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Distinction of three species of *Ctenactis* (Scleractinia, Fungiidae) by multivariate analysis

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Abstract

A computer-assisted discriminant analysis was performed on size-independent morphological variables of fungiid coral skeletons. The method allowed a complete separation of three species of *Ctenactis* (Fungiidae) : *C. echinata, C. crassa* and *C. albitentaculata,* and confirmed the distinction made of these species based on field observations by a numerical approach.
Key words : reef corals, morphology, *Ctenactis*, discriminant analysis.

Résumé

Une analyse discriminante réalisée à partir de données morphométriques indépendantes de la taille a permis de séparer trois espèces du genre *Ctenactis* (Fungiidae). Cette méthode d'analyse a confirmé d'un point de vue numérique, la distinction entre *C. crassa, C. echinata* et *C. albitentaculata* déjà mise en évidence par des observations sur les polypes vivants.
Mots-clés : coraux, morphologie, *Ctenactis*, analyse discriminante.

Introduction

Despite the conspicuous appearance and abundance of mushroom corals (Fungiidae) in the shallow water reef environment of the tropical Indo-Pacific, the taxonomic status of some species or groups of species remains unclear. Recent field observations have allowed an easier distinction between species that until now had a doubtful taxonomic status (HOEKSEMA, 1989, CLAEREBOUDT & HOEKSEMA, 1987). Most corals are identified and placed in their taxonomic position through the examination of skeletal features; it is therefore most important to relate new methods of identification such as field observations of live specimens to methods based on skeleton analysis. Numerical taxonomy is still rarely used in reef coral systematics. WALLACE (1974) applied multivariate analysis to measurements of morphological features as a means to classify specimens of *Acropora*. LAMBERT (1984) used a continuous size independent variable to differentiate two species of Fungiidae (*Polyphyllia talpina* and *P. novaehiberniae*). CAIRNS (1982) at the generic level and later HOEKSEMA (1989) at the specific level used a cladistic approach to the morphological variation in the fungiid family.

This paper deals with the taxonomic status of *Ctenactis echinata* (PALLAS, 1766), *Ctenactis albitentaculata* (HOEKSEMA, 1989), and *Ctenactis crassa* (DANA, 1846) in the light of computer-assisted work based on multivariate analysis of size-independent morphological variables.

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Material and methods

All corals used in this study were collected at Laing Island (King Leopold III Biological Station, Papua New Guinea) between January 1984 and December 1985. All specimens were collected on a protected slope between 6 and 12 m in depth, and were identified and labeled as *C. echinata, C. albitentaculata* and *C. crassa* according to their morphological aspects as they appeared under water :

C. crassa has a polystomatous corallum with large triangular septal teeth and costae bearing fine spines. Its color is generally brown with cream patches.

C. echinata generally has multiple mouth openings, the septal ornaments are smaller and the costae bear large spinulose spines.

The color of the living specimen resembles that of *C. crassa*.

C. albitentaculata is easily identified in the field by its distinctive white tenctacles which are extended during daytime hours (pers. observation, HOEKSEMA, 1989). The color of the living specimen is maroon brown.

Specimens were studied in the laboratory and morphological analysis was performed on the cleaned skeletons. A total of 132 coralla, including 49 specimens of *C. albitentaculata*, 35 specimens of *C. crassa*, and 48 specimens of *C. echinata*, was examined. The measurements on each corallum were (Fig. 1) :

1\. Length of the corallum (L); 2. Width of the corallum (l); 3. Surface of the corallum (S); 4. Weight of the corallum (W); 5. Number of septa reaching the fossa (Nbsm); 6. Number of main septa measured along the edge of the skeleton (Nbs); 7. Length of the fossa (LM); 8. Number of calices (NbM); 9. Number of teeth per unit of septal length (NbST); 10. Number of teeth per unit of costal length (NbCT).

The surface of the coralla were estimated by weighing the cut-out projection of their outline on a sheet of paper and lengths were measured with analogic calipers to the nearest mm.

