The effects of press and pulse disturbance by long and short-term pollution on the fish community in the Sinos River, RS, Brazil

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Abstract

The fish fauna of the Sinos River has been subjected to severe pollution since the 1970´s. Continuous discharges of industrial and municipal sewage cause hypoxia and often even fish kills. The objectives of the present study are to assess long-term effects of pollution on the fish community over a time scale of approximately ten years and to investigate recuperation of the fish fauna after a massive fish kill in 2006. To assess the long-term impacts, seasonal sampling was conducted from September 2007 to March 2009 in four sites which were investigated in 1998/99 with the same methodology. The effects of the fish kill were investigated by comparing the present fauna in the affected river stretch with the fauna of an unaffected adjacent river stretch. The collective community properties richness and Shannon diversity changed during the ten year interval in a consistent pattern. Richness and Shannon diversity increased significantly in all sites, abundance values, however, did not. Analysis of species constancy and cluster analysis showed that the differences between the 1998/99 and 2007/09 studies were relatively small. The comparison of the reaches affected by the 2006 fish kills showed a rapid recovery within one year. Probably the Sinos fish fauna suffered the most severe impacts in the 70s of the last century, which could not be documented by this study. After an initial decline, the community displays relatively stable patterns with a tendency of recovery. After a severe fish kill, faunal recovery was rapid, probably favoured by the proximity of unpolluted source areas and physical habitat integrity of the Sinos River.

Keywords: sewage, fish kill, community stability, resilience.

Efeitos de distúrbios contínuos e pulsados da poluição aguda e de longo prazo sobre a comunidade de peixes no Rio dos Sinos, RS, Brasil

Resumo

A fauna de peixes do Rio dos Sinos vem sendo exposta a uma poluição grave desde os anos 70 do século passado. Descargas contínuas de esgotos industriais e urbanos causaram hipóxia e recorrentes mortandades de peixes. Os objetivos do presente estudo são: avaliar os efeitos de longo prazo da poluição sobre a comunidade de peixes e investigar a recuperação da ictiofauna após uma mortandade severa em 2006. Para avaliar os impactos de longo prazo, foram realizados amostragens sazonais entre setembro de 2007 a março de 2009 em quatro locais que foram investigados em 1998/99 com a mesma metodologia. Os efeitos da mortandade de peixes foram investigados comparando a fauna no trecho afetado pela mortandade com o que não foi afetado. As propriedades coletivas da comunidade íctica riqueza e diversidade de Shannon aumentaram durante o intervalo de 10 anos em todos os pontos de amostragem, porém os valores da abundância ficaram estáveis. A análise da constância das espécies e a análise de agrupamento mostraram que as diferenças encontradas entre os estudos 1998-1999 e 2007/09 são pouco expressivas. A comparação dos trechos afetados e não afetados pela mortandade de peixes mostrou uma rápida recuperação da fauna que ocorreu em um ano. A ictiofauna do Rio dos Sinos sofreu provavelmente os impactos mais graves nos anos 70 do século passado, contudo, não documentado por este estudo. Depois de um declínio inicial a comunidade exibiu padrões relativamente estáveis com tendências de recuperação. Após as mortandades de 2006 a recuperação da fauna foi rápida, provavelmente favorecida pela proximidade de áreas de fonte não poluídas e pela integridade física dos habitats do Rio dos Sinos.

Palavras-chave: esgoto, mortalidade de peixes, estabilidade da comunidade, resiliência.

1. Introduction

The Sinos River, in Brazil's southernmost state, Rio Grande do Sul, has received large quantities of domestic and industrial sewage since the 1970's (Rio Grande do Sul, 1999). Monitoring conducted by the State Department of Environmental Protection between 1990 and 2010 shows that only the headwaters are still in good condition. Mean dissolved oxygen concentrations are above 7.0 mg/L. The water quality is Class I, which is the second best in the Brazilian ranking system. Water quality gradually decreases to Class III in agricultural areas of the upper floodplain section. However, downriver sections in urban areas are Class IV, which is the worst in the Brazilian ranking system, with mean annual oxygen concentrations lower than 3.0 mg/L in some years (Rio Grande do Sul, 2013).

