ENVIRONMENTAL CHARACTERISATION OF "STº. CRISTO" COASTAL LAGOON (S. JORGE, AZORES)

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With 10 figures and 1 table

ABSTRACT. The coastal lagoon of "Santo Cristo" (north coast of São Jorge Island, Azores archipelago), is a small brackish polyhaline-euryhaline lagoon (500 m length, 300 m wide and 4 m average depth) connected to the sea by two tidal channels. Due to the lack of streams the freshwater imput comes from, rainfall and underground seapage. A barrier of smooth boulders, built up by winter storms separates the sea from the lagoonal environment which is a unique habitat of this kind in all the archipelago. This lagoon is both economically and socially important due to the exploitation of clams (*Tapes decussatus*). A study of its fauna as well as water and sediment was carried out from July 28 to August 5th, 1992. Due to the inaccessibility of the lagoon, comprehensive surveys have not been undertaken, however, a small survey was undertaken and the results are presented here. From these data one may say that the general features of an halmiric habitat, namely the confinement gradient of production and sedimentation, have been found in this lagoon located in the middle of the Atlantic.

INTRODUCTION

The coastal lagoon of "Santo Cristo" is a brackish environment on the north coast of São Jorge Island and a unique habitat in the archipelago of the Azores. The colonisation process of these brachish water environments is particular interesting in the Azores due to their middle Atlantic location. The commercial exploitation of the clam (*Tapes decussatus*) population is also unique in the Azores archipelago, and is the main commercially exploited species of the lagoon.

Freshwater enters this brackish coastal system by rainfall and possibly through subterranean seapage, since there are no surface streams. The waterbody is separated from the sea by a barrier of smooth boulders built up by winter storms, going on approximately 8.7 ha lagoon, with an average depth of 4 m and a maximum of 6 m. The lagoon is connected

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to the sea by two tidal inlets (Fig. 1). Gravel, shingle and some boulders form the inner margin (intertidal zones) of the lagoon, retaining interstitial particles of finer sediments (sands and muds).

Since 1984 the lagoon has been recognised by the Regional Government as an important ecological site (Natural Parcial Reserve, D.L.R. no. 14/84/A and Ecological Special Area of S^{to}. Cristo Lagoon D.L.R. 6/89A). Although there are several regional laws which are supposed to regulate the activities in the area, this is not enough for adequate management. The enlargement of the protected area and new rules for human utilisation, especially tourism, are now necessary. Intensive studies have been difficult due to its inaccessibility. However, several surveys have been done (Table 1), mainly by the DOP (Dept. of Oceanography and Fisheries) of the University of Azores, primarily at the clam fishery.

A survey of the fauna (macrobenthos and ichthyofauna) as well as surface and near bottom water and surface sediment was carried out from July 28 to August 5th, 1992.

This paper presents some of the results of this survey, which deal with the characterisation of the lagoonal environment.

METHODS

In order to determine the environmental characteristics of the "Santo Cristo" lagoon, an intensive sampling survey was carried out. Both the water and sediment were studied. Water samples, were collected from six stations at two levels (M1 to M6, surface and near bottom - Fig. 2) at both high and low tide. Temperature, salinity, dissolved oxygen, turbidity and pH were measured *in situ* with sensors (HORIBA U-7 and YSI mod. 33 SCT). Depth was measured at each sampling station and water samples were collected with a Van Dorn bottle for laboratory determinations of phytopigments (Chl a and phaeopigments following LORENZEN, 1967; carotenoids according to STRICKLAND & PARSONS, 1972). Margalef (STRICKLAND & PARSONS, 1972) and degradation (LORENZEN, 1967) indices were calculated. Low tide samples were also collected for nutrient determinations (ammonia, nitrite, nitrate, silicate, phosphate) using a Technicom auto-analyser, total seston (by filtration, drying at 70°C and the gravimetric method) and suspended organic matter (filtration, drying at 70°C, loss on ignition - 12 hr. at ±500°C - and gravimetric method).

