HISTORY OF THE STUDY OF THE RADULAR TOOTH IN CONUS AND A NEW METHOD OF COMPARISON EMPLOYED FOR THE ANGOLAN SPECIES

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KEY WORDS: Radula, radular studies, radular tooth, *Conus,* Angola.

ABSTRACT

The studies made on the radular tooth of the genus *Conus* are mentioned and their utilization in species separation. A comparison of some characters of the radular teeth in species of the genus *Conus* from Angola is made. A statistic method is employed and also a graphic representation showing a profile formed by the numerical values of five characters which have been shown to be more useful in this group of vermivorous species. The present work is a complement to the previous one describing Angolan *Conus.*

Received: 15 - XII - 99; accepted: 14 - I - 00

INTRODUCTION

TROSCHEL (1868) showed first drawings of the radular tooth of *Conus.* BERGH (1895) represented a high number of teeth in species of this genus with many other morphological details.

In the last century, SHAW (1914) described the radular teeth of two species of *Conus* and THIELE (1929-1931) and PEILE (1939) continued depicting the teeth of many others showing their differences.

Other works where the radular teeth of *Conus* were represented are CLENCH (1942), CLENCH & KONDO (1946), KOHN (1956, 1959), BARNARD (1958), WARMKE (1960), CROSS (1967a, 1967b, 1967c, 1968), LIM (1969), NYBAKKEN (1970, 1978), KILBURN (1971, 1973, 1974, 1975), CHANEY (1987), TROVÃO (1975a, 1975b, 1978a, 1978b, 1979) and JAMES (1980). Photographs of the teeth by Scanning Electronic Microscopy are showed in COTTON (1945), KOHN (1959), KOHN, NYBAKKEN & VAN MOL (1972), THOMPSON & BEBBINGTON (1973), BANDEL & WILS (1977), MARSH (1977), JAMES (1980), BANDEL (1984), VINK & COSEL (1985), ROLÁN & RAYBAUDI (1994b). ZELAZNY (1974) drew an extended radular tooth of *Conus* in order to shown better its different parts.

The utilization of the radular tooth in taxonomy is implicite in most of the works which showed different teeth for different species. PEILE (1939) differentiated the teeth drawn in several groups trying to make a classification. LIM (1969) separated the *Conus* species on the basis of teeth characters in vermivorous, piscivorous and molluscivorous species, although some of these prey differences had already been mentioned in PEILE (1939), KOHN (1959), ENDEAN & RUDKIN (1965), and by NYBAKKEN (1970).

The toxic action of the venom, its toxic effect on the humans and the mechanism of the capture of the prey have been studied by many researchers and are mentioned in ROLÁN (1992).

The radular tooth differences have been considered useful in specific separation, as in BANDEL & WILS (1977), MCLEAN & NYBAKKEN (1979). In an other way, NYBAKKEN (1970, 1988), NYBAKKEN & PERRON (1988) mention that there are differences in the radular tooth in juvenile and adult specimens. These differences were confirmed by ROLÁN (1986) and NYBAKKEN (1990), they are also shown by ROLÁN (1992) to be present only in very juvenile specimens, and they are more important in piscivorous species.

Many manuscripts describing new species of *Conus* were acompanied by a description of the radular teeth, as in VAN MOL, TURSCH & KEMPF (1967, 1971), AZUMA & TOKI (1970), AZUMA (1972, 1973), RABESANDRASANA (1974), TROVÃO (1975a, 1975b, 1978a, 1978b, 1979), RÖCKEL, COSEL & BURNAY (1980), ROLÁN (1980, 1986, 1990), RÖCKEL (1985, 1986, 1987), DA MOTTA (1986, 1987), DA MOTTA & HARLAND (1986), TROVÃO & ROLÁN (1986), TROVÃO, ROLÁN & FÉLIX-ALVES (1990), PIN & TACK (1995) sometimes using the characters of the radular tooth in a different way in order to separate species.

The names of the different parts of the radular tooth first appeared in PEILE (1939). WARMKE (1960) shows

these terms in a drawing. They were kept by JAMES (1980) and NYBAKKEN (1970) who increased them.

The first systematic work completing the terminology and making comparative studies of several species was made by ROLÁN (1992). Also it was proposed that there exist some evolutionary lines by ROLÁN (1993); this was complemented by ROLÁN & RAYBAUDI MASSILIA (1994a, 1994b). KOHN, NISHI & PERNET (1999) and NISHI & KOHN (1999) make a comparative analysis of the radular teeth in general and in molluscivorous species.

A revision on Angolan Conidae is begun in the previous work of the present magazine (ROLÁN & RÖCKEL, 2000), describing the previously known taxa and some new species. In that work, the radular tooth of every species is shown and is also compared with those that are morphologically close.

The objective of the present work is to make a quantitative comparison of some characters of the radular teeth of those species described in ROLÁN & RÖCKEL (2000) showing them through statistical and graphical methods. In this sense this work may be consider as a complement of that work.

