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NOTE

Effects of environment on regeneration rate of tissue lesions in the reef coral *Montastrea annularis* (Scleractinia)

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ABSTRACT: Regeneration rates of tissue lesions and linear growth rates (density bands) were compared in the coral *Montastrea annularis* for 2 localities at reefs along the leeward coast of Curacao. One site was adjacent to the discharge from a combined desalination-power plant; the second was situated at a pristine reef on the southeastern tip of the island. In addition, we made measurements on a series of corals transplanted from the pristine reef to the desalination-power plant site. We found that the environment played an important role in controlling the regeneration rate of lesions but observed results were the converse of those expected; all lesions located at the desalination-power plant site regenerated significantly faster than those located at the pristine reef. There was no significant difference in growth rates between sites nor was there any discernable correlation between growth rate and regeneration rate. It is hypothesized that occasional influxes of colder oceanic water masses are responsible for the retarded regeneration rates observed at the pristine reef.

Coral growth has been shown to be affected by a wide variety of environmental factors (e.g. Buddemeier & Kinzie 1976). We hypothesized that lesion regeneration as a closely related process (Bak 1983), involving both tissue growth and calcification, might also be affected by environmental influences. Given the basic similarities between these 2 processes (coral growth and regeneration), we thought that they would probably respond to similar environments in much the same way. This supposition led us to believe that the study of regeneration in corals might lead to a viable technique for assessing and monitoring the 'health' of coral communities.

Regeneration in scleractinian corals has long been a topic of investigation (Wood Jones 1907, Stephenson & Stephenson 1933, Fishelson 1973) but quantitative studies have only more recently become available (Loya 1976, Bak et al. 1977, Bak & Steward-van Es 1980, Bak & Criens 1982, Bak 1983). Bak and coworkers have shown that the regenerative capacity of corals is dependent upon the species of coral and the extent and nature of the damage incurred by the organism.

This study was designed to investigate the influence of environment on the regeneration rates of artificially induced tissue lesions in the scleractinian coral *Montastrea annularis* (Ellis and Solander). In addition, linear growth rates were obtained from experimental colonies.

Materials and methods. Experiments and observations were conducted at 2 study sites on the fringing reefs along the leeward coast of Curacao, Netherlands Antilles, between September 1982 and February 1983. The first site was situated approximately 100 m downcurrent from the discharge of a combined desalination-power plant. The second site, Awa Blancu, was located on a pristine reef towards the southeastern tip of the island (Fig. 1).

Logistic problems prevented continuous recording of temperature and salinity. However, at each visit to the sites we measured temperature and determined salinity (sample depth 6 m). Max-minimum thermometers were employed from 18 Nov 1982 to 21 Jan 1983. There exists ample additional information on environmental conditions at the desalination-power plant site (Hoppe unpubl.).

We made 1 tissue lesion per experimental coral (*Montastrea annularis,* method Bak et al. 1977), on the horizontal plane of the colony. The initial size of the lesions was $\pm$ 0.8 cm^2. All colonies used were restricted to a depth range of 5 to 9 m.

Three series of lesions were made: one on corals at the desalination-power plant (series DPP, n = 24), another on corals located at Awa Blancu (series AB, n = 25), and a third on corals which were transplanted from Awa Blancu to the desalination-power plant

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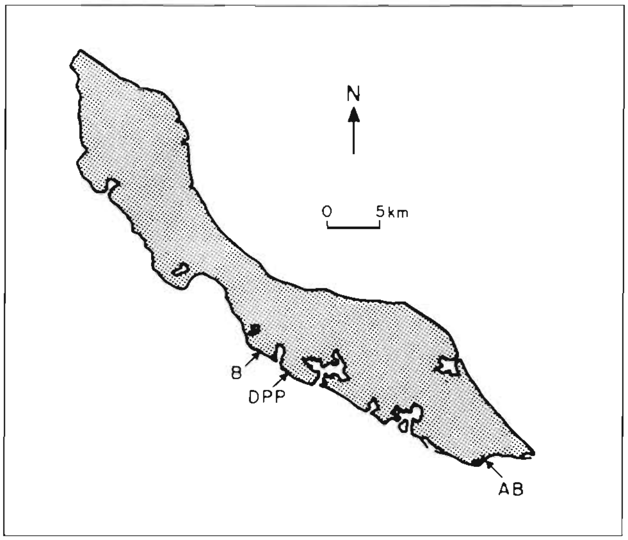

Fig. 1. Map of Curacao showing the locations of the study sites. DPP: desalination-power plant; AB: Awa Blancu; B: Location experiment Bak et al. 1977. Transplants were made from AB to DPP

