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Osteological Differences in Species of *Sebastes* on Flemish Cap

by

F. Saborido-Rey
Instituto de Investigaciones Marinas
Eduardo Cabello nº 6, 36208, Vigo, Spain

Introduction

The genus *Sebastes* (Cuvier, 1829), called redfish, contains around 104 species, but in the North Atlantic only four species occur: *S. marinus* (Linnaeus, 1758), *S. mentella* (Travin, 1951), *S. fasciatus* (Storer, 1854) and *S. viviparus* (Kroyer, 1845).

Until a few years ago, it was considered that there were only North Atlantic two species: *S. marinus* and *S. viviparus*, the former composed of two subspecies, *S. marinus marinus* (Linnaeus, 1758) and *S. marinus mentella* (Andriashev, 1954); later these two subspecies were raised to species. Barsukov (1968) suggested that there was a fourth species: *S. fasciatus*, which had been described by Storer (1854). Since the late 70's, it has been accept that there are four species in the North Atlantic. Ni (1981b) reported that the passage of the extrinsic gas bladder musculature between different ventral ribs was the most accurate character for distinguishing them.

The four species have sympatric distributions in most parts of the North Atlantic, and although all four are not found together, it is common to find three species in the same area (Norway, Newfoundland Grand Bank, Flemish Cap,...). Though it is accepted they are valid species, the taxonomy of this group is complex and problematic, since the morphological differences between the species are subtle, as is characteristic of the Subfamily *Sebastinae*. During the last decade, several have examined the morphological and genetic differences between the species (Ni, 1981a; Misra and Ni, 1983; Nedreaas and Naevdal, 1987; Reinert and Lastein, 1992; Nagel et al, 1991; Barsukov, 1990; Power and Ni, 1985), but redfish differentiation is still unresolved. It is necessary to make a independent population analyses, because in most of the areas where there are redfish, they are treated as a single population due to the taxonomic difficulties.

On Flemish Cap, *S. marinus*, *S. mentella* and *S. fasciatus* occur and catches are increasing year by year. However, the three redfish species are treated as a single population. This procedure has influenced the population structure of redfish (Saborido-Rey, 1993).

In this paper, the morphometric differences between several bones of the three species present on Flemish Cap are analyzed. 24 morphometric measurements were taken and a

Principal component analysis and a discriminant analysis made using standard length as covariant in order to eliminate the effect of size in the variables, due to the individuals sampled had different lengths and the variables were allometric in relation to standard length. A cluster analysis was also made with all specimens. Though sample size is only 36, the results are significant.

MATERIALS AND METHODS

In July 1989, EEC made a stratified bottom trawl survey on Flemish Cap. The redfish samples were frozen for later study in the laboratory. The species were identified with the passage of the extrinsic gas bladder musculature between different ventral ribs (Ni, 1981b). 36 individuals were analyzed, 13 *S. marinus*, 12 *S. mentella* and 11 *S. fasciatus* (Table 1). 24 measurements were taken of each individual besides standard length (Table 1). Fig. 1 shows the variables measured. All measurements were to 0.01 mm (Fig. 1).

The bones and the measurements taken were chosen following Morales and Roselund (1979) in cod. 8 of the bones belong to the splancnocranium, 2 to the opercular system, and one each to the scapular belt, the pelvic belt and the neurocranium. Most of the bones belong to the splancnocranium because these bones vary more than those of the neurocranium, due to the environmental adaptation of each species, in relation to, feeding, respiration, etc. and they give us more interspecific difference information. However, taking into account the characteristics of the order Scorpaeniformes, i.e. the numerous head spines and the variability between species, the neurocraniums were examined, though the differences have not been quantified.

Logarithmic (base 10) transformation was applied to the data for multivariate analysis, because linearity and multivariate normality are often more closely approximated by logarithms than by the original variables (Pimentel, 1979).

