



HAL
open science

Effects of a nuclear power plant thermal discharge on habitat complexity and fish community structure in Ilha Grande Bay, Brazil

Tatiana Pires Teixeira, Leonardo Mitrano Neves, Francisco Gerson Araújo

► **To cite this version:**

Tatiana Pires Teixeira, Leonardo Mitrano Neves, Francisco Gerson Araújo. Effects of a nuclear power plant thermal discharge on habitat complexity and fish community structure in Ilha Grande Bay, Brazil. *Marine Environmental Research*, 2009, 68 (4), pp.188. 10.1016/j.marenvres.2009.06.004 . hal-00563082

HAL Id: hal-00563082

<https://hal.science/hal-00563082>

Submitted on 4 Feb 2011

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Accepted Manuscript

Effects of a nuclear power plant thermal discharge on habitat complexity and fish community structure in Ilha Grande Bay, Brazil

Tatiana Pires Teixeira, Leonardo Mitrano Neves, Francisco Gerson Araújo

PII: S0141-1136(09)00069-5

DOI: [10.1016/j.marenvres.2009.06.004](https://doi.org/10.1016/j.marenvres.2009.06.004)

Reference: MERE 3346

To appear in: *Marine Environmental Research*

Received Date: 23 July 2008

Revised Date: 7 April 2009

Accepted Date: 2 June 2009



Please cite this article as: Teixeira, T.P., Neves, L.M., Araújo, F.G., Effects of a nuclear power plant thermal discharge on habitat complexity and fish community structure in Ilha Grande Bay, Brazil, *Marine Environmental Research* (2009), doi: [10.1016/j.marenvres.2009.06.004](https://doi.org/10.1016/j.marenvres.2009.06.004)

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

Effects of a nuclear power plant thermal discharge on habitat complexity and fish community structure in Ilha Grande Bay, Brazil

Tatiana Pires Teixeira^a, Leonardo Mitrano Neves^a, Francisco Gerson Araújo^{a,*}

^a*Universidade Federal Rural do Rio de Janeiro, Laboratório de Ecologia de Peixes, Km 47, Antiga Rodovia Rio – São Paulo, 23851-970, Seropédica, RJ, Brazil*

* Corresponding author. Tel.: +55 21 94541989; fax: +55 21 37873983;

E-mail address: gerson@ufrj.br (F. G., Araújo)

ABSTRACT

Fish communities and habitat structures were evaluated by underwater visual censuses a rocky location impacted by thermal discharge (I) and at two control locations, one in a *Sargassum* bed (C1) and the other in a rocky shore with higher structural complexity (C2). Habitat indicators and fish communities exhibited significant differences between the impacted and control locations, with the impacted one showing a significant decrease in fish species richness and diversity, as well as a decrease in benthic cover. At the I location, only 13 fish species were described, and the average water temperature was 32 ± 0.4 °C, compared with 44 species at C1 (25.9 ± 0.3 °C) and 33 species at C2 (24.6 ± 0.2 °C). Significant differences in fish communities among locations were found by ANOSIM with *Eucinostomus argenteus*, *Mugil* sp and *Haemulon steindachneri* typical of location I, while *Abudefduf saxatilis*, *Stegastes fuscus* and *Malacoctenus delalandi* were typical of the control locations. Our study shows that thermal pollution alters benthic cover and influences fish assemblages by altering composition and decreasing richness.

Keywords: thermal pollution, community composition, fish, visual census, rocky shore, habitat, Brazil.

1. Introduction

Fish assemblages are widely used in applied ecology to detect human impact on marine environments (Warwick and Clarke, 1993; Contador, 2005). Some variations in species assemblages can allow early detection and monitoring of human impacts on natural ecosystems.

Temperature is a crucial environmental factor affecting marine organisms and ecosystems. It affects the distribution of populations on both small and large geographical scales (Wilson 1981), and determines the structure of communities and ecosystems (Glynn 1988) by affecting the physiological processes and behavior of fish species (Dembski et al. 2006). Reefs and marine ecosystems around the world are exposed to the effects of thermal phenomena such as global warming, El Niño and localized thermal pollutants (Forchhammer et al., 2000). Heated effluents introduced on the marine environment may induce dramatic and unpredictable effects, depending on the amount and temperature of discharged material, as well as the climatic, hydrological and biological features of the local environment (Lardicci et al., 1999). Fish are mobile, and most can migrate to safe areas when chronic low levels of heat pollution. However, many of their food sources (i.e. corals, sponges, macroalgae, etc) are sessile, and may be adversely affected. Apart from simply leaving an area, reef fish may be indirectly affected by the decreasing quality of food resources. Given the intensity and frequency of human disturbance and the ecological importance of coastal areas, it is critically important to understand the different aspects of the thermal effect on tropical rock shore

1 organisms. Although there have been numerous studies performed on the impacts of
2 heat pollution on coral reef environments (Roberts and Ormond 1987, Chabanet et al.
3
4 1997, Öhman and Rajasuriya 1998), little is known about the impact of thermal
5
6 modification on tropical rocky shores.
7

8
9 Changes in water temperature caused by power station thermal discharge affect fish
10 assemblages by decreasing species richness (Rong-Quen et al., 2001). Furthermore,
11
12 rocky shores have a variety of microhabitats, which increase fish diversity (Luckhurst
13
14 and Luckhurst, 1978). Thermally polluted rocky substrate may be unable to support
15
16 sessile invertebrates or macroalgal vegetation and will have a negative impact on fish
17
18 using the habitat for shelter, food, nesting and juvenile settlement. A decrease in habitat
19
20 complexity can also decrease species richness.
21
22
23
24

25
26 The southeastern coast of Brazil does not support any true coral reefs, and rocky
27
28 shores are the main habitat for reef fish and reef-associated biota (Floeter et al., 2007).
29
30 The Ilha Grande Bay, a relatively well-preserved coastal system, is exposed to the
31
32 thermal discharge of the Brazilian Nuclear Power Plant (BNPP), and provides a unique
33
34 opportunity to evaluate thermal effects on the fish community. The current study will
35
36 contribute to an early assessment of the global warming and some specific changes in
37
38 the rocky habitat structure.
39
40
41
42

43
44 In the present study, tropical rock reef fish were sampled in a location exposed to
45
46 thermal discharge and at two controls areas of natural thermal conditions in order to
47
48 evaluate the effect of thermal pollution on habitat structure of local fish assemblages.
49

50
51 All sites have similar dimensions, type of substrate and depth. It was hypothesized that
52
53 thermal pollution alters habitat structure changing fish assemblages. We focused on two
54
55 specific research goals: to find out whether the cooling power station alters the habitat
56
57 structure, and whether fish assemblages in this location shift in composition and
58
59
60
61
62
63
64
65

1 richness, due to the thermal effect. In addition, we determined whether both control
2 locations varied in structural complexity and, consequently, in fish assemblage
3 composition.
4
5
6
7
8

9 **2. Material and Methods**

10 *2.1. Study area*

11
12
13
14
15
16
17
18
19 The study was conducted at a rocky shore in Ilha Grande bay, close to the discharge
20 water of the Brazilian Nuclear Power Plant (BNPP), the only one in Brazil. The plant
21 began commercial operation in 1985 and consists of two sections, producing 600MW
22 and 1300MW, respectively, and the cooling water flow discharge into the sea is $40 \text{ m}^3 \text{ s}^{-1}$
23 and $80 \text{ m}^3 \text{ s}^{-1}$, respectively, from each of the sections. Three study locations were
24 chosen for sampling near BNPP (Fig. 1).
25
26
27
28
29
30
31
32

33
34 The mean temperature of the seawater surface ranged from $29.5 \text{ }^\circ\text{C}$ in winter to $36.5 \text{ }^\circ\text{C}$
35 in summer at a distance of approximately 100 m from the outfall in the impacted
36 location (I). The thermal effluent produced a mean increase of 8°C in the discharge area
37 (Bandeira et al., 2003). Two control locations (C1 and C2) with similar depth (1 – 2.5
38 m) were chosen at approximately 10 km (C1) and 9 km (C2) from the impacted location
39 (I), following the coastline. Surface temperature was measured to be 23°C in winter to
40 $28 \text{ }^\circ\text{C}$ in summer. Salinity was found to be $34.5 (\pm 1.2 \text{ SE})$ in all locations, consistent
41 throughout the year.
42
43
44
45
46
47
48
49
50
51
52

