3-D distribution of nongeniculate corallinales: a case study from a reef crest of South Sinai (Red Sea, Egypt)

A. Caragnano · F. Colombo · G. Rodondi · D. Basso

Abstract An innovative technique for the estimation of species and growth-form abundance of coralline algae, including information on their vitality, was adopted on the reef crest of Ras Nosrani and Coral Bay, South Sinai. Data of coralline abundance from visual census and collection of voucher specimens were plotted on a 3-D sketched representation of the horizontal and vertical planes of the reef crest and of its crannies. Coralline dominance at the two investigated sites was not significantly different, with values ranging from 8.55 and 10.06% on the vertical plane and from 5.3 to 7.17% on the horizontal plane. About one-third of total corallines of the South Sinai reef crest was located in crannies, where the algae are completely overlooked by routine field surveys. Pink to violet, healthy corallines with encrusting growth-form, mainly belonging to *Hydrolithon onkodes* and *Neogoniolithon*, with subordinate fruticose *Lithophyllum kotschyanum* dominated the reef crest at both sites. The fruticose growth form, usually associated with *L. kotschyanum*, was more common in the horizontal than in the vertical plane. Purple, healthy, encrusting *Sporolithon* uncommonly occurred. Whitish, gray or green unhealthy or dead corallines were more common on the horizontal plane at both sites, possibly resulting from excessive solar radiation.

Keywords Nongeniculate Corallinales · Gulf of Aqaba · Reef crest · Visual census

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Introduction

Non-geniculate coralline algae (NCA) are multicellular plants, heavily calcified by calcite crystals embedded in the cell walls, which protect against grazing by herbivores and provide mechanical resistance (Fabricius and De'ath 2001). They are found in a wide range of climatic belts, from tropical to polar, and in light environments ranging from those of shallow tropical intertidal reef flats to almost complete darkness (Fabricius and De'ath 2001). Individual species or genera cannot be distinguished in rapid ecological field assessment, since their morphology and coloration is highly variable and not diagnostic (Woelkerling 1988). Species identification requires special staining and sectioning techniques, followed by light microscopy or scanning electron microscopy (Woelkerling 1988).

On coral reefs, light availability and grazing intensity by herbivores are major factors influencing growth rates of NCA which can be major space occupiers (Steneck and Testa 1997; Fabricius and De'ath 2001). NCA cover two key functional roles in coral reef environments. The most prominent role is their contribution to limestone formation and cementation of the reef (Littler 1971; Barnes and Chalker 1990; Macintyre 1997). Rock-hard encrustations of NCA reinforce the skeletal structures of dead corals and fill cracks in the reef substratum thereby maintaining topographic complexity and reducing reef erosion (Fabricius and De'ath 2001). The second NCA key functional role is as substratum for the settlement of many benthic organisms (Steneck and Testa 1997; Fabricius and De'ath 2001). Changes in NCA abundance on reefs can indicate changes in the structure and function of coral reef ecosystems (Steneck and Testa 1997). Shallow zones where rates of herbivory and predation are enhanced have the greatest abundance of shelter-providing calcareous algae (Steneck and Testa 1997).

Surveys on coral reefs showed a successional sequence of algae and invertebrates. The successional development of colonization of a bare substrate starts with an algal turf of filamentous green algae and cyanobacteria which is followed by other algae such as NCA, fleshy brown algae, and sessile reef invertebrates such as soft and hard corals (Littler and Littler 1984; McClanahan 1997; Coleman 2003; Diaz-Pulido and McCook 2004). The relationship between algae and invertebrates and the role that abiotic and biotic factors play in mediating, switching the direction, or arresting the succession of species after disturbances, are recently being elucidated (Steneck et al. 1991; Steneck and Dethier 1994; McClanahan 1997). Corals benefit from NCA as suitable substrates for larval metamorphosis and as consolidators of the coral build-up (Bégin and Steneck 2004; Westmacott et al. 2000).

Coral reefs are currently under serious threats resulting from a variety of natural and human disturbances. In the northern Red Sea, sources of contaminants can be grouped into three categories: urbanization and tourism, oil, and other industrial inputs (Dicks 1987). The enclosed nature of the Red Sea in conjunction with the limited water exchange with the Indian Ocean considerably reduces the potential for the dispersion of the pollutants, which is especially true for the extended gulfs of Suez and Aqaba (Walker and Ormund 1982; Dicks 1987). The magnificent marine life of the Red Sea coral reefs is a major economic source of income based on tourism. Urban development alongside the Egyptian Red Sea coasts extended very rapidly and the tourism activity increased tremendously during the last years (Kotb et al. 2001). Accordingly, increased activity of coastal construction frequently causes sedimentation in adjacent areas, leading to degradation of coral communities (Ormond 1987). The resilience of coral reefs depends on high rates of coral recruitment. Impacted reefs (increase of nutrients, reduce in grazing) can undergo a phase-shift from algal turf to macroalgae, which may reduce the abundance and diversity of NCA by fast overgrowth and shadowing, and consequently cause a sharp decline in coral recruits (Adey 1998; Lirman 2001; McCook et al. 2001; Bégin and Steneck 2004).

