies · m^{-2}. Laboratory measurements of volume, skeleton weight, surface and number of corallites per colony, coupled with mean annual growth rates evaluated through sclerochronology, allowed for the estimation of biomass, skeleton bulk density, calcimass (carbonate standing stock) and secondary production (both organic and inorganic) of two *C. caespitosa* beds at 4 and 9 m depth. The mean colony biomass varied between 0.73 and 0.99 kg dw · m^{-2}, corresponding to a calcimass between 2 and 5 kg $CaCO_3$ · m^{-2}. Organic secondary production was 215.5 – 305.4 g dw of polyps · m^{-2} · y^{-1}, while the potential (mineral) production was 1.1 - 1.7 kg $CaCO_3$ · m^{-2} · y^{-1}, for the year 1996-1997.

These values show that *C. caespitosa* is one of the major carbonate producers within the Mediterranean and one of the major epibenthic species originating stable carbonate frameworks both in recent and past times.

1 INTRODUCTION

The evaluation of the biogenic carbonate standing stock in the sea is important to assess the influence of the bioconstructions on the surroundings ecosystems (Laborel, 1987; Bianchi & Morri 1996), to understand the sedimentary dynamics and evolution of the carbonate frameworks (Freiwald & Henrich, 1994) and to relate them to climatic and sea-level changes (Laborel & Laborel-Deguen, 1994; Sartoretto et al., 1996). From an economic point of view the estimation of carbonate amount coupled with secondary production may be crucial in fishery exploitation of biogenic constructions of commercial importance such as corals and maerl. Moreover, carbonate estimation is often coupled with cartography to know the extension of biogenic facies (Tongpenyai & Jones, 1991) and to assess human and natural disturbances on bioconstruction (Maragos, 1993; Johnson et al., 1995; Sammarco, 1996 ; Highsmith, 1980; Done & Potts, 1992).

As outlined by Henrich et al. (1995) little is known on the extension and importance of carbonate production of non-tropical species that both in past and recent times participated in CO_2 trapping and the edification of carbonate framework and build-ups. Among these species *Cladocora caespitosa* (L.) is the main Mediterranean zooxantellate coral abundant both in past and recent times. Fossil remains are known throughout the Mediterranean countries (see Peirano et al., 1998 for a review). Large fossil formations (banks and /or reefal frameworks) of this coral dated back to Pleistocene were found submerged in Aegean Sea (Laborel, 1961; Kühlmann, 1996), south and east coast of Majorca (Cuerda, 1975) and along the east coast of Cape Bon, Tunisia (Poizat, 1970; Zibrowius, 1980). Emerged patch reefs of *C. caespitosa* were found in Spain (Aguirre & Jimenez, 1998), in Italy (Palmentola et al., 1990; Dai Pra et al., 1993; Bernasconi et al., 1997) and in Cyprus (Dornbos & Wilson, 1999). Large living banks are rare in recent times (Morri et al., 1994). *C. caespitosa* occurs, when abundant, in shallow bottoms in 'beds', i.e. numerous, distinct, hemispherical colonies living more or less close to each other on boulders and cobbles (Peirano et al., 1998, 1999). The present paper uses geometric relationships to compute the number of corallites, biomass, skeleton weigth and bulk density of *C. caespitosa* from simple, basic measurements taken underwater. Such relationships, coupled with sclerochronology, are used to evaluate the secondary organic production and the mineral potential production, i.e., the amount of $CaCO_3$ produced per unit area (Chave et al., 1972).

2 MATERIALS AND METHODS

Numerous samples of *Cladocora caespitosa* were collected by SCUBA divers in La Spezia region (Ligurian Sea, NW Mediterranean) in the years 1994-1997 (Peirano et al., 1999) (Fig 1). Before collecting, the diameter D (in round-shaped colonies) or the major axis D1 and the minor axis D2 (in elliptical-shaped colonies) and the height H of each colony were measured *in situ* with a plastic ruler with half cm accuracy. Mean number of corallites per cm^2 per colony was estimated underwater counting the number of corallites in three replicated quadrats 3 x 3 cm.