53 **Fig 1**

54 *2.2. Sampling design and methods*

1
2 Our sampling methods allowed an in-depth comparison of the rock reef fish
3 community features, and their relationship with local habitat structures, both at a
4 location close to the BNPP effluent outlet, and at two undisturbed control locations.
5
6 Monthly surveys were conducted between October 2005 and July 2006. The impacted
7 location was chosen on the basis of high temperature (a mean value of 7 °C higher than
8 the control locations).
9
10
11
12
13
14
15
16
17
18

19 2.3. Habitat structure

20
21
22
23
24 The study area is characterized by rocky shores covered by granitic boulders and a
25 sandy bottom. All three study locations (C1, C2 and I) are typically rocky shores. The
26 first area is characterized by *Sargassum* beds (C1), the second exhibits a comparatively
27 more complex habitat structure (C2), and the third is impacted by heated effluent
28 discharge (I), with the presence of rock rubble in some places.
29
30
31
32
33
34
35

36 Quadrants of 2 m² were used to quantify the variables describing physical structure.
37
38 The crevices in each quadrant were counted and pooled into three size classes (Ca = <
39 30 cm; Cb = 30 cm - 1 m; Cc = > 1 m), as well as the rocks, which were also counted
40 and pooled into four size classes (Ra = <30 cm; Rb = 30 cm - 1 m; Rc = 1 m - 3 m; Rd
41 = > 3 m). In each area, a visual census estimated the percent benthic cover of the
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100

2.4. *Rocky fish*

1
2
3
4
5 The composition and relative abundance of fish species were surveyed using the
6
7 non-destructive visual census diving transect technique adapted from Sale (1997). The
8
9 technique was selected as the most appropriate for surveying both smaller specimens
10
11 and fast-swimming species (Harmelin-Vivien and Francour, 1992). Underwater visual
12
13 censuses were performed by SCUBA diving and snorkeling during a census parallel to
14
15 the coastline along transects 30 m long and 3 m wide. Transects were each observed
16
17 twice. The first time, the observer recorded the conspicuous species, and the second
18
19 time focused the search beneath rocks and in all crevices to observe the more cryptic
20
21 species (Aburto-Opereza and Balart, 2001). Surveys were carried out in shallow waters
22
23 (0.5 to 2.5 m) because benthic communities in these areas are generally primary
24
25 producers with relevant secondary production, and they maintain the richest
26
27 ichthyofauna (Bouchereau and Lam Hoai, 1997; Methven et al., 2001). Three repeated
28
29 censuses were performed at each of the three locations during the ten field trips,
30
31 yielding a total of 90 samples.
32
33
34
35
36
37
38
39
40

2.5. *Data analysis*

41
42
43
44
45
46 Patterns of fish data were assessed by non-metric multidimensional scaling (nMDS)
47
48 using the Bray-Curtis measure of similarity. A fourth root transformation (Field et al.,
49
50 1982) was performed on the abundance data prior to the analyses. Differences in fish
51
52 communities between locations were performed using “Analysis of Similarities”
53
54 (ANOSIM), and the “Similarity of Percentage” procedure (SIMPER) was employed to
55
56 identify the contribution of each species to differences between sites (Clarke, 1993).
57
58
59
60
61
62
63
64
65

1 The Shannon–Wiener (H') index described differences in the heterogeneity of each
2 community. These analyses were performed with the software package PRIMER
3 (Plymouth Routines Multivariate Ecological Research) (Clarke and Warwick, 1994).
4
5

6
7 The mean value and the standard error of each habitat descriptor were calculated for
8 each location. Differences in habitat descriptors were compared among the three
9 locations using one-way analysis of variance (ANOVA) and a *post-hoc* multiple
10 comparisons Tukey HSD test. A principal component analysis (PCA; correlation
11 matrix) on the log-transformed ($x + 1$) environmental variables matrix was performed to
12 detect any spatial pattern. For this later analysis, only descriptors that show differences
13 between locations were used. ANOVA and PCA were conducted using Statistica 7.1
14 software (StatSoft, Inc., 2005).
15
16
17
18
19
20
21
22
23
24
25
26
27
28

29 **3. Results**

30 *3.1. Habitat complexity*

31
32
33
34
35
36
37 The impacted location (I) consisted mainly of bare rock, rock rubble and branched
38 calcareous algae. Rock rubble and branched calcareous algae were found exclusively in
39 this habitat. The C1 location was characterized by coverage of *Sargassum*, encrusting
40 calcareous algae and sponge colonies, while C2 consisted mainly of crevices and rocks,
41 with coverage by *Palythoa* and several types of Phaeophyta algae (Table 1).
42
43
44
45
46
47
48
49

50 The results of the PCA analysis show the relation between geographic locations and
51 habitat descriptors (Fig. 2). The PCA of habitat descriptors is shown in Table 2, with the
52 two first axes accounting for 43% of the total variance. The first axis summarizes
53 thermal influence on benthic cover between locations. In C2, the density of Phaeophyta
54 and encrusting calcareous algae was highest, while opportunistic branched calcareous
55
56
57
58
59
60
61
62
63
64
65

algae and bare rocks were rare. In location I, this situation was reversed (Fig. 2).

Locations I and C2 were separated along the axis 1.

The second PCA axis corresponded to the influence of the *Sargassum* bed on structural complexity (Fig. 2). The sample scores for the second axis were positively correlated with *Sargassum* (little physical structure), and negatively correlated with crevices, *Palythoa* and other types of Phaeophyta algae (considerable physical structure). Locations I and C2 were separated from C1 along this axis.

Tables 1 and 2, Fig 2

3.2. Fish community

A total of 44 species and 31 families were recorded throughout the study period (Table 3). Mugilids were not identified at species level due to the difficulty of specific determination by visual observation. Five families showed a high prevalence of species: Chaetodontidae, Pomacentridae and Haemulidae, Blenniidae and Labrisomidae. The twelve most abundant species accounted for 94% of all the fish, each one contributing more than 0.1% of relative abundance: *Eucinostomus argenteus*, *Abudefduf saxatilis*, *Haemulon steindachneri*, *Sardinella janeiro*, *Diplodus argenteus*, *Mugil* sp, *Stegastes fuscus*, *Orthopristis ruber*, *Malacocteus delalandi*, *Chaetodon striatus*, *Pempheris schomburgkii*, *Sphoeroides greeleyi*. The most abundant species in C1 was *S. janeiro*, in C2 was *A. saxatilis*, and in I was *E. argenteus*.

Table 3

3.3. Comparison of fish between the studied locations

1
2 A significant decrease in the mean species richness was described at site I compared
3
4 to the control locations ($F = 45.83^{**}$, $p < 0.05$; Fig. 3), although no difference was
5
6 found in total fish abundance between the three locations. A greater number of species
7
8 was recorded at the two control sites (C1 = 40; C2 = 33) compared to I (13). These
9
10 differences were due to 18 fish that were only observed at the control sites. Eleven
11
12 species were common to the three locations and no species were exclusive to site I.
13
14
15

16
17 The Shannon-Wiener diversity index showed significant differences between I and
18
19 the controls ($F = 19.82^{**}$, $p < 0.05$). This trend was inversely related to temperature
20
21 (Fig. 4).
22
23

24 **Figs 3 and 4**

25
26
27
28 ANOSIM showed significant differences ($R = 0.592$, $p < 0.01$) between locations
29
30 (Table 4). *Post-hoc* pairwise comparisons exposed significant differences between I and
31
32 the controls (C1 and C2), although the two controls did not significantly differ from one
33
34 another. The MDS configuration of individual replicates (Fig. 5) shows that the fish
35
36 community in site I is clearly distinct from those recorded at the two controls, with the
37
38 latter grouping indistinguishably. SIMPER provided evidence that *E. argenteus* and *A.*
39
40 *saxatilis* mostly contributed to the dissimilarity between each control and I (Table 4).
41
42
43
44

45
46 SIMPER analysis identified the species that made the greatest contribution to the
47
48 fish composition similarities within the locations (Table 5). Within C1, Pomacentridae
49
50 *S. fuscus* (12%), *A. saxatilis* (17.8%) and Labrisomidae *M. delalandi* (16.8%) were
51
52 responsible for most of the similarity within this location. In C2, *A. saxatilis* (25%), *S.*
53
54 *fuscus* (26%) made the greatest contribution to the average similarity. In total, these two
55
56 Pomacentrids accounted for over 30% of the average similarity for C1, and 51% for C2.
57
58
59
60
61
62
63
64
65