I then calculated 6 shape indices which were size-independent in addition to the septal and costal teeth counts :

a. W/S (weight/surface); b. L/l (length/width); c. Nbm/L (Number of calices/length of the corallum); d. LM/L (Length of the fossa/length of the corallum); e. Nbsm/L (Number of septa reaching the calice/length of the

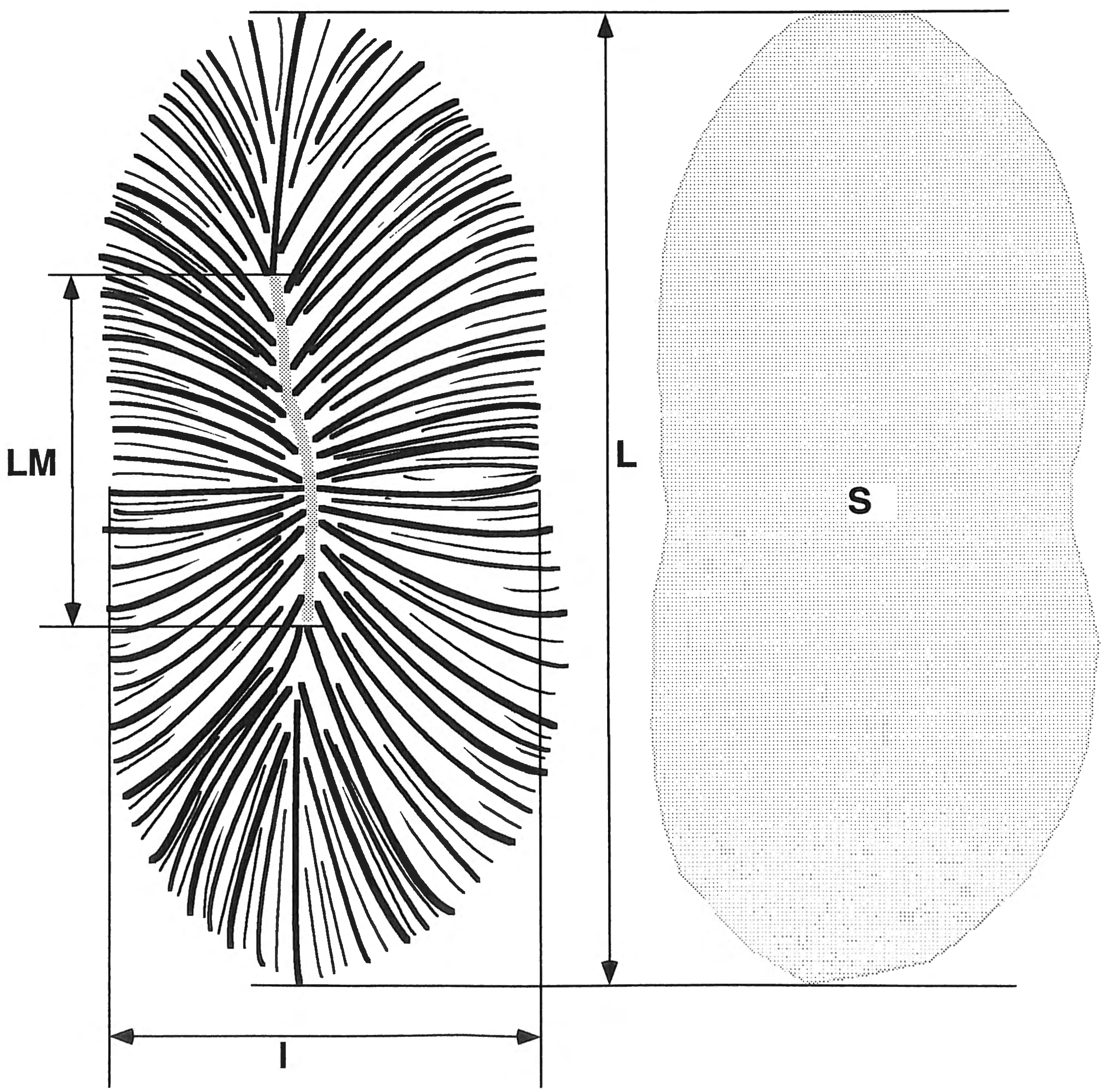

Fig. 1. – *Sketch of a simplified* Ctenactis *corallum showing the measured variables. L : length, l : width, LM : calice length, S : surface (shadowed). All main septa are figured (NbS), the main septa reaching the mouth are thickened (Nbsm).*