Samples for the study of the sediment parameters were obtained from ten subtidal stations (S1 to S10 - Fig. 2) with a modified, hand operated Van Veen grab (0.05 m2 - model Sousa Reis/LMG). Two sub-samples were taken: a 15 cm section for the grain-size analysis and an upper layer (1 cm) for water content, organic matter and phytopigments determinations. A gravimetric procedure was used for estimations of sediment water content (24 to 36 hr. drying at 70°C) and organic matter content (loss on ignition, 24 hr. at ±500°C). The evaluation of phytopigments concentration was done following PLANTE-CUNY (1974), after a 24 hr.

cool and dark extraction in 90% acetone. Margalef (STRICKLAND & PARSONS, 1972), MOSS (MOSS, 1967) and degradation (LORENZEN, 1967) indices were also calculated. For grain-size purposes, mud (<62 μm, >4ø), sand (62-2000 μm, 4ø to -1ø), and gravel (>2000 μm, < -1ø) were separate by wet sieving (BULLER & MCMANUS, 1979). Sand grain-size distribution was also determined to phi (ø) level.

Cluster analysis was used to group parameters and stations (Q and R mode analysis and UPGMA method with Bravais-Pearson correlation coefficient and Euclidean distance - SNEATH & SOKAL, 1973) and calculations were performed with the NTSYS software package for PC compatible computers (ROHLF, 1988).

RESULTS AND DISCUSSION

Comparison of water parameters that were measured both at low and high tides show higher average values for low tide records with the exception of temperature, salinity and dissolved oxygen (Fig. 3). Subtidal salinity (S‰) was between 34 and 35.5‰ (low tide) and 35.5 and 37‰ (high tide). Extreme high values were recorded for pore water at intertidal stations (30 and 37.5‰). These values are among the highest recorded S‰ values for the Sto Cristo lagoon and they are of the same order of those refered by MORTON (1967), also obtained during Summer. Lower values at the southern margin of the lagoon, indicating the importance of the freshwater subterranean flows into the system.

The available data suggests that during the greater part of the year the average salinity values stay within the poly-euryhaline zone of the classification for brackish waters defined in the 1958 Venice Symposium (AMANIEU, 1967).

A cluster analysis (Euclidean distance coefficient) was performed to group stations (Q mode analysis) and characteristics (R mode analysis). The results of the latter show, for the low tide values, that there is a relationship between pigments and nutrients, as well as organic seston and turbidity, while the oxygen content of water appears to be independent of other parameters (Fig. 4a). In spite of some missing data for high tide, the grouping indicates the same general trend (Fig. 4b).

Analysis in the Q mode for low tide characteristics emphasises a difference between surface and bottom samples, M2 bottom joining the surface sampling points probably due to its very shallow depth (Fig. 5a). The analysis performed on the high tide values separates M1 (surface and bottom) station from the others (Fig. 5b). The available data suggests that during the rising tide, the main circulation occurs in the eastern part of the lagoon, probably resulting in the isolation of the western part (station M1).

Soft bottom sediment samples obtained from subtidal stations were classified as sand (stations 2,3,4,5 and 10), muddy sand (stations 1 and 6) and sandy mud (stations 7,8 and 9), after plotting sediment grain-size percent on modified (BUCHANAN & KAIN, 1971)

Shepard Triangular Diagrams (Fig. 6).

A map of these sediment types (Fig. 7) emphasises the existence of a sedimentary gradient from the main channel (between the sea and the lagoon) (S3) through the most confined inner areas (S9). This sequence is further illustrated by grain-size distribution per station relative to its distance from the main inlet (Fig. 8). As usual in these lagoonal environments, average grain-size decreases from areas influenced by the sea to the interior, where deposition of finer particles predominantly takes place (BARNES, 1980; GUELORGET & PERTHUISOT, 1983; MAGALHÃES *et al.*, 1987; CANCELA DA FONSECA, 1989).