In the Sinos River basin water quality degradation is related to the discharge of large amounts of organic and industrial sewage. Only one municipality out of 32 operates sewage treatment plants. Urban streams were converted into sewage ditches. During Stream Walk Surveys, organised by the local water committee Comitesinos, 2,697 pipes discharging untreated sewage were recorded (Schulz et al., 2006). As a result, fecal coliform counts exceed frequently 10^5/L and may reach almost $2*10^5$/L in some cases (Blume et al., 2010; Rio Grande do Sul, 2013).

In addition to organic discharges, industrial effluents contribute to water quality decrease. The Sinos River basin is a national centre of leather processing industries, including tanneries and shoe production facilities (Figueiredo et al., 2010). Additionally metallurgic factories are concentrated in the urban areas. All of them use heavy metals in the production process. Chromium, copper and nickel occur in more than 50% of all analyses in concentrations attributed to water quality class four (Rio Grande do Sul, 2013). In the decade of the 1970s uncontrolled industrial discharges reached the maximum. From the 1980's onwards, occasional discharges continued, but the industrial sector was more efficiently controlled by the state's environmental agency. Bender et al. (1984) consider these long-term impacts of sewage press disturbances. They occur in periods which are longer than the life span of the longest-lived species of the community.

Sublethal concentrations of pollutants have been shown to weaken fish by immunodepression (Sövényi and Szakolczai, 1993). This process may lead to a higher susceptibility to attack by pathogens (Austin, 1998). Large amounts of organic sewage induce hypoxia and even anoxia, particularly during summer with high water temperatures. Prolonged hypoxia may change species composition and decrease species richness (Diaz and Rosenberg, 1995). In the long term, a shift from K to r selected species may be observed (Pihl et al., 1991). Enduring low oxygen concentrations may reduce growth and reproduction success (Schulz and Martins-Junior, 2001; Karim et al., 2003). In this context, fish species richness is known to be a sensitive indicator of the condition and degradation of rivers and lakes since the decrease in the number of fish species is clearly confirmed in locations where aquatic pollution is high (Magurran and Phillip, 2001; Barrella and Petrere, 2003).

In the Sinos River, small scale fish kills are frequent, particularly during summer with high temperatures and low water flow, conditions which favour hypoxia. Statistics on these events do not exist since they are not always reported to environmental agencies. Additionally large scale fish kills occur, as the two events in October 2006 (Naime and Fagundes, 2005). On 6th of October 2006, moribund or dead fish were detected at the mouth of the Portão River, one of the most polluted tributaries of the Sinos in the lowland section. During the following two days an estimated quantity of 100 t fish died. The cause of this fish kill was never determined, but moribund fish did not display typical symptoms of hypoxia. The intensity and the dynamics of the event indicated the discharge of a highly toxic substance of unknown origin. In the same month, a second fish kill occurred in the same river section. The latter clearly was the consequence of enduring hypoxia, with moribund fish swimming at the surface in an attempt to breathe atmospheric oxygen (Rio Grande do Sul, 2007). Both fish kill episodes may be considered pulse disturbances (Bender et al., 1984). Pulse disturbances are discrete events, shorter than the maximum life span of the longest lived species of the affected community, and are typically caused by point source inputs or short and intense hydrologic events like flash floods.

The present study has two objectives. First we compared the collective fish community properties richness, abundance and Shannon diversity at four sites collected in 2007/09 with collections made at the same sites in 1998/99 to test the hypothesis that press disturbance of long-term pollution induces changes of these parameters. Second we compared the fish fauna of the river stretch affected by the 2006 fish kills with the adjacent unaffected upstream river stretch to test if the community recovered from the effect of the pulse disturbance.

2. Material and Methods

2.1. Study area

The original vegetation in the watershed is deciduous seasonal forest and, according to the Köppen classification, the predominant climate in the region is subtropical humid with precipitation throughout the year (Moreno, 1961).

