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Original research article

Ecological analysis of the ichthyofaunal community ten years after a diesel oil spill at Serra do Mar, Paraná state, Brazil

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ABSTRACT

In February 2001, an accidental spill dumped 52,000 litres of diesel oil in Serra do Mar, Paraná state, Brazil, contaminating streams. This study aimed to evaluate if fish communities currently inhabiting environments exposed to the oil spill still showing evidence of spill-related impacts. Ichthyofauna communities were monitored in five rivers located in the region of the spill. Two sites exposed to oil (Meio and Sagrado rivers) were considered treatment sites, and three unexposed sites with environmental characteristics similar to the treatment sites (Pinto, Passa Sete and Marumbi rivers) were considered control sites. Analysis of water quality parameters indicated that sites within rivers were more similar than sites among rivers. The diversity and species composition of fish communities differed between the treatment and control groups and among the rivers. The distribution and species composition of ichthyofaunal communities likely reflect the environmental characteristics of each river and not related to the environmental contamination resulting from the oil spill.

1. Introduction

In February 2001, the rupture of an oil pipeline at Serra do Mar, Morretes city, Paraná state, southern Brazil, caused a spill of approximately 52,000 litres of diesel oil. Oil spread into several local rivers, including the Carambuí, Meio, Sagrado, Neves, and Nhundiaquara rivers. Five containment barriers were installed as an effort to minimise the downstream spread of oil. However, oil contamination extended approximately 28 km from the spill site along these rivers, crossing environment with geomorphology and geologic features distinct and varying your behaviour for transporting and stocking in environment (Albarello, 2012).

According to the American Petroleum Institute (1994), the effect of an oil spill on the environment is a function of the total area affected, combined to the level of impact depending on several factors, including petroleum characteristics. The

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Table 1
Physical and chemical water parameters measured at each site.

Parameters	Unit	Equipment	Model
Temperature	°C	Oxymeter	YSI550
Dissolved Oxygen	mg/L and %	Oxymeter	YSI550
pH	–	Portable pH Meter	HI8424
Electric conductivity	µS	Conductivity Meter	pHtek

aquatic habitats differ in their sensitivity to oil spills. In addition to affecting many abiotic parameters, hydrocarbons may also affect biological systems, altering their natural variability through time, depending on the type of the compound spilt (Mosbech et al., 2004).

According to Ullrich and Millemann (1983), diesel oil is a complex combination of alkanes, mainly linear, branched, and cyclic (constituting 60%–90% of the total volume), aromatic compounds, particularly alkylbenzenes (5%–40% of the total volume), and small quantities of alkenes (0%–10% of the total volume). Its solubility in water is low and its density ranges from 0.82 to 0.85 kg/L. These properties permits this oil to float easily in streams. Following a spill, the most toxic elements in diesel oil are reduced by weathering processes (i.e., exposure to air, sunlight, and water turbulence) and through microbial biodegradation (American Petroleum Institute, 1994). However, reduction rates of environmental contamination depend on the physical and chemical attributes of the spill area (Pritchard and Karlson, 2002).

A combination of individual, population, and community-level studies is essential for understanding the effects of an oil spill on ichthyofauna. Variation in individual responses to hydrocarbon exposure may promote negative effects on community dynamics and its stability (Bowyer et al., 2003). However, studies of the effects of oil on freshwater communities focus primarily on macroinvertebrates (Crunkilton and Duchrow, 1990; Smith et al., 2010) or microinvertebrates (Lytle and Peckarsky, 2001), molecular methods of detection (Lee et al., 2011), the use of fish as bioindicators (Zhang et al., 2003; Damásio et al., 2007; Silva et al., 2009; Wang et al., 2010), or the toxigenic (Moles, 1998; Bhattacharyya et al., 2003; Akaishi et al., 2004), histopathological (Boeger et al., 2003; Giari et al., 2011; Troncoso et al., 2011), and reproductive effects of oil (Blazer, 2002; Ferreira et al., 2011). Few studies have directly addressed the impacts of hydrocarbons on freshwater environment, particularly fish community dynamics (highlighting Hampton et al., 2002; Damásio et al., 2007; Kubach et al., 2011; Liess and Beketov, 2011).