corallum); f. NbS/L (Number of main septa/length of the corallum); g. NbST (Number of teeth per unit of septal length); h. NbCT (Number of teeth per unit of costal length).
A computer-assisted search was used to outline significant discontinuities in the variable distributions. Discriminant analysis (LEGENDRE & LEGENDRE, 1984) was performed on the set of data to separate the different groups of coralla that were initially identified by field observations.

Results

Table 1 summarizes the data for the three groups of coralla before and after standardization by size (length or surface). Most variables were unable to separate statistically the three groups of corals (t-test, P>0.05) (Table 2). Even when statistical significance was observed between the 3 groups (Lm/L and Nbs/L), large overlaps in the distribution of the variables prevented an absolute identification of the coralla by morphological measurements. For example, the distribution of variable d (length of the fossa/length of the corallum : LM/L) for all specimens indicates three overlapping subdistributions corresponding to *C. albitentaculata, C. echinata* and *C. Crassa* specimens, respectively (Fig. 2). The means of the three distributions were all significantly different (t-tests, P<0.05) (Table 2). A better separation of the species was obtained in some two dimensional plots : e.g. variable b versus variable d (L/l vs. LM/L) (Fig. 3). Similar partial separations were obtained with variable f versus variable b (Nbs/L vs. L/l), variable e versus b (Nbsm/L vs. L/l) and variable d versus e (LM/L vs. Nbsm/L). Although indicative of plurimodal distributions none of the mono- or bi-variable representations allowed for an absolute distinction of the species : overlaps were present in all cases. An almost complete separation — or *a posteriori* identification — of the three species was obtained with the use of discriminant analysis (Fig. 4, 5). The first axis (discriminant variable #1) explained 57 % and the second axis (discriminant variable #2) 38 % of the total variance between groups. The eigenvectors (normed to unity) were : (0.10, 0.22, 0.32, 0.12, 0.40, 0.10, 0.56, -0.58) for the first axis and (0.077, -0.16, 0.49, -0.17, -0.22, -0.21, 0.54, -0.54) for the second axis. The 3 coralla of *C. albitentaculata* and *C. echinata* that were associated by the discriminant functions with the "wrong" species were all very young (very small specimens).
The numerical analysis also put forward the differences in the tendency to create additional calices displayed by