Organic matter in the sediments (Fig. 9a) is inversely related to particle size of the sediments (Fig. 7), and the higher values are coincident with the most confined zone. The same features are seen in the chlorophyll a and phaeopigments distributions (Figs. 9c, 9d). Sediment pigment values seem to indicate that the more productive area is around S9, which contains the largest amount of functional Chl. a and presents a high value for the Moss index (Fig. 9b) as shown in the Sto André lagoon, SW coast of Portugal (CANCELA DA FONSECA, *et al.*, 1987; BERNARDO, 1990). This fact also agrees with the highest nitrogen values recorded near bottom.

To summarise the available information, cluster analysis were done (Bravais-Pearson correlation coefficient) on all the data relating to the sediment parameters. Analysis in the R mode (Fig. 10a) emphasises, as usual (MAGALHÃES *et al.*, 1987; CANCELA DA FONSECA *et al.*, 1987), two major groups, one including all the parameters associated with fine sediment particles (organic matter, water content, phytopigments) and the other including the sands. The Q mode analysis suggests the existence of a gradient of confinement starting at the group {S2, S3, S4, S5, S6, S10} and progressing through S1 and {S7, S8} to S9, the most confined station (see Fig. 10b for details).

The results discussed here stress for the middle Atlantic Sto Cristo lagoon the same general gradients for physical, chemical and production parameters generally found for these kind of coastal brackish habitats (BARNES, 1980; 1987; GUELORGET & PERTHUISOT, 1983), which are sedimentation basins of both terrestrial and marine mineral and organic materials, and it is similar to those existing in other Portuguese coastal lagoons (MAGALHÃES *et al.*, 1987; CANCELA DA FONSECA *et al.*, 1987; QUINTINO, 1988). Usually its structure depends from the sea-lagoon interaction, the main factor building the gradients of the lagoonal environment, both in sediments and in water mass (CANCELA DA FONSECA, 1989).

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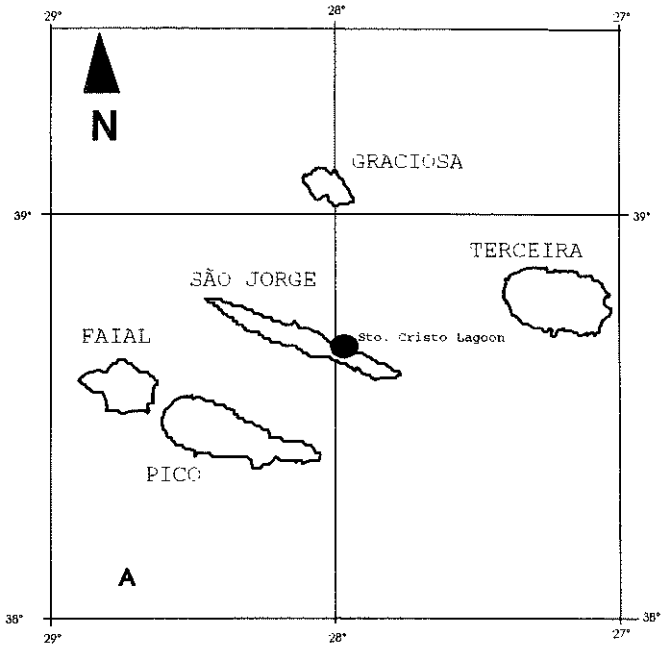