The study of biological fish communities can provide measures of the ecological integrity of ecosystems, incorporating the effects of multiple impact agents and providing an aggregate measure of them (Barbour et al., 1999). Communities within aquatic ecosystems are composed of organisms that are adapted to local environmental conditions and that have varying ranges of tolerance to environmental impacts (Alba-Tercedor, 1996). Biological monitoring is a tool for evaluating the responses of biological communities to changes in the environmental conditions.

This study aimed to evaluate whether fish communities within environments exposed to oil still showing evidence of impacts, ten years after the diesel oil spill.

2. Materials and methods

Five rivers were chosen for the monitoring: two (the Meio and Sagrado rivers) exposed to oil following the spill (treatment group) and three unexposed (the Pinto, Passa Sete and Marumbi rivers) (control group). The unexposed rivers have environmental characteristics similar to the treatment rivers. The use of control rivers from the same region was necessary due to the absence of diversity and distribution data on the fish communities at the affected sites prior to the oil spill.

Three sampling sites were chosen per river. However, on the Meio river (the nearest to the oil spill), only one sampling site was chosen due to the high steepness, small area, and low water flow of this river.

The five rivers monitored in this study lie within the littoral basin of the Paraná state (Fig. 1). They are positioned approximately 50 km apart, forming a coastal plain. The surrounding region is considered the best preserved area in Paraná state (Lautert, 2010; Parolin et al., 2010), containing a complex mosaic of conservation units and protected areas (Menezes, 1996).

Fish were sampled during five campaigns, between April 2010 and January 2011. At each sampling site, the following physical and chemical water parameters were measured: temperature (°C), dissolved oxygen concentration (mg/L) and saturation (%), pH, and conductivity (µS) (Table 1).

Fish were sampled using electro-narcosis equipment ("electrical fishing"). This equipment consists of two hand nets with metal rods that are connected to a power generator (Honda EB 1000), producing an electrical discharge of approximately 120 V in water. Samples were taken in the downstream–upstream direction, using the hand nets moving parallel to each other through a standardised water surface area of 250 m^2, in both river rapids and backwater areas. For each sampling event we spanned about one hour. Sampled fishes were kept alive in a container filled with local river water until the event was complete. The animals were later desensitised by severing the spinal cord and then fixed. Fixation involved injection of a formaldehyde 10% buffered solution into the coelomic cavity, with the subsequent submersion of the entire body into the same solution.

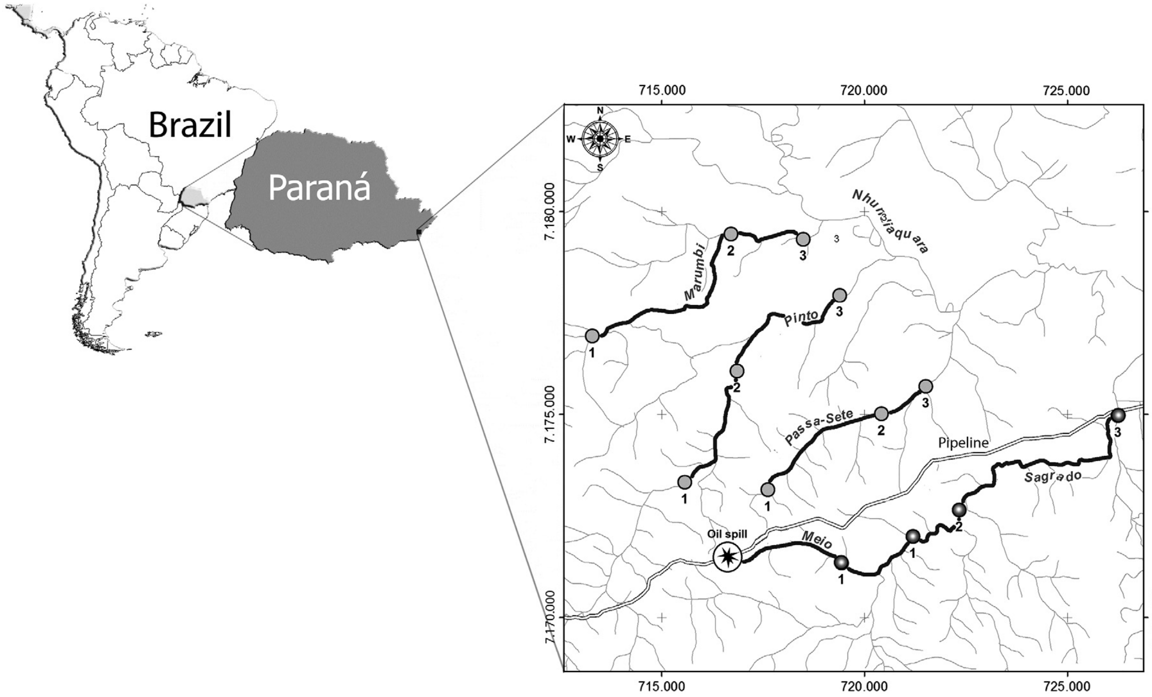

Fig. 1. Location of rivers and sampling sites monitored in the Paraná State Serra do Mar. Note the oil pipeline and the site (*) of the accident.