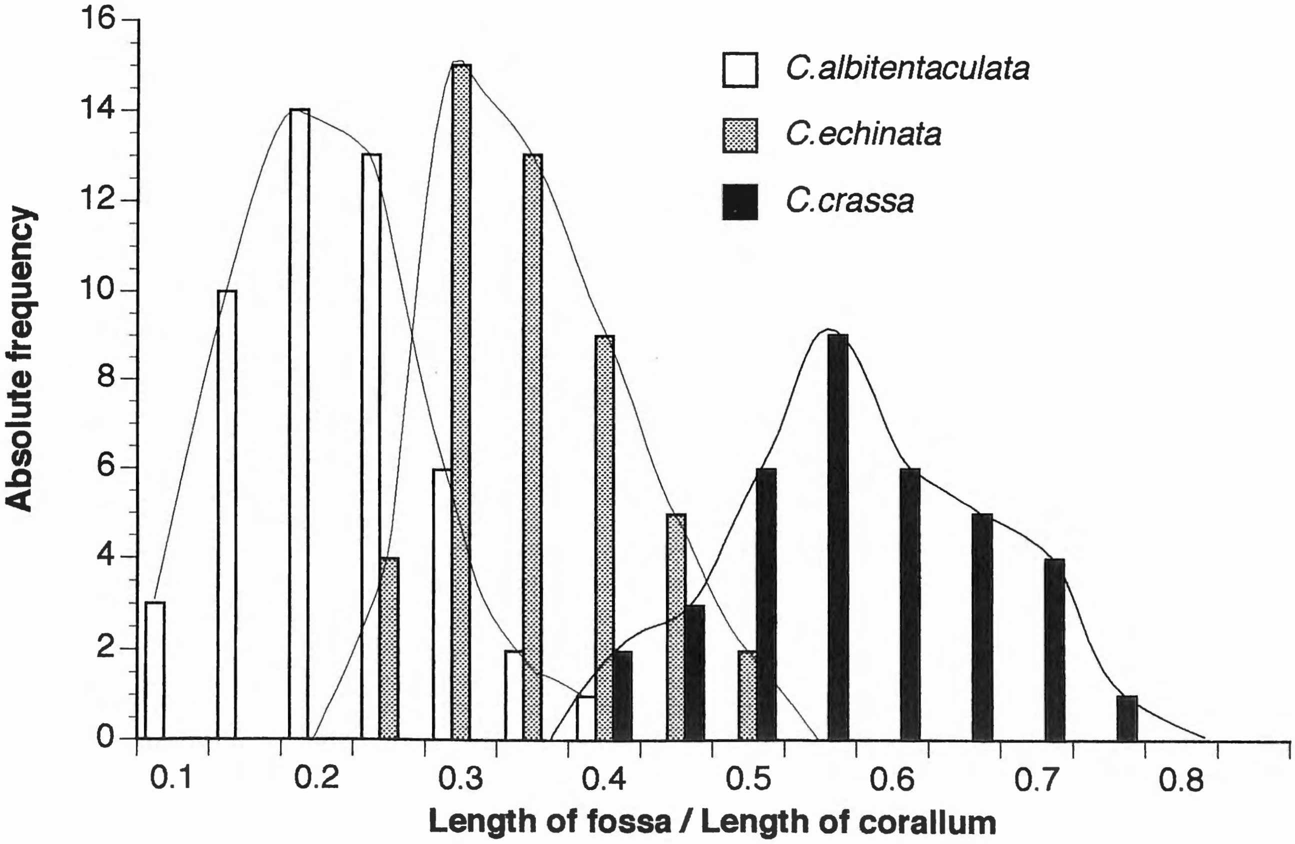

Fig. 2. – *Absolute frequency of the length of the fossa/length of the corallum : LM/L (variable d). A spline curve has been added for each distribution.*

Table 1.
Measurements taken on 132 specimens of Ctenactis. *1 : length, L (mm) – 2 : width, l (mm) – 3 : surface, S (cm²) – 4 : weight, W (gr) – 5 : number of septa reaching the fossa (Nbsm) – 6 : number of main septa (NbS) – 7 : length of the fossa, LM (mm) – 8 : number of mouths (NbM) – 9 : number of teeth per cm of septa (NbST) – 10 : number of teeth per cm of costa (NbCT), a : W/S, b : L/l, c : NbM/L, d : NM/L, e : Nbsm/L, f : Nbs/L, g : NbST, h : NbCT.*