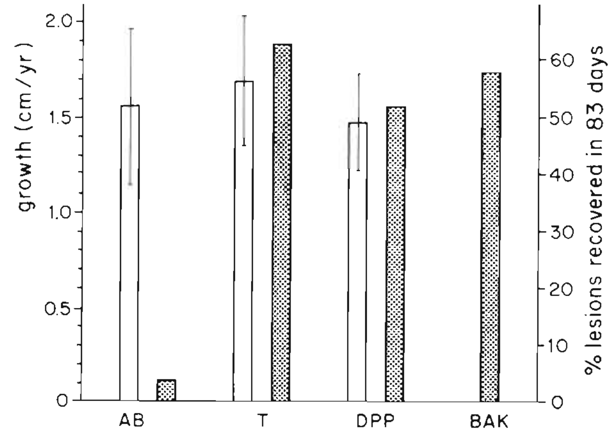

Fig. 2. *Montastrea annularis.* Recovery rate and growth rates for each experimental series. White bars: mean width of growth bands, s.d. indicated (AB: n = 10; T: n = 22; DPP: n = 11). Stippled bars: percentage of lesions completely recovered (AB: n = 25; T: n = 25; DPP: n = 24; Bak et al. 1977: n = 27)

(series T, n = 25). Corals in the latter series received experimental treatment (lesions) at the Awa Blancu site and were subsequently transported 21 km downcurrent to the DPP site. During transplant procedures, corals were kept in seawater at stable temperatures of 27 to 28 °C. Size of lesions was determined weekly. The DPP and AB series were each measured for 14 wk and the T series was measured for 12 wk.

In August of 1983 (approximately 6 mo after regeneration measurements had ceased) a total of 43 corals from all 3 series were collected and measured for annual growth increments as determined by X-radiographic analysis (method Buddemeier et al. 1974, Dodge 1980).

Results. Salinities and temperatures measured were within the normal range for the Curacao reefs, 35 to 36 ‰ and 26.5 to 28 °C. However, exceptions to this pattern were recorded for the desalination-power plant site where maximum temperatures reached 30 to 32 °C.

Both series of lesions located at the desalination-power plant (series DPP and T) regenerated much more rapidly than the lesions on corals located at Awa Blancu (series AB, see Fig. 2). At the end of the experiment 64 % and 63 % of lesions in the DPP and T series, respectively, had recovered completely, whereas the control series (AB) displayed a recovery rate of only 8 %.

Data on the mean percent surface area of lesions recovered after 12 wk was compared using the Mann-Whitney U test. Significant differences existed (t_s = 5.200, $p < 0.001$) between the series at the desalination-power plant (DPP and T) and the series located at Awa Blancu (AB). However, no significant difference was obtained (t_s = 0.180, $p > 0.5$) when comparing corals native to the desalination-power plant (DPP) with those that had been transplanted from Awa Blancu (T).

There were no significant differences in growth rate between the series (Fig. 2), nor was there any discernable correlation between growth rate and recovery rate ($n = 34$, $r = 0.22$, $p > 0.05$).

Discussion. Significant differences in recovery rates in different environments were found, although results were exactly the converse of those that had been expected. Lesions on corals at the desalination-power plant healed more rapidly than those at the pristine reef (AB). It is striking that the recovery rates displayed by the corals at the desalination-power plant (series DPP and T) are similar to measurements made from a previous study, 3 km northwest along the same coast (Bak et al. 1977). The reef at the desalination-power plant site is occasionally exposed to plant effluent, which is mainly characterized by higher than ambient temperatures (Hoppe unpubl.). At the depth of the experiment (6 m) corals are exposed for short time periods to maximum temperatures of 32 °C, a 4 to 5 °C increase over ambient temperatures (Hoppe unpubl., this paper). The similarities in the recovery rates of corals along this part of the coast imply that lesion regeneration was not appreciably affected by the power plant effluent and that some larger scale factor governs regeneration rates here. There is another reason to assume that these short term exposures had no detrimental effect upon the corals: the colonies did not show any signs of bleaching (loss of symbiotic algae), an indication of stress at elevated temperatures (Shinn 1966, Jokiel & Coles 1974, 1977, Coles 1975, Jaap 1979, Yang et al. 1980, Yamazato 1981).

The series transplanted to the desalination-power plant site (T) showed a dramatically accelerated recovery rate, compared with the control series at Awa Blancu (AB), approximating that of corals (DPP) native to the plant site. Consequently we have data on 3 experimental series recovering at the same rate (DPP, T, data Bak et al. 1977) and a series from Awa Blancu which appears anomalous in its ability to regenerate lesions. Apparently, the transplanted corals (series T) became rapidly adapted to their new environment. Rapid adaptation to different temperature regimes is known to occur in corals (Clausen & Roth 1975, Coles & Jokiel 1977, 1978) and this fact would implicate temperature as a possible cause of the retarded regeneration rates observed at Awa Blancu.

Due to its location on the coast, Awa Blancu has open exposure to oceanic water masses and seems to be subjected to occasional influxes of colder water (below 26 °C), originating at greater depths (Bak unpubl.). Occasional contact with these cold water masses would happen on a time scale of days rather than minutes/hours, the time scale of events at the desalination-power plant, and this may interfere with regeneration but not with long-term linear extension. The similarity of growth rates between our 3 experimental series suggests this to be the case.