Nongeniculate corallines are considered as one of the best (paleo-) bathymetric indicators due to their general wide depth distribution on one hand, and sensitive reaction to light conditions on the other (Rasser and Piller 1997). Paleoecological studies based on fossil NCA associations and growth forms suffer from the lack of a good data base of modern examples from different biogeographic regions (Rasser and Piller 1997).

Studies of the NCA distribution in the Red Sea are scarce. Rasser and Piller (1997) observed that the associations of encrusting organisms of the fringing coral reefs of Safaga (northern Red Sea) are dominated by coralline algae between 0 and 35 m depth.

Visual census methods (Stoddard and Johannes 1978) provide quantitative data for measuring changes in diversity and abundance of conspicuous species on uppermost reef surfaces. The method allows accurate measurements of species abundance, thus reducing the errors from inter-observer variability and achieving more consistent results, in both spatial and temporal context (Murray and Nature 2001). It includes different techniques such as quadrats and transects. However, a visual census misses undersides of ledges and crannies, which are more commonly colonized by NCA than upper surfaces, thus underestimating coralline abundance in reefs (Fabricius and De'ath 2001).

This article (1) describes a new method of field survey allowing the reconstruction of the three-dimensional distribution and abundance of corallines, and (2) demonstrates its application along the fringing reef crest of two tourist localities close to Sharm El Sheikh (South Sinai).

Materials and methods

The Egyptian Red Sea coast includes more than 1,080 Km of coral reefs on the western side of Gulf of Aqaba, both sides of Gulf of Suez, and along the proper coast of the Red Sea extending to the Sudanese border (Kotb et al. 2001). Climate in the entire Sinai Peninsula is arid but localized heavy rains (especially in winter) can lead to flashfloods carrying terrestrial material into the ocean. Air temperatures vary from 14°C in winter to 30°C in summer on the average, but can reach 47°C in the Sharm El Sheikh area (Geister et al. 1996). Due to the climatic conditions, the reefs in the Gulf of Aqaba are among the most northern-ones in the world (Edwards and Head 1987; Sheppard and Sheppard 1991). In the Gulf of Aqaba, sea surface temperatures vary between 20°C and 26°C, and surface salinities between 40.03‰ and 40.51‰ (Geister et al. 1996). In order to compensate for evaporation loss in the Gulf of Aqaba, surface water flows northwards through the Strait of Tiran from the Red Sea into the Gulf (Geister et al. 1996). However, the uppermost (>1 m) surface water layer is driven southward by the prevailing northerly winds. Average tidal range is less than 1 m (Reiss and Hottinger 1984).

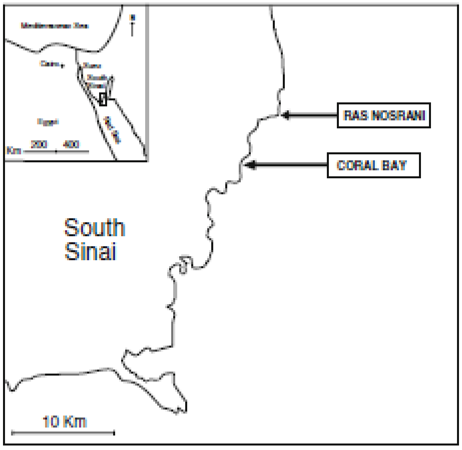


Fig. 1 Map of the survey area. The position of the two sampling sites is indicated

The NCA survey was performed along the South-Eastern coast of the Sinai Peninsula, at the entrance of the Aqaba Gulf, the Tiran Straits, at Ras Nosrani (27°58,136′N, 34°25,167′E) and at Coral Bay (27°55,730′N, 34°22,014′E) (Fig. 1).

Coral Bay opens to the East into the Strait of Tiran. It is a small bay entirely encircled by strongly eroded Pleistocene reef terraces. It has a narrow reef flat, about 44 m in width, whose proximal part is blanketed by mixed carbonate-siliciclastic sediment. The reef structure and benthic zonation conform to the pattern in literature (Fig. 2a) (Loya 1972; Edwards and Head 1987; Sheppard and Sheppard 1991; Geister et al. 1996; Kotb et al. 2001).

The Ras Nosrani reef flat is approximately 120 m wide, and the shore opens toward the East in front of Tiran Island. In this site the reef structure and benthic zonation also conform to pattern described in the previous studies conducted in this area (Fig. 2b) (Loya 1972; Edwards and Head 1987; Sheppard and Sheppard 1991; Geister et al. 1996; Kotb et al. 2001).

At both sites numerous resorts occur and reefs are subjected to intense tourist activity by SCUBA diving and snorkeling.

