

## Density and compressive strength of the coral *Siderastrea siderea* (Scleractinia: Siderastreidae): Intraspecific variability

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**Resumen:** Se determinó la densidad y fuerza de compresión en diferentes secciones de siete colonias del coral *Siderastrea siderea* recolectadas en cuatro arrecifes del Caribe de Costa Rica. La densidad fue mayor en las secciones más viejas de las colonias, mientras que la fuerza de compresión no mostró ninguna tendencia; varió significativamente solo en las secciones más jóvenes. Contrario a lo esperado, la densidad y la fuerza de compresión no están correlacionadas. La densidad promedio de colonias vecinas del mismo arrecife variaron significativamente, y fue mayor en arrecifes expuestos a turbulencia y sedimentación. Lados opuestos de la misma colonia presentaron diferencias en densidad y, en menor grado, en fuerza de compresión. Estos resultados preliminares indican que el arrecife es un ambiente hidrodinámicamente heterogéneo, con micro-condiciones diferentes alrededor de las colonias. Por esta razón, se debe tener cuidado cuando análisis de parte de una colonia se interpretan como representativos de toda la colonia.

**Key words:** Density, compressive-strength, variability, coral-skeleton, *Siderastrea*.

Structural characteristics of ramose corals may vary in different parts of the branches due to different growth patterns (Tunnicliffe 1982). Nevertheless, in massive corals, which have radial growth (Barnes 1973), it is considered that skeletal structure will not vary significantly within the same colony (Schneider and Smith 1982, Hughes 1987).

In this study the density and compressive strength of the coral *Siderastrea siderea* (Ellis and Solander 1786) was determined to test the "homogeneity" of skeletal structure of massive corals.

Seven whole colonies of *Siderastrea siderea* were collected from four reefs (Fig. 1). The colonies were collected from shallow (0.5 - 1.5 m), turbulent (but not high energy) and turbid environments, and were slabbbed parallel to their growth axis using a rock saw (Fig. 2a). From the slabs, cubes 2.5x2.5x2.5 cm were cut from six positions (Fig. 2b), and enumerated from one to six, from the growing edge to the base. The relative position of the sample on the colony was also noted (Fig. 2c).

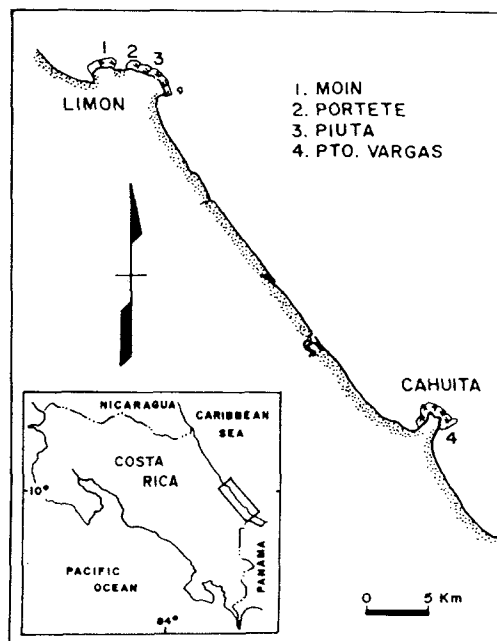


Fig. 1. Localities of collection on the Caribbean coast of Costa Rica: Moín (3 colonies), Portete (1), Piuta (2) and Puerto Vargas (1).