		Original data Mean	Standard deviation			Transformed data Mean	Standard deviation
			Total (n = 132)				
1	L	187.96	62.57	a	W/S	2.52	2.07
2	l	91.29	26.89	b	L/l	2.33	0.40
3	S	173.80	65.70	c	NbM/L	1.13	0.96
4	W	438.32	410.89	d	LM/L	0.40	0.15
5	Nbsm	62.59	19.83	e	Nbsm/L	0.35	0.10
6	NbS	209.57	61.77	f	Nbs/L	1.16	0.29
7	LM	79.66	40.61	g	NbST	6.88	4.78
8	NbM	1.93	1.66	h	NbCT	10.05	4.28
9	NbST	6.88	4.78				
10	NbCT	10.05	4.28				
			Ctenactis albitentaculata (n = 49)				
1	L	199.28	65.97	a	W/S	2.76	1.11
2	l	98.88	28.69	b	L/l	1.99	0.30
3	S	215.65	88.24	c	NbM/L	0.59	0.36
4	W	595.22	471.98	d	LM/L	0.28	0.12
5	Nbsm	47.95	11.42	e	Nbsm/L	0.27	0.14
6	NbS	175.46	48.73	f	Nbs/L	0.91	0.13
7	LM	57.02	26.93	g	NbST	7.82	3.75
8	NbM	1.00	0.00	h	NbCT	7.48	1.59
9	NbST	7.82	3.75				
10	NbCT	7.48	1.59				
			Cteanactis echinata (n = 48)				
1	L	192.77	59.32	a	W/S	2.18	0.70
2	l	76.57	20.93	b	L/l	2.50	0.28
3	S	176.14	65.22	c	NbM/L	0.66	0.27
4	W	384.57	349.86	d	LM/L	0.38	0.15
5	Nbsm	62.36	19.83	e	Nbsm/L	0.35	0.10
6	NbS	218.69	56.03	f	Nbs/L	1.25	0.23
7	LM	85.46	40.35	g	NbST	8.15	1.44
8	NbM	1.22	0.54	h	NbCT	8.05	1.24
9	NbST	8.15	1.44				
10	NbCT	8.05	1.24				
			Ctenactis crassa (n = 35)				
1	L	167.25	57.34	a	W/S	2.67	3.61
2	l	65.72	18.10	b	L/l	2.51	0.37
3	S	118.20	85.37	c	NbM/L	2.42	0.85
4	W	315.61	339.02	d	LM/L	0.58	0.15
5	Nbsm	78.47	19.43	e	Nbsm/L	0.48	0.07
6	NbS	239.80	63.70	f	Nbs/L	1.39	0.36
7	LM	100.05	41.59	g	NbST	3.83	0.59
8	NbM	4.08	1.86	h	NbCT	16.38	2.30
9	NbST	3.83	0.59				
10	NbCT	16.38	2.30				

Table 2.
Student t-test probability of a difference in mean between the three species of Ctenactis.
ns = non significant at the 0.05 level.

Variable	*C. albitentaculata vs C. echinata*		*C. echinata vs C. crassa*		*C. albitentaculata vs. C. crassa*	
W/S	P = 0.004		P = 0.370	ns	P = 0.876	ns
L/l	P < 0.0001		P = 0.890	ns	P < 0.0001	
Lm/M	P = 0.290	ns	P < 0.0001		P < 0.0001	
NbM/L	P = 0.001		P < 0.0001		P < 0.0001	
Nbsm/L	P = 0.067	ns	P < 0.0001		P < 0.0001	
Nbs/L	P < 0.0001		P = 0.037		P < 0.0001	
NbST	P = 0.572	ns	P < 0.0001		P < 0.0001	
NbCT	P = 0.056	ns	P < 0.0001		P < 0.0001	

the three groups of coralla. Corals showed a large variation in the number of mouths along the fossa, going progressively from an almost consistent monostomatous state in *C. albitentaculata*, towards a consistent polystomatous state in *C. crassa* (Fig. 6). When *C. albitentaculata* increased in size, the length of the fossa increased slowly without forming additional calices. In this species only 1 % of the observed specimens showed a secondary mouth. *C. echinata,* while increasing in size, also shows an increased length of the fossa until a critical length (± 10 cm) is reached. At this stage, most of the coralla grow a secondary mouth and