MATERIAL AND METHODS

The material studied is that mentioned in the previous work (ROLÁN & RÖCKEL, 2000).

The preparation method of the the radulae, their observation and the related terminology were mentioned in ROLÁN (1992).

In the comparison of the radular tooth of two species of *Conus* we can find two very different types of teeth (for example, one of them being vermivorous and the other piscivorous). In this case, the reader, by simple observation, not even being an expert on such studies, can apreciate their differences. But on many occasions, we need to compare the radular teeth of two species which are very close phylogenetically, having the same ancestor, living in a similar habitat and probably capturing on similar prey (Polichaetae). In these cases, the speciation was probably produced by allopatric evolution, not having differences in those factors (habitat and prey) which usually represent the conditions of the evolution and changes; hence, the radular tooth of two distinc species did not need to be different at all, or they had only indifferent changes.

In order to obtain a general picture of the radulae shape rather than size, we chose two measurements (ND, D) plus a few ratios (LC/DR, DR/PA, 100*F/PA), which have been noticed to be those more variable among the Angolan *Conus* with vermivorous radular teeth, and so, being the most useful; we have plotted graphics employing these 5 radular characters which are:

1) number of teeth in the radula (ND),
2) number of denticles in serration (D),
3) length of the shell/length of the radular tooth (LC/DR) (ratio)
4) total length of radular tooth/apical portion (DR/PA) (ratio)
5) extension of the apical portion covered by the blade (F) (100*F/PA), shown as (%PA).

In order to represent the five characters within the same graphic, DR/PA was increased x 20. Other characters, as base of the tooth, arrangement of D in S, ABS, APA, etc. not plotted out have been commented on in the text in ROLÁN & RÖCKEL (2000) when necessary.

The measurements were used to estimate the overall morphological dissimilarity by the Euclidean distance obtained by the SPSS/PC package (the Euclidean distance is calculated by obtaining the square root of the mean square of the trait differences across traits and between species). The index range is between zero (for those identical population) and infinity (for those populations infinitely different). The significance of the trait differences between pairs of species were calculated by a classical oneway ANOVA following SOKAL & ROHLF (1995).

The order of the comparison of species is that presented in ROLÁN & RÖCKEL (2000).

RESULTS

Comparison of *C. bulbus: C. bulbus* is the oldest taxon for Angola; it will be compared in the study of the following taxa. See below.

Comparison of *C. aemulus: C. aemulus* is the second oldest taxon for Angola and will be compared in the taxa which follow; it has no apparent shell morphological relationship with *C. bulbus* and they do not need to be compared, but the comparison of their rather similar radular characters appear in the Fig. 2.

Comparison of *C. africanus: C. africanus* has a similar size of shell to *C. bulbus*. The comparison of the radular tooth characters of both is in the Fig. 1.

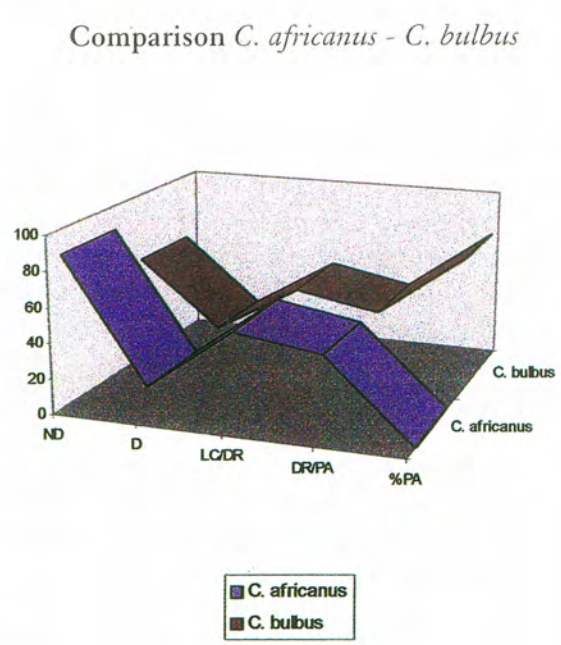

Figure 1. Comparison of some characters of the radular teeth of *C. africanus* (n=5) and *C. bulbus* (n=8).

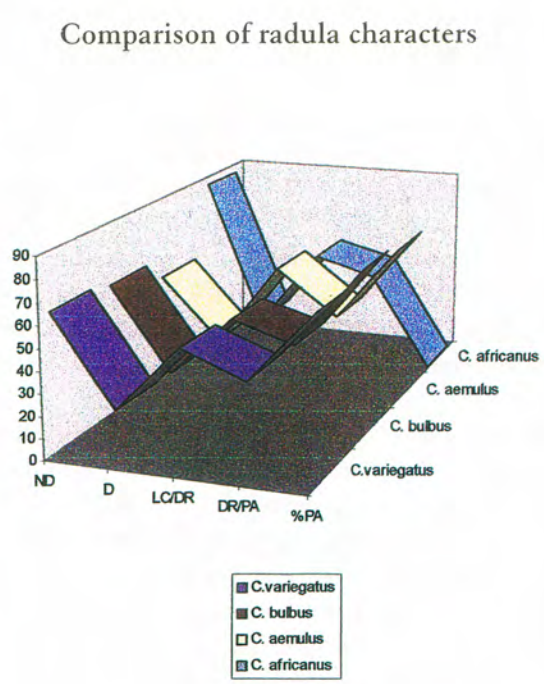

Figure 2. Comparison of some characters of the radular teeth of *C. variegatus* (n=9), *C. bulbus* (n=8) *C. africanus* (n=5) and *C. aemulus* (n=4).