Addresses: Dr. A. Peirano, Dr. C.N.Bianchi and Dr. R. Rodolfo-Metalpa, ENEA-Centro Ricerche Ambiente Marino, CP 224, I-19100 La Spezia, Fax: 0039/0187978273, email: peirano@santateresa.enea.it; Dr. C. Morri, DipTeRis, Università di Genova, Corso Europa, 26, I-16132, Genova, fax: 0039/0103538209, email: morric@dipteris.unige.it

Fig. 1. Location of the three sampling site in the Ligurian Sea: Bocca di Magra (4 m depth), Punta Bianca and Fiascherino (9 m depth).

To estimate secondary production, additional subsamples were collected in September 1997. Three or four corallites were isolated underwater from each of 79 colonies. Calix diameter (Cd) of corallites was measured with a calliper at 1/10 of mm accuracy level in laboratory. Mean annual growth rates per colony for the year 1996-1997 were estimated through sclerochronology (Peirano et al., 1999).

Biomass, calcimass (carbonatic standing stock) and both organic and inorganic secondary production of 'beds' of *C. caespitosa* were evaluated in three shallow sites (4 - 9 m depth): Bocca di Magra, Punta Bianca and Fiascherino (Fig. 1). In each site, size and density of *C. caespitosa* were recorded in 1 m^2 quadrats randomly placed along transects 50 - 75 m long. Differences between sites were investigated with one-way analysis of variance and Tukey test; data were log transformed when not satisfying the assumption of homogeneity of variances.

2.1 Skeleton weight

The true volume (V) of eighteen collected colonies was measured in cm^3 through the immersion technique (Schiller, 1993). Colony volumes varied from 40 to 11400 cm^3. To measure skeleton weight (SkW) colonies were washed to remove the sediment that filled the interstices among corallites. Usually, during this treatment colonies collapsed and it was possible to isolate the corallites and detach the epibionts. To remove all the organic matter, polyps included, the colonies were immersed in a peroxide solution for a day, and then were rinsed again and dried at 80° C for 48 hours to constant weight. Colony skeleton weigth resulted between 6 and 7336 g.