The study was performed in May and June 2004. A GPS-positioned transect line, 10 m long (Loya 1978) was stretched tightly following the depth contour on the reef crest. Two replicates were surveyed at each site. Data were collected by snorkeling and recorded on slates. The transect was used as a reference to position the 50 cm × 50 cm quadrats (Fig. 3). Quadrats were placed both on the horizontal plane and on the vertical plane along the reef crest. Both the distribution and the percentage cover of non-geniculate Corallinales were recorded by observations on the vertical and horizontal surfaces of the crest, and down to 50 cm inside crannies or fissures of the reef. Each quadrate was divided into 64 smaller quadrates 6.25 × 6.25 cm each, in order to facilitate coralline cover quantification. The algae were classified by color and growth form as observed during the field work, by extensive use of underwater digital photographs (Table 1). Color was considered as an index of NCA vitality. Pink-violet thalli were considered typical of healthy and vital corallines. Gray, green, and white thalli correspond to dead corallines or reduced photosynthetic activity (also by pigment degradation under direct sunlight) (Bressan and Babbini-Benussi 1996).

The three-dimensional NCA distribution was graphically elaborated by Rhinoceros 3.0 Evaluation, Adobe Photoshop 7.0 software. The reef crest of these survey sites has a step shape, which can be represented in three-dimensions (3-D) by a parallelepiped. The coralline database was used to create the 3-D Corallinales distribution and cover on the reef crest, by considering three types of data. The first was the NCA percentage cover on observable surface areas of the horizontal and vertical planes of the reef crest referred to the total surface of the plane. The second type included the NCA surface area (cm^2) inside crannies and fissures on the horizontal and vertical planes of the reef crest. Percentage distribution of coralline categories from crannies refers to the total surface of detected corallines, since the total surface of the crannies is unknown. Therefore, the data on surface percentage cover and on total surface in crannies are not comparable since they are based on different units. The third type corresponded to the NCA color, as indicator of vitality. These different types of data were represented by circular colored patches on the parallelepiped which indicate the Corallinales cover in square centimeters. In order to improve graphic representation, data concerning corallines in crannies and fissures (second type) were summarized into three size ranges (Table 2). Each size range was displayed into the parallelepiped using different cylinders height (5 cm radius), which represent the crannies.

At each site, the quantitative results (cm^2) from surfaces (horizontal and vertical planes) were related with those from crannies and fissures through a surface/cranny coralline ratio:

$$(TC_{Hor} + TC_{Vert})/TC_{Cra}$$

where TC is the total coralline cover in square centimeter for the horizontal (Hor), vertical (Vert) planes, and crannies (Cra).

For each category, several samples of NCA were collected and identified by Scanning Electron Microscopy

Fig. 2 Schematic bionomic profiles showing changes in benthic assemblages along the depth contour at a Coral Bay and b Ras Nosrani. Layers thickness is arbitrary

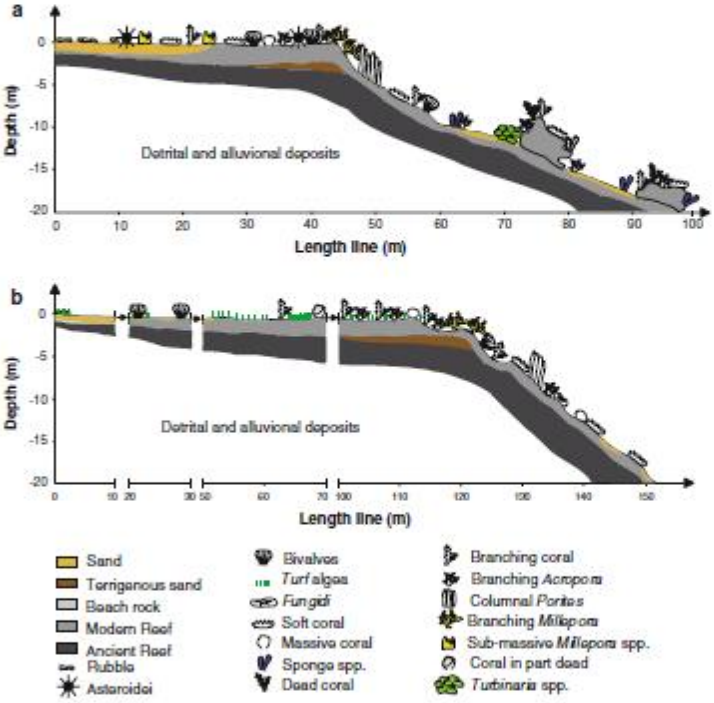


Fig. 3 Sampling quadrate, 50 cm × 50 cm in size

Table 1 Non geniculate coralline categories based on underwater observations of color and growth-form

Code	Description	*Genus or category*
IRoP	Purple, encrusting	*Sporolithon*
IVSL	Gloss dark violet encrusting	*Sporolithon*
IRT	Light pink, encrusting	*Hydrolithon*
IRVP	Pink-violet encrusting to warty	*Hydrolithon*
IRV	Pink-violet, encrusting	*Neogoniolithon*
IRTP	Light pink encrusting to warty	*Neogoniolithon*
RRV	Pink-violet fruticose	*Lithophyllum*
RRG	Pink-yellow fruticose	Unhealthy *Lithophyllum*
IRA	Pink-orange encrusting	Unhealthy NCA
OV	Green, encrusting	Unhealthy NCA
AM	White, encrusting	Dead NCA

(SEM) at the Milano-Bicocca facilities and by Optical Microscopy (OM) at the Milano University facilities. SEM and OM techniques for NCA identification are found in Basso and Rodondi (2006).