In this study we try to obtain morphological differences between the species independently individual size. As the morphometric variables are allometric in relation to standard length, this dependence masks other differences between groups if the individuals have different standard lengths, as in these data.

In this study we use a multivariate approach of the residual method described by Reist(1986). A multiple regression analysis was applied to log-transformed data using standard length as covariant. The residuals obtained in this analysis are used in subsequent analyses, Principal Component Analysis, discriminant and cluster analysis. The slopes of the regression lines of each group (the species) should not be statistically different.

The discriminant analysis were made with all three species together, and for sets of two species. Jackknife validation was used to classify the cases. In this validation each specimen was assigned according to the values obtained from the discriminant function, which was calculated using all data except the observations for the specimen being classified. To determine the importance of the variables which enter in each step of the discriminant analysis we use Wilks's λ (Wilks, 1932). This is a multivariate test of equality of group centroids at each step after a new variable is entered into the function. In the 0 step λ is 1.000, i.e. the group centroids are equal, and in each step λ reduces. BMDP software (Dixon et al, 1990) was used for all statistical analyses.

The proportion between the two measurements taken on each bone was studied to analyzed their variation in relation to size: Height/Length in Premaxilla, Articular, Quadrate, Hyomandibular, Opercular and Basipterygium; Height/Width in Urohyal; Length/Width in Maxilla; Width2/Width1 in Vomer; Length2/Length1 in Dentary and 3 points Length/Cordal Length in Cleitthrum. The longest measurement was always divided by the other one (Fig. 1).

RESULTS

Table 2 shows the basic statistics for each variable and each species.

PCA

The Principal Component Analysis resulted in the extraction of two factors (PC1 and PC2) which explained 80 % of the variance in the data set. Figure 2 show the plot of these two factors which form three clusters, each corresponding to different species; so the initial separation of redfish species is very good. It is difficult to interpret which variables are more important in PC1, since most of them have high values. However, PC2 is composed mainly for BASLON.

Discriminant analysis

Discriminant analysis results were:

	Set A	Set B	Set C	Set D
	All species	*S. marinus* vs *S. mentella*	*S. marinus* vs *S. fasciatus*	*S. mentella* vs *S. fasciatus*
Number of specimens	36	25	24	23
Variable (Wilks's λ)	BASLON (0.5791) DENL2 (0.2025) BASALT (0.1122) ARTALT (0.0819) MAXLON (0.0530) OPLON (0.0398)	BASLON (0.6065) DENL2 (0.1805)	BASLON (0.6536) CLECO (0.2518) BASALT (0.2059) ARTALT (0.1519) MAXLON (0.1088)	BASALT (0.4389) MAXAN (0.2278) CUALON (0.1392)
Jackknifed classification	97 %	95.7 %	95.7 %	100 %
Canonical correlation	0.93674 / 0.82180	0.9053	0.9440	0.9278

The square of the canonical correlation is the proportion of variability in the discriminant function that is explained by the groups. The canonical variables histograms of discriminant analysis of sets B, C and D are shown in Figure 3. Plot of canonical variables of discriminant analysis of set A is shown in Figure 4.

BASLON and DENL2 are the variables that best discriminate in the analysis of all species together. A analysis using only these two variables classified correctly 84,8 % of the individuals.

The discriminant analysis of *S. marinus* vs *S. fasciatus* selected five variables, but with the entering of the first two variables Wilks's λ is reduce to 0.2518, while with the subsequent variables λ reduce only to 0.1088. Using those two variables the analysis classified 91,8 % of the individuals correctly.

Using only BASALT in the *S. mentella* vs *S. fasciatus* analysis Jackknife method classified 85 % accurately.

Cluster Analysis

The dendrogram of the cluster analysis of the cases is shown in Figure 4. *S. mentella* is separated from *S. marinus* and *S. fasciatus*. However, these two species are separated in two cluster: On the one hand, only *S. marinus* and on the other hand all *S. fasciatus* with four *S. marinus*. These four *marinus* also are separated from *S. fasciatus*, but at a lower level (Fig. 4).