To relate underwater measurements of size (cm) to SkW

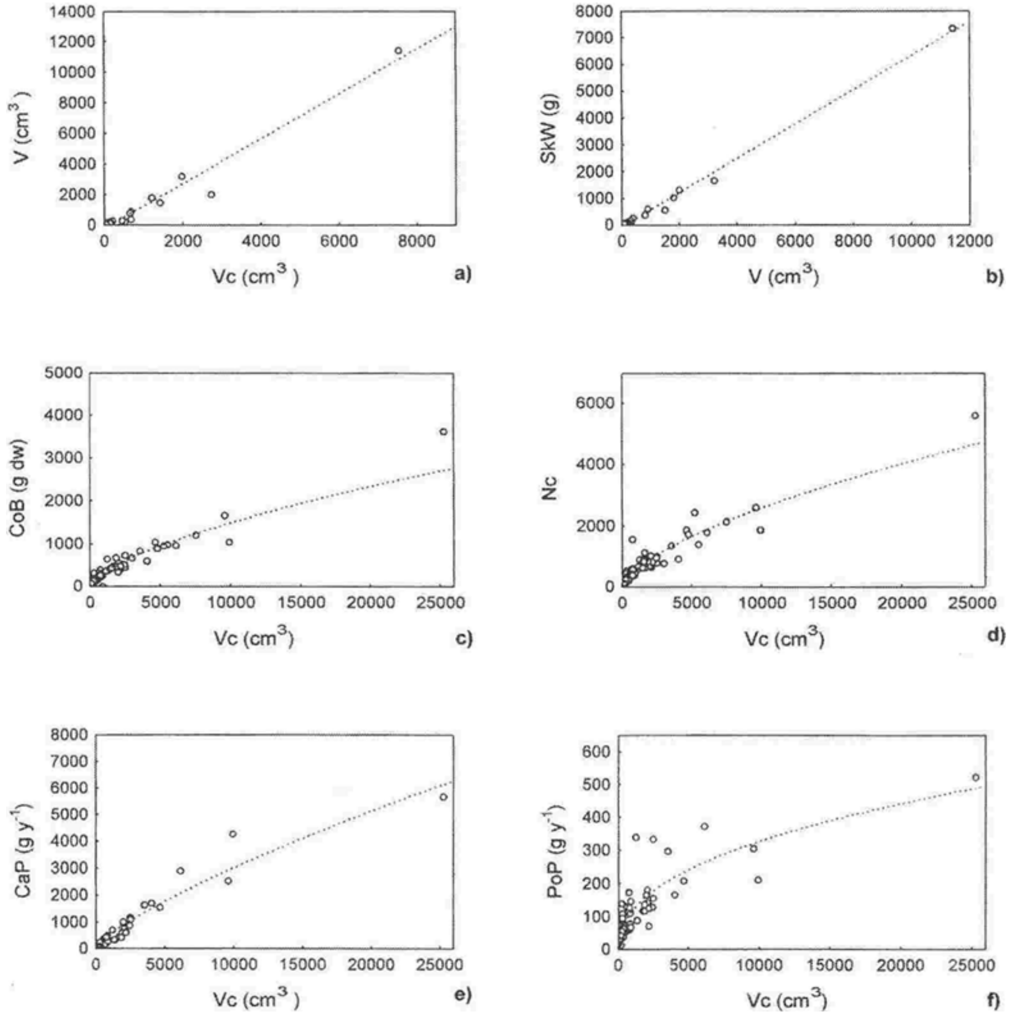

Fig. 2. Curves relating the true volume (V) to the skeleton weight (SkW), and the volume calculated from underwater measurements (Vc) to the true volume (V), colony biomass (CoB), number of corallites per colony (Nc), production per colony of CaCO$_3$ (CaP) and biomass (PoP).

(g) we first calculated the theorical colony volume (Vc) in cm^3 using the equations proposed by Maragos (1978), so modified:

$Vc = 2/3 \cdot \pi \cdot H \cdot (D/2)^2$ for round shaped colonies

$Vc = 2/3 \cdot \pi \cdot H \cdot (D1/2) \cdot (D2/2)$ for elliptical shaped colonies

Paired t-test was used to assess differences between underwater replicated measurements taken by two trained divers and one non-experienced diver. The differences between the computed volumes (Vc) calculated from the measurements achieved by divers were not significant. However, the difference between measurements taken by the two experienced divers was much lower ($P = 0.602$) than differences among the experienced and the non-experienced diver ($P= 0.083$ and $P= 0.051$).

The following equations, resulting from regression analysis, allowed the estimation of true skeleton weight SkW (g) from V (cm^3) and Vc (cm^3) :

$V = 1.4144 \cdot Vc$ ($R^2 = 0.96$, $P < 0.0001$) (Fig. 2 a)

$SkW = 0.6295 \cdot V$ ($R^2 = 0.99$, $P < 0.0001$) (Fig. 2 b)

2.2 Biomass

Colony biomass was calculated as the sum of individual polyps weight through the following procedure:

a) The colony surface (S) in cm^2 was calculated from underwater measurements using the formula:

$$S = \pi \cdot c \cdot \left[c + \frac{a^2}{\sqrt{(c^2 - a^2)}} \cdot \log \left[\frac{\sqrt{(c^2 - a^2)} - c}{a} \right] \right]$$

where: $c = H$ and $a = D1$ when $H > D1/2$

or $c = D1/2$ and $a = H$ when $H < D1/2$.