From the mouth of the Paranhana River, the Sinos is a seventh order river. The total extension is 190 km. The drainage area is approximately 3.800 km² (Figueiredo et al., 2010). The headwaters are located at 700 m above sea level (a.s.l.) in the Serra Geral highlands, and its mouth is at 10 m a.s.l. in the Jacuí Delta, close to the state capital, Porto Alegre. The most important tributaries are the Rolante, Ilha and Paranhana Rivers (Petry and Schulz, 2006).

The headwaters are characterised by steep slopes and an entrenched stream bed with two waterfalls (>25m) within the first 5 km, and a riffle-pool-run structure between the sampling sites Fraga (P1) and Caraá (P2; Figure 1). This section has a low impact level. The Sinos above
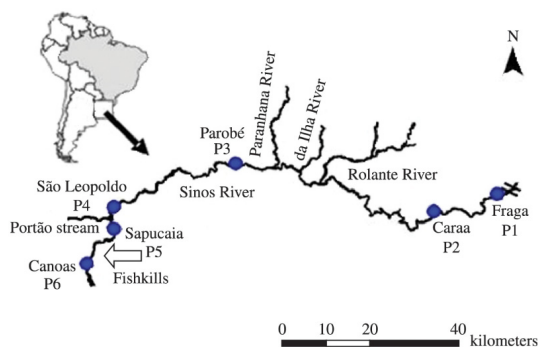
Figure 1. Sampling sites along the Sinos River. Sites P1 to P4 were sampled in 1998/99 and 2007/09 and used to investigate long-term effects. Sites P5 and P6 were affected by the 2006 fish kills and compared to adjacent unaffected P4 and P3; Sites P1 and P2 are headwater sites, all other are lowland sites. The lowland section begins 10 km downstream of P2. // above Fraga indicate two upstream waterfalls.

Fraga is water quality Class I (Brasil, 2005), and below Fraga, quality Class II (Rio Grande Sul, 1999), with small quantities of domestic and agricultural effluents (Petry and Schulz, 2006). When the Sinos River enters the floodplain, water quality decreases to Class III. From the confluence with the Paranhana River Class IV persists until the Sinos River mouth. In this lowland section, the river meanders in the low gradient floodplain, which gradually becomes more urbanised along the longitudinal gradient (Petry and Schulz, 2001). The sites Parobé (P3), São Leopoldo (P4), Sapucaia (P5) and Canoas (P6) are located in the lowland section.

2.2. Sampling process

Each of the six sites was sampled four times (seasonally) from September 2007 to March 2009. The sites from Fraga (P1) to São Leopoldo (P4) were used to investigate the long-term changes of the fish fauna, comparing the community of the 2007/09 collection with the community sampled in 1998/99, at the same sites and with the same methodology. Sample sites Sapucaia (P5) and Canoas (P6) were affected by the 2006 fish kills. They were compared to the adjacent not affected upstream sections, represented by the sites São Leopoldo (P4) and Parobé (P3).

In the present study, the sampling procedures of the 1998/99 study (Petry and Schulz, 2006) were replicated. Sampling consisted of a set of seven gill nets with mesh size ranging from 15 to 50 mm (15, 20, 25, 30, 35, 40 and 50) between adjacent knots and electrofishing along the margins of the Sinos River for 50 minutes. The nets remained set during 16 hours, from 16.00 h to 08.00 h of the following day. One pass electrofishing was conducted along the margins of each location using an aluminum boat and a model FEG 800 generator (EFKO, Leutkirch Germany) with 7.5 kW and 750 volts unpulsed direct current. The extension of the sampled river stretch was about 200 m at each site.

The captured individuals were anesthetised in 50 mgL^{-1} clove oil and fixed on-site in 10% formalin. After at least one week they were transferred into 70% ethanol at the Unisinos Fish Ecology Laboratory.