Benthic percentage cover on the reef crest at both sites was also investigated by Line Intercept Transect (LIT), visual census method, using a transect line 10 m long. A metric tape was tightly placed parallel to shoreline, following the depth contour (English et al. 1997). Four replicate transects were located haphazardly with no overlap. At any change of the benthic organism or substratum, the

Table 2 Three-dimensional size ranges for Corallinales percentage cover inside crannies

Size range (cm^2)	Cylinder height (cm)
0–195	5
195–390	10
390–586	15

transition point in centimeters and the benthos or substratum categories were recorded. Details of the LIT method are given in English et al. (1997).

A statistical analysis was conducted with the package Statistica 6.0 (StatSoft 2001). Statistical differences on the NCA distribution and abundance between both planes and sites were analyzed with non-parametric Kruskal–Wallis test.

Results

The total survey area at both sites is 5 m^2 for each vertical and horizontal plane.

During the visual census survey with the Line Intercept Transect technique, NCA percentage cover was zero at both sites (Ras Nosrani and Coral Bay). Results obtained after the survey with the 3-D technique are detailed below.

Ras Nosrani

The Corallinales total percentage cover on the Ras Nosrani reef crest is 10.06% (SE 7.11) on the vertical plane and 5.30% (SE 0.80) on the horizontal plane (Fig. 4). The pink-violet NCA and light pink NCA with encrusting growth form dominate on the vertical plane (Fig. 5a). On the horizontal plane the encrusting, light pink NCA dominate, along with fruticose, pink-yellow NCA (Fig. 5b). The fruticose coralline algae, although never dominant, are more abundant on the horizontal plane (12.33% SE 9.12) than on the vertical plane (32.04% SE 16.63).

The vivid pink-violet Corallinales at Ras Nosrani, comprise 79.24% (SE 3.29) of the total in the vertical plane, and 61.82% (SE 10.48) on the horizontal plane. Dead thalli (white) are 13.23% (SE 2.28) on the vertical plane, and on the horizontal plane pale gray algae are 25.61% (SE 15.28) (Fig. 5a, b). Encrusting growth forms with pink-violet color also dominate the cryptic environment of crannies and fissures (Fig. 5c). The white dead algae are only 3.41% (SE 2.15) and pale gray algae are 17.23% (SE 10.12) (Fig. 5c). The resulting surface/cranny coralline ratio is 3.95.

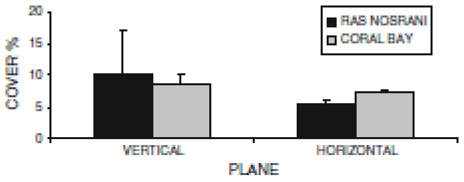


Fig. 4 NCA mean percentage cover (+SE) on the reef crest of Ras Nosrani and Coral Bay on the vertical and horizontal planes

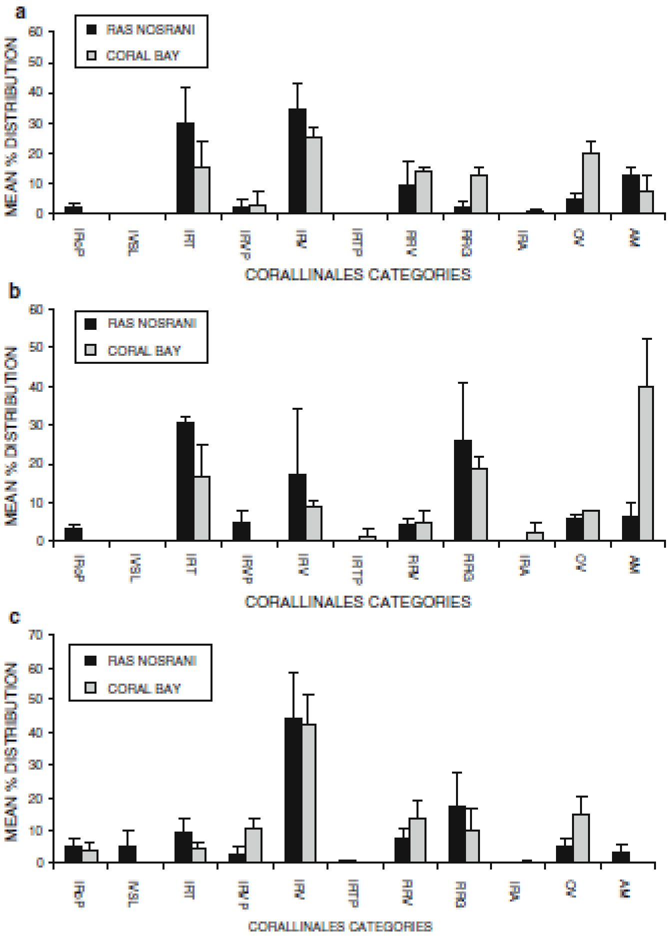
The 3-D representation of the Ras Nosrani reef crest (Fig. 6a-d) shows an uneven distribution of the coralline categories along both vertical and horizontal planes and in crannies. In the first 5 m of the first transect, pink NCA dominate (Fig. 6a), whereas between 5 m and 10 m of the same transect the pink-violet NCA thalli are smaller, more abundant, and concentrated at the end of the transect. Unhealthy corallines (green and gray thalli) become increasingly abundant toward the end of the transect (Fig. 6b). In the second transect the coralline distribution is more uniform than in the first one, and there is a predominance of NCA in crannies (Fig. 6c, d).