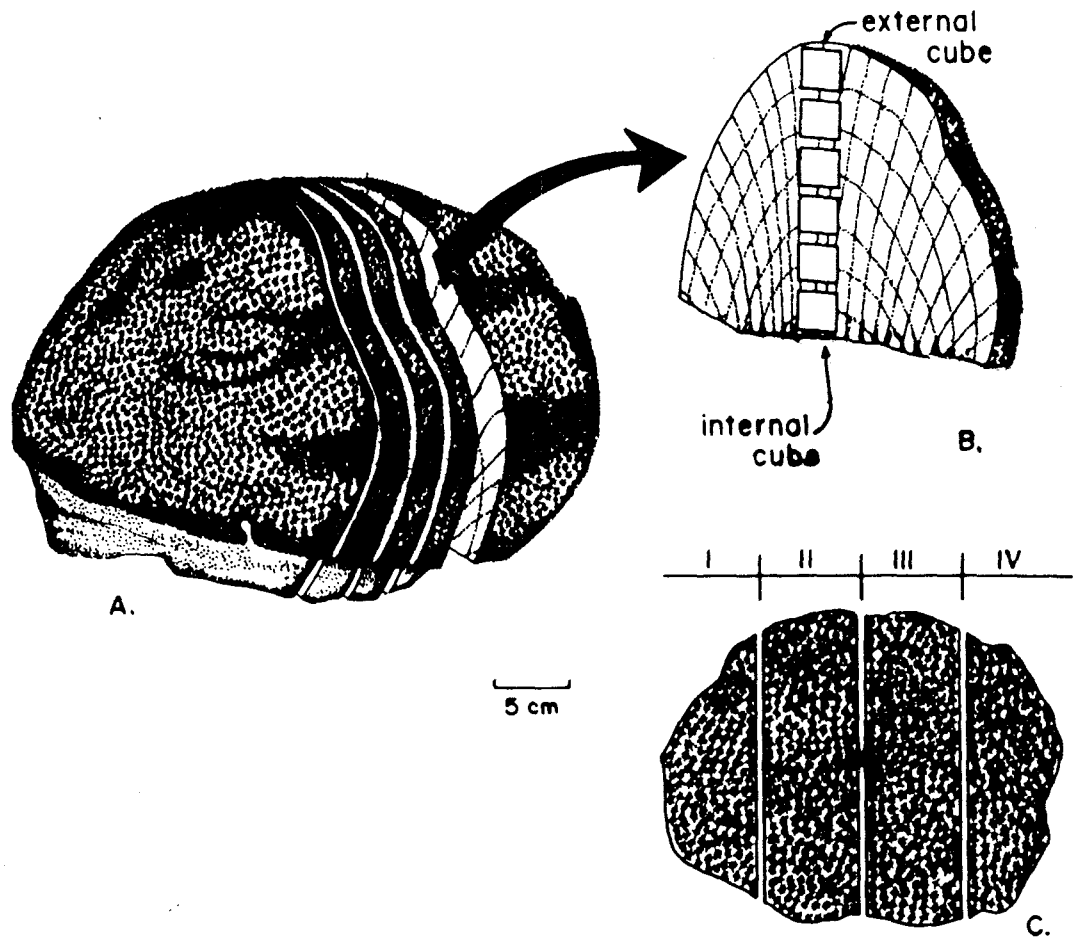


Fig. 2. a. Slabs parallel to the growth axis. b. Cubes obtained from the slabs. c. Relative position of slabs on the colonies.

Density was determined by saturating the cubes in water (Scott and Risk 1988) and applying the relationship of weight in the air versus weight in the water (Grauss and Macintyre 1982). Compressive tests (i.e., the force necessary to fracture the sample) were done following the conventional methods described by Storer (1986), and using a Riehle mechanical press. The force was applied parallel to the growth axis (Chamberlain 1978) on cubes that showed no signs of bioerosion or changes in axis orientation.

Density increased significantly from the external to the internal sections of the colonies (ANOVA  $P < 0.01$ , Fig. 3a). Positions one to three are different (Tukey,  $P < 0.01$ ) to positions

four to six. This density gradient is not a product of secondary infilling as observed in ramose corals (Gladfelter 1982), because of the absence of internal canals in massive corals (Hughes 1987). Infiltration and compaction of inorganic cements in coral skeletons reduce porosity and increase the density of the older sections of the corallum (Gvirtzman and Friedman 1977, Chamberlain 1978). Since this infiltration is a passive process, not controlled by the polyp, the variability observed (Fig. 3a) may indicate that infiltration was different in each colony.