Fixed specimens were transferred to the ichthyological research group at the Capão da Imbuia Natural History Museum, Curitiba, Paraná state, for species identification. The bibliographic references used for identification were: Lucena and Lucena (1992), Reis and Schaefer (1998), Pereira and Reis (2002), Kullander and Lucena (2006), Menezes et al. (2007), and Lucinda (2008). The taxonomic nomenclature followed Buckup et al. (2007). After identification, specimens were transferred to the Histology and Microbiology Laboratory of the Integrated Group for Aquaculture and Environmental Studies of the Federal University of Paraná. At this laboratory, specimens were grouped by species, rivers, and sampling sites. Then, these specimens were quantified, total length (CT/cm) and standard length (CP/cm) measured with a calliper rule Vonder^{TM} (200 mm/0.05 mm) and total weight (PT/g) with an analytical balance Bel Engineering^{TM}. Analysis of multiple independent variables was performed through the Kruskal–Wallis method to test the differences in abiotic variables among rivers. River grouping was performed via multivariate cluster analysis of the same abiotic variables, using the complete linkage with Euclidean distance method.

Variation in fish species composition and abundance within and among rivers was evaluated through Non-metric Multidimensional Scaling (NMDS), Analysis of Similarity (ANOSIM), and Similarity Percentages Analysis (SIMPER) (Clarke and Warwick, 2001). Similarity matrices were built from spatial (river and sampling sites) and temporal data (sampling campaigns) using the Bray–Curtis coefficient. Data were transformed to $\text{Log}_{10}(x + 1)$ before analysis aiming to reduce the variance among samples.

Ordination analysis (NMDS) was used to represent sample dispersal in two-dimensional space, indicating the stress level (suitability of the configuration of samples in ordination space) by the spatial representation. ANOSIM was used to test for differences in fish communities within and among rivers. This test compares the similarity within pre-defined sampling groups with the similarity between groups (treatment and control). Values near $+1$ indicate differences between or among groups. The SIMPER analysis was employed to detect the percentage of contribution of each species in the rivers. Statistical analyses were performed using the software PRIMER 6.0 (Clarke and Warwick, 2001).

3. Results

The results of the analysis of abiotic parameters are presented in Table 2. Only electrical conductivity differed significantly among rivers and sites, as verified through multiple comparison analyses. Sites 2 and 3 of the Pinto river and site 1 of the Sagrado river were the only sites that did not differ in electrical conductivity from the other sites. The Meio river showed the greatest differences, differing most extensively from site 1 of the Pinto and Marumbi rivers, and from sites 2 and 3 of the Sagrado and Marumbi rivers.

Although sites were chosen in an attempt to maximise similarity among rivers, the cluster analysis shows that the complete linkage distances were generally smaller between sites within rivers than between similar sites among rivers (Fig. 2).

Table 2
Average value of abiotic parameters measured in sampling sites for each river. T = temperature, OD = dissolved oxygen, C = electrical conductivity. Minimum and maximum measured values are shown (in parentheses). Different letters (a–d) indicate significant differences ($p < 0.05$) among sites.