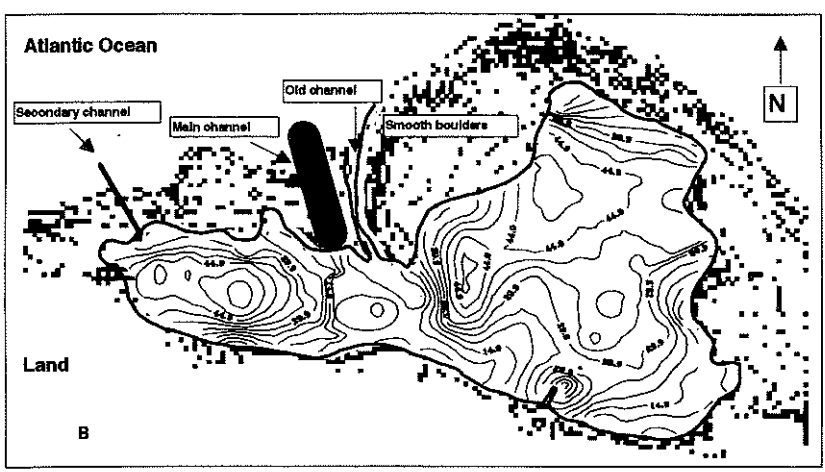

Figure 1 - A. Central group of Azores archipelago indicating the geographical position of Sto. Cristo lagoon in north coast of São Jorge Island. B. Depth isolines of Sto. Cristo lagoon - decimeters (dcm). (Adapted from SANTOS & MARTINS, 1986).

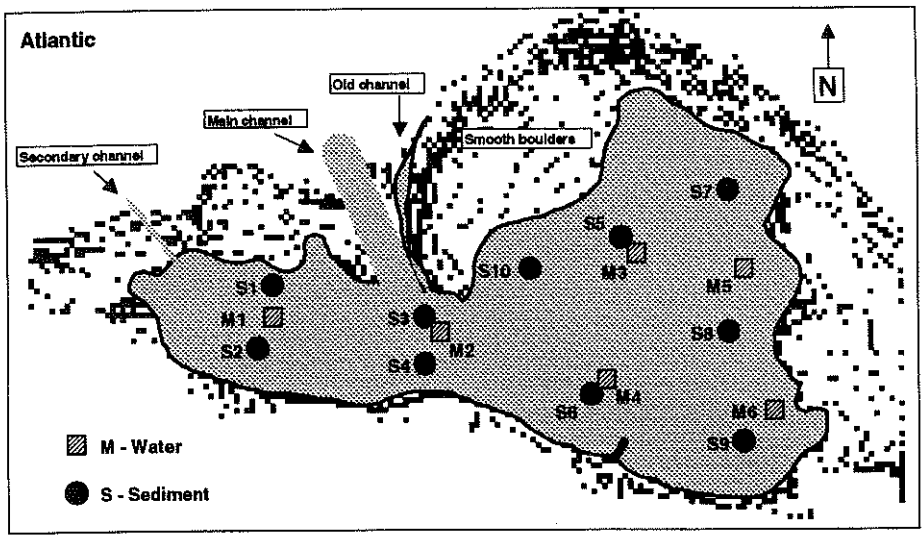

Figure 2 - Sediment (S) and water (M) sampling stations.

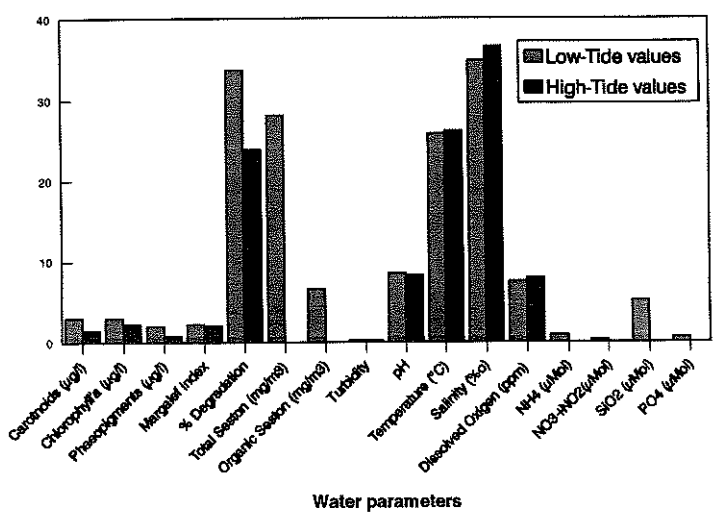

Figure 3 - Average values of water parameters in low-tide and high-tide.