The compressive strength did not show a tendency (ANOVA  $P > 0.1$ ), for position, similar to that of density (Fig. 3b), indicating little or

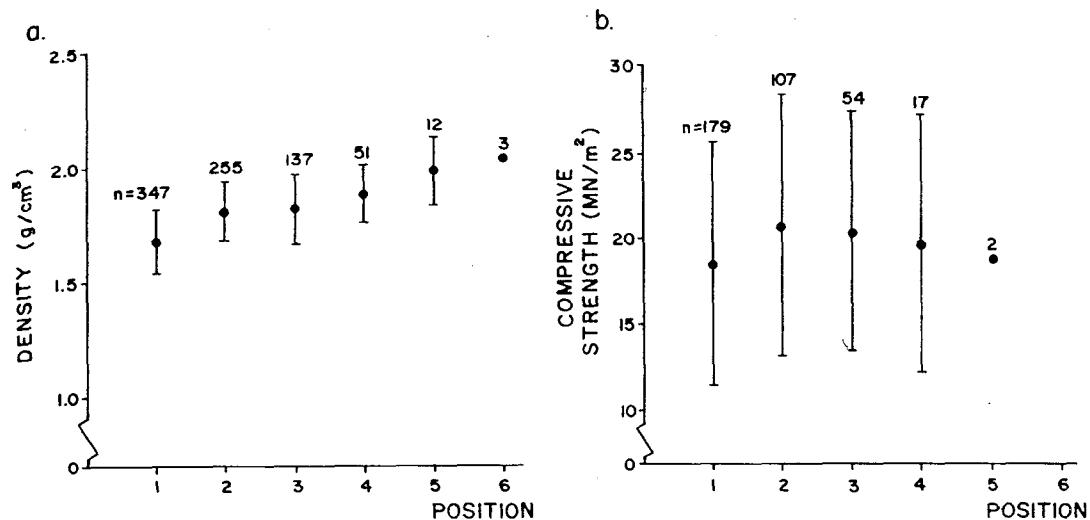


Fig. 3. Density ( $\text{g/cm}^3$ ) and compressive strength (meganewtons per  $\text{m}^2$  of coral skeleton) of *Siderastrea siderea* at different positions in the colonies. Bars indicate standard deviation when more than 5 samples were available. n = number of cubes. a. Average density of all the cubes (n = 805). b. Average compressive strength of the cubes without bioerosion (n = 359). Position 1 = external, 6 = internal.

no increase in resistance caused by cements. Both density and compressive strength are poorly correlated ( $r = -0.09$ ) opposite to expectations; a denser material needs a greater compressive force to fracture (Schuhmacher and Plewka 1981).

One colony from Moín and another one from Piuta (MO2, PIU6) presented differences between compressive strength and position (ANOVA  $P < 0.05$ ), though it was not possible to identify where the difference was (using a Tukey test). This did not allow the identification of a gradient in the effort but indicate a variability in skeletal components in the different colonies.

The compressive strength of the outermost position varied significantly between all colonies (ANOVA  $P < 0.01$ ) and in all reefs ( $P < 0.03$ ) but, it was not possible to identify which colony or reef was significantly different. These observations indicate that compressive strength depends on meso-architecture of the skeletal elements (Barnes and Devereux 1988, Scott and Risk 1988), and on a lesser extend on micro-architecture. Considering that the theca and septa can be influenced by environmental factors, such as wave energy (Foster 1980), and that the presence and ordering of aragonite crystals may vary with available light (Hidaka

1988), it is probable that the variability observed on the most external samples (position 1, where skeletogenesis is taking place) is due to environmental factors.

Average densities of the colonies were significantly different within the same reef (Tukey  $P < 0.05$ ). This can be explained, if the reef is a heterogeneous environment (Isdale 1977) where the factors that influence density are distributed randomly. Variability, though, may also be due to genetic differences (Foster 1980), or even represent morphotypes, with different growth patterns (N. Knowlton per. comm. 1992).