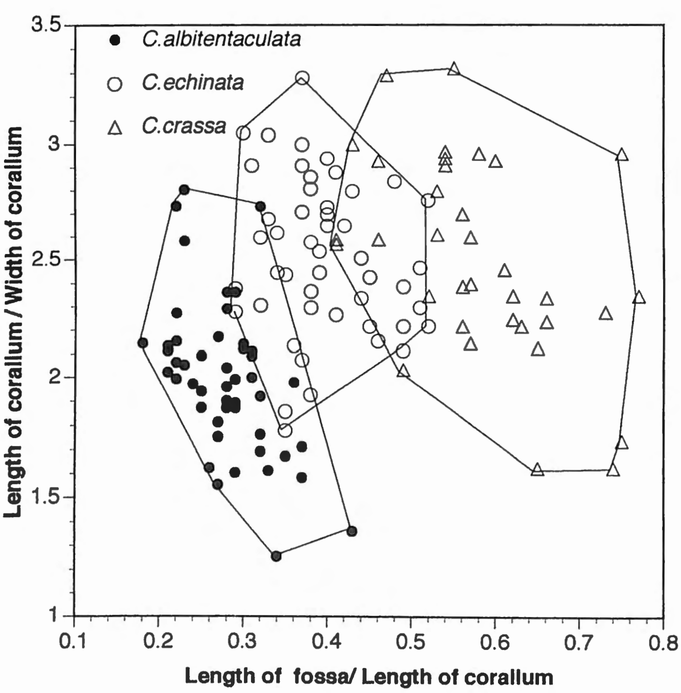

Fig. 3. – *Two-dimensional diagram of the measured specimens with their minimum convex polygones. Axis 1 : variable d (LM/L), axis 2 : variable b (L/l).*

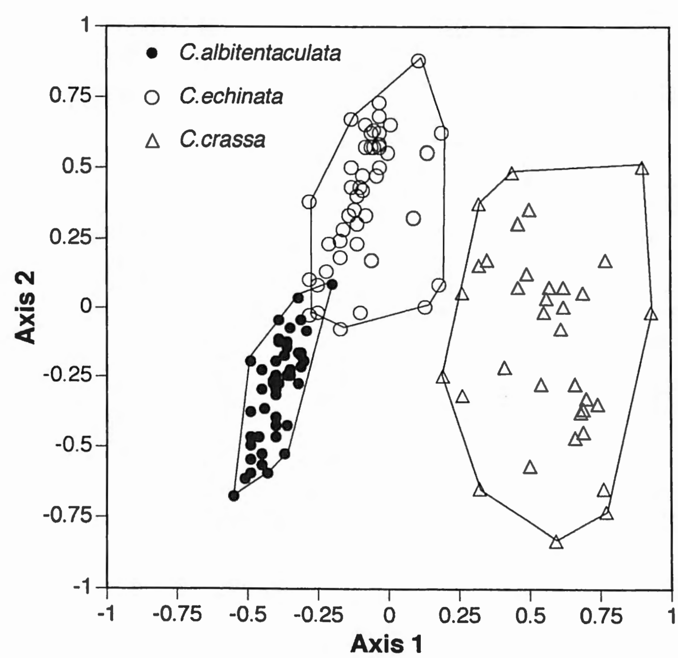

Fig. 4. – *Discriminant two-dimensional diagram with minimum convex polygones of the 132 analysed specimens. First discriminant axis : 57 % of the inter-group variance, second discriminant axis : 38 % of the inter-group variance.*

sometimes a third one in the largest specimens. A polystomatous state was present in 8 of the 48 specimens (16 %). When *C. crassa* grows, the length of the fossa and the number of mouths increases almost linearly with the size of the corallum. The only monostomatous specimens of this species were very small (very young).

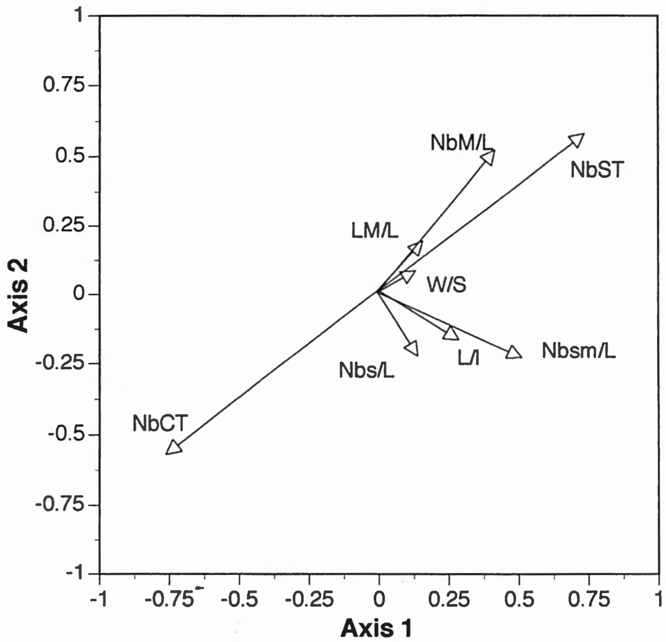

Fig. 5. – *Position of the original variables in the discriminant plane. The coordinates of each variable represent its correlations with the discriminant axis.*