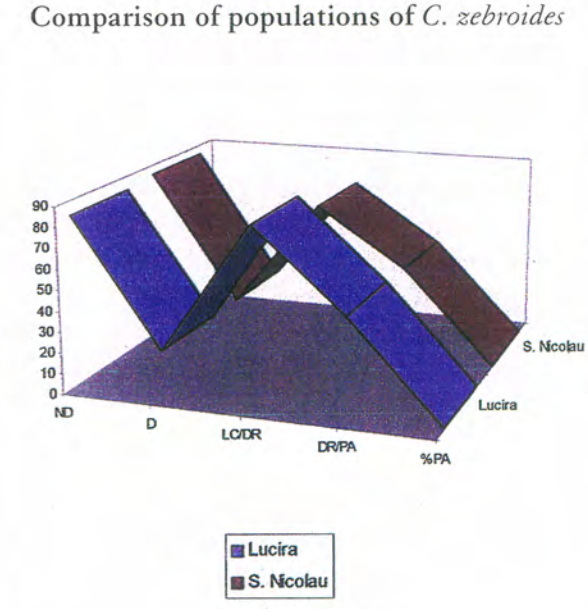

Figure 3. Comparison between some characters of the radular teeth of typical *C. zebroides* (n=16) from Lucira and the dark form (n=10) from S. Nicolau and Chapeu Armado.

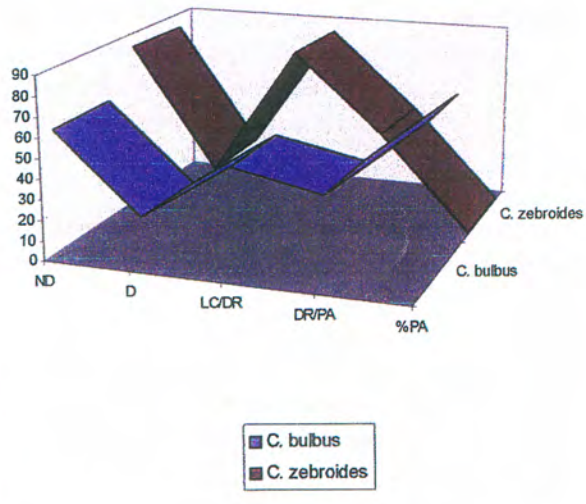

Figure 4. Comparison of some characters of the radular teeth of *C. bulbus* (n=8) and *C. zebroides* (n=16).

Comparison of *C. neoguttatus: C. neoguttatus* has a big shell and is not related to the other species previously mentioned. See below for comparison with others.

Comparison of *C. variegatus:* Comparison of this species must be made with *C. africanus* and *C. bulbus* because its size and with *C. aemulus* because its pattern. This comparison is seen in the Fig. 2. It can be seen that the radular tooth of *C. variegatus* is very similar to that of *C. bulbus* (in the five compared characters) and is also similar to that of *C. aemulus,* being very different from that of *C. africanus.*

Comparisons of *C. zebroides: C. zebroides* has two separate populations with a different pattern: one from north of Lucira and other from São Nicolau and Chapeu Armado. The comparison of the teeth of both populations (see ROLÁN & RÖCKEL, 2000, fig. 119) shows a great similarity (see Fig. 3) which reinforced the opinion that both populations are conspecific.

C. bulbus has a smaller shell than *C. zebroides,* but, as in some works they have been synonymized, we present the comparison of the radular teeth of both species in Fig. 4.

Comparison of *C. chytreus:* Comparison (see Graphic 5) must be made with *C. variegatus* because of its similar form and size, and with *C. fuscolineatus* because of its pattern. The three radular teeth are a little similar but shown significant differences in some characters (see Table 1).

Comparison of *C. carnalis:* This species is very different from the other endemic species from Angola and its radular tooth also is very different, so it is not nacessary ant comparison with the other vermivorous species.

Comparison of *C. fuscolineatus:* The species which can have a similar size and pattern are *C. chytreus* and *C. variegatus.* See Fig. 5.

Comparison of *C. cepasi:* In spite of shell differences *C. cepasi* must compared with *C. bulbus, C. zebroides* and with *C. naranjus* which have an axial pattern (see Fig. 6).

Comparison of *C. nobrei: C. nobrei* can be compared with *C. albuquerquei* by its pattern (see below).