Factor	Rivers												
	Meio	Sagrado			Passa Sete			Pinto			Marumbi		
	Sampling Sites												
	1	1	2	3	1	2	3	1	2	3	1	2	3
T (°C)	20.7 (19–22.2)	21.2 (19–23.2)	22 (19.6–24.2)	21.4 (19.1–23.7)	21 (20–22)	21.6 (19.6–23.5)	22 (20.1–23.7)	20.7 (19–22.3)	21.5 (19.5–23.3)	22.5 (20–24.8)	20.2 (18.2–22.1)	20.7 (18.5–22.7)	21.6 (19.4–23.6)
DO (%)	88.3 (82.4–94.2)	83.1 (74.5–91.5)	80.8 (68.8–92.7)	88.1 (83.7–92.3)	87.6 (82–93.2)	82.8 (74.7–90.7)	78.6 (73.4–83.7)	88.1 (79.3–96.8)	84.2 (76.8–91.5)	87.5 (79.8–85)	88.7 (82.1–95.2)	87.6 (82.7–92.4)	90.2 (82–98.2)
DO (mg/L)	8.1 (7.2–9)	7.7 (6.8–8.4)	7.2 (6.2–8)	7.7 (7.2–8.2)	7.8 (7.3–8.2)	7.2 (6.2–8.1)	6.7 (6.0–7.3)	7.8 (7–8.6)	7.8 (7.2–8.3)	7.2 (6.2–8.1)	7.8 (7.3–8.2)	7.8 (7.3–8.2)	7.9 (7.2–8.5)
pH	7.7 (7.4–8)	7.5 (6.7–8.3)	7.5 (7.1–7.9)	7.4 (6.9–7.9)	7.6 (7.4–7.8)	7.4 (7.1–7.6)	7.2 (6.8–7.5)	7.6 (7.2–7.9)	7.7 (7.2–8.1)	7.4 (7.1–7.8)	7.7 (7.4–8.1)	7.6 (7–8.1)	7.6 (7.2–7.9)
C (μs)	90.2^{a} (72–108.3)	69.5^{ab} (41.5–97.4)	49.8^{bcd} (46–56.4)	49.4^{bd} (44.5–54.3)	79.6^{ac} (73–86.1)	70.8^{ad} (66.2–75.3)	72.4^{ad} (63–81.8)	51.4^{bcd} (46.5–56.2)	54.1^{ab} (51–57.5)	56.2^{ab} (52.7–60)	35.3^{b} (30.3–40.2)	36.1^{b} (30.5–41.6)	38.5^{b} (33.5–43.4)

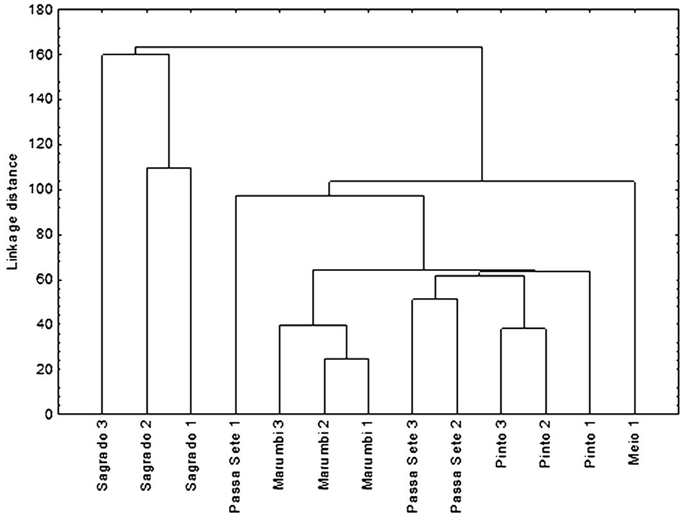

Fig. 2. Cluster analysis using the complete linkage method (Euclidean distance), grouping sampling sites according to their abiotic characteristics.

Table 3
Distribution and diversity of specimens among the different families obtained in the studied rivers.

Family	River													
	Meio	Sagrado			Passa Sete			Pinto			Marumbi			
	Sampling sites													
	1	1	2	3	1	2	3	1	2	3	1	2	3	Total
Callichthyidae	4	12	52	1	0	29	11	39	220	66	8	18	40	500
Characidae	58	39	62	85	87	290	254	33	101	39	27	36	74	1185
Cichlidae	7	10	25	3	0	10	5	3	2	4	2	3	16	90
Crenuchidae	0	18	15	11	18	26	47	163	284	70	97	147	318	1214
Curimatidae	0	0	0	0	0	2	2	0	0	0	0	0	0	4
Erythrinidae	0	1	1	0	0	6	3	0	2	0	3	0	9	25
Gymnotidae	8	2	2	2	2	3	6	3	2	1	0	1	10	42
Gobiidae	0	2	3	18	0	0	0	0	2	3	0	0	8	36
Loricariidae	0	35	114	93	0	58	36	16	191	268	75	69	216	1171
Pimelodidae	7	7	6	1	18	17	20	59	16	8	63	23	11	256
Poecicliidae	43	13	24	6	4	4	12	1	8	37	1	6	59	218
Synbranchidae	8	16	4	1	0	2	2	7	17	1	9	8	8	83
Pseudopimelodidae	0	0	0	0	0	0	0	0	0	1	0	0	1	2
Trichomycteridae	0	0	0	0	0	0	0	2	0	0	1	1	1	5
Total	**135**	**155**	**308**	**221**	**129**	**447**	**398**	**326**	**845**	**498**	**286**	**312**	**771**	**4831**

A total of 4831 specimens, representing 48 species, 14 families, and six orders were obtained. The orders Characiformes and Siluriformes represented over 91% of specimens.

