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A Photographic, Computerized Method for Measurements of Surface Area in *Millepora*

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Abstract

A method for measuring the surface area of the hermatypic hydrocoral *Millepora dichotoma* is described. Data were collected using a camera with a close-up attachment and a fixed frame. The photographs were digitized and analyzed by a program which computes the area and circumference of the colonies. This technique may be applied to a field survey and allows the measurement of the growth of the colony without handling or disturbing the colonies.

Keywords: photography, computer, surface area, *Millepora*

1. Introduction

The most striking characteristic of tropical seas are the coral reefs which develop along their shores. These reefs are composed of a great variety of organisms, many of which contribute significantly to their formation with their calcareous skeletons. Most reef building organisms belong to the Cnidaria and are termed hermatypes (Schumacher and Zibrowius, 1985). Repeated surface area measurements of a colony furnish information on its growth rate, which in turn provides one of the essential keys to understanding the dynamics of the reef. Many methods were devised to measure the growth of hermatypic organisms. These techniques were based on sampling branches at known time intervals, and are reviewed by Buddemeier and Kinzie (1976). These methods are destructive, involving breakage of branches or removal and killing of the colonies and include following ^{14}C or ^{45}Ca incorporation into skeletal material (Goreau, 1963), Alizarine Red-S staining (Barnes, 1972, 1973), and X-ray analyses of the skeletons (Buddemeier, 1978). Other methods, like repeated weighing (Jokiel et al., 1978; Bak, 1973), and displacement volume measurements (Buddemeier and Kinzie, 1976) require traumatic manipulations and may affect the natural growth, as suggested from transplantation studies (Yap and Gomez, 1985). The first study on coral growth using photography was reported by Mayer in 1918, who photographed colonies on the Great Barrier reef 23 years after they had been previously photographed by Saville-Kent in 1893 (Buddemeier and Kinzie, 1976). The growth rate in this study was measured as changes in length of the branches. Barnes and Crossland (1980) measured short term (hours) elongation rates of coral branches. An additional photographic method was described by van Moorsel (1985) for juvenile colonies of *Agaricia.* Two different studies measuring increments in the growing edges of *Millepora complanata* were reported by Stromgren (1975) and by de Weerdt (1981), both involving colony transplantations.

In this paper we describe a non-destructive *in situ* technique which allows the measurement of surface area of the hermatype hydrocoral *Millepora dichotoma.* This method was used to follow the growth of a *Millepora* colony under natural conditions over a 13 month period and briefly reported elsewhere (Rahav et al., 1990). Such a method is of great potential for long-term monitoring of coral growth and is of special importance for the study of the effects of anthropogenic stresses on corals and coral reefs.

2. Methods

Samples of the hydrocoral *Millepora dichotoma* (Milleporidae, Hydrozoa), one of the most abundant hermatypic species on the reef (Loya, 1972) were photographed using a Nikonos-4 underwater camera equipped with a 35 mm lens and a close-up attachment (Nikon) with a fixed frame. The frame ascertained the accurate positioning of the camera on the colony while a rule attached to the frame provided a constant scale. The coral was photographed at purposely distorted angles of $\pm 5°$, $\pm 10°$ and $\pm 15°$ from the perpendicular in order to determine the effect of inaccurate repositioning of the camera. In the laboratory, slides of the colonies were projected on paper attached to a board and the perimeters of the colonies were traced. The slide projector was placed at such a distance from the board as to reproduce an exact outline of the colony.

The traced outlines of *M. dichotoma* colonies were transferred to a PC compatible, equipped with a Hercules graphics monitor, using a Houston Instrument Hipad Digitizer. The digitizer, which provided a fast and accurate method of data entry, was connected to the computer via a standard RS-232 serial interface. Digitization was effected by moving a cross-hair cursor along the perimeter of the tracing. By utilizing the digitizer's "swift stream" mode, an operator controlled, continuous flow of x-y data pairs is fed into the computer where it is graphed in real-time, logged and filed according to specimen and date using a Turbo Pascal (Borland International) program developed for this project. Since manual digitization is likely to result in discontinuous and irregular data sections (due to jerky hand movements, for example), an interpolation algorithm was developed to fill-in and smooth the digitized data points. A second algorithm was developed to calculate the actual surface area of the three dimensional specimen. This was accomplished by first numerically integrating the entire planar area enclosed within the colony's perimeter, A_C, and then subtracting the integrated area of the "holes", $\sum A_H$, in the specimen. Multiple tracings of the same coral sample were prepared and digitized by three separate investigators in order to determine the reproducibility of the method. These computed values were compared to values obtained using a video camera set up to record the planar area of irregular shapes.

The actual surface area, S, of the three-dimensional branched *Millepora* colony was then calculated using the following formula:

$$S = 2\left(A_C - \sum A_H\right) + 1.14 \cdot \frac{1}{2}R \cdot \left(C_C + \sum C_H\right)$$

Where R is the average face to face thickness of the colony, measured using a specially modified plastic caliper, and C_C and $\sum C_H$ are the circumferences of the entire colony and holes, respectively. The factor of $1.14 \cdot 1/2R$ corrects for the ellipsoidal cross-section of the *Millepora* branch edges which are approximated as half circles of radius $1/2R$ (Fig. 1).