1 The most prominent species in I were *E. argenteus* and *Mugil* sp, which contributed
2 42.71% and 19.3% respectively to the average similarity. These species were nearly
3
4 absent in the control locations. Another important species in this analysis was *H.*
5
6 *steindachneri*, which contributed to average similarity for all locations, particularly in
7
8 site I.
9
10

11 **Table 4 and 5, Fig. 5**

12 **4. Discussion**

13 *4.1. Habitat complexity*

14
15
16
17
18
19
20
21
22
23
24
25
26
27 This study provides compelling evidence that heated effluents can affect habitat
28
29 structure and, consequently, community structure and spatial distribution. The heat-
30
31 impacted location showed low benthic cover and was characterized mainly by bare
32
33 rock. In addition, vermitids were found only at I, indicating that these organisms are
34
35 opportunistic and tolerant to high temperatures (>30 °C). Thermal discharge has been
36
37 shown to reduce species richness of algal and zoobenthic communities, to increase the
38
39 abundance of the so-called opportunistic or ephemeral species and to alter the
40
41 population dynamics of the most abundant species (Devinny, 1980; Mahadevan, 1980;
42
43 Verlaque et al., 1981; Bamber and Spencer, 1984; Suresh et al., 1993; Qian et al., 1993).
44
45
46 However, Lardicci et al. (1999) studied the influence of thermal discharge on spatial
47
48 variability and abundance of meiobenthic and macrobenthic communities in the Gulf of
49
50 Follonica (Western Mediterranean), and found that heated effluent did not appear to
51
52 influence community structure or spatial distribution of the study taxa. Vilanova et al.
53
54 (2004) studied the effect of thermal discharge on sponge community in an area
55
56
57
58
59
60
61
62
63
64
65

1 influenced by the BNPP, and found that species richness, diversity and community
2 density were lower than in control locations. Overall, sessile benthic organisms have
3 been reported as particularly susceptible to heated effluents, and an increase of a few
4 degrees centigrade can threaten their survival (Laws, 1993; Logue et al., 1995).
5 According to Mate (1997), lethal temperatures to reef corals exist within or below the
6 30-35° C range, which is often reached in the impacted location by BNPP, suggesting
7 that thermal pollution is the main factor in reducing composition and abundance of
8 benthic assemblages.
9

10 Other factors introduced by BNPP, including chlorine pollutants and outflow
11 currents, may also influence community density and/or richness in this area. Chlorine is
12 added to the power station cooling water for antibiotic purposes (Jenner et al., 1997),
13 and chlorination byproducts (CBPs) may act as biocides once the water is introduced
14 into the ocean. The chemical reactivity and biocidal properties of these oxidants are well
15 known, and, in principle, both micro- and macro-biota can be inhibited on any given
16 site. Additionally, many benthic marine plants and animals release propagules that serve
17 as the organism's dispersal mechanism. Although propagules are able to explore and
18 select an appropriate settlement site, a wide range of flow regimes exist under which
19 these organisms are unable to explore the surface (Abelson and Denny, 1997). Pawlik
20 and Butman (1993) observed the "erosion" of larvae from the bed at shear velocities
21 (measuring the magnitude and correlation of turbulent fluctuations in velocity near the
22 substratum) higher than 1.03 cm s^{-1} . Under such flow conditions, propagule swimming
23 is entirely ineffective.
24

25 Physical structure has been directly correlated with species richness. Characteristics
26 including rock size, hollows and bottom types provide the organisms with shelter and
27 reproductive habitat. Most studies on habitat complexity have examined the effects of
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1 both habitat variables (abiotic physical structure and biotic benthic cover) on fish
2 communities, without discriminating the influence of each variable separately. Physical
3 structure such as rugosity (topographic complexity) is reliable predictor of fish diversity
4 and, to a lesser extent to their abundance (Chabanet et al., 1997). Ferreira et al. (2001)
5 found rugosity to be a poor descriptor of fish density in rocky shore habitats. In the
6 present work the physical structure was assessed by counting and measuring crevices
7 and rocks in order to have a more detailed information on the habitat.
8
9

10
11
12
13
14
15
16
17 *Sargassum* bed was the main factor differentiating structural complexity between the
18 two control locations, with lower structural complexity (physical structure) at C1, and
19 higher complexity (physical and benthic cover) at C2. The impacted location showed
20 physical structure comparable to the control location C2, and no significant differences
21 were found in the number of crevices and size of rocks present. However, the locations
22 clearly differed in benthic cover, which was significantly higher at C2. Benthic cover
23 forms a complex framework and supports a variety of microhabitats, thus increasing the
24 potential for fish diversity. Laegdsgaard and Johnson (2001) added artificial mangrove
25 structures to field areas, and found that the increase in fish number was relatively small
26 compared to unstructured areas. However, introduction of artificial structures with
27 accumulated algae attracted approximately four times the number of juvenile fish than
28 either bare stakes or no structure. Many forms of vegetation allow the growth and
29 accumulation of small invertebrates (Stoner, 1982; Robertson, 1984; Lubbers et al.,
30 1990; Schneider and Mann, 1991; Ornellas and Coutinho, 1998), which are an
31 important food source for many juvenile fish species. In the present work, benthic
32 cover, rather than the physical structure, was found to be the underlying factor
33 correlating with fish species richness at the control sites, since a low number of species
34 was found at site I even though high physical structure was present at that location.
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

Correlation is less consistent between habitat structural complexity and fish abundance (Friedlander and Parrish, 1998), although it has been suggested that fish abundance on different reefs increases with structural complexity (Gladfelter et al., 1980). According to Laegsgaard and Johnson (2001), structural complexity alone may not be greatly attractive to juvenile fish independently of the structure benefits, including shelter or increased surface area for food accumulation. Habitat descriptors showed a little influence on fish community structure in the controls, since most species, with few exceptions, were found to be present in both locations in similar abundance. The ANOSIM showed low R-values in comparing C1 and C2, and the MDS confirmed this trend by showing the control locations scattered mainly along the right side of the diagram (Fig. 5).

4.2. *Fish communities*

Heated effluent appears to influence the fish community structure and the eco-spatial distribution in BNPP area. A thermal discharge effect was detected with the impacted location (I) significantly different from the controls, which exhibited the highest number of fish species. Species richness did not differ between the controls, and was 2.5 to 3-fold higher at the controls than at I. Previous studies examining environmental impacts on fish communities have reported conflicting results. Rong-Quen et al. (2001) performed long-term monitoring of reef fish communities around a nuclear power station, found some inconsistency in the temporal variations of the local fish communities. Since water temperature variations are minor at underwater stations, such temporal variations may be due to natural environmental fluctuations.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

Low species richness in the impacted location may be due to the low benthic cover availability, and the resulting limited food availability. With exception of *H. steindachneri*, which is typically associated with rocky shores (Ferreira et al., 2001; Floeter et al. 2007), the abundant species *E. argenteus* and *Mugil* sp have been reported mostly in sandy banks and muddy flat areas, respectively (Benetti and Neto, 1991; Alvarez-Lajonchere et al., 1992; Chaves and Otto, 1999; Gaelzer and Zalmon, 2003). These species are likely specialized to exploit the available resources in high temperature areas where others species are not able to thrive.

Our description of species compositions provides evidence that opportunistic or tolerant species are present at the impacted location. *E. argenteus*, a genera considered tolerant of thermal stress, was the most abundant species near the power station discharge. In addition, *Mugil* sp and *H. steindachneri* were observed frequently in high numbers at I. Mora and Ospina (2001) determined the critical thermal maximum (CTM) of reef fish from the tropical eastern Pacific and found that the CTMs ranged from 36 °C for *H. steindachneri*, 38 °C for *Eucinostomus gracilis* and 40.8 °C for *Mugil curema*. According to Urban (1994), reef fish are more tolerant on increased temperatures than invertebrates such as bivalves and corals, which almost entirely disappeared from the impacted location.