In the study of the proportions between the measurements taken in each bone, the relation was different between species in Dentary, Premaxilla, Maxilla, Urohyal, Quadrate, Opercular, Cleithrum and Basipterygium (Fig. 5). In all bones except Quadrate and Basipterygium, *S. mentella* have a variation opposed to another species. In Quadrate and Basipterygium is *S. marinus* who differ. So,

a) The length of the quadrate of *S. marinus* increase with age equally with height (Fig. 5), while in *S. fasciatus* and *S. mentella* the length of the bone increases with age more than height, so the slope of the regression is negative.

b) The height and length of the Opercular in *S. marinus* and *S. fasciatus* maintain the same proportion with age, but in *S. mentella* the length increases proportionally more than height.

In the preliminary analysis of the neurocranium of the three species, differences were observed only in the spine of the parietal bone. In *S. marinus* and *S. fasciatus*, these spines are arranged a conspicuous ridges which arise backward, giving the redfish an external aspect of humpback. In *S. mentella*, these ridges are flattened and the humpback is not so clear. The body height at the cranium base was used to discriminate between *S. marinus* and beaked redfish (Power and Ni, 1985)..

CONCLUSIONS

The Basipterygium seems be the bone which best discriminates between the three species: BASLON separate *S. marinus* from the other two species and BASALT separate *S. mentella* from *S. fasciatus*.

But between *S. marinus* and *S. mentella*, DENL2 is also a very good discriminant. Between *S. marinus* and *S. fasciatus* CLECO is also selected. The classification a posteriori of the specimens using the discriminant functions is always very high.

Eight of the thirteen bones measured have different proportional growth between species. *S. mentella* is different from *S. fasciatus* and from *S. marinus* in six bones (Dentary, Premaxilla, Maxilla, Urohyal, Opercular and Cleithrum). The parietal spines are similar in *S. fasciatus* and *S. marinus* but are different in *S. mentella*.

The cluster analysis and the results mentioned above indicate that *S. marinus* and *S. fasciatus* are species more closely related than with *S. mentella*. *S. fasciatus* and *S. mentella* are included in the same group called beaked redfish, due to difficulties to identify them because the morphology is very similar. However, *S. fasciatus* is more similar to *S. marinus* than to *S. mentella*. In fact, on the basis of external morphology, it is easier to confuse *S. fasciatus* with *S. marinus* than with *S. mentella*.

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Table 1.- Sampled individuals. Obtained in Flemish Cap, Summer 1989.

Order	Species	Sex	Weight	Total length	Standard len.
1	*S. marinus*	no data	no data	no data	460
2	"	1	299.6	257	220
3	"	1	278.5	253	216
4	"	2	336.8	278	230
5	"	1	135.4	198	171
6	"	2	278.5	251	213
7	"	1	228.6	236	207
8	"	2	150.7	204	169
9	"	2	1616.7	488	403
10	"	1	681.8	355	297
11	"	2	719.3	351	247
12	"	1	315.2	266	217
13	"	2	205.2	235	205
14	*S. mentella*	2	217.4	255	218
15	"	2	666.9	358	311
16	"	2	418.4	318	269
17	"	2	508.3	328	273
18	"	1	540	346	293
19	"	2	799.8	394	326
20	"	2	710.3	367	307
21	"	1	322.3	306	258
22	"	2	663	376	306
23	"	2	325.2	300	253
24	"	2	490.8	331	279
25	"	1	208.2	231	203
26	*S. fasciatus*	2	880.1	394	371
27	"	2	172.3	222	189
28	"	2	903	364	311
29	"	1	144.9	203	174
30	"	1	167.7	214	187
31	"	1	248.3	250	211
32	"	1	299.5	265	222
33	"	1	314	272	229
34	"	1	252	249	210
35	"	2	428.1	295	251
36	"	1	119.1	190	164

Table 2.- Basic statistics of sampled individuals.