Growth rates (annual linear extension) are high for Curacao, 1.7, 1.6 and 1.5 cm for series T, AB and DPP respectively, compared to the range of growth rates collected for *Montastrea annularis* at other sites along this coast (0.8 to 1.5 cm, Bak 1976, Hoppe unpubl.). They are also high compared with growth rates recorded at other Caribbean localities (Gladfelter et al. 1978, Hudson 1981). This underlines the most curious aspect of our results: corals, all in optimum growth conditions and not distinguishable in linear growth, register some environmental factor which results in extreme differences in recovery rate of lesions.

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LITERATURE CITED

Bak, R. P. M. (1976). The growth of coral colonies and the importance of crustose coralline algae and burrowing sponges in relation with carbonata accumulation. Neth. J. Sea Res. 10: 285–337

Bak, R. P. M. (1983). Neoplasia, regeneration and growth in the reef-building coral *Acropora palmata*. Mar. Biol. 77: 221–227

Bak, R. P. M., Brouns, J. J. W. M., Heys, F. M. L. (1977). Regeneration and aspects of spatial competition in the scleractinian corals *Agaricia agaricites* and *Montastrea annularis*. Proc. Third Int. Coral Reef Symp. Miami 1: 143–148

Bak, R. P. M., Criens, S. R. (1982). Survival after fragmentation of colonies of *Madracis mirabilis, Acropora palmata* and *A. cervicornis* (Scleractinia) and the subsequent impact of a coral disease. Proc. Fourth Int. Symp. Coral Reefs, Manilla 1981 2: 221–227

Bak, R. P. M., Steward-van Es, Y. (1980). Regeneration of superficial damage in the scleractinian corals *Agaricia agaricites* F. *purpurea* and *Porites astreoides*. Bull. mar. Sci. 30: 883–887

Buddemeier, R. W., Kinzie, R. A. (1976). Coral growth. Oceanogr mar. Biol. A. Rev. 14: 183–225

Buddemeier, R. W., Maragos, J. E., Knutson, D. W. (1974). Radiographic studies of reef coral exoskeletons: rates and patterns of coral growth. J. exp. mar. Biol. Ecol. 14: 179–200 lit

Clausen, C. D., Roth, A. A. (1975). Effect of temperature and temperature adaptation on calcification rate in the hermatypic coral *Pocillopora damicornis.* Mar. Biol. 33: 93–100

Coles, S. L. (1975). Comparisons of effects of elevated temperature *versus* temperature fluctuations on reef corals at Kahe Point, Oahu. Pacif. Sci. 29: 15–18

Coles, S. L., Jokiel, P. L. (1977). Effects of temperature on photosynthesis and respiration in hermatypic corals. Mar. Biol. 43: 209–216

Coles, S. L., Jokiel, P. L. (1978). Synergistic effects of temperature, salinity and light on the hermatypic coral *Montipora verrucosa*. Mar. Biol. 49: 187–195

Dodge, R. E. (1980). Preparation of coral skeletons for growth studies. In: Rhoads, D. C., Lutz, R. A. (ed.) Skeletal growth of aquatic organisms, Vol. 1 Plenum Press, New York, p. 615–618

Fishelson, L. (1973). Ecological and biological phenomena influencing coral-species composition on the reef tables at Eilat (Gulf of Aqaba, Red Sea). Mar. Biol. 19: 183–196

Gladfelter, E. H., Monahan, R. K., Gladfelter, W. B. (1978). Growth rates of five reef-building corals in the northeastern Caribbean. Bull. mar. Sci. 28: 728–734

Hudson, J. H. (1981). Growth rates in *Montastrea annularis:* A record of environmental change in Key Largo reef marine sanctuary, Florida. Bull. mar. Sci. 31: 444–459

Jaap, W. C. (1979). Observations on zooxanthellae expulsion at Middle Sambo reef, Florida Keys. Bull. mar. Sci. 29: 414–422

Jokiel, P. L., Coles, S. L. (1974). Effects of heated effluent on hermatypic corals at Kahe Point, Oahu. Pacif. Sci. 28: 1–18

Jokiel, P. L., Coles, S. L. (1977). Effect of temperature on the mortality and growth of Hawaiian reef corals. Mar. Biol. 43: 201–208

Loya, Y. (1976). Skeletal regeneration in a Red Sea scleractinian coral population. Nature 261: 490–491

Shinn, E. A. (1966). Coral growth rate, an environmental indicator. J. Paleont. 40: 233–240

Stephenson, F. A., Stephenson, A. (1933). Growth and asexual reproduction in corals. Scient. Rep. Gt Barrier Reef Exped. 3: 167–217

Wood Jones, F. (1907). On the growth-forms and supposed species in corals. Proc. Zool. Soc. Lond. p. 518–556

Yamazato, K. (1981). A note on the expulsion of zooxanthellae during summer, 1980 by the Okinawan reef-building corals. Sesoko Mar. Sci. Lab. Tech. Rep. 8: 9–18

Yang, R., Yeh, S., Sun, C. (1980). Effects of temperature on reef corals in the Nan-Wan Bay, Taiwan. Institute of Oceanography, National Taiwan University, p. 1–27

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