Coral Bay

The Corallinales percentage cover in the reef crest at Coral Bay is 8.55% (SE 1.60) on the vertical plane and 7.17% (SE 0.56) on the horizontal plane (Fig. 4). On the vertical plane the two most common growth forms, encrusting and fruticose, are more or less equally represented (Fig. 5a). The light and violet pink encrusting algae dominate as well as the violet and yellow-pink fruticose algae. Unhealthy encrusting corallines (green thalli) are dominant on the vertical plane, whereas the white (dead) NCA dominate on the horizontal plane (39.91% SE 8.60) (Fig. 5a, b). On the basis of the growth form, encrusting NCA dominate the vertical plane as well as the horizontal plane. On the basis of the color, pink-violet algae dominate the vertical plane while on the horizontal plane white dead algae predominate (39.91% SE 8.60) (Fig. 5a, b). In crannies and fissures the pink-violet, encrusting NCA dominate, whereas no white dead algae occur (Fig. 5c). The resulting surface/cranny coralline ratio is 3.29.

The 3-D representation of the distribution of Corallinales at Coral Bay (Fig. 7a–d) shows, as in Ras Nosrani, an uneven distribution of the coralline categories along the reef crest, on both planes and in crannies. In the first 5 m of the first transect the pink-violet NCA dominate, and they are clustered in the first half of the transect where unhealthy (green) coralline algae are also abundant (Fig. 7a). The second part of the first transect shows a more uniform

Fig. 5 Corallinales categories average percentage distribution (+SE) on the vertical plane (a), horizontal plane (b) and in the crannies (c) on the Ras Nosrani and Coral Bay reef crest. Percentages are referred to the respective total corallines cover at each site



distribution of NCA than the first one, and the pink-violet and light pink thalli always dominate. In the horizontal plane there are abundant unhealthy (gray) coralline algae in the crannies (Fig. 7b). The first 5 m of the second transect show a denser NCA cover than the other parts of the two transects. Pink-violet coralline algae always dominate and some green NCA occur in the crannies, particularly on the horizontal plane (Fig. 7c). The last part of the second transect shows a uniform distribution of mainly pink-violet and light-pink coralline algae. Among the unhealthy NCA, green and gray thalli appear common in crannies on the vertical and horizontal plane (Fig. 7d).

However, analysis of the distribution of sites and planes of the reef crest by the Kruskal–Wallis non-parametric test shows that no significant differences can be detected on the distribution of the NCA categories.

Among the specimens analyzed by SEM and OM, *Hydrolithon onkodes* (Heydrich) Penrose and Woelkerling 1992, *Lithophyllum kotschyanum* Unger 1858 and *Neogoniolithon* Setchell and Mason 1943 were identified as the most abundant coralline species occurring on the reef crest, while *Sporolithon* sp. Heydrich 1897 seldom occurs (Figs. 8 and 9). The IRV, IRTP, and IRVP algae (see Table 1 for Codes) were identified as Mastophoroideae

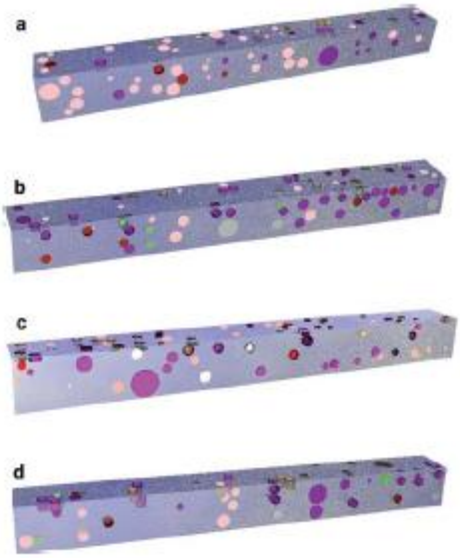


Fig. 6 Three-dimensional representation of Corallinales distribution on the Ras Nosrani reef crest. Each parallelepiped is 5 m long, 50 cm wide and 50 cm high. **a** 0–5 m of the first transect; **b** 5–10 m of the first transect; **c** 0–5 m of the second transect; **d** 5–10 m of the second transect