Comparison of *C. musivus: C. musivus* must be compared with the most similar *C. bulbus* (Fig. 7). They have similar radular teeth in the characters studied.

Comparison of *C. naranjus: C. naranjus* must be compared with shells with axial stripes: *C. bulbus, C. zebroides* and *C. cepasi.* See Fig. 6.

Comparison of *C. albuquerquei: C. albuquerquei* must be compared with *C. africanus* because of its pattern and size (Graphic 8), and with *C. nobrei* due to the fact that some apparent intergradation has been found. In the last case the radular teeth are very similar and the statistical studies are not conclusive because only one specimen of *C. albuquerqui* was studied from the population considered corresponding to the species.

Comparison of *C. bocagei: C. bocagei* can have a similar pattern to some forms of *C. variegatus* but is different in other characters. The radular comparison can be seen in Fig. 5.

Comparison of *C. xicoi: C. xicoi* lives sympatrically with *C. aemulus* although different in size. The similarity of the radula (except in LC/DR) (Fig. 9) may mean evolutionary convergence or a common ancestor.

Comparison of *C. gabrielae:* Comparison of *C. gabrielae* must be made with *C. franciscoi* and *C. africanus,* because of its colour (Figs. 10 and 12).

Comparison of *C. micropunctatus:* The shell of *C. micropunctatus* has a pattern with some similarity to *C. neoguttatus* and *C. fuscolineatus,* so, their radular teeth are compared in Fig. 11.

Comparison of *C. filmeri: C. filmeri* because its white colour can have some similarity with *C. flavusalbus.* Their radular teeth are compared in the Fig. 14.

Comparison of *C. franciscoi: C. franciscoi* must be compared with *C. bulbus, C. zebroides* (Fig. 12) and *C. africanus.* Comparison with *C. gabrielae* is made (Fig. 12).

Comparison of *C. trovaoi:* Although with morphological differences in the shell, the size and profile show that there may be a relationship between *C. trovaoi* and *C. neoguttatus* (Fig. 13) their radular teeth are also similar only differing in LC/DR.

Comparison of *C. flavusalbus: C. flavusalbus* has a very different pattern from the other Angolan *Conus.* The closest species may be *C. fuscolineatus* (see Fig. 14).

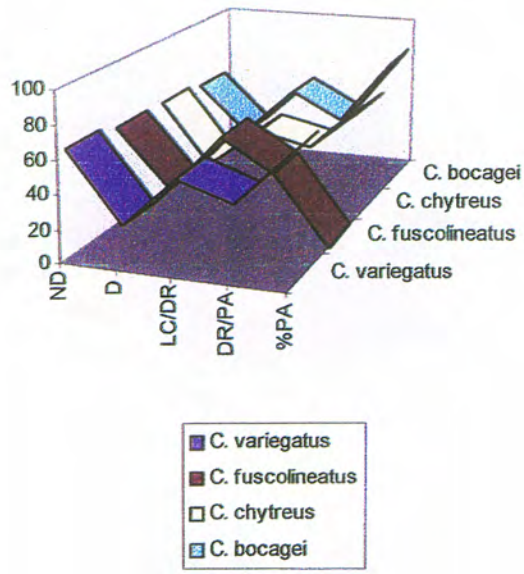

Figure 5. Comparison of some characters of the radular teeth of *C. variegatus* (n=9), *C. fuscolineatus* (n=6), *C. chytreus* (n=10) and *C. bocagei* (n=3).

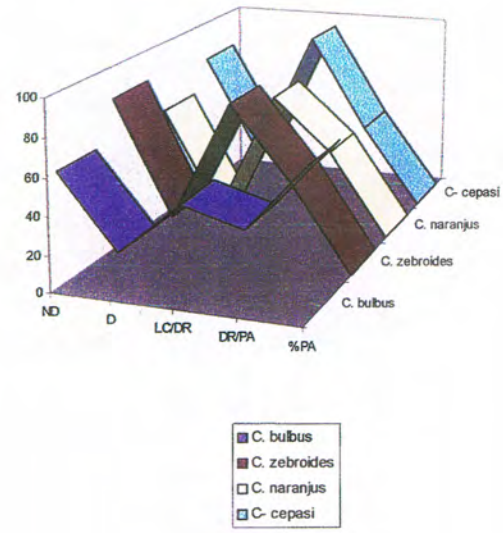

Figure 6. Comparison of some characters of the radular teeth of *C. bulbus* (n=8), *C. zebroides* (n=16), *C. naranjus* (n=2) and *C. cepasi* (n=4).