Effect of thermal discharge on freshwater fish has also been studied in temperate areas. Luksiene and Sandström (1994) documented recruitment failure in a roach (*Rutilus rutilus*) population exposed to cooling water from a Swedish nuclear power plant. Madenjian et al. (1986), studying abundance of alewife (*Alosa pseudoharengus*) and yellow perch (*Perca flavescens*) in a nuclear power plant area in southeastern Lake Michigan found a significant decrease in abundance at the plant-discharge transect relative to the reference transect when plant operation began. The impacts of thermal

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

effluent from a nuclear power plant on the smallmouth bass *Micropterus dolomieu* population in Baie du Doré, Lake Huron was also detected by Shuter et al. (1985), who observed negative effects on growth and spawning timing.

5. Conclusions and future concerns

This study showed that there are different responses of fish assemblage structures, community attributes (species richness and total number of fish), and fish abundance to thermal impact. Heated effluent affected fish assemblage structure at a small spatial scale, and also affected benthic cover, which indirectly impacted the fish community. As observed in this study, areas with no impact by heated water didn't show the benthic cover having significant effect on fish community structure. Conversely, in thermally impacted areas, shifts in the composition and structure of the communities are common and severe. As a rule, heated effluent effect on water temperature is a point-source disturbance that gradually decreases at higher distances from the outflow site. In this area, even though the outflow volumes are comparatively small ($40 \text{ m}^3\text{s}^{-1}$ and $80 \text{ m}^3\text{s}^{-1}$), their effects were observed as far as 500-600 m from the impacted site.

Our study confirms that thermal pollution induces changes in the marine environment. This is the first result from a South American tropical bay. Our results provide compelling evidence that the benthic cover reduction caused by heated effluent affects fish communities and populations, and the potential consequences that need to be thoroughly investigated. This negative ecological impact can be controlled and mitigated by management and monitoring plans. In addition, our results may provide a critical assessment of potential impacts of global warming on coastal shallow waters, which has already been associated with negative changes in several marine populations.

Acknowledgements

We thank André Luiz Balbino dos Santos and Hamilton Hissa Pereira for their help in the field work. We are particularly grateful to Áurea Maria de Oliveira Teixeira for invaluable laboratory activities. Condomínio Barlavento harbors the boat and equipments to perform the visual census. This study was partially financed by CNPq - Brazilian National Counsel for Research Development (Proc. 474813-03-7).

References

- Abelson, A., Denny, M. 1997. Settlement of marine organisms in flow. *Annual Review of Ecological Systems* 28, 317–339.
- Aburto-Opereza, O., Balart, E.F. 2001. Community structure of reef fish in several habitats of a rocky reef in the Gulf of California. *Marine Ecology* 22, 283–305.
- Alvarez-Lajonchere, L., Trewavas, E., Howes, G.J. 1992. *Mugil curema* and *Mugil liza* Valenciennes in Cuvier and Valenciennes, 1836 (Osteichthyes, Perciformes): proposed conservation of the specific names. *Bulletin of Zoological Nomenclature* 49, 271–275.
- Bamber, R.N., Spencer, J.F. 1984. The benthos of a coastal power station thermal discharge canal. *Journal of the Marine Biological Association of the United Kingdom* 64, 603–623.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

Bandeira, J.V., Barreto, A.A., Bomtempo V.L., Moreira R.M., Salim, L.H. 2003. The performance of a surface jet on a closed bay: The reality compared with the theory. In: Proceedings of the 6th International Conference on Coastal and Port Engineering in Developing Countries. COPEDEC VI, Colombo, Sri Lanka, 1 CD-ROM.

Benetti, D.D., Neto, E.B.F. 1991. Preliminary results on growth of mullets (*Mugil liza* and *Mugil curema*) fed artificial diets. *World-Aquaculture* 22, 55–57.

Bouchereau, J.L., Lam Hoaï, T. 1997. The ichthyofauna of the Lavezzi Island (Corsica, France) at depths between 0 and 1m: inventory, quantitative evaluation and recolonisation after experimental destruction. *Oceanological Studies* 2-3, 191–207.

Chabanet, P., Ralambondrainy, H., Amanieu, M., Faure, G., Galzin, R. 1997. Relationships between coral reef substrata and fish. *Coral Reefs* 16, 93–102.

Chaves, P.T.C., Otto, G. 1999. The mangrove as a temporary habitat for fish: The *Eucinostomus* species at Guaratuba Bay, Brazil (25°52'S; 48°39'W). *Brazilian Archives of Biology and Technology* 42, 61–68.

Clarke, K.R. 1993. Non parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* 18, 117–143.

Clarke, K.R., Warwick, R.M., 1994. Change in Marine Communities. An Approach to Statistical Analysis and Interpretation. Natural Environment Research Council, Plymouth, UK, 144 pp.

- 1
2 Contador, J.F.L., 2005. Adaptive management, monitoring, and the ecological
3 sustainability of a thermal-polluted water ecosystem: a case in SW Spain.
4 Environmental Monitoring and Assessment 104, 19–35.
5
6
7
8
9
10
11 Dembski, S., Masson, G., Monnier, D., Wagner, P., Pihan, J.C. 2006. Consequences of
12 elevated temperatures of life-history traits of an introduced fish, pumpkinseed *Lepomis*
13 *gibbosus*. Journal of Fish Biology 69, 331–346.
14
15
16
17
18
19
20
21 Devinnny, J.S. 1980. Effects of thermal effluents on communities of benthic marine macro-
22 algae. Journal of Environmental Management 11, 225–242.
23
24
25
26
27
28
29 Ferreira, C.E.L., Gonçalves, J.E.A., Coutinho, R. 2001. Community structure of fishes and
30 habitat complexity on a tropical rocky shore. Environmental Biology of Fishes 61, 353–
31 369.
32
33
34
35
36
37
38
39 Field, J.G., Clarke, K.R., Warwick, R.M. 1982. A practical strategy for analysing
40 multispecies distribution patterns. Marine Ecology Progress Series 8, 37–52.
41
42
43
44
45
46 Floeter, S.R., Krohling, W., Gasparine, J., Ferreira, C.E.L., Zalmon I. 2007. Reef fish
47 community structure on coastal islands of the southeastern Brazil: the influence of
48 exposure and benthic cover. Environmental Biology of Fishes 78, 147–160.
49
50
51
52
53
54
55
56 Forchhammer, M.C., Pots, E., Kozlov, M.V., Hughes, L. 2000. Climatic signatures in
57 ecology. Trends in Ecology and Evolution 15, 286–287.
58
59
60
61
62
63
64
65

1
2 Friedlander, A.M., Parrish, J.D. 1998. Habitat characteristics affecting fish assemblages on
3
4 a Hawaiian coral reef. *Journal of Experimental Marine Biology and Ecology* 26, 65–84.
5
6

7
8
9 Gaelzer, L.R, Zalmon, I.R . 2003. The influence of wave gradient on the ichthyofauna of
10
11 southeastern Brazil: Focusing the community structure in surf-zone. *Journal of Coastal*
12
13 *Research* 35, 456–462.
14
15
16

17
18
19 Gladfelter, W.B., Ogden, J.C., Gladfelter, E.H. 1980. Similarity and diversity among coral
20
21 reef communities: A comparison between tropical western Atlantic (Virgin Islands) and
22
23 tropical central Pacific (Marshall Islands) patch reefs. *Ecology* 61, 1156–1168.
24
25
26

27
28
29 Glynn, P.W.1988. El Niño-Southern Oscillatio 1982-1983: near-shore population,
30
31 community, and ecosystem responses. *Annual Review of Ecological Systems* 19, 309–
32
33 345.
34
35
36

37
38
39 Harmelin-Vivien, M.L., Francour, P. 1992. Trawling or visual censuses? Methodological
40
41 bias in the assesement of fish populations in seagrass beds. *Marine Ecology* 13, 41–51.
42
43
44

45
46 Jenner, H.A., Taylor, C.J.L., Donk, M. van, Khalanski, M. 1997. Chlorination by products
47
48 in chlorinated cooling water of some European costal power station. *Marine*
49
50 *Environmental Research* 43, 279–293.
51
52
53

54
55
56 Laegdsgaard, P., Johnson, C. 2001. Why do juvenile fish utilise mangrove habitats? *Journal*
57
58 *of Experimental Marine Biology and Ecology* 257, 229–253.
59
60
61

1
2 Lardicci, C., Rossi, F., Maltagliati, F. 1999. Detection of thermal pollution: Variability of
3
4 benthic communities at two different spatial scales in an area influenced by a coastal
5
6 power station. *Marine Pollution Bulletin* 38, 296–303.
7
8