	UROAN	UROALT	PAL	VOMAN1	VOMAN2	HIOALT	HIOAN	CUALON	CUAALT	CLECO	CLE3	PREOP
S. marinus												
Number	12	12	13	13	13	13	13	13	13	13	13	13
Range	4.420	4.230	16.100	10.810	12.550	19.080	31.280	20.060	23.130	75.330	68.130	46.510
Mean	4.075	5.006	14.196	8.991	10.171	14.391	26.711	16.101	18.468	64.279	59.888	43.277
Variance	1.688	2.059	24.024	10.416	14.720	32.426	87.336	36.780	46.932	549.905	458.073	206.535
Skewness	1.146	0.837	1.339	1.453	1.369	1.507	1.424	1.378	1.432	1.295	1.259	1.272
cv	0.319	0.287	0.345	0.359	0.377	0.396	0.350	0.377	0.371	0.365	0.357	0.332
S. mentella												
Number	9	9	12	12	12	12	12	12	12	11	11	12
Range	2.380	2.920	8.730	4.500	6.670	10.040	16.040	10.240	10.870	38.590	32.730	25.890
Mean	4.828	5.384	16.633	9.393	11.728	16.945	31.459	18.117	20.118	73.355	67.249	50.471
Variance	0.549	0.962	6.723	2.003	4.320	9.942	29.019	9.340	9.978	176.190	128.314	73.423
Skewness	-0.587	-0.569	-0.769	-1.125	-0.761	-0.347	-0.531	-0.591	-0.472	-0.619	-0.777	-0.432
cv	0.153	0.182	0.156	0.151	0.177	0.186	0.171	0.169	0.157	0.181	0.168	0.170
S. fasciatus												
Number	9	9	11	10	10	11	11	11	11	11	11	11
Range	4.620	4.040	6.630	6.230	7.390	10.650	18.770	11.380	11.410	45.210	44.210	29.620
Mean	4.553	4.949	12.345	7.994	8.888	12.527	24.771	14.345	16.539	58.481	53.842	39.474
Variance	2.225	1.456	7.978	3.815	5.816	11.148	34.637	12.119	13.111	209.503	178.481	87.415
Skewness	0.412	0.327	0.663	0.826	0.530	0.779	0.660	0.798	0.532	0.871	0.775	0.511
cv	0.328	0.244	0.229	0.244	0.271	0.267	0.238	0.243	0.219	0.248	0.248	0.237

	OPLON	OPALT	PREML	PREMA	MAXAN	MAXLON	DENTL	DENL2	ARTLON	ARTALT	BASLON	BASALT
S. marinus												
Number	13	13	13	13	13	13	13	13	13	13	13	13
Range	33.800	29.270	32.690	10.580	8.280	40.140	39.020	19.130	36.840	20.940	46.910	10.090
Mean	27.439	27.168	27.835	10.170	6.904	35.898	33.808	17.794	35.076	19.638	43.700	9.351
Variance	102.581	92.028	95.131	11.394	6.391	158.196	150.899	35.677	135.267	48.686	220.340	9.141
Skewness	1.478	1.035	1.054	1.088	1.291	1.089	1.235	1.186	1.166	1.099	1.237	1.079
cv	0.369	0.353	0.350	0.332	0.366	0.350	0.363	0.336	0.352	0.355	0.340	0.323
S. mentella												
Number	12	12	12	12	12	12	12	12	12	12	11	12
Range	16.700	14.340	15.440	5.340	4.150	18.180	18.700	10.710	17.070	10.110	18.620	5.120
Mean	30.028	29.822	32.308	11.351	7.910	40.083	37.983	20.900	36.485	20.987	43.121	9.625
Variance	28.359	22.495	25.300	3.066	1.723	34.574	32.781	10.523	29.761	10.903	39.563	2.550
Skewness	-0.710	-0.325	-0.661	-1.020	-0.885	-0.640	-0.445	-0.450	-0.856	-0.795	-0.312	-0.339
cv	0.177	0.159	0.156	0.154	0.166	0.147	0.151	0.153	0.150	0.157	0.146	0.166
S. fasciatus												
Number	11	11	11	11	11	11	11	11	11	11	11	11
Range	18.790	21.600	19.570	6.130	4.880	25.090	23.000	11.390	21.350	12.950	27.510	7.310
Mean	24.550	24.505	24.848	8.931	5.908	31.884	30.165	16.238	28.743	16.639	37.088	8.868
Variance	37.573	44.983	35.977	3.450	2.198	64.097	49.028	12.400	42.488	17.262	73.833	5.178
Skewness	0.649	0.583	0.955	0.374	0.799	0.853	0.853	0.612	0.719	0.689	0.905	0.837
cv	0.250	0.274	0.241	0.214	0.251	0.251	0.232	0.217	0.227	0.250	0.232	0.257