When $H = D1/2$ the classical formula for the calculation of hemispherical solid surface was used:

$$S = 2 \cdot \pi \cdot H^2$$

b) The number of corallites per colony (Nc) was calculated multiplying S by the mean number of corallites per cm^2 measured underwater. The quality of the approach was tested on 13 collected colonies with D1 ranging from 6.5 to 17 cm and resulted highly significant ($R^2 = 0.96$, $P<0.0001$).

c) To calculate the individual polyp weight, we used Schiller's (1993) equation that relates calix diameter Cd (mm) to polyp tissue dry weight (mg dw):

$$\text{Polyp weight} = 0.807 \cdot Cd^{1.750}$$

d) Finally, polyp weight was multiplied by the number of corallites per colony (Nc) to obtain colony biomass (CoB). Two general equations that related underwater measurements, in term of colony volume Vc (cm^3), to CoB (g dw) and number of corallites NC were calculated iteratively:

$CoB = 3.9390 \cdot Vc^{0.6445}$ ($N = 114$; $R^2 = 0.97$; $P < 0.0001$) (Fig. 2c)

$NC = 7.0849 \cdot Vc^{0.8908}$ ($N = 155$; $R^2 = 0.97$; $P < 0.0001$) (Fig. 2d)

2.3 Organic + $CaCO_3$ production

Since colonies of *C. caespitosa* are phaceloid in form, with corallites separated from each other (Peirano et al., 1999), the growth of the colony, both in volume and surface, coincides with the increase of the number of corallites (and polyps) produced by scission. Hence, the total secondary production of a colony may be considered divided into two terms: mineral ($CaCO_3$) production = CaP ($g \cdot yr^{-1}$) and polyps (organic) production = PoP ($mg\ dw \cdot yr^{-1}$). The former (CaP) was evaluated as the rate of increase in skeleton weight (SkW), the second (PoP) was evaluated as the rate of increase in biomass (CoB) due to new polyps produced between 1996 and 1997. Thus, the two components of *C. caespitosa* secondary productions were:

$$CaP = SkW_{1997} - SkW_{1996}$$

$$PoP = CoB_{1997} - CoB_{1996}$$

Growth rates were indipendent from depth and no correlations were found between corallite's diameter and growth rates ($R^2 = 0.024$; $P = 0.26$), colony diameter ($N=149$, $R^2 = 0.096$; $P = 0.26$) or colony heigth ($R^2 = 0.0021$; $P = 0.59$). Therefore, mean growth rates, ranging from 0.53 to 5 $mm \cdot year^{-1}$, were used to back-calculate the size of colonies in 1996. The following two general equations relating CaP ($g \cdot yr^{-1}$) and PoP ($g\ dw \cdot year^{-1}$) to Vc (cm^3) were calculated iteratively :

$CaP = 2.63 \cdot Vc^{0.7651}$ ($N = 71$; $R^2 = 0.95$, $P < 0.0001$) (Fig. 2e)

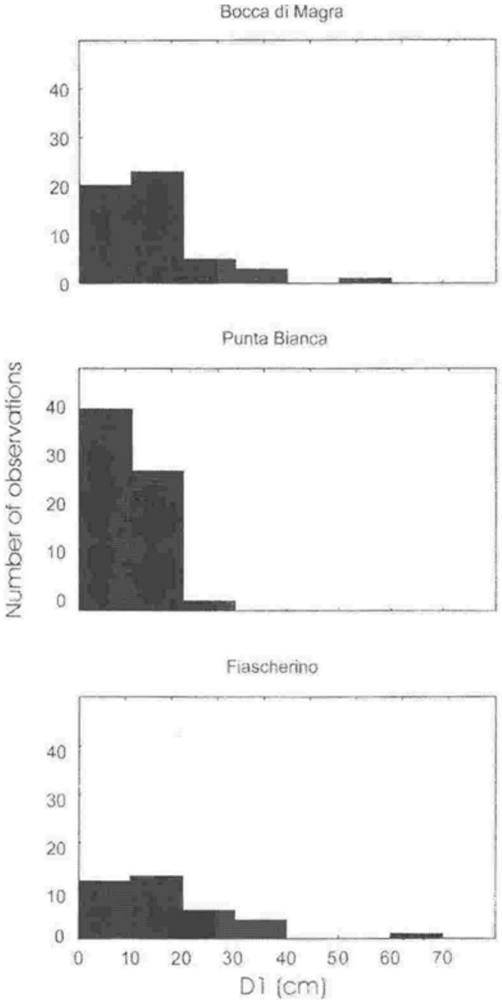

Fig. 3. Size-frequency istograms of the three populations of *Cladocora caespitosa* investigated.