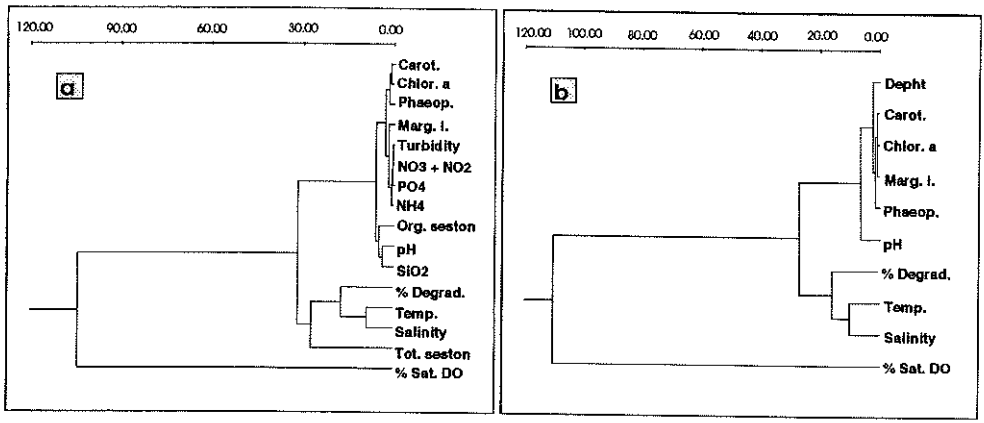

Figure 4 - Cluster analysis of water parameters: a - Euclidian distance on R mode in low-tide; b- Euclidian distance on R mode in high-tide.

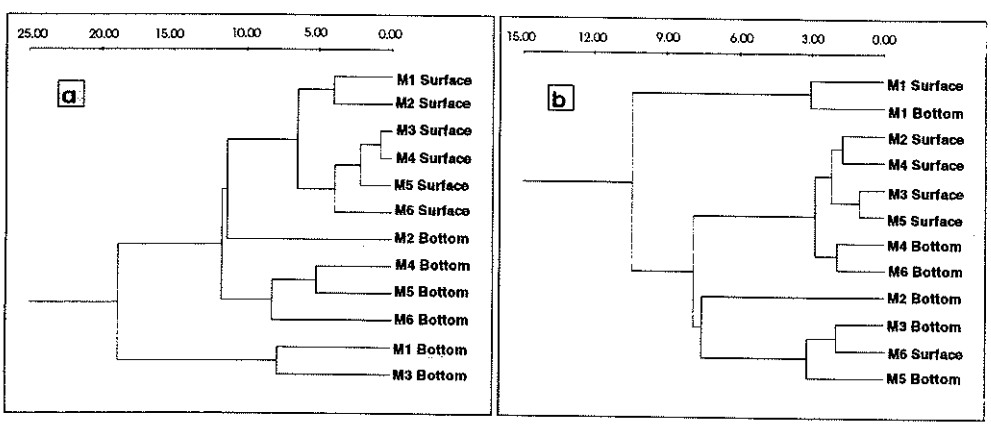

Figure 5 - Cluster analysis of water parameters: a - Euclidian distance on Q mode in low-tide; b - Euclidian distance on Q mode in high-tide (see Fig. 2).

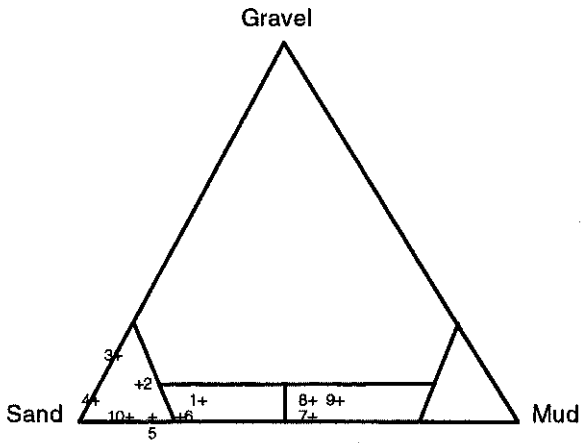

Figure 6 - Subtidal sediments classification of Sto. Cristo lagoon: 2, 3, 4, 10 - sands; 1, 6 sandy mud; 7, 8, 9 - mudy sand. (Modified Shepard triangular diagram - BUCHANAN & KAIN, 1971).