9
10
11 Laws, E.A. 1993. *Aquatic Pollution - An Introductory Text*. John Wiley and Sons Inc.,
12
13 New York, 611pp..
14
15

16
17
18 Logue, J., Tiku, P., Cossins, A.R. 1995. Heat injury and resistance adaptation in fish.
19
20
21 *Journal of Thermal Biology* 20, 191–197.
22
23

24
25
26 Lubbers, L., Boynton, W.R., Kemp, W.M. 1990. Variations in structure of estuarine fish
27
28 communities in relation to abundance of submersed vascular plants. *Marine Ecology*
29
30 *Progressive Series* 65, 1–14.
31
32

33
34
35
36 Luckhurst, B.E., Luckhurst, K. 1978. Analysis of the influence of the substrate variables on
37
38 coral reef fish communities. *Marine Biology* 49, 317–323.
39
40

41
42
43 Luksiene, D., Sandström, O. 1994. Reproductive disturbance in a roach (*Rutilus rutilus*)
44
45 population affected by cooling water discharge. *Journal of Fish Biology* 45, 13–625.
46
47

48
49
50
51 Madenjian, C.P., Jude, D.J., Tesar, F.J. 1986. Intervention analysis of power-plant impact
52
53 on fish populations. *Canadian Journal of Fisheries and Aquatic Sciences* 43, 819–829.
54
55

1 Mahadevan, S. 1980. A study on the effects of power plant thermal discharges on benthic
2 infaunal communities at Big Bend, Tampa Bay (Florida). Florida Science 43, 7.
3
4

5
6
7 Mate, J.L.T. 1997. Experimental responses of Panamanian reef corals to high temperatures
8 and nutrients. In: Proceedings of the 8th International Coral Reef Symposium,
9 Smithsonian Tropical Research Institute, Panama, pp. 515–520.
10
11
12
13

14
15
16 Methven, D.A., Haedrich, R.L., Rose, G.A. 2001. The fish assemblage of a New Foundland
17 estuary: diel, monthly and annual variation. Estuarine, Coastal and Shelf Science 52,
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000

999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175
2176
2177
2178
2179
2180
2181
2182

1
2 Qian, S., Chen, H., Zhao, X., Zhang, Q. 1993. A study of the effect of thermal pollution on
3 seaweeds. *Journal Ocean University of Qingdao* 23, 22–34.
4
5
6

7
8
9 Roberts, C.M., Ormond, R.F.G. 1987. Habitat complexity and coral reef fish diversity and
10 abundance on Red Sea fringing reefs. *Marine Ecology Progressive Series* 41, 1–8.
11
12
13

14
15
16 Robertson, A.I., 1984. Trophic interactions between the fish fauna and macrobenthos of an
17 eelgrass community in Western Port, Victoria. *Aquatic Botany* 18, 135–153.
18
19
20

21
22
23 Rong-Quen, J., Jeng-Ping, C., Chun-Yu, L., Kwang-Tsao, S. 2001. Long-term monitoring
24 of the coral reef fish communities around a nuclear power plant. *Aquatic Ecology* 35,
25 233–243.
26
27
28
29

30
31
32 Sale, P. F. 1997. Visual census of fishes: how well do we see what is there? In: *Proceedings*
33 of the 8th International Coral Reef Symposium, Smithsonian Tropical Research Institute,
34 Panama, pp. 1435–1440.
35
36
37
38
39

40
41
42 Schneider, F.I., Mann, K.H. 1991. Species specific relationships of invertebrates to
43 vegetation in a seagrass bed. I. Correlational studies. *Journal of Experimental Marine*
44 *Biology and Ecology* 145, 101–117.
45
46
47
48
49

50
51
52 Shuter, B.J., Wismer, D.A., Regier, H.A., Matuszek, J.E. 1985. An Application of
53 Ecological Modelling: Impact of Thermal Effluent on a Smallmouth Bass
54 Population. 1985. *Transactions of the American Fisheries Society* 114, 631–651.
55
56
57
58
59
60
61
62
63
64
65

1
2 StatSoft, Inc. 2005. STATISTICA (data analysis software system), version 7.1.

3
4
5 www.statsoft.com.

6
7
8
9 Stoner, A.W. 1982. The influence of benthic macrophytes on the foraging behaviour of
10 pinfish, *Lagodon rhomboides* (Linnaeus). Journal of Experimental Marine Biology and
11 Ecology 58, 271–284.
12
13
14
15

16
17
18
19 Suresh, K., Ahamed, M.S., Durairaj, G., Nair, K.V.K. 1993. Impact of power plant heated
20 effluent on the abundance of sedentary organism, off Kalpakkam, east coast of India.
21 Hydrobiologia 268, 109–114.
22
23
24
25

26
27
28
29 Urban, J. 1994. Upper temperature tolerance of tem bivalve species off Peru and Chile
30 related to El Niño. Marine Ecology Progressive Series 107, 139–145.
31
32
33
34

35
36 Verlaque, M., Giraud, G., Boudouresque, C.F. 1981. Effects of a thermal power plant on
37 the Mediterranean marine hythobenthos: the area of high frequency temperature
38 changes. Botanica Marina 24, 69–87.
39
40
41
42

43
44
45
46 Vilanova, E., Pinto, M.M., Curbelo-Fernandez, M.P., Silva, S.H.G. 2004. The impact of a
47 nuclear power plant discharge on the sponge community of a tropical bay (SE Brazil).
48 Boll.Mus.Ist.Biol.Univ.Genova 68, 647–654.
49
50
51
52

53
54
55
56 Warwick, R.C., Clarke, K.R. 1993. Increased variability as a symptom of stress in marine
57 communities. Journal of Experimental Marine Biology and Ecology 172, 215–226.
58
59
60
61

1
2 Wilson, J.G. 1981. Temperature tolerance of circatidal bivalves in relation to their
3
4 distribution. *Journal of Thermal Biology* 6, 279–286.
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

Table 1. Mean values (\pm standard error) and F-values from ANOVA comparisons of the habitat descriptors measured in 26 replicates of 2 m² quadrants among locations (I = Impacted, C1 and C2 = Controls) at Ilha Grande Bay. (-: absence of descriptor).

Habitat descriptors	C1	C 2	I	F	Tukey <i>pos- hoc</i>
Physical structure (number)					
Crevices < 30 cm	0.77 \pm 0.34	10.15 \pm 1.57	1.69 \pm 0.90	33.15 ^b	C2 > C1, I
Crevices 30 – 1 m	0.08 \pm 0.08	0.92 \pm 0.33	0.85 \pm 0.30	3.8 ^a	C2, I > C1
Crevices > 1 m	0.08 \pm 0.08	0.23 \pm 0.17	-	n.s.	
Rocks < 30 cm	10.08 \pm 5.11	9.23 \pm 2.72	59.46 \pm 20.84	n.s.	
Rocks 30 cm – 1 m	4.38 \pm 1.08	5.77 \pm 1.35	1.92 \pm 0.61	4.02 ^a	C1, C2 > I
Rocks 1 m – 3 m	0.46 \pm 0.18	0.69 \pm 0.31	2.00 \pm 0.80	n.s.	
Rocks > 3 m	0.08 \pm 0.08	0.23 \pm 0.12	-	n.s.	
Benthic cover (%)					
Bare rock	12.00 \pm 3.93	1.35 \pm 0.82	31.35 \pm 5.91	20.48 ^b	I > C1 > C2
Sand	8.27 \pm 3.69	18.27 \pm 7.34	3.27 \pm 1.64	n.s.	
<i>Sargassum</i>	53.27 \pm 8.68	11.65 \pm 5.15	-	31.55 ^b	C1 > C2
<i>Palythoa</i>	6.54 \pm 3.86	17.19 \pm 5.86	-	6.19 ^a	C2, C1 > I
Encrusting calcareous algae	8.08 \pm 2.52	9.23 \pm 2.80	-	9.49 ^b	C1, C2 > I
Phaeophyta algae	9.62 \pm 3.52	38.35 \pm 6.76	-	34.25 ^b	C2 > C1 > I
Branched calcareous algae	-	-	51.15 \pm 6.61	122.0 ^b	I > C1, C2
Sponge	1.65 \pm 0.59	1.08 \pm 0.77	-	3.63 ^a	C1, C2 > I
Barnacle	-	2.12 \pm 1.60	1.15 \pm 0.54	n.s.	
Vermetid	-	-	13.08 \pm 4.68	10.80 ^b	I > C1, C2

Significance level: ^a $p < 0.05$; ^b $p < 0.01$; n.s. - non significant.