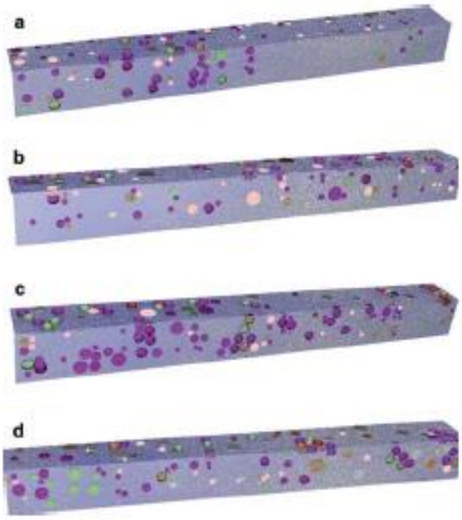


Fig. 7 Three-dimensional representation of Corallinales distribution on the Coral Bay reef crest. Each parallelepiped is 5 m long, 50 cm wide, and 50 cm high. **a** 0–5 m of the first transect; **b** 5–10 m of the first transect; **c** 0–5 m of the second transect; **d** 5–10 m of the second transect

(*Neogoniolithon* cf. *brassica-florida* or *H. onkodes*), the IRT as *H. onkodes*, the smooth IRoP, and IVSL as *Sporolithon* sp., the RRV as *L. kotschyanum* and the RRG as unhealthy *L. kotschyanum*. Further investigations on coralline taxonomy are in progress.

Discussion

The most important factors known to affect the growth of encrusting Corallinales in the subtidal environment are (1) *light intensity*; only few species of NCA tolerate bright light (Johansen 1981) and they show noticeable differences in their color depending on the characteristics of the light field (Payri et al. 2001); plants under strong solar radiation generally modify their pigment content to prevent photo damage (Beach and Smith 1996); (2) *sedimentation rate*: fine sedimentation threatens corallines survival by smothering, since they are slow-growing plants (Dethier and Steneck 2001); (3) *hydrodynamics*: a moderate water movement is required to keep the coralline surface clean and prevent poisoning by water stagnation (Steneck and Adey 1976; Wilson et al. 2004; Kleypas et al. 2006); (4) *intensity and type of herbivory*: a moderate herbivory is vital to corallines since herbivores keep NCA free from excessive over shading by fast-growing soft algae (Steneck 1983, 1986); (5) *water chemistry*: the requirement of NCA in macro and microelements is not fully understood. They appear to be less sensitive than corals to moderate organic pollution and nutrient increase (Walker and Ormond 1982; Szmant 2001) and to be severely inhibited under conditions of elevated carbon dioxide concentration (Kuffner et al. 2007).

The apparent differences observed for healthy (vivid pink-violet algae) and unhealthy (gray, green, and orange in color) NCA distribution at the two sites and on the two planes, however, are not statistically significant.

Encrusting NCA dominate both vertical and horizontal planes, in agreement with previous studies of shallow zones, where the highest rates of herbivory and predation occur and where the hydrodynamism is stronger than in other reef zones (Steneck and Testa 1997; McClanahan 1997; Adey 1998). The abundance of herbivores on the coral reef regulates the abundance of other components such as coral and macroalgae (Steneck and Testa 1997). Therefore, the greatest abundance of fruticose NCA is expected in crannies, which are the most sheltered part of the reef crest from herbivory, predation, and water movement. On the contrary, crannies were dominated by encrusting calcareous algae, although fruticose NCA were also abundant. Roaming herbivorous fishes influence algal