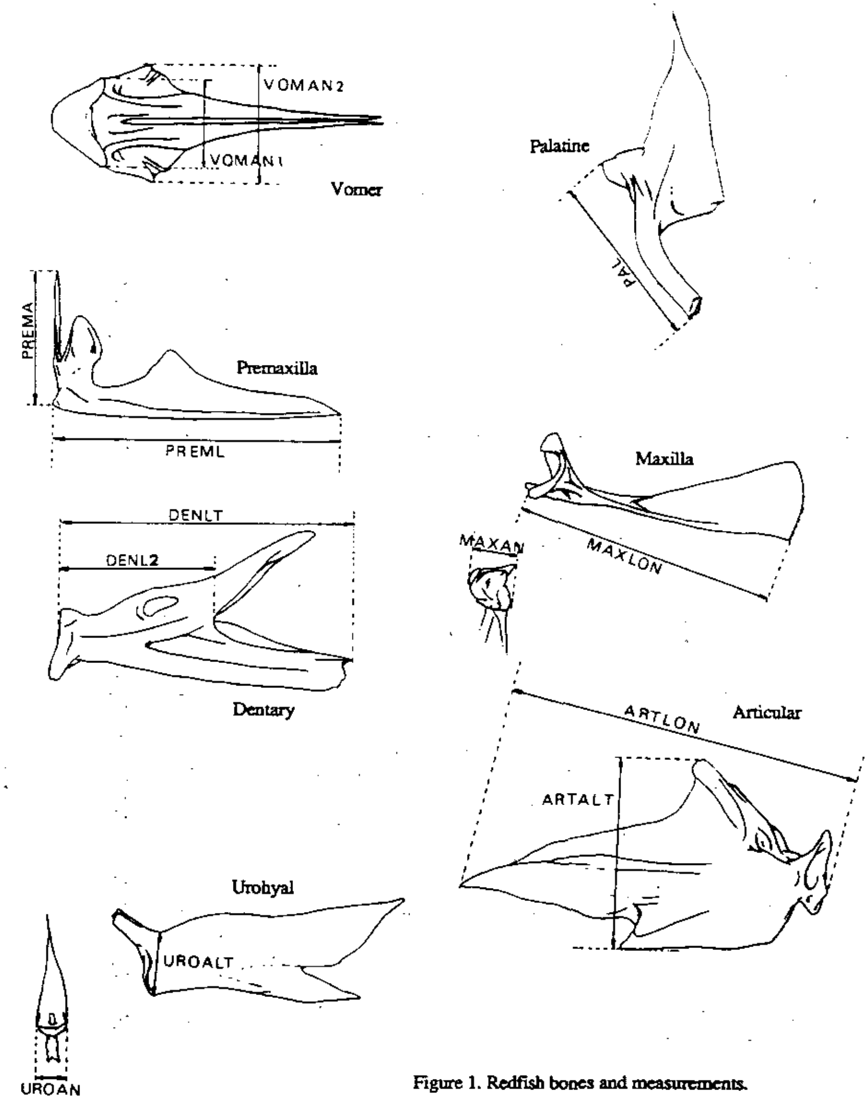

Figure 1. Redfish bones and measurements.