Table 2. Results of Principal Components Analysis based on habitat descriptors at the studied sites in Ilha Grande bay. Values higher than 0.6 are indicated in bold.

Variables	Axis 1	Axis 2
Crevices < 30 cm	-0.573	-0.594
Crevices 30 cm – 1 m	0.029	-0.393
Rocks 30 cm – 1 m	-0.424	-0.078
Bare rock	0.650	0.047
<i>Sargassum</i>	-0.121	0.805
<i>Palythoa</i>	-0.464	-0.352
Encrusting calcareous algae	-0.605	0.081
Phaeophyta algae	-0.745	-0.193
Branched calcareous algae	0.716	-0.383
Sponge	-0.403	0.170
Vermetid	0.427	-0.494
Eigenvalue	2.944	1.753
% variance explained	26.7	15.9

Table 3. Total composition as determined by visual census at the studied locations. Density per 540 m² (mean ± SE), total number of specimens counted (n) and percent of total observed. The twelve most abundant species are indicated in bold. Locations: I = impacted; C1 and C2 = Controls.

Family/Species	C1			C2			I		
	Density	n	%	Density	n	%	Density	n	%
Acanthuridae									
<i>Acanthurus chirurgus</i>	1.06 ± 0.47	38	1.90	0.93 ± 0.36	28	0.86	–	–	–
Belontiidae									
<i>Strongylura timucu</i>	0.03 ± 0.03	1	0.05	–	–	–	–	–	–
Blenniidae									
<i>Parablennius</i> sp	0.08 ± 0.05	3	0.15	0.23 ± 0.10	7	0.21	–	–	–
Carangidae									
<i>Caranx latus</i>	–	–	–	0.03 ± 0.03	1	0.03	–	–	–
<i>Trachinotus carolinus</i>	–	–	–	0.07 ± 0.07	2	0.06	–	–	–
Centropomidae									
<i>Centropomus undecimalis</i>	0.11 ± 0.07	4	0.20	–	–	–	–	–	–
Chaetodontidae									
<i>Chaetodon striatus</i>	2.36 ± 0.36	85	4.25	1.73 ± 0.29	52	1.59	–	–	–
Clupeidae									
<i>Sardinella janieiro</i>	13.53 ± 8.07	487	19.59	6.00 ± 2.91	180	5.22	–	–	–
Dactylopteridae									
<i>Dactylopterus volitans</i>	0.64 ± 0.33	23	1.15	–	–	–	0.07 ± 0.07	2	0.06
Dasyatidae									
<i>Dasyatis americana</i>	–	–	–	0.03 ± 0.03	1	0.03	–	–	–
Diodontidae									
<i>Chilomycterus spinosus</i>	0.14 ± 0.06	5	0.25	0.10 ± 0.06	3	0.09	–	–	–
Gerreidae									
<i>Diapterus rhombeus</i>	0.03 ± 0.03	1	0.05	–	–	–	1.57 ± 1.13	47	1.47
<i>Eucinostomus argenteus</i>	0.72 ± 0.69	26	1.30	0.03 ± 0.03	1	0.03	75.03 ± 22.35	2251	70.37
Haemulidae									
<i>Anisotremu surinamensis</i>	0.33 ± 0.11	12	0.60	0.67 ± 0.21	20	0.61	0.03 ± 0.03	1	0.03
<i>Anisotremus virginicus</i>	0.83 ± 0.23	30	1.50	0.57 ± 0.22	17	0.52	–	–	–
<i>Haemulon aurolineatum</i>	0.14 ± 0.14	5	0.25	0.23 ± 0.13	7	0.21	–	–	–
<i>Haemulon steindachneri</i>	7.33 ± 3.27	264	13.21	18.37 ± 6.26	551	16.87	12.60 ± 3.59	378	11.82
<i>Orthopristis rubber</i>	6.72 ± 2.54	242	12.11	5.40 ± 2.03	162	4.96	0.07 ± 0.07	2	0.06
Holocentridae									
<i>Holocentrus adscensionis</i>	0.22 ± 0.12	8	0.40	0.23 ± 0.08	7	0.21	0.03 ± 0.03	1	0.03
Kyphosidae									
<i>Kyphosus incisor</i>	0.03 ± 0.03	1	0.05	–	–	–	–	–	–
Labridae									
<i>Halichoeres poeyi</i>	0.72 ± 0.18	26	1.30	0.47 ± 0.13	14	0.43	–	–	–
Labrisomidae									
<i>Labrisomus nuchipinnis</i>	0.92 ± 0.18	33	1.65	0.63 ± 0.18	19	0.58	–	–	–
<i>Malacoctenus delalandii</i>	6.39 ± 0.96	230	11.51	3.73 ± 0.66	112	3.43	0.27 ± 0.11	8	0.25
Lutjanidae									
<i>Ocyurus chrysurus</i>	0.03 ± 0.03	1	0.05	–	–	–	–	–	–
Monacantidae									

1	<i>Monacanthus ciliatus</i>	0.33 ± 0.12	12	0.60	0.07 ± 0.05	2	0.06	–	–	–
2	<i>Stephanolepis hispidus</i>	0.19 ± 0.10	7	0.35	–	–	–	–	–	–
3	Mugilidae									
4	<i>Mugil</i> sp	0.36 ± 0.33	13	0.65	0.63 ± 0.33	19	0.58	12.73 ± 3.35	382	11.94
5	Mullidae									
6	<i>Pseudupeneus maculatus</i>	0.78 ± 0.21	28	1.40	0.50 ± 0.18	15	0.46	–	–	–
7	Muraenidae									
8	<i>Gymnothorax funebris</i>	0.03 ± 0.03	1	0.05	0.03 ± 0.03	1	0.03	–	–	–
9	Ostraciidae									
10	<i>Acanthostracion polygonius</i>	0.03 ± 0.03	1	0.05	–	–	–	–	–	–
11	Pempheridae									
12	<i>Pempheris schomburgkii</i>	–	–	–	3.30 ± 1.75	99	3.03	–	–	–
13	Pomacentridae									
14	<i>Abudefduf saxatilis</i>	9.42 ± 1.74	339	16.96	50.23 ± 9.30	1507	46.13	2.40 ± 0.80	72	2.25
15	<i>Chromis multilineata</i>	0.06 ± 0.04	2	0.10	0.20 ± 0.09	6	0.18	–	–	–
16	<i>Stegastes fuscus</i>	3.64 ± 0.51	131	6.55	9.30 ± 0.88	279	8.54	–	–	–
17	<i>Diplodus argenteus</i>	9.17 ± 4.98	330	16.51	9.60 ± 4.67	288	8.82	–	–	–
18	Scaridae									
19	<i>Sparisoma</i> sp	0.06 ± 0.04	2	0.10	0.47 ± 0.18	14	0.43	–	–	–
20	Sciaenidae									
21	<i>Pareques acuminatus</i>	0.25 ± 0.12	9	0.45	0.27 ± 0.11	8	0.24	–	–	–
22	Scorpaenidae									
23	<i>Scorpaena plumieri</i>	0.31 ± 0.12	11	0.55	–	–	–	–	–	–
24	Serranidae									
25	<i>Mycteroperca acutirostris</i>	0.83 ± 0.17	30	1.50	0.17 ± 0.07	5	0.15	–	–	–
26	<i>Mycteroperca bonaci</i>	–	–	–	–	–	–	–	–	–
27	<i>Serranus flaviventris</i>	0.31 ± 0.10	11	0.55	0.17 ± 0.08	5	0.15	0.07 ± 0.07	2	0.06
28	Sphyraenidae									
29	<i>Sphyraena barracuda</i>	0.03 ± 0.03	1	0.05	–	–	–	–	–	–
30	Syngnathidae									
31	<i>Micrognathus crinitus</i>	0.03 ± 0.03	1	0.05	–	–	–	–	–	–
32	Tetraodontidae									
33	<i>Sphoeroides greeleyi</i>	0.86 ± 0.17	31	1.55	0.47 ± 0.18	14	0.43	1.60 ± 0.35	48	1.50
34	<i>Sphoeroides testudineus</i>	0.03 ± 0.03	1	0.05	0.03 ± 0.03	1	0.03	0.17 ± 0.14	5	0.16
35	Total		2486			3447			3199	

Table 4. Results of one-way ANOSIM (R values and significance levels) and SIMPER analysis on the species abundance from three locations of the rocky shore in Ilha Grande Bay (I = Impacted; C1 and C2 = Controls).