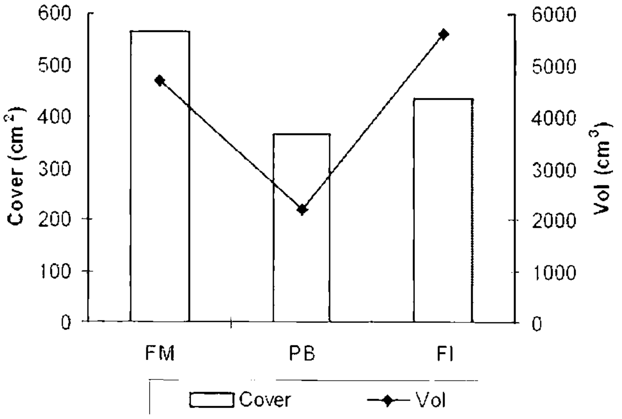

Fig. 4. Mean volume and cover of colonies of *Cladocora caespitosa* in the three studied sites.

$$PoP = 5.8725 \cdot Vc^{0.4362} \ (N = 63 \ ; R^2 = 0.87 \ , P = < 0.0001) \quad \text{(Fig. 2f)}$$

3 RESULTS AND DISCUSSION

The three *Cladocora caespitosa* beds investigated were mainly formed by colonies with diameter smaller than 20 cm (Fig. 3). Maximum densities were found at Punta Bianca (8 colonies $\cdot$ m^{-2}) where the abundance of small colonies indicated high recruitment. Maximum colony diameter (65 cm) was recorded at Fiascherino.

Dispersion patterns were tested for agreement with a Poisson distribution. Hypothesis of randomness was not disproved for Fiascherino (N = 40; $\chi^2 = 55$, $P > 0.05$) and Punta Bianca (N = 18; $\chi^2 = 21.9$, $P > 0.05$) while at Bocca di Magra dispersion of the population was contagious (N = 23; $\chi^2 = 41.2$, $P < 0.05$). *C. caespitosa* showed lower colony densities at Fiascherino and differed significantly from Bocca di Magra beds ($P < 0.01$). No differences were found between colonies of Fiascherino, Bocca di Magra and Punta Bianca in cover, volume, colony biomass, and carbonate budget (Fig. 4 and Tab. 1).

From the equation relating skeleton weight SkW to volume V we deduced a skeletal bulk density, or 'colony density' following Heiss (1995), of 0.63 g of $CaCO_3 \cdot cm^{-3}$ that is below the values recorded for the Mediterranean scleractinian *Madracis pharensis* and closer to the minimum values recorded for tropical corals (Table 2).

Assuming a density value of 2.94 g $\cdot$ cm^{-3} for the pure aragonite (Dustan, 1975; Rice & Hunter, 1992) the porosity resulted 21.4 % , a value not much different from 24.4 - 35.5 %, calculated for *Acropora* spp (Schumacher, 1984), and from 29 % for *M. pharensis* (Morri et al., 2000).

Site	Colonies (n)	Density (col.m^{-2})	Cover $dm^2.m^{-2}$	Colony Biomass (kg dw.m^{-2})	Calcimass $CaCO_3$ (kg.m^{-2})	Colony Secondary Production	
						Polyps (g.dw.m^{-2}.yr^{-1})	$CaCO_3$ (kg.m^{-2}.yr^{-1})
FM	52	2.9±0.4	5.67±6.58	0.99±1.10	4.2±6.8	305.4±269.3	1.7±2.2
PB	73	4.0±0.5	3.67±3.65	0.73±0.69	2.0±2.5	281±218.3	1.1±1.2
FI	36	1.9±0.4	4.34±6.06	0.80±1.09	5.0±13.2	215.5±169.0	1.6±2.8

Tab. 1. Characteristics of the three *Cladocora caespitosa* beds. FM = Bocca di Magra, PB = Punta Bianca, FI = Fischerino. Parameters are expressed as average ±standard deviation.