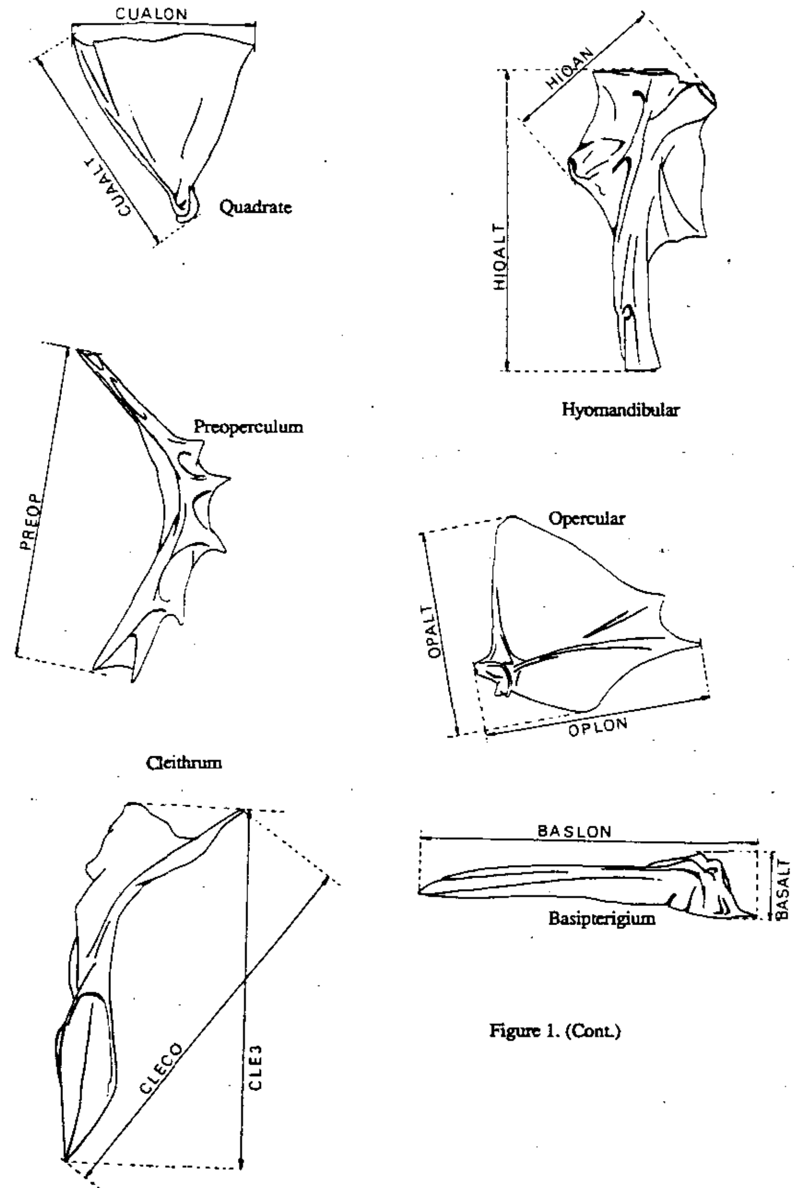

Figure 1. (Cont.)