The most abundant family was the Crenuchidae (1214 specimens), followed by the Characidae (1185) and Loricariidae (1171) (Table 3). The most numerous species were *Characidium lanei* (694), *Deuterodon langei* (624), *Hisonotus leucofrenatus* (518), *Rineloricaria* sp. (517) and *Characidium pterostictum* (513).

River abundances were as follows: Pinto river, 1669; Marumbi river, 1369; Passa Sete river, 974; Sagrado river, 684; Meio river (one sampling site only), 135. Across sites, site 2 of the Pinto river had the greatest abundance (845), while site 1 of the Passa Sete river had the smallest (129).

The highest values of species richness were detected at sites 1, 2 and 3 of the Marumbi river, with 29, 26, and 32 species, respectively. Site 1 of the Passa Sete river had the lowest species richness, with 10 species.

The determination of population structures of each family captured in rivers this study were obtained with biometric parameters analysis and confidence intervals (Table 4).

Significant differences in fish community composition were detected among sites and rivers as identified through NMDS ordination and ANOSIM, this latter with a global R value of 0.36 and $P < 0.01$ (Fig. 3). Significant difference ($P < 0.01$) between the treatment and control groups were detected, with the ANOSIM with a global R value of 0.27 (Fig. 4). The global R and P values indicate that communities differed among rivers and between river groups (treatment and control), whereas communities within rivers were similar. Paired tests indicated significant differences between rivers in all comparisons, except between the Pinto and Marumbi rivers ($P = 0.16$) (Table 5).

Table 4
Mean values of biometric variables and confidence intervals of families captured in evaluated rivers. CT = total length, CP = standard length, PT = total weight, C = control, T = treatment.

Family	CT (cm)		CP (cm)		PT (g)	
	C	T	C	T	C	T
Callichthyidae	6.1 (1.8–9.4)	5.3 (1.9–15.2)	4.6 (1.3–8.8)	3.8 (1.4–11)	3.8 (0.02–10.8)	3.5 (0.07–39.8)
Characidae	5.9 (1.7–12.8)	4.6 (1.8–12.8)	4.6 (1.1–11.8)	3.5 (1.3–10.8)	4.3 (0.01–30.8)	1.6 (0.08–29.1)
Cichlidae	7.5 (1.8–15.7)	6.5 (1.3–15.1)	6.8 (1.3–19)	4.9 (1–11.8)	9.4 (0.1–34.1)	6.1 (0.05–39.1)
Crenuchidae	5.1 (2.2–9.4)	5.6 (2.8–7.9)	4.1 (1.3–8.1)	4.5 (2.2–6.6)	1.5 (0.1–11.3)	2 (0.2–5.5)
Curimatidae	7.4 (5.1–9.7)	–	6.1 (3.9–7.6)	–	7.2 (1.8–14.6)	–
Erithrinidae	14.4 (7.8–21.3)	12.2 (8–15.4)	12.6 (6.4–19.8)	9.9 (6.5–12.4)	43.3 (4.9–128.3)	22.9 (5–39)
Gobiidae	4.8 (3.5–10.7)	4.1 (2.9–5.8)	3.8 (2.8–8.9)	3.2 (1.9–4.7)	1.4 (0.3–10.9)	0.6 (0.2–1.1)
Gymnotidae	15.7 (3–22.9)	16.1 (6.3–24.3)	–	–	16 (1.1–46.5)	17.2 (1.6–56)
Loricariidae	6.4 (1.9–17.3)	6.9 (2.2–20.6)	5.2 (1.4–14.8)	5.8 (1.7–17.5)	2.5 (0.1–31.7)	3.2 (0.1–59)
Pimelodidae	10.9 (2.9–23.1)	10.3 (5–19.9)	9.6 (2.3–27.2)	8.8 (2.3–23.5)	12.7 (0.1–110.5)	12 (0.8–63.4)
Poecicliidae	3.1 (1.8–10.8)	3.4 (2.1–6)	2.3 (1.3–4.6)	2.7 (1.6–5)	0.4 (0.04–3.9)	0.6 (0.1–3.5)
Pseudopimelodidae	4.4 (3.9–5.0)	–	3.6 (3.3–4)	–	1 (0.6–1.3)	–
Symbranchidae	22.2 (3.2–46.2)	25.9 (12.1–38.8)	–	–	17.9 (0.4–116.2)	25.1 (2.3–74)
Trichomycteridae	5.1 (3.9–6.5)	–	4.3 (3.2–5.6)	–	1.1 (0.5–1.9)	–

