Fifty years of changes in the seaweed flora of a polluted bay in southeast Brazil

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The first comprehensive seaweed flora of a Brazilian region was published by A.B. Joly in 1957, describing and illustrating 105 taxa. Twenty years later E. C. Oliveira and F. Berchez resurveyed the area and could find only 69 taxa; among them, only six of the sixteen species of Phaeophyta were found. In another survey performed in the early 1990s, at the three stations with the largest species richness the same reduction trend was found and no brown algae were observed. This reduction in biodiversity was attributed to the increased pollution load in the area. A new survey described here shows the return of some species recorded in the first survey, including seven species of brown algae. This increase in species number is thought to be a consequence of the efforts made by the local government to control air pollution and the building of a sewage terminal in the late 1980s.

1. INTRODUCTION

Although there is little quantitative evidence to show the effects of pollutants on marine communities, it has been generally accepted that increased levels of pollution will lead to a decrease in biological diversity. In a few cases this has been documented for seaweed dominated ecosystems (e. g., 1, 2, 3, and 4).

The utilization of sessile organisms to assess pollution has been considered more advantageous than direct chemical analysis because of integrating its effects in a larger span of time instead of the punctual and instantaneous measurement as provided by chemical analysis (5).

A classic approach to measuring the effects of pollutants on seaweeds is exemplified by Thursby and Steele (6) with *Champia parvula*, a species of red alga. However this approach can be considered a bioassay, testing specific chemicals on an unialgal culture. In Brazil, as well as in other tropical regions, there is very little published information of this type (7, 8). Seaweed assemblages to assess pollution effects on macroalgal communities have been used by Littler and Murray, (9) and Kindig and Littler, (10) among others. We believe that this approach, which provides information on the consequences of pollution on an entire seaweed flora, is environmentally significant and compensate the investments. In Brazil, the only two studies reporting the changes in a seaweed flora over time were carried out by Oliveira and Berchez (11) and Berchez and Oliveira (12) in Santos Bay. These were only possible because the first well-documented study of a marine benthic flora in Brazil was published by Joly (13) dealing with Santos Bay. According to that publication there were 105 species in Santos Bay in the early 1950s: 4 Cyanophyta, 22 Chlorophyta, 16 Phaeophyta and 63 Rhodophyta.

Twenty years after the initial survey, Oliveira and Berchez (11) re-surveyed the same region and found only 68 species: 4 Cyanophyta, 19 Chlorophyta, 5 Phaeophyta and 40 Rhodophyta, a reduction of 35% of the original flora within a period of 20 years. The decreased biodiversity was attributed to the increased level of pollution in the area.

During the winter of 1991 Berchez and Oliveira (12) studied three of the stations with the largest biodiversity and found a total of only 29 species, including three new records to the bay since 1978. A significant aspect of this work was that no single taxa of Phaeophyta was found at the stations sampled. Although their data was not comprehensive because of the limited time and number of sampling sites, it remains indicative of the continuous trend in decreased species richness. They concluded that this decrease in biodiversity was a signal that pollution levels could be increasing despite investments made by the local government to treat and control the emission of pollutants.

The results presented in this paper is a condensation of a larger project (14) to investigate the causative factors that affect the seaweed species diversity of a polluted bay, and includes experimental approaches such as *in vitro* cultivation, transplantation and re-introduction of sensitive species, and measurements of heavy metal accumulation *vis a vis* the available data on coliform indices and pollutants measured by chemical methods which have been supplied by an environmental agency.

2. THE SANTOS BAY AREA

Santos, and its twin city São Vicente, is located in what is known locally as Santos Bay, and has undergone continuous development since the Portuguese pilgrims settled in the area in the 1500s. In this century Santos gradually became one of the main seaports in South America, being surrounded by an important industrial area. The increase in the activities of the port, heavy industrialization as well as increasing urbanization in the last few decades, has resulted in serious problems of pollution, negatively affecting tourism which was flourishing a few decades ago.

Since 1975 an environmental state agency (CETESB) has been monitoring certain pollutants and determining coliform bacteria indices in the bay. This provided weekly reports on the balneability of the local beaches, and in the resultant banning of water sports activities on locations within the bay. Acute cases of pollution occurring in the surrounding industrial areas of the bay and the decrease in touristic activities lead the government to embark upon a series of measures to reduce pollution including the building of a sewage terminal in the late 1980s.

The availability of environmental data in addition to the seaweed flora of the region (13) has made Santos Bay an unique place to follow floristic changes over long periods of time. This information could be related to fluctuation in levels of pollution and to assess global changes in a seaweed dominated community.

3. METHODS

The area was visited regularly during the periods of low water springtides between 1996 and 1997. Sampling stations used were the same as those defined by Joly (13). Careful positioning of the stations by GPS were taken to facilitate future surveys. A qualitative sampling strategy was used with the aim of collecting the largest possible number of taxa and in particular looking for taxa already recorded at the sites in previous surveys. Collected materials was preserved in 5 % formalin in seawater and brought to the laboratory. Voucher collections are deposited at the Phycological Herbarium of the University of São Paulo (SPF). The adopted nomenclature follows Silva et al. (15) and Wynne (16).

4. RESULTS

One hundred and eleven taxa of algae have been identified in this survey, of which 20 are Cyanobacteria, 58 Rhodophyta, 11 Phaeophyta and 22 Chlorophyta (Table 1).

Table 1
Changes of the number of species and proportion of three main groups of marine algae in Santos Bay in different surveys (Cyanobacteria were not included).