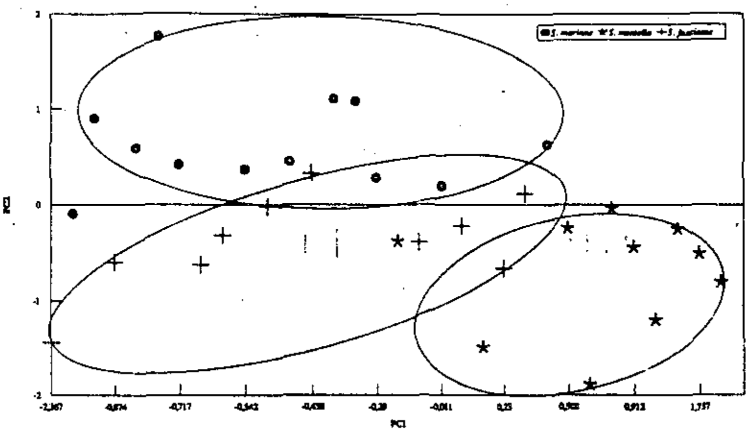

Fig. 2. Plot of the Principal component 1 (PC1) against Principal component 2 (PC2).

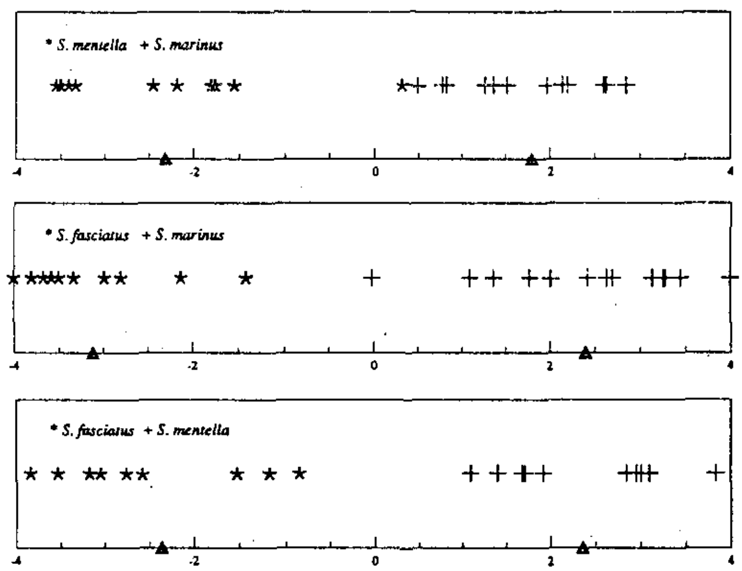

Fig. 3. Histograms of canonical variables from the discriminant analysis for the three sets considered. ▲ indicate the group means.

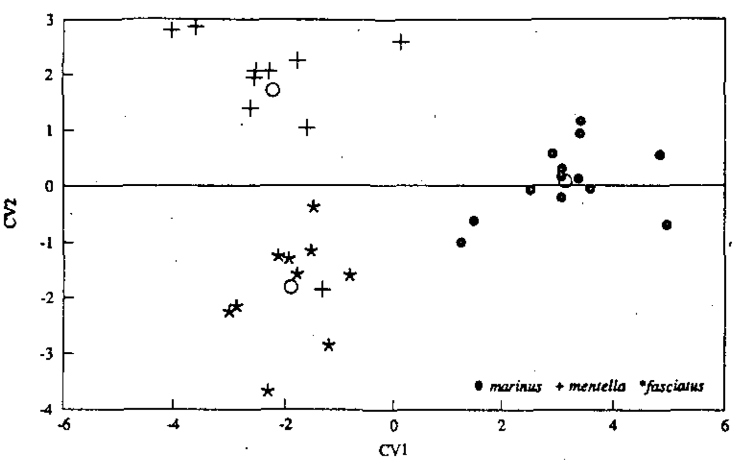

Figure 4. Plot of the Canonical varables from discriminat analysis. ○ represent group means.