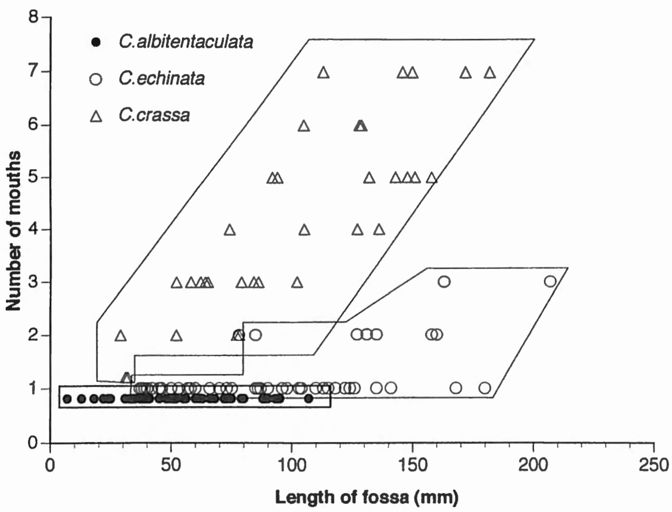

Fig. 6. – *Two-axis diagram of the number of mouths (NM) versus the length of the fossa (Lm) in mm.*

Discussion

The study of each of the variables individually suggests one polymorphic species of *Ctenactis* with all possible intergrades between extremes. On a multivariate scale however, complete separation of the three species is possible and supports the existence of three taxonomic entities. The recent review of the Fungiidae by HOEKSEMA (1989) enabled the identification of each of my specimens as one of the three species of the genus *Ctenactis*. In a previous review of the family, WELLS (1966) considered the genus *Herpetoglossa* with the single species *H. simplex* (= *Ctenactis crassa* according to HOEKSEMA, 1989) to be a seperate monospecific genus of Fungiidae because of the polystomatous state of the coralla. The data presented here shows that the multivariable distances between the three taxa are similar and do not support the separation of *C. crassa* from the two other taxa. This observation is in agreement with HOEKSEMA's (1989) review. He separates the genus *Ctenactis* from *Fungia* on the basis of the elongated corallum shape and classifies the three species, *C. crassa, C. albitentaculata* and *C. echinata* in one genus.

The appearance of successive mouths in the three groups of specimens is different and validates further the separation into three separate taxonomic entities. The observed patterns of mouth budding in the three species are in accordance with WELLS' (1966), CAIRNS' (1984) and HOEKSEMA's (1989) evolutionary models in the Fungiidae characters : i.e. the monostomatous state is considered as plesiomorph state whereas the polystomatous state is considered apomorph : *C. albitentaculata* showing the most "primitive" character state of the three species. Its known geographic range which is restricted to the central Indo-Pacific region, is also the smaller of the three species (HOEKSEMA, 1989). The two other species are found from the Red Sea and the Comoro Islands (pers. observation) to Okinawa (pers. observation) and Tahiti (HOEKSEMA, 1989).

The three *Ctenactis* species are easily distinguished under water by the living polyp and the costal ornamentation. In the laboratory, *C. crassa* is readily identified by the number of mouths and the fine ornamentation of the costae (Table 1). *C. albitentaculata* can be separated from *C. echinata* because (1) the ratio of length/width of the coralla (variable b) is smaller, (2) the ratio of number of primary septa reaching the mouth/the length of the coralla (variable g) is also sensibly smaller and (3) the ratio of length of the mouth/ length of the coralla (variable f) is much smaller (Table 1).

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