2.3. Data analysis

The long-term effects of press disturbance effects on the fish community and the recovery of the sites affected by the pulse disturbance of the 2006 fish kills were assessed by comparing rarefied species richness, total abundance (number of individuals in gill nets + number of individuals captured by electrofishing) and Shannon diversity. To estimate long-term effects of press disturbance the captures at the sites that were sampled in 1999/99 (Fraga P1, Caraá P2, Parobé P3 and São Leopoldo P4) were compared to the captures at the same sites in 2007/2009. Mean rarefied richness (Krebs, 1998), abundance, and Shannon diversity of the seasonal samples of the 1998/99 samples were compared to the mean rarefied richness, abundance, and Shannon diversity of the seasonal 2007/09 samples by bifactorial ANOVA to test the effects of longitudinal distribution of the sampling sites and sampling periods. When significant effects were detected post hoc Bonferroni test was applied. All variables met the criterions of normality and homogeneity of variances without transformations.

For each site from P1 to P4 we also compared the species' rank abundances between the1998/99 and the 2007/09 samples by using the Spearman's coefficient of rank correlation for all species with a relative abundance > 2%. Lower abundances were not included to cut off possible spurious correlations due to the influence of rare species (Meffe and Sheldon, 1990).

Additionally Bray-Curtis similarity between the fish fauna in the 1998/99 and the present 2007/09 study was compared by the hierarchical cluster analysis (Pinto-Coelho, 2000). The index is based on composition as a function of species abundance.

The effect of pulse disturbance was estimated by pooling the seasonal captures of the sampling sites Canoas (P6) with Sapucaia (P5), which were affected by the 2006 kills. Mean rarefied richness, abundance and Shannon diversity of these sites were compared by Student-t test to the pooled captures of São Leopoldo (P5) and Parobé (P4). The latter sites were unaffected by the 2006 fish kills.

Shannon biodiversity and rarefied richness were calculated by using the PAST software (Hammer et al., 2003). Bifactorial ANOVA and Student-t test were run by SPSS vers. 21 (IBM, 2012).

3. Results

At the six sampling sites in this 2007/09 study, a total of 8,481 individuals of seven orders, 21 families and 68 species were collected. The most abundant species were *Astyanax fasciatus* (Cuvier, 1819) (19.1%), *Hyphessobrycon luetkenii* (Boulenger, 1887) (10.8%), *Cyphocharax voga* (Hensel, 1870) (9.9%) and *Astyanax jacuhiensis* (Cope, 1894)

(8.87%). The dominant orders were Characiformes (35%) and Siluriformes (30%) and the families with the greatest species richness were Characidae (26.5%), Loricariidae (19.2%) and Cichlidae (13.3%).

At the sites P1 to P4 4,600 individuals were captured during the 2007/09 study. At these sites, a total of six orders, 19 families and 63 species were identified. In the 1998/99 study, Petry and Schulz (2006) registered a total of 4,143 individuals belonging to six orders, 20 families and 58 species.

Bifactorial ANOVA showed significant effects of sampling sites on mean rarefied richness ($F_{3,24}$= 8.475, p=0.001) along the longitudinal gradient from the headwaters at Fraga to the lowland site São Leopoldo (Figure 2). In both investigation periods, rarefied richness was highest in Caraá, near the headwater-lowland transition. The effect of sampling periods also was significant ($F_{1,24}$= 7.638; p=0.011). During the 2007/09 study mean richness values increased at all sites (Figure 2; Table 1). However, both effects were independent, no interaction of the variables sampling sites and sampling period was observed ($F_{3,24}$=0.189; p=0.903). Pos hoc Bonferroni tests indicated significant differences between Fraga and Caraá (p=0.003), Fraga and Parobé (p=0.024), Caraá and São Leopoldo and Parobé and São Leopoldo (p=0.045). Figure 2 shows that the distribution pattern of rarefied richness along the longitudinal gradient was similar in both investigation periods. Sampling sites ($F_{3,24}$=0.754; p=0.531) and sampling period ($F_{1,24}$=0.49; p=0.656) had no significant effect on abundance. The effect of sampling sites ($F_{3,24}$=6.722; p=0.002) and sampling period ($F_{1,24}$=4.204; p=0.051) on Shannon diversity was similar to rarefied richness. Both effects were independent from each other ($F_{3,24}$=0.909; p=0.451). The post hoc Bonferroni test showed significant differences between Caraá and São Leopoldo(p=0.001) and between Parobé and São Leopoldo (p=0.05).