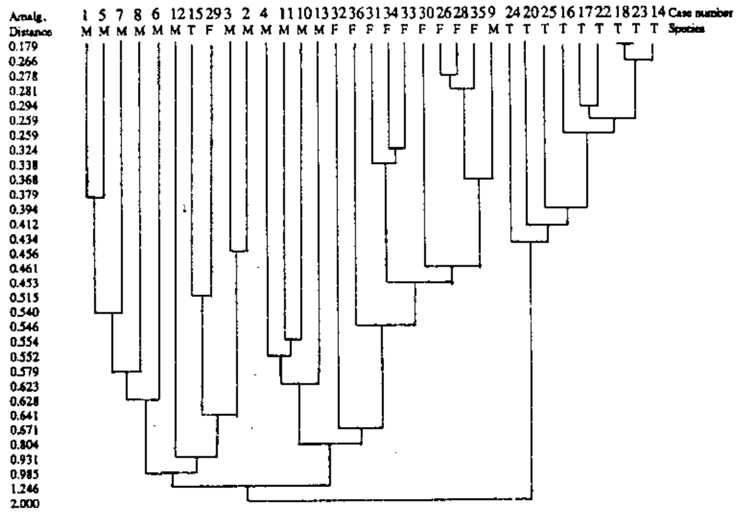

Figure 5. Dendogram of cluster analysis. M = *S. marinus*; T = *S. mentella*; F = *S. fasciatus*

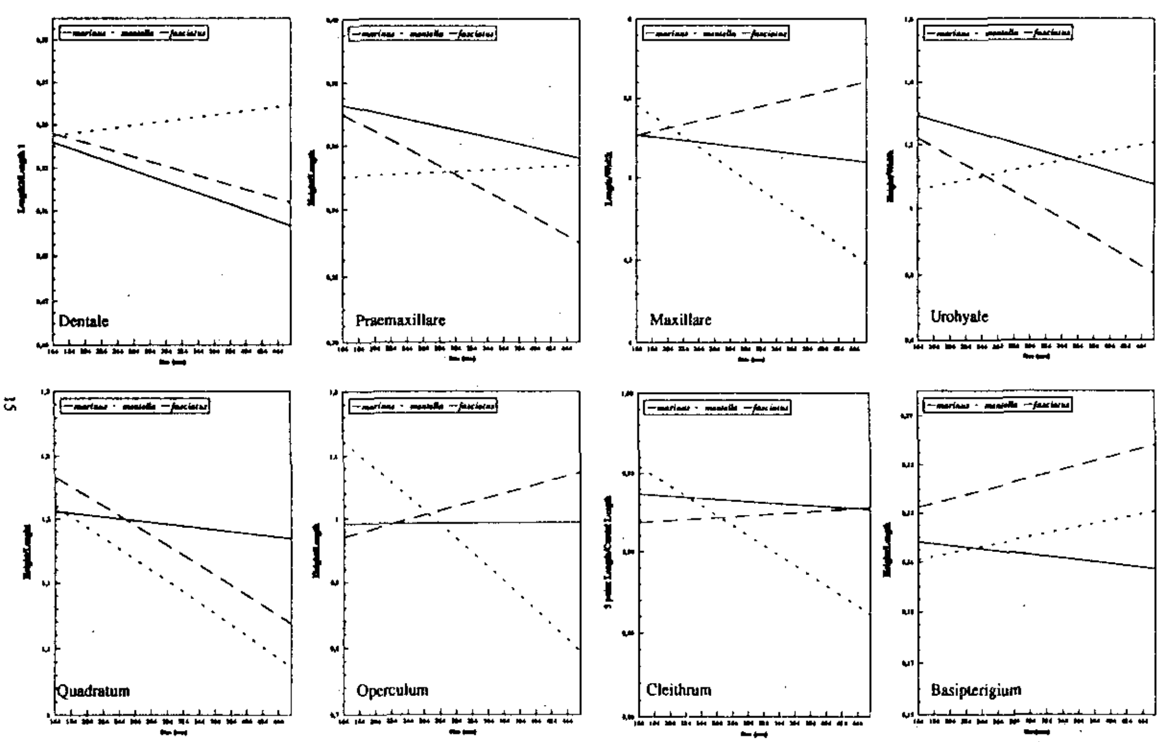

Fig. 6. Relations between the measurementes taken in each bone. Plot only the significative bones.