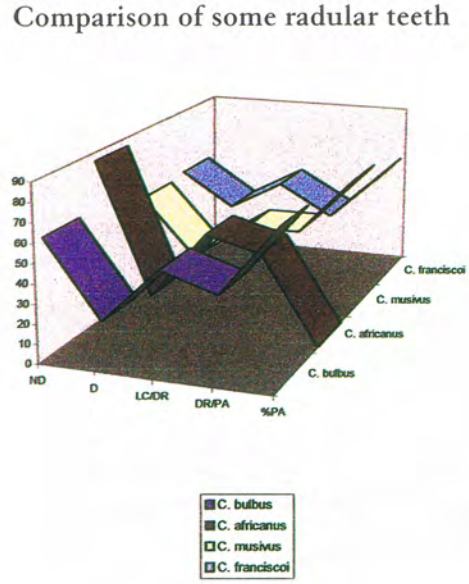

Figure 7. Comparison of some characters of the radular teeth of *C. bulbus* (n=8), *C. africanus* (n=5), *C. musivus* (n=8) and *C. franciscoi* (n=5).

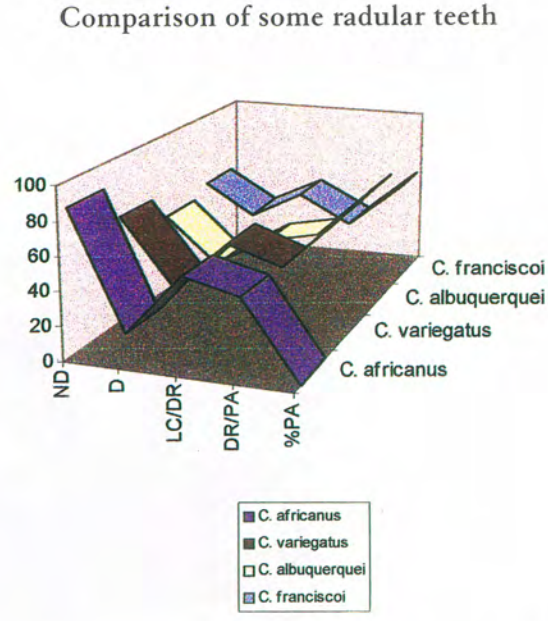

Figure 8. Comparison of some characters of the radular teeth of *C. africanus* (n=5), *C. variegatus* (n=9), *C. albuquerquei* (n=4) and *C. franciscoi* (n=5).

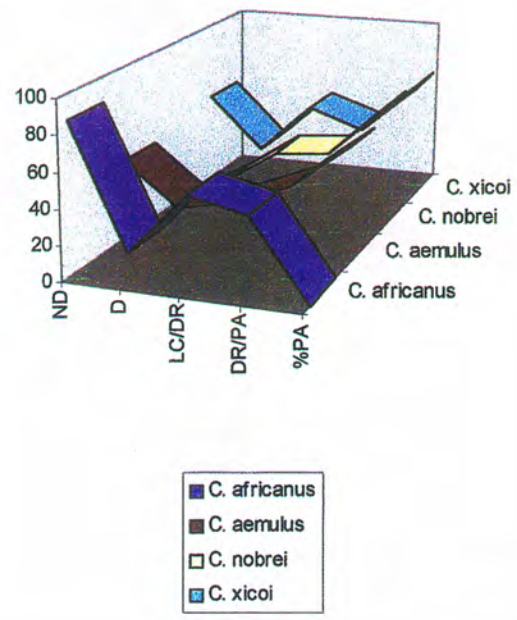

Figure 9. Comparison of some characters of the radular teeth of *C. africanus* (n=5), *C. aemulus* (n=4), *C. nobrei* (n=1) and *C. xicoi* (n=4).

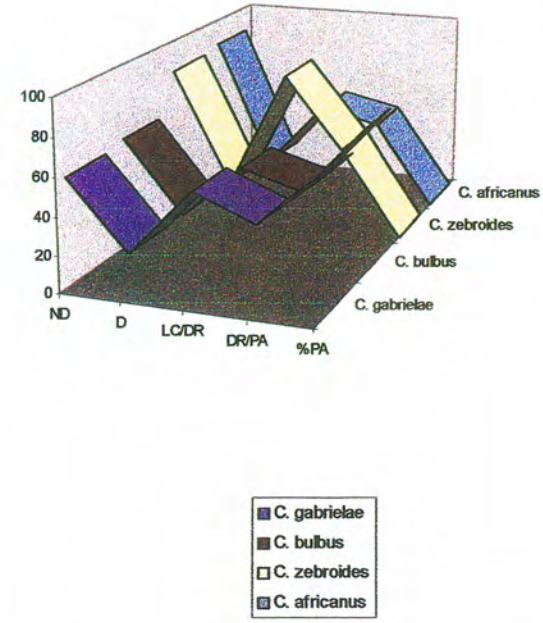

Figure 10. Comparison of some characters of the radular teeth of *C. gabrielae* (n=8), *C. bulbus* (n=8), *C. zebroides* (n=16) and *C. africanus* (n=5).