The surface areas of the same colonies were determined experimentally using melted paraffin. The preweighed samples were dipped in melted paraffin (60°C) and reweighed. The amount of adhered paraffin was calculated from the difference in weight. A calibration curve was prepared using small rectangular pieces of *Millepora dichotoma* whose surface area was accurately determined using a caliper. These samples were dipped in the same paraffin solution and a value for surface area per gram paraffin was calculated. Results so obtained were compared to those calculated by computer.

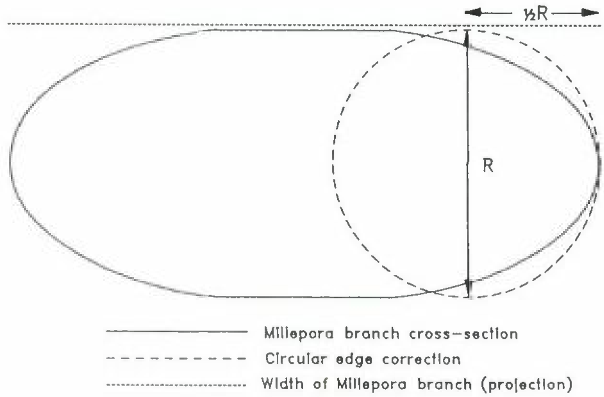

Figure 1. Correction for the ellipsoidal cross-section of the *Millepora dichotoma* branch edges

3. Results

Figure 2 presents the outline drawing of a sample *M. dichotoma* colony used in the calculations. Table 1 presents the calculated planar areas obtained using

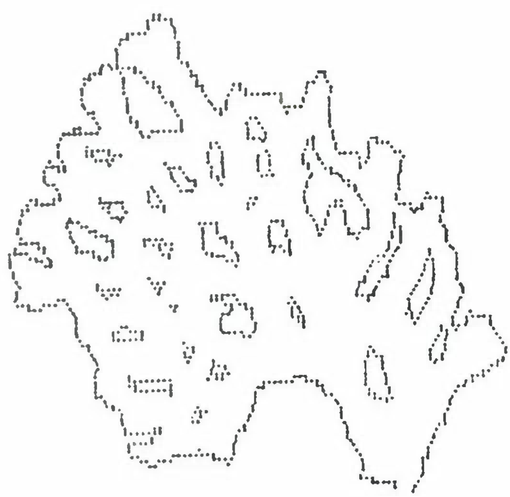

Figure 2. An outline drawing of a sample *Millepora dichotoma* colony used in the calculations

two different methods, a triangular integration and a linear integration, both of which gave identical results. These values deviated from that obtained using a video camera by not more than 3.5%. Planar area determinations on a given coral specimen, by the same or different person were found to be reproducible to within 0.6–1.0%. The calculated surface areas deviated from those obtained by the paraffin method by 6% at most.

Table 1. Calculated three-dimensional surface area of two *Millepora* samples

Coral	Planar area			Surface area		
	Video	Calc'd	% Dev	Wax	Calc'd	% Dev
A	25.7	26.5	3.3	62.2	65.9	6.0
B	31.8	32.3	1.6	89.4	92.4	3.4

Variability of the area as a result of changing the camera angle is presented in Table 2. As is to be expected, greater deviations can be observed for increased angular shift. It should be noted that at a 15° shift, which is in reality quite exaggerated, the deviation observed is less than 5%.

4. Discussion

In this paper we describe a reliable method for non-destructively calculating the actual surface area of the hermatype *Millepora dichotoma*. By repeatedly photographing the same colony from an identical position at various intervals, this technique enables the continued monitoring of the organism's growth as well as documenting natural changes like modifications in the shape of the skeleton, branching of colonies, closure of gaps within the branches, fusion of branches, breakage and regeneration. A preliminary application of the method was reported (Rahav et al., in press). Van Moorsel (1985) applied a similar approach to juvenile colonies of *Agaricia humilis* and *Agaricia agaricites*, whose coralum, at that stage of their development have a two-dimensional structure.

Table 2. The calculated planar area as a function of camera angle deviation from the perpendicular

Angle (±)	Area (cm sq)	% Dev
0	28.2 ± 0.5	1.8
5	29.0 ± 0.4	1.5
10	28.1 ± 0.8	2.9
15	28.5 ± 1.2	4.4
overall	28.5 ± 0.87	3.0

Millepora dichotoma was selected for this study because its colonies are comprised essentially of flat plates with holes and branches. Clearly, further development is needed in order to use this method for accurate growth estimation in corals having more complex geometries.

Copies of the above mentioned program will be gladly furnished upon receipt of a 5.25″ or 3.5″ diskette.

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