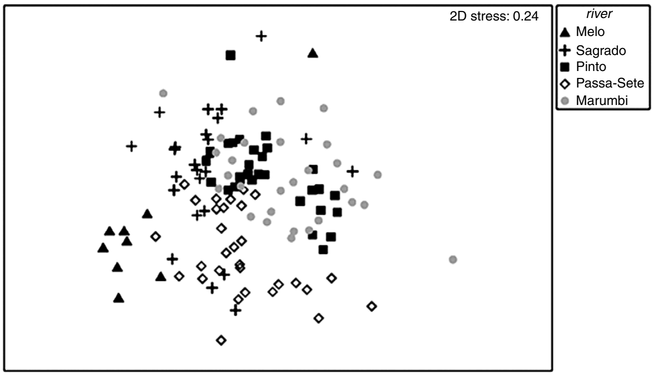

Fig. 3. Non-metric Multidimensional Scaling (NMDS) analysis, grouping all rivers, all sites, and the two sampling periods (morning and afternoon) of each sampling campaign.

The SIMPER analysis identified the species most abundant in each environment and those that contributed most strongly to the significant differences among rivers. The Meio river showed the highest percentage of similarity (46.3%), with *Mimagoniates microlepis* and *Hollandichthys multifasciatus* representing almost 60% of obtained specimens. The Pinto river exhibited the second highest percentage of sample similarity (42.3%), where the most abundant species were *Scleromystax barbatus* and *Characidum lanei*, representing 21.5% and 18.1%, respectively, of specimens. On the Passa Sete river, 37.1% of samples were similar, with *Deuterodon langei* representing 51.8% of specimens. Other species in this river with high contribution were *Characidium pterostictum*, with 9.3%, and *M. microlepis*, with 7.6%. In the Sagrado river, *Hisonotus leucofrenatus* (22.2%) and *Rineloricaria* sp. (18.7%) were the most important contributors to the observed similarity value (33.2%). The similarity among samples of the Marumbi river was 32.3%, with *C. lanei* (20.5%) and *C. pterostictum* (19.1%) being

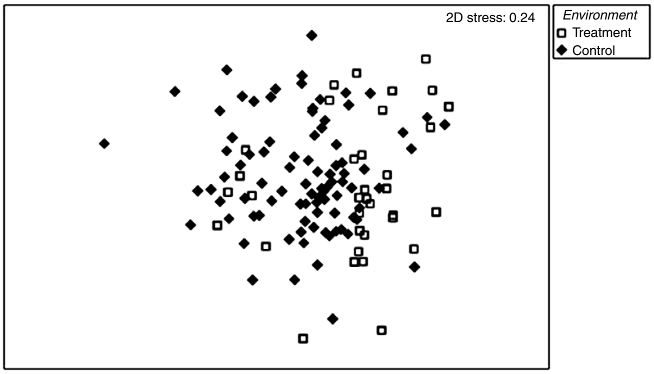

Fig. 4. Non-metric Multidimensional Scaling (NMDS) analysis, grouping control and treatment river groups, and the two sampling periods (morning and afternoon) of each sampling campaign.

Table 5
River pairs tested with *R* values and statistical significance levels. $p < 0.05$ indicates a significant difference as determined by the ANOSIM.

Rivers pairs	Global *R*	*p*
Meio. Sagrado	0.521	<0.01
Meio. Pinto	0.871	<0.01
Meio. Passa-Sete	0.716	<0.01
Meio. Marumbi	0.673	<0.01
Sagrado. Pinto	0.282	<0.01
Sagrado. Passa-Sete	0.349	<0.01
Sagrado. Marumbi	0.256	<0.01
Pinto. Passa-Sete	0.392	<0.01
Pinto. Marumbi	0.058	*0.16*
Passa-Sete. Marumbi	0.39	<0.01

Table 6
Percentage contribution of each species to the similarity values obtained via SIMPER analysis, by river.