Density had a positive gradient with respect to turbulence and sedimentation (Fig. 4a). There was a tendency toward a density increase in *S. siderea* in the more turbulent reefs, as was also observed by Scoffin *et al.* (1992) in *Porites lutea*. Compressive strength did not present a tendency (Fig. 4b), but the way in which the samples from the most turbulent and silted reef (Puerto Vargas) fractured were notably different to the rest. Samples from that reef shattered to small pieces, almost powder, while samples from other reefs fractured conserving some cohesion between fragments, and their sizes were larger. The possibility that higher siltation at Puerto Vargas (Cortés and Risk

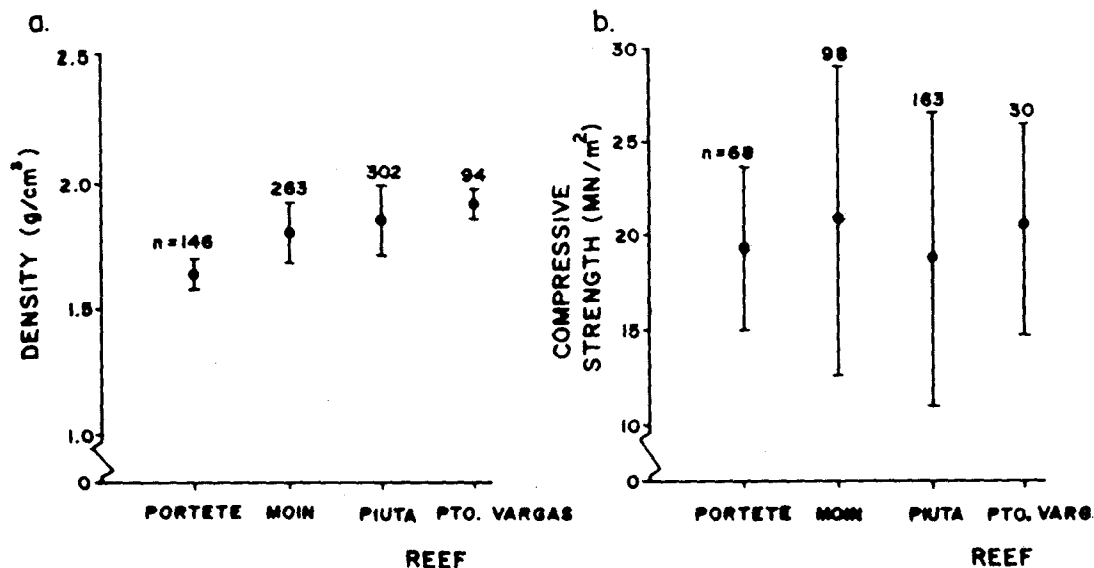


Fig. 4. Density ( $\text{g/cm}^3$ ) and compressive strength (meganewtons per  $\text{m}^2$  of coral skeleton) of *Siderastrea siderea* at the different reefs ranked in order of increased turbulence (to the right). Bars indicate standard deviation.  $n$  = number of cubes. Average density; b. Average compressive strength.

1985), is interfering with skeletogenesis of *S. siderea* is being investigated.

Average density of the samples per section varied in four of the colonies (MO2, PIU5, PIU6 and PVAR7) and in three of them (MO2, PIU6 and PVAR7) some sections were significantly different to the rest (Tukey  $P < 0.05$ ). Compressive strength was different in two of the colonies (MO2 and PIU5) and only in one (PIU5), was it possible to significantly differentiate one section from the rest (Tukey  $P < 0.05$ ).

The fact that sections on opposite sides of a massive colony are different, suggest structural heterogeneity of the skeletons. It has been shown that reproductive capacity, polyp vitality, stable isotopic composition and micro-architecture of the skeleton varied on different positions on the colony (Jell 1974, Land *et al.* 1977, Goreau 1977, Jackson 1985, Constantz 1986). It is possible that the differences in density are caused by the existence of hydraulic micro-environments around a colony, depending on orientation to currents (Chamberlain and Grauss 1975, Grauss *et al.* 1977, Schiller and Herndl 1989). These differences in water motion can be translated into differences in cement infiltration or on direct effects on the polyps, modifying skeletogenesis and as such the density of different parts of the colony. The

results of this work suggest that caution must be taken when studies are based on only a section of a colony, and assuming that what observed there is representative of the rest of the colony.

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