	1957		1978		1998	
Chlorophyta	23	23%	19	30%	22	24%
Phaeophyta	15	15%	5	8%	11	12%
Rhodophyta	62	62%	40	62%	58	64%
Total	100		64		91	

From the 91 taxa identified, except the 20 Cyanophyta, 66 species were present in the first survey carried out by Joly (13). Among the original 66 species, 41 species were recorded in three surveys, and 25 species not found in the 1978 survey were encountered again in 1998. Twenty five species were new records including sixteen species never before found in the study area.

The relative proportion of Chlorophyta increased from 23% (in 1957) to 30% (in 1978) and decreased to 24% (in 1998). The Phaeophyta decreased sharply from 15% (in 1957) to 8% (in 1978), but increased to 12% in 1998. The proportion of Rhodophyta changed very little over time, from

62% in the 1950's and 1970's to 64 % in this present survey (Table 1).

5. DISCUSSION

Since the early 1980s serious efforts have been taken to control pollution, the most important one was the building of a sewage terminal in 1989. Despite this the effects of these efforts to ameliorate pollution were not evident in 1991 when Berchez and Oliveira (12) performed their partial survey. They concluded that the continued decrease in biodiversity was a signal that pollution levels were increasing despite the investments made by the local government to treat and control the emissions. Although that survey was carried out at three stations only, differences in the flora of those stations between 1992 and 1998 are marked with a considerable increase in total number of species in 1998. The number of the species at station 8 in 1998 was twice that found in 1992, while stations 4 and 5 also increased total number of species recorded by 72% and 18% respectively (Table 2).

Table 2
Variation in the composition of marine algae at stations 4, 5, and 8 in Santos Bay.

	1978			1992			1998		
Stations	4	5	8	4	5	8	4	5	8
Chlorophyta	12	6	9	8	5	7	14	8	13
Phaeophyta	1	4	0	0	0	0	2	1	3
Rhodophyta	28	13	26	15	10	12	26	11	28
Total	41	23	35	23	15	19	42	20	44

Therefore, the continued reduction in species number evident in 1992 can be explained by the fact that despite the improvement in the quality of environment, the return of the flora is a slower process and requires a longer period of time to reverse or decline.

The relative increase in the proportion of Chlorophyta from the 1950s to the early 1990s shows that this group has higher tolerance to pollution, as already referred to in the literature (e.g. 3, 17). The opposite is true of the Phaeophyta, whose diversity was severely restricted until 1992, and only started to recover thereafter. The sensitivity of the brown algae to pollution, and particularly to hydrocarbons, is also known in temperate waters (18). During our sampling we sometimes noticed an oily film covering the water surface of some stations what could be related to the absence of Phaeophyta in the early 1990s survey.

Occhipinti (19) mentioned that levels of pollution on Santos Bay had been increasing year by year, as shown by the concentration of colliform bacteria which increased more than 10 times as since 1970. According to the environmental agency (20), at the 46 sampled stations the concentrations of mercury were much higher than the acceptable standards of EPA (21). Data on accumulation of mercury and other heavy metals by some keystone species in Santos Bay will be reported elsewhere.

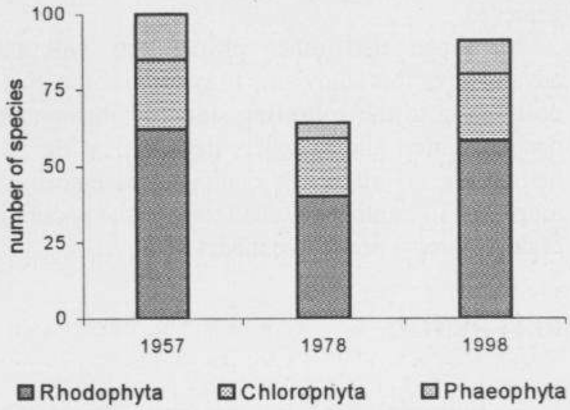

Fig. 1. Changes of the number of species of marine algae in Santos Bay in different surveys.

The floristic changes observed in Santos Bay in the last four decades (Fig. 1) become still more dramatic if we consider the assumption made by Oliveira and Berchez (11) that the region was already polluted in the 1950s when Joly undertook his survey. Unfortunately there is no information about the composition of the flora prior to the release of significant amount of pollutants in Santos or at other equivalent areas in the southeast coast of Brazil. We should also take into account that reduction in species number is not even larger because new records were always found on different surveys. However, we do not know if this is just a natural process of migration and dispersion, or if the newcomers became established because of empty niches.

In this last survey (14) the total number of species recorded was considerably higher than in 1992 and even to the 1978 survey, albeit to a lesser degree. Particularly relevant is the return of brown algal species belonging to the genera *Sargassum* and *Padina*, which are very common macroalgae in the southeast coast of Brazil. Because of the sensitivity of brown algae to pollution they may serve as good indicators of environmental changes.

In conclusion, our data show that the seaweed flora of Santos bay has undergone major changes in the past 40 years and that biodiversity has been severely affected. However, the data also show that mitigating measures to decrease the input of pollutants can allow the return of several taxa, although complete recover, perhaps, can never be achieved.

We hope that other phycologists will take advantage of this study area in years to come. Better positioning of the collecting stations, photographic documentation and vouchers deposited at the SPF herbarium, all allow the continued assessment of long term in Santos Bay changes and the possibility of developing a predictive model.

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