Species	Rivers (% of similarity)				
	Meio (46.3)	Sagrado (33.22)	Passa Sete (37.06)	Pinto (42.35)	Marumbi (32.33)
M. microlepis	32.45		7.58		
H. multifasciatus	27.22				
P. harpagos	21.78				
G. pantherinus	10.01				
H. leucofrenatus		22.16		11.62	10.53
Rineloricaria sp.		18.68		10.66	8.12
S. barbatus				21.49	
C. lanei				18.14	20.49
C. pterostictum			9.35	15.78	19.15
D. langei			51.85	6.90	
R. transfasciatus					9.25

most abundant. The percentage values of other species contributions to sample similarity are presented in Table 6. Overall percentage values for each river pair and the main species that contributed to among-river dissimilarity are presented in Table 7.

4. Discussion

Many studies have investigated the effects of changes in environmental conditions on biological communities (Araújo, 1998; Cunico et al., 2006; Ferreira and Casatti, 2006). Their results suggest that fish communities respond to external impacts by modifying their structural and functional characteristics. According to Winemiller et al. (2008), fish community abundance is associated with species habitat type and region, providing an ecological strategies of adaptation in response to temporal and spatial variation within habitats.

According to the US Environmental Protection Agency (USEPA, 1999), petroleum derived compounds in streams and rivers of low water flow tend to remain in the environment for an extended periods, settling in riverside grasses or river bottom sediments, affecting the trophic relations of organisms that occupy these microenvironments. The effects of an oil spill could therefore potentially be detected in freshwater environments over years later.

Table 7
Percentage contribution of each species to among-river dissimilarity. Values obtained through the SIMPER analysis of the Meio (M), Sagrado (S), Pinto (P), Passa Sete (PS), and Marumbi (Ma) rivers.

Species	Rivers (% of dissimilarity)									
	M/S (81.78)	M/P (87.51)	S/P (69.82)	M/PS (84.83)	S/PS (75.12)	P/OS (71.79)	M/Ma (87.09)	S/Ma (74.64)	P/Ma (64.48)	PS/Ma (76.53)
Rineloricaria sp.	10.04	8.49	9.14		9	8.82				
H. leucofrenatus	9.9				8.24				8.61	
C. lanei		10.54	9.94			9.91	10.26	9.34	9.29	9.46
S. barbatus		10.28	9.98			10.47			9.03	
D. langei				19.46	13.99	11.36				12.9
P. harpagos	9.45			10.26			8.05			
M. microlepis				10.12						
C. pterostictum		9.75	8.85				9.24	8.19	8.53	8.09

Albarello (2012), in study of rivers affected by oil diesel spill from OLAPA pipeline, was found BTEX (Benzene, Toluene, Ethylbenzene and Xylene), PAH (Polycyclic Aromatic Hydrocarbon) and TPH (Total Petroleum Hydrocarbon) below the reference values or not were able detecting in soil samples, superficial water and sediment in excerpts from Meio and Sagrado rivers. This author concluded that stocking these composts in soil, even low concentration, do not have relation with oil diesel spill quantity, but have relation with soil composition. The combination between clay material and organic matter created conditions to oil preservation for ten years after accident.

Among the analysed parameters, electrical conductivity had the highest variation among sites. According to Johnson and Romanenko (1989), hydrocarbon input increases the respiration rates of autotrophic communities, increasing CO_2, decreasing pH, and consequently, alkalinity and water conductivity. However, regarding to petroleum and its by-products, it tends to be a short-term process, particularly in turbulent environments (Levy, 1971; Page et al., 2002).

Diurnal and seasonal fluctuations of conductivity and other physical and chemical variables are typical in rivers. The interaction between photosynthesis, respiration, and gas exchange results in diurnal variation in oxygen (Odum, 1956) and carbon dioxide (Wright and Mills, 1967) concentrations, which are also affected by variation of the daily temperature (Drysdale et al., 2003). Dissolved carbon dioxide variation, in turn, continuously changes the equilibrium of inorganic carbon species present in the environment. This results in fluctuations of total dissolved solids and, consequently, of conductivity. They reflect the seasonal nature of biogeochemical cycles and in local hydrological regimes (Vogt et al., 2010). Moreover, water conductivity is greatly influenced by ions naturally found in substrate sediments, primarily Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, SO_4^-, HCO_3^- and CO_3^- (Zinabu et al., 2002). Thus, we are unable to conclude that the greater conductivity detected on the Meio river is due to the oil spill; rather, it is likely a function of the intrinsic characteristics of the river.