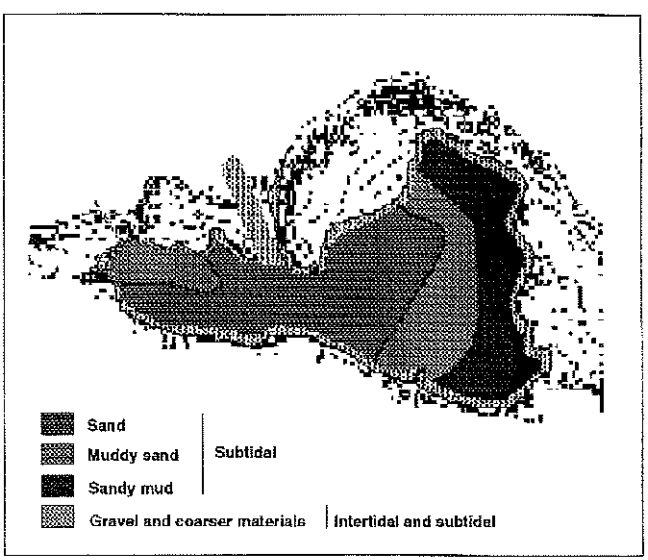

Figure 7 - Cartographic draft of sediment types of Sto. Cristo Lagoon.

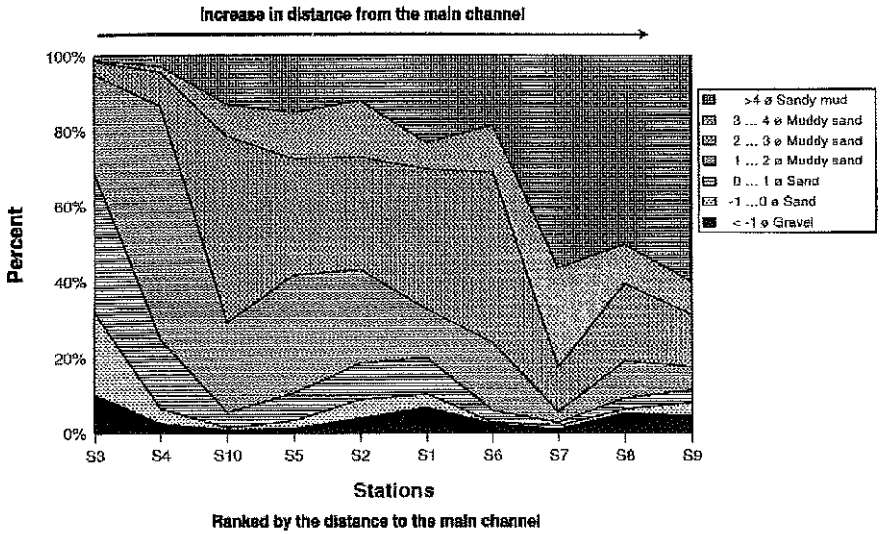

Figure 8 - Sediment granulometry per station. Stations are ranked according to its distance to the main channel.