Groups	ANOSIM		SIMPER		
	<i>R</i>	<i>p</i>	Average dissimilarity (%)	Discriminating Species	Contribution (%)
I, C1	0.800	< 0.001	83.97	<i>E. argenteus</i>	13.21
I, C2	0.835	< 0.001	84.76	<i>E. argenteus</i>	13.32
C1, C2	0.113	< 0.001	58.42	<i>A. saxatilis</i>	8.28

Table 5. Discriminating species at each location using SIMPER analysis. Locations: I = Impacted; C1 and C2 = Controls.

Average Similarity (%)	C1 (43.80)	C2 (45.64)	I (48.93)
<i>A. saxatilis</i>	17.71	24.92	
<i>C. striatus</i>	9.14	6.91	
<i>D. argentus</i>		3.92	
<i>E. argenteus</i>			42.71
<i>H. steindachneri</i>	6.14	9.62	12.24
<i>L. nuchipinnis</i>	4.56		
<i>M. acutirostris</i>	5.62		
<i>M. delalandi</i>	16.77	9.45	
<i>Mugil</i> sp			19.30
<i>O. ruber</i>	6.56	3.29	
<i>S. fuscus</i>	12.16	26.46	
<i>S. greeleyi</i>	4.74		18.43

1
2 Figure captions
3
4
5
6

7 Fig. 1 – Map of the study area in Ilha Grande bay, Brazil: Thermal impacted site (I) and
8 controls (C1 and C2) locations.
9

10
11
12
13
14 Fig. 2. Scores on the first two axes from PCA on habitat descriptors in Ilha Grande Bay.
15
16 Samples code: I = Impacted location; C1 and C2 = Control locations.
17
18
19
20

21
22 Fig. 3. Mean total number of individuals (column) and species (line) in 540 m². I =
23 Impacted location; C1 and C2 = Control locations.
24
25
26
27

28
29 Fig. 4. Spatial patterns of the Shannon-Wiener diversity index (H') of rock fish (dotted
30 line) and water surface temperature (solid line) in Ilha Grande Bay. I = Impacted
31 location; C1 and C2 = Control locations.
32
33
34
35
36
37

38 Fig. 5. MDS ordination plot of the relationship between fish community and locations:
39
40 O = Impacted; ▲ C1 and ▼ C2 = Controls.
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