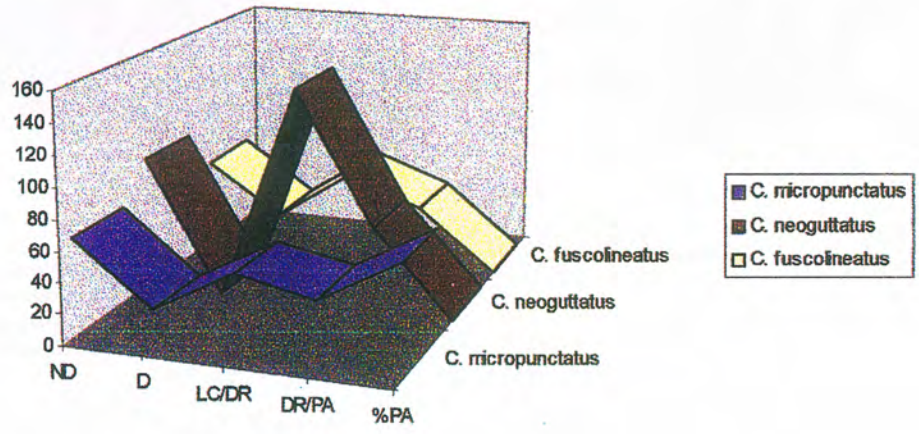

Figure 11. Comparison of some characters of the radular teeth of *C. micropunctatus* (n=7) and *C. neoguttatus* (n=4) and *C. fuscolineatus* (n=6).

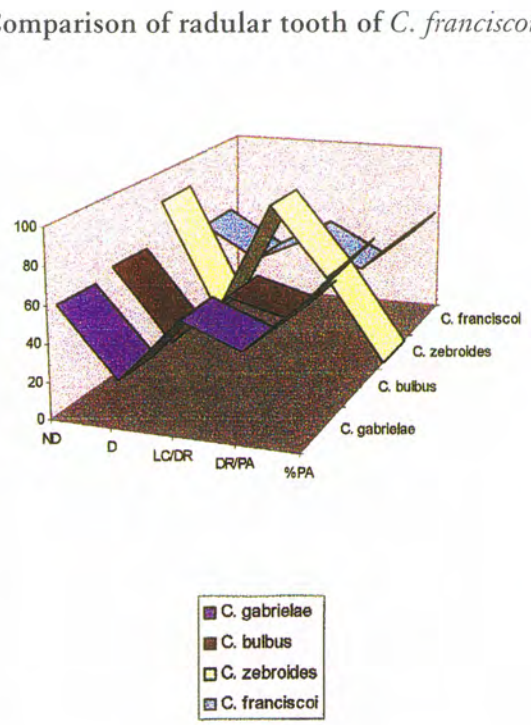

Figure 12. Comparison of some characters of the radular teeth of *C. gabrielae* (n=8), *C. bulbus* (n=8), *C. zebroides* (n=16) and *C. franciscoi* (n=5).

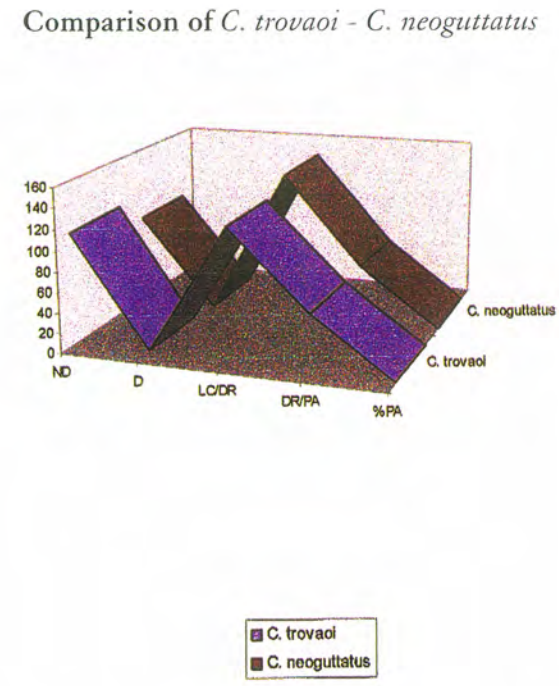

Figure 13. Comparison of some characters of the radular teeth of *C. neoguttatus* (n=4) and *C. trovaoi* (n=5).