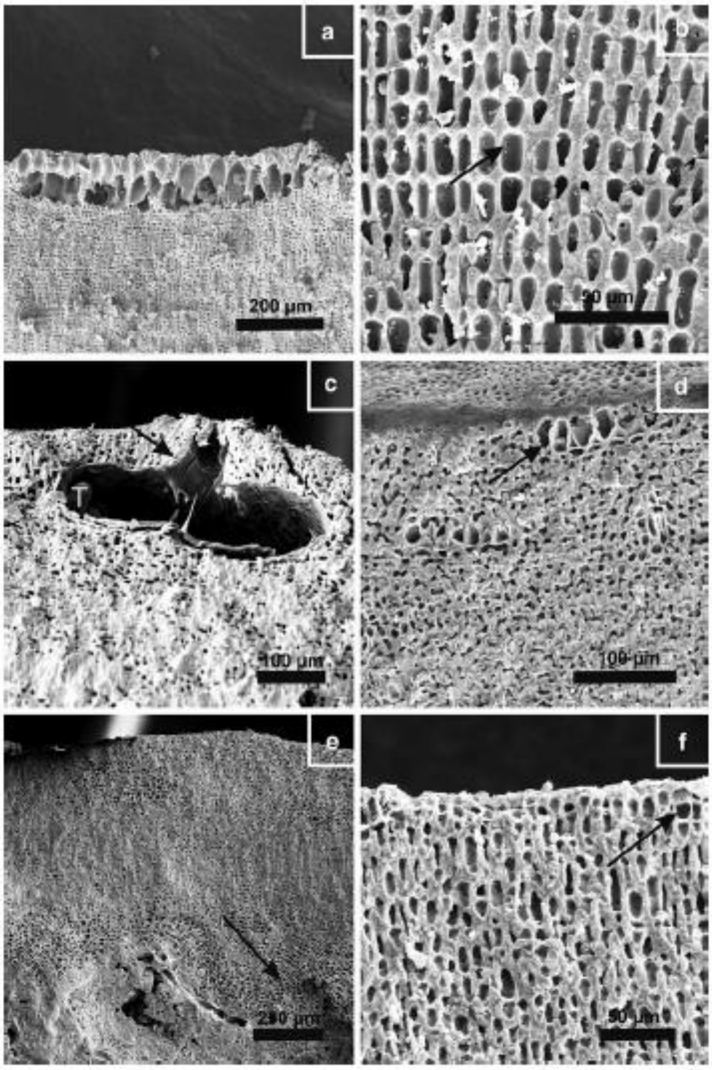


Fig. 8 SEM photographs of: **a** *Sporolithon ptychoides* Heydrich 1897 with a sporangial sorus; **b** *Lithophyllum kotschyanum* Unger 1858 showing numerous secondary pit-connections (*arrow*); **c** *Hydrolithon onkodes* (Heydrich) Penrose and Woelkerling 1992 uniporate tetrasporangial conceptacle showing a tetraspore (T) and longitudinal cells on the base of the conceptacle pore canal (*black arrow*); **d** *Hydrolithon onkodes* showing horizontally arranged trichocytes (*arrow*); **e** *Neogoniolithon* cf. *brassica-florida* (Harvey) Setchell and Mason 1943 longitudinal section of the thallus showing coaxial arrangement of the hypothallium (*arrow*) and **f** *Neogoniolithon* cf. *brassica-florida* with solitary or vertically arranged trichocytes (*arrow*)

succession (McClanahan 1997). Corallines require herbivores to remove fouling filamentous epiphytes in turbulent shallow zones (Steneck 1997; Hixon 1988). In the study area, abundant herbivores like some Acanthuridae and Scaridae promote the succession of species overgrowing the algal turf, such as coralline, and other calcareous and fleshy macroalgae (Steneck 1988). The inverse relationship between corallines and fleshy turf algae may be stressed by algal-trapped sediments smothering the corallines (McClanahan 1997; Adey 1998). Such sediment-trapping may be less effective between the widely-spaced fronds of macroalgae growing in shallow, wave-exposed fore reef environments, because of the sweeping effect of water movement (Steneck 1997).

On the reef crest in Ras Nosrani, the average percentage cover of turf algae from LIT data was 10.98% (SD 8.80),

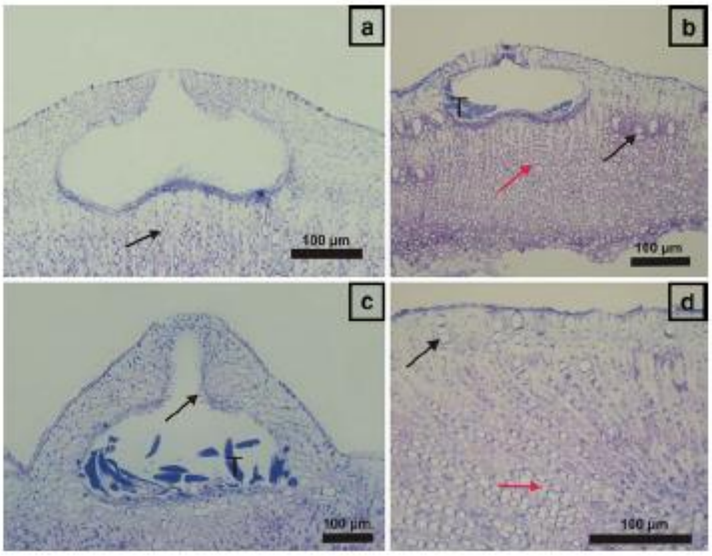


Fig. 9 OM photographs of: **a** *Lithophyllum kotschyanum* Unger 1858 uniporate tetrasporangial conceptacle, and secondary pit-connections between cells of contiguous vegetative filaments (*arrow*); **b** *Hydrolithon onkodes* (Heydrich) Penrose and Woelkerling 1992 uniporate tetrasporangial conceptacle showing a tetraspore (T), horizontally arranged trichocytes (*black arrow*) and vegetative filaments joined by cells fusions (*red arrow*); **c** *Neogoniolithon* cf. *brassica-florida* (Harvey) Setchell and Mason 1943 uniporate tetrasporangial conceptacle showing a tetraspore (T) and horizontal cells on the base of the conceptacle pore canal (*black arrow*); **d** *Neogoniolithon* cf. *brassica-florida* (Harvey) Setchell and Mason 1943 with vertically arranged trichocytes (*black arrow*) and vegetative filaments joined by cells fusions (*red arrow*)