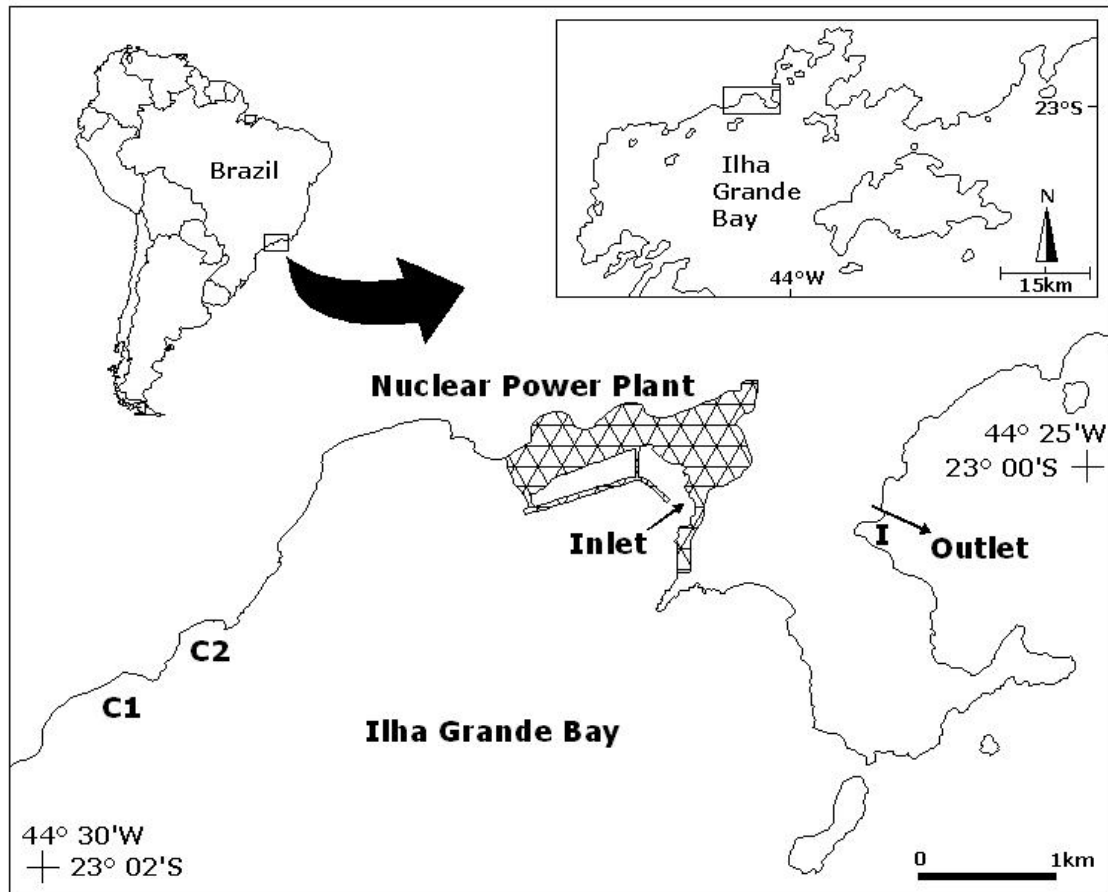


Fig. 1

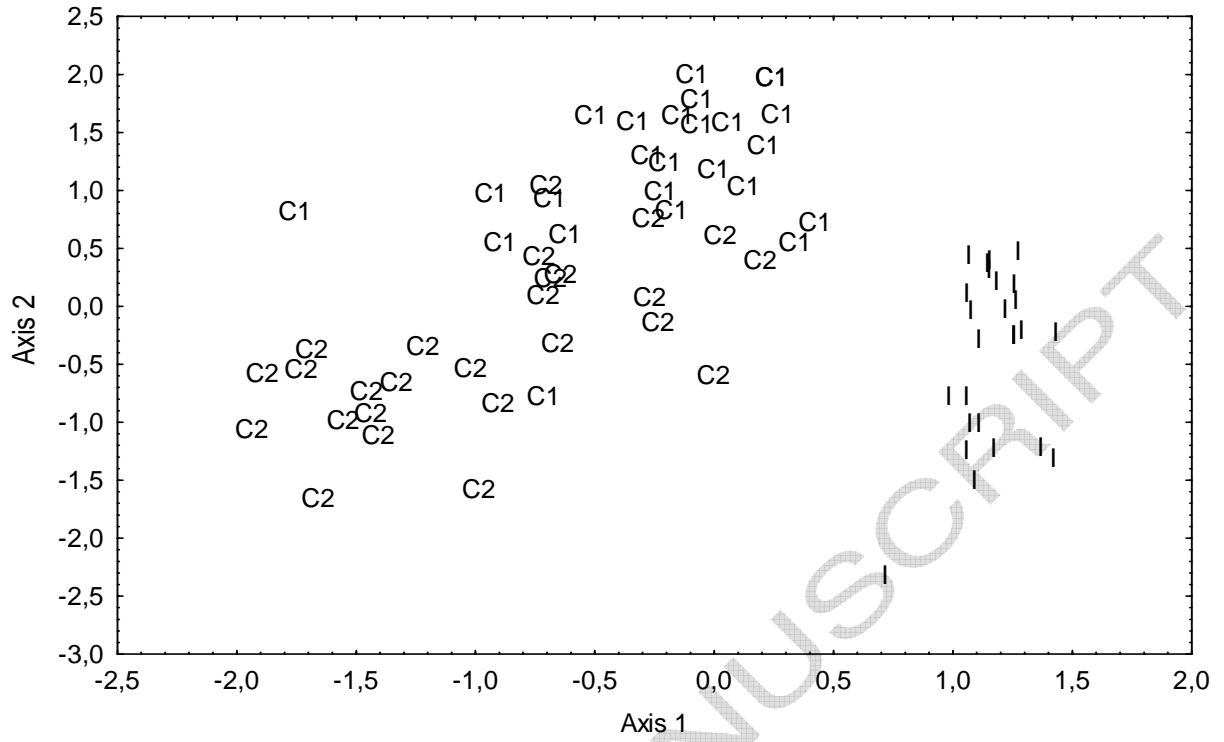


Fig. 2

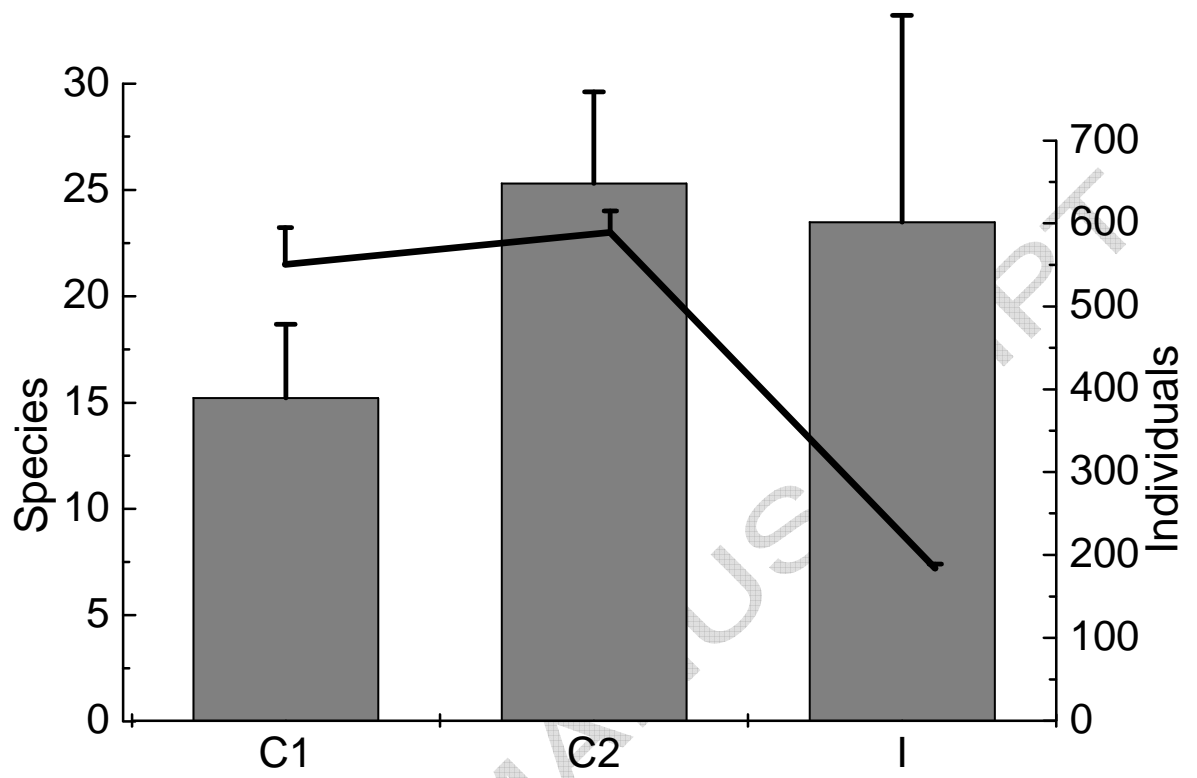


Fig. 3

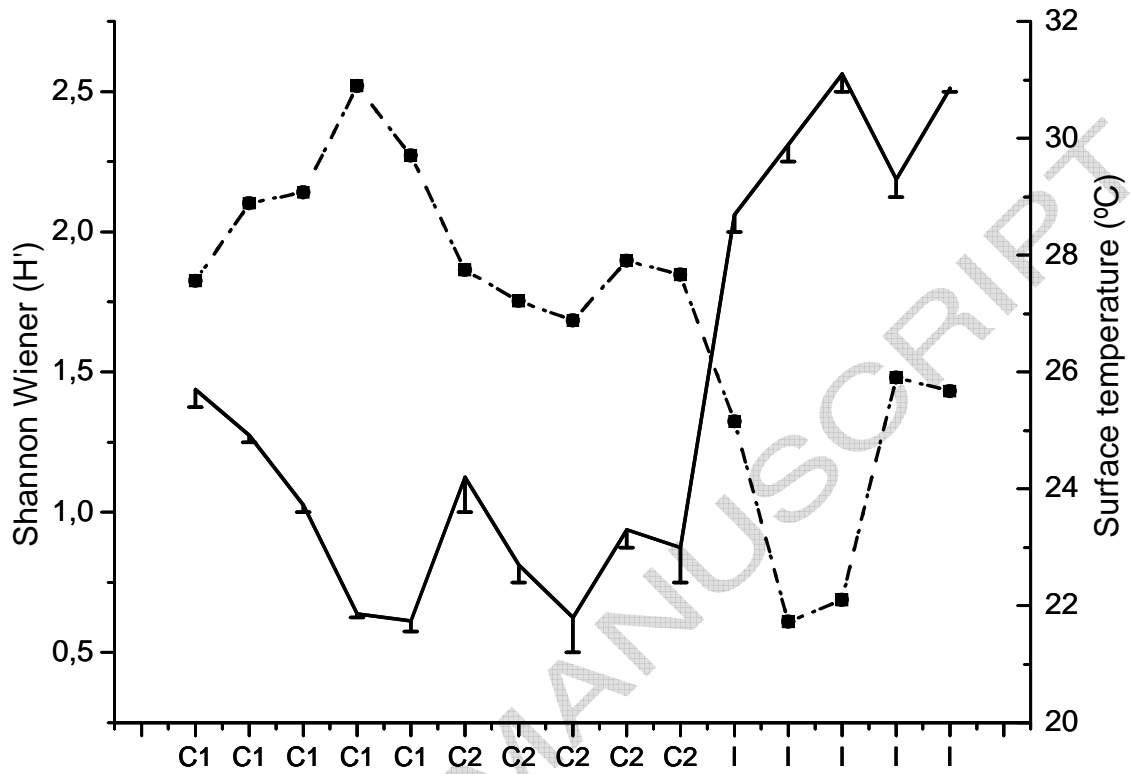


Fig. 4

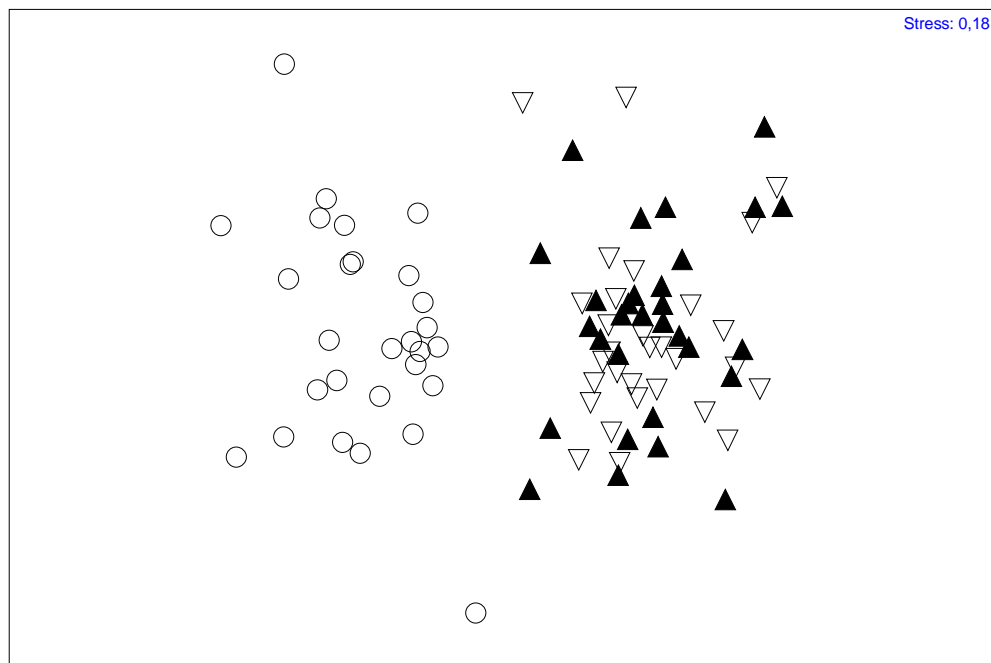


Fig. 5