In contrast, many studies conducted in freshwater streams have demonstrated that elevated electrical conductivity may directly influence the dynamics of ichthyocenoses (Braga and Andrade, 2005; Fialho et al., 2008; Araújo and Tejerina-Garro, 2009). Our observations of the Meio river suggest such a relationship, with this river exhibiting the highest conductivity values and a low number of sampled specimens.

However, following environmental disturbance, small streams are expected to exhibit lower diversity indices and slower recovery rates. Kubach et al. (2011) evaluated the impact of a diesel oil spill in a small river in South Carolina, USA, and found that local fish communities required 16–52 months to recover, whereas larger rivers had a 52–112 month recovery time.

Winkelmann et al. (2003) found that aquatic environments, particularly streams, rarely show high indices of abiotic similarity. Thus, the small number of fish sampled in the Meio river may reflect other environmental characteristics of this river, which has a small area and low water flow.

According to Damásio et al. (2007), petroleum spill residues have lasting effects on environments and on individuals that inhabit exposed sites. Silva et al. (2009) observed that five years after the oil spill, petroleum was still evident at Saldanha stream, in Paraná State, Brazil.

Similarity analyses of ichthyofauna communities indicated differences among rivers and between treatment and control groups. Kubach et al. (2011) also detected dissimilarity between communities in environments exposed and not exposed to oil on the Reedy river, South Carolina, USA. They detected lower species richness in environments exposed to oil and higher abundance in control environments 52 months after the oil spill. After 52 months, the communities in each environment became similar.

Hampton et al. (2002) compared fish communities before and after a fuel oil spill in the Easter Walker river, California, USA. They found that the number of fish was significantly reduced a year after oil exposure and concluded that this was due to a lack of food. They also observed a high mortality rate of macroinvertebrates, an important food source. In the Cayuga Inlet stream, New York, USA, macroinvertebrate density was lower in environments exposed to diesel oil three months after the spill. However, after a year, communities had recovered, with high similarity indices between the affected and reference environments (Lytle and Peckarsky, 2001). These results indicate that macroinvertebrate communities tend to recover in a relatively short time.

In the same area as the present study, Lana et al. (2011) characterised and monitored associations of macroinvertebrates in the Nhundiaquara, Sagrado and Meio rivers (where the oil spill occurred). Based on environmental quality indices, they concluded that variation in faunal associations was not correlated with the oil spill ten years earlier. Rather, the observed differences were related primarily to temporal variability (correlated with different water flow regimes) of the sampled sub-environments or to spatial variability. That is, there was no longer evidence of impacts on the food web.

In a study on the Pedras river, Paraná, Brazil, Wolff (2007) found that the fish community differed spatially in species composition in relation to environmental conditions and specific habitat preferences.

According to Martin-Smith (1998), fish communities may vary in their preferences for different habitats, resulting in different fish assemblies (Walters et al., 2003; Fialho et al., 2007; Valério et al., 2007). Lemes and Garutti (2002) state that streams show both spatial and temporal plasticity, resulting in a fish community composition that responds to the environment according to its abilities and biological imperatives.

In the present study, sites varied in environmental characteristics other than those analysed here, even within the same geographical region, at similar altitudes and with similar physical conformations.

The Meio river differed from the others in having reduced water flow, a small area and complete coverage by vegetation, characteristics rarely found in the other rivers studied. Only sites 1 and 3 of the Passa Sete river had similar environmental characteristics, although structural differences were evident.

The three sampling sites of the Passa Sete river presented the higher dissimilarities, both environmental and biotic, as these provide a variety of habitat types occupied by the different species present.

Although the Sagrado river showed a high degree of environmental similarity with the Pinto and Marumbi rivers, the number of specimens was relatively low. The Pinto and Marumbi rivers were the only ones that did not differ significantly; these rivers also resemble each other in their dimensions, characteristics of the riverside vegetation, and substrate.

Our results do not exclude the possibility that the differences found between fish communities in exposed and unexposed rivers is related to the oil spill. However, there is evidence that the structure and composition of fish communities reflect the environmental characteristics intrinsic to each river.

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