Species	Skeletal bulk density (g $CaCO_3$. cm^{-3})	Source
Acropora hyacinthus	1.97	Hibino & Van Woesik (2000)
Acropora spp	0.08 - 2.80	Harriott (1997)
Cladopora caespitosa	0.63	(Present work)
Favia pallida	1.35 - 1.55	Heiss (1995)
Goniastrea spp	1.7 - 2.06	Heiss (1995)
Madracis pharensis	1.95 - 2.10	Morri et al. (2000)
Montastrea annularis	1.58 - 2.09	Dustan (1975)
Montipora verrucosa	1.28 - 1.51	Heiss (1995)
Pavona spp	1.44 - 1.86	Heiss (1995)
Pocillopora damicornis	~ 1	Heiss (1995)
Porites spp	1.26 - 1.85	Heiss (1995)
Porites sp.	0.99 - 1.55	Lough & Barnes (1997, 2000)
Porites spp	1.35	Hibino & Van Woesik (2000)

Tab. 2. Skeletal bulk density of corals from literature review.

Even if coral density varies directly with distance from shore and inversely with extension rate and depth (see Heiss, 1995 and Lough & Barnes, 2000 for a review) and the massive presence of *C. caespitosa* in the Pleistocene and Holocene with large banks and reefal formations suggest past Mediterranean environmental conditions different from recent ones, we propose a rough value of 630 kg of $CaCO_3 \cdot m^{-3}$ to calculate the carbonatic budget of fossil build-ups. The ratio carbonatic weight to biomass varied from 4.24 at 4 m depth to 2.73 – 6.25 at 9 m depth.

Although no data are available for Mediterranean scleractinians we may consider these values in the range of those calculated for some Mediterranean gorgonacean that varied from 2.2 in *Paramuricea chamaleon* to 6.8 in *Corallium rubrum* (Bellan-Santini, 1968).

Comparing literature data on potential production and carbonate stock of main modern reef building species

	Potential Production (kg $CaCO_3$. m^{-2}.yr^{-1})
Arctic Regions	
Lithothamnion cf. *glaciale* and *Phymatolithon* sp. (1, 2)	=.4 - 1.4
Temperate Regions	
Lithothamnion coralloides (1)	0.08-0.9
Phymatolyton calcareous (1)	0.08 - 0.4
Lithophyllum incrustans (1)	
Peyssonellia spp (3)	0.17 - 0.25
Ficopomatus enigmaticus (4)	6
Pentapora fascialis (4)	2.8
Cladocora caespitosa (present work)	0.004 - 12.8
Tropical Regions	
Porites spp (5)	11.1 - 20.5
Porites spp (6)	4.5 - 17
Favia pallida (6)	5.9 - 13
Goniastrea retiformis (6)	8.3 - 14.5
Pocillopora spp (6)	9.6
Palythoa caribaeorum (7)	0.07
Acropora spp (8)	100
Halimeda spp (8)	10
Halimeda incrassata (9)	~ 0.05

Tab. 3. Carbonatic budget and potential carbonate production of major epibenthic species originatin stable carbonate frameworks from literature review. 1) Freiwald & Henrich (1994), 2) Henrich et al. (1995), 3) Ballesteros (1994), 4) Bianchi (1997), 5 Lough & Barnes (2000), 6) Heiss (1995), 7) Mueller & Haywick (1995), 8) Chave et al. (1972), 9) Wefer (1980).

showed that the constructional ability of *C. caespitosa* is below that of most tropical species (Table 3). W ith a carbonate production of up to 12.8 kg $\cdot$ m^{-2} $\cdot$ y^{-1}, however, this coral may be considered as one of the majors contributors to the edification of stable carbonate framework within the Mediterranean Sea, where, according to Bellan-Santini (1968) and Cébrian et al. (2000), the total carbonate standing stock of infralittoral assemblages is comprised between 2.1 and 13.2 kg $\cdot$ m^{-2}

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