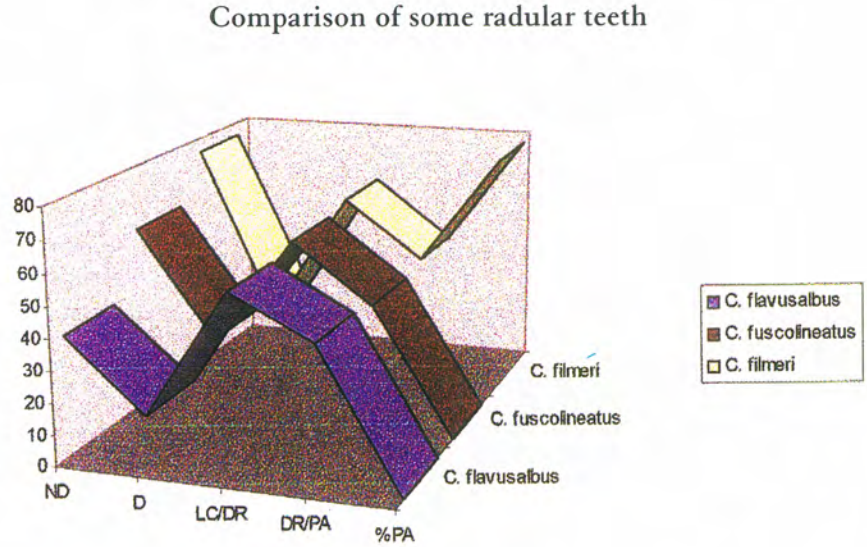

Figure 14. Comparison of some characters of the radular teeth of *C. flavusalbus* (n=4), *C. fuscolineatus* (n=6) and *C. filmeri* (n=6).

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
C. bulbus	(1)	-	1	4	5	3	0	2	2	3	3	0	1	2	0	0	3	2	5	0	3	1
C. aemulus	(2)	29.0	-	4	5	3	1	2	1	3	3	0	1	2	0	0	3	1	5	1	3	1
C. africanus	(3)	81.5	81.4	-	5	1*	2	4	2	2*	1*	0*	4	3	3	2	4	2	4*	3	0*	3
C. neoguttatus	(4)	126.7	142.1	93.5	-	3	4	5	3	0	2	0*	5	5	5	5	5	4	1	5	3	4
C. zebroides	(5)	87.7	95.3	33.5	62.8	-	2	4	2	1*	0*	1*	4	2	2	2	4	3	3*	2	1*	2
C. variegatus	(6)	5.3	32.1	78.0	122.2	83.3	-	3	1	3	2	0	1	2	1	0	3	0	5	0	2	1
C. chytreus	(7)	12.9	22.1	71.6	124.3	80.6	13.2	-	3	4	4	1	0	3	1	0	2	2	5	2	4	3
C. fuscolineatus	(8)	77.9	75.0	28.5	93.3	35.3	74.9	67.3	-	1	1	0	2	3	1	0	3	2	4	1	2	1
C. naranjus	(9)	77.9	75.0	28.5	93.3	35.3	74.9	67.3	0.0	-	1*	0*	3	4	2	2	4	3	2	2	1*	3
C. cepasi	(10)	90.1	98.6	42.7	57.0	10.6	85.7	83.5	38.7	38.7	-	0*	3	3	3	2	5	2	4*	2	1*	1
C. nobrei	(11)	12.5	13.6	73.8	128.7	86.0	15.0	10.7	75.7	75.7	90.7	-	0	0*	0*	0*	2	0	1*	0	0*	2
C. musivus	(12)	14.4	14.8	80.0	132.8	89.8	17.7	10.5	74.4	74.4	92.5	4.1	-	0	2	1	4	1	5	1	3	2
C. albuquerquei	(13)	19.1	13.8	85.9	138,1	96.2	23.3	18.3	80.1	80.1	98.9	4.0	8.2	-	4	2	4	1	5	1	2	1
C. bocagei	(14)	9.7	33.4	87.0	126.8	90.4	11.3	19.3	81.0	81.0	91.8	20.3	19.1	22.7	-	1	3	2	5	0	3	2
C. xicoi	(15)	11.0	25.1	76.9	123.0	82.7	11.8	9.4	72.2	72.2	84.6	13.6	11.5	17.6	12.8	-	2	1	5	0	1	2
C. franciscoi	(16)	22.3	29.3	73.0	123.4	78.8	32.3	16.5	64.2	64.2	80.4	24.6	20.8	28.0	22.2	16.0	-	3	5	3	3	4
C. gabrielae	(17)	9.6	31.3	76.7	118.8	80.7	7.8	13.1	71.3	71.3	82.6	17.4	17.1	22.3	11.5	7.3	19.8	-	5	0	1	1
C. trovaoi	(18)	124.5	140.5	84.1	27.6	57.1	119.7	121.9	91.7	91.7	55.2	118.8	131.3	137.2	126.2	122.3	122.2	117.8	-	5	4*	5
C. micrpunctatus	(19)	6.4	30.9	75.8	121.8	81.8	2.6	11.2	72.9	72.9	84.4	13.7	16.9	22.9	13.2	11.3	20.1	8.1	119.0	-	1	0
C. flavusalbus	(20)	80.8	73.2	46.6	101.2	52.0	78.8	69.9	22.4	22.4	53.1	74.8	74.7	78.7	83.0	71.3	67.6	73.6	104.5	77.0	-	2
C. filmeri	(21)	18.4	46.0	79.3	116.4	81.9	14.8	26.1	79.7	79.7	84.3	22.7	32.0	36.8	21.6	25.6	32.9	19.6	112.2	15.8	86.1	-

* cases analysed for less than five variables

GENERAL DISCUSSION

A simple method is presented showing graphics where in the first version some characters of the radular teeth of Angolan cones are compared which appear to be more useful for comparison.
Some statistical information on these characters is showed in Table I. *C. carnalis* was excluded because its different radular tooth, suppose a different origen.