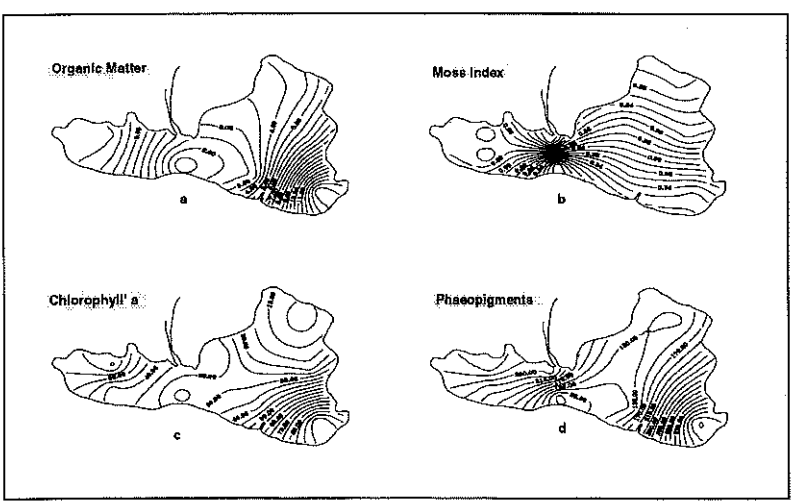

Figure 9 - Isolines of sediment parameters of the lagoon: a - Organic matter; b - Moss Index; c - Chlorophyll'a; d - Phaeopigments.

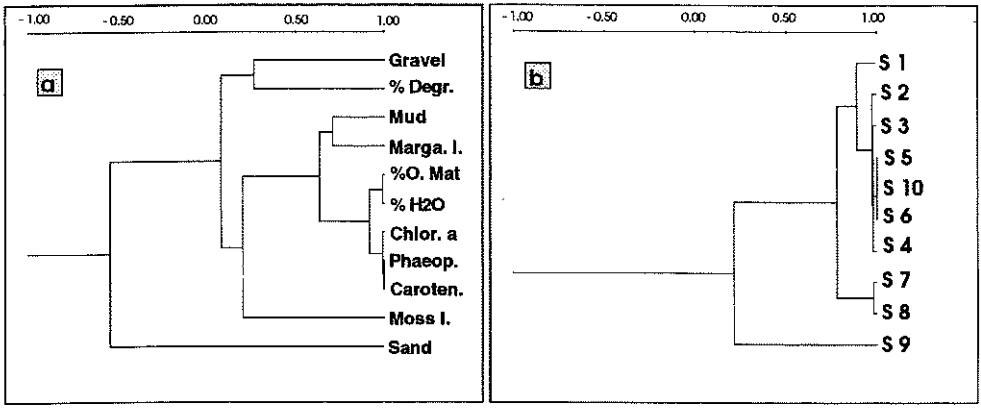

Figure 10 - Cluster analysis of subtidal sediments parameters: Bravais-Pearson correlation coeficient; a - R-mode; b - Q-mode.

TABLE 1 - Puntual studies carried out in "Santo Cristo" coastal Lagoon.

Year	Name of the study/ project/ expedition.	Stydy period	Main objectives	Organization/ Institution	Document produced
1965	Azores - Schelsea College Expedition	September/ October	Faunal inventariation/ biology of clams/ water characterization	Chelsea College/ U.K.	Morton (1967)
1981	The CAN-CAP Expedition	13-14 July	Faunal inventariation/ water characterization	Lieden Natural History Museum/ Nethelands	
1985	DOP Study	November	Biology of clams/ water characterization	DOP/ University of Azores.	Santos (1985)
1986	DOP Study	August	Bivalves inventariation/Biol ogy of clams/ water characterization	DOP/ University of Azores.	Santos & Martins (1988)
1988	DOP Study	February/ May/July	Faunal inventariation/ clam`s biology/ water characterization /	DOP/ University of Azores.	Santos et al. (1990)
1990	Eastern Atlantic Expedition - R/V "Sea Diver"	01/ August	Faunal and floristic inventariation/	Harbour Branch Oceanog. Institute/ U.S.A.	Reed (1991)
1992	"Expedição S.Jorge- 92"	July 1992	Terrestrial molluscs / clams abundance/ hidrology	Department of Biology, University of Azores.	Morton & Cunha (1993)
1992	This study.	28 July to 06 August	Faunal benthos (intertidal and subtidal)/ fish species inventariation/ clams abundance and biomass/ water characterization	DOP/ University of Azores.	