data on macroalgae were not collected and hard corals represented 29.10% (SD 7.47). On the reef crest in Coral Bay they were respectively 0.38% (SD 0.75), 1.20% (SD 1.17), and 46.33% (SD 10.04). Both sites are under the same hydrodynamic condition and both undergo the same intensity of human impact. Competition between corals and macroalgae is considered fundamental to overall status of coral reefs (Littler and Littler 1984; McCook et al. 2001) and is a critical step in reefs degradation (McCook et al. 2001). Decrease of herbivores and increase of available nutrients leading to a decline of coral cover correspond to an increase of macroalgae (Adey 1998; Lirman 2001; McCook et al. 2001; Bégin and Steneck 2004). From this point of view, the comparison of NCA data recorded by quadrats with the LIT data suggests that the reef environments of Ras Nosrani and Coral Bay are very similar and, since NCA and other macroalgae are recorded as minor component, these reefs may be considered in good condition, despite intense tourism along the coast.

Non-geniculate coralline algae can develop a suite of diverse growth forms and shapes. They can develop thin, flat encrusting thalli, or thick and massive thalli with laminar surface, or produce a variable number and size of protuberances (fruticose growth form; Woelkerling et al. 1993). The ecological significance of shapes and growth forms of attached corallines is still under debate, however, it seems that a combination of species-specific growth forms and environmental variables account for most of the observed patterns (Reid and Macintyre 1988). According to Steneck and Adey (1976), attached, densely fruticose thalli occur in sheltered sites, while thalli with few protuberances are more frequent on the reef crest where water movement is the highest among all sectors of the reef. The results of this research confirm this pattern, since the greatest abundance of encrusting NCA was observed on vertical and horizontal planes. Although never dominant, the fruticose forms were more abundant on the horizontal plane, possibly indicating a lower intensity of wave action or a higher sedimentation rate. In contrast with Steneck and Adey (1976), in the sheltered habitat of crannies the most abundant category was still the encrusting NCA, while the fruticose NCA were not as abundant as expected. In both vertical and horizontal planes unhealthy and dead NCA were more abundant than in the crannies. The crannies are the most sheltered area of the reef crest, which have lower light intensity and fish predation with respect to the horizontal and vertical planes.

This study describes the distribution and abundance of NCA in the crannies and fissures of the reef. The surface/cranny coralline ratio suggests that about one-third of the total NCA on the reef crest occurred in crannies at both sites. In this cryptic habitat corallines are more abundant than other benthic organisms. NCA flourish in these cryptic environments because there is little competition from other members of the reef community, most notably, corals, hydrocorals, sponges, and fleshy algae (Adey and MacIntyre 1973). NCA have rarely been examined quantitatively or experimentally (Steneck 1997). The LIT allows exclusively the identification of the first visible category under the transect line, therefore failing to spot corallines at both sites. NCA on the vertical and horizontal surfaces of the reef crest at Ras Nosrani and Coral Bay went undetected, compared with the mean 7.77% (SE 0.98) revealed by quadrates. This result confirms the observation that in many instances the visual census techniques severely underestimates the abundance of coralline algae (Fabricius and De'ath 2001), since NCA are often hidden under other benthic organisms or are recorded as biogenic rock. NCA are considered in many ecological, geological, and palaeontological studies; however, it is recognized that their use as an ecological and paleoecological tool is still limited by the lack of a good database of modern examples from different biogeographic regions (Rasser and Piller 1997). A proper technique of data collection on living NCA from solid substrate is crucial in building such a database.

Rasser and Piller (1997) reported four species associations in their depth zonation of the Northern Red Sea. Following Rasser and Piller (1997) *Lithophyllum kotschyanum* is dominant on the intertidal reef flats and *Hydrolithon onkodes* dominates on the reef crest down to 15 m depth. Similarly, the reef crest in Ras Nosrani and Coral Bay is characterized by *Lithophyllum* sp. in association with *Hydrolithon*. *Neogoniolithon* sp. is also abundant on reef crest of these sites, in agreement with Rasser and Piller (1997). Specimens of *Sporolithon* sp. were collected also on the reef crest, although with low frequency. Despite a considerable degree of variability, some correspondence between color, growth form, and taxonomy was observed. The fruticose pink-violet corallines were invariably identified as *Lithophyllum* sp. and the purple and pink-violet encrusting thalli corresponded to mastophoroids. Color and growth form resulted to be variable among the mastophoroids, although purple NCA corresponded more often to *Neogoniolithon* sp. and pink encrusting thalli were *Hydrolithon* sp. The purple, smooth or even glossy NCA usually corresponded to *Sporolithon* sp.

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