TABLE I: The table represents the morphological dissimilarity between different pair combinations of the 21 Conus species. Below the diagonal is presented the Euclidean dissimilarity index for the five radular characters studied, (the square root of the mean square of trait differences between species). Above the diagonal is presented the number of traits (from 0 to 5) which show significant differences between a particular pair of species by a oneway ANOVA.

ACKNOWLEDGEMENTS

I thank Emilio Rolán Álvarez, for his help in some statistical studies in the present work, Liliam María Díaz for her help in the graphics, Amarillo Ramalho for his help on information and Mike Filmer for his critical reading of the manuscript.

This work was partially supported by the project XUGA 30105B98.

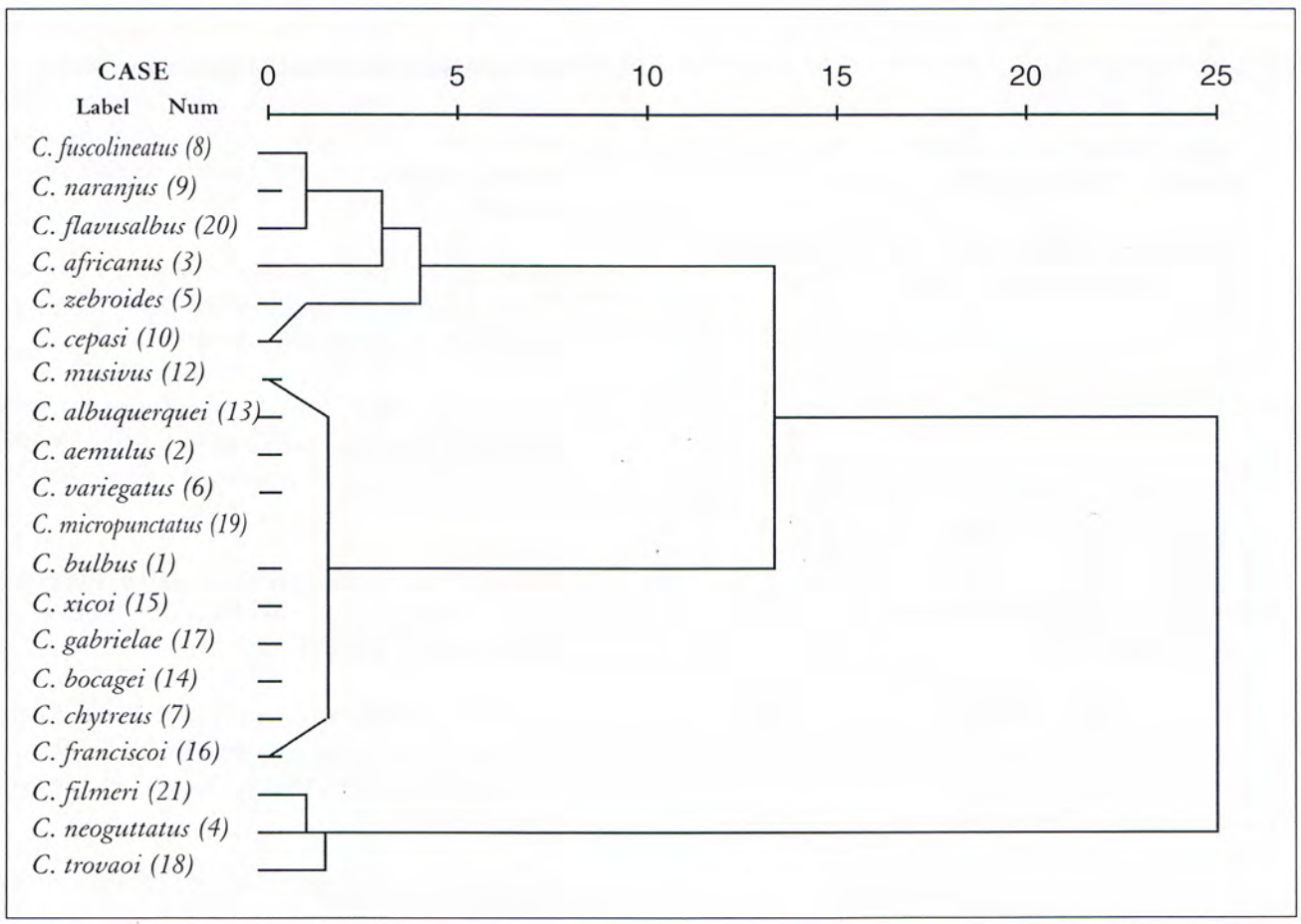

FIGURA 15. Dendrogram using Average Linkage (Between Groups) rescaled distance Euclidean dissimilarities. Species codes are like those in Table 1.

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