Species rank correlations were significant for all headwater sites (Fraga p<0.001; P1; Caraá p<0.001; P2) and for Parobé (p=0.002; P3). Only at São Leopoldo the species rank correlation was not significant (p=0.709). The coefficient of determination R^2 was considerably higher at the headwater sites (Figure 3).

The similarity dendrogram showed the formation of two large clusters with 32% similarity between the fish community compositions (Figure 4). One group was represented by headwater site Fraga (P1) in both studies and had a similarity of 75% among the groups and 68% with Caraá (P2) of the 2007/09 study. In the other group, floodplain site Parobé (P3) had a similarity composition of 61% between the two studies and was 59.2% similar with São Leopoldo (P4) in both studies. The composition at P4 was 59.5% similar between the two studies.

The effect of pulse disturbance was assessed by comparing fish community parameters of the sites Canoas (P6) and Sapucaia (P5), which were affected by the 2006 fish kills, with São Leopoldo (P4) and Parobé (P3). Mean rarefied richness, Shannon diversity and abundance did
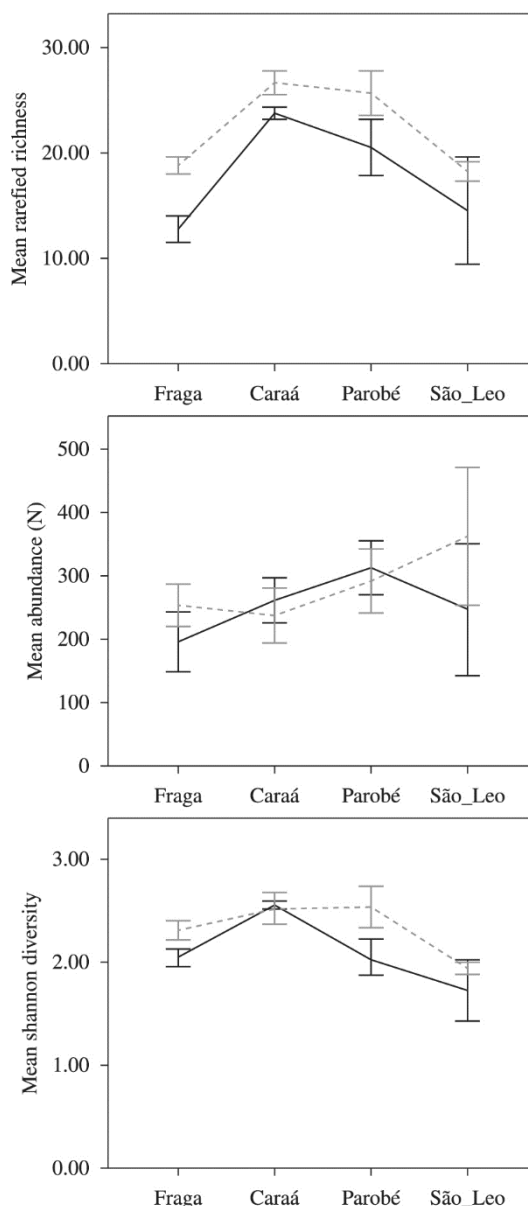

Figure 2. Mean rarefied species richness, abundance and Shannon diversity along the longitudinal gradient, as tested by bifactorial ANOVA. (Solid black line: 1998/99 collection; dashed grey line: 2007/09 collection; bars are standard errors).

not differ significantly between the sites, although mean abundance was considerably higher in the affected river stretch (Table 2).

4. Discussion

The comparison of rarefied species richness, total abundance and Shannon index of diversity did not reveal a clear tendency of press disturbance on these collective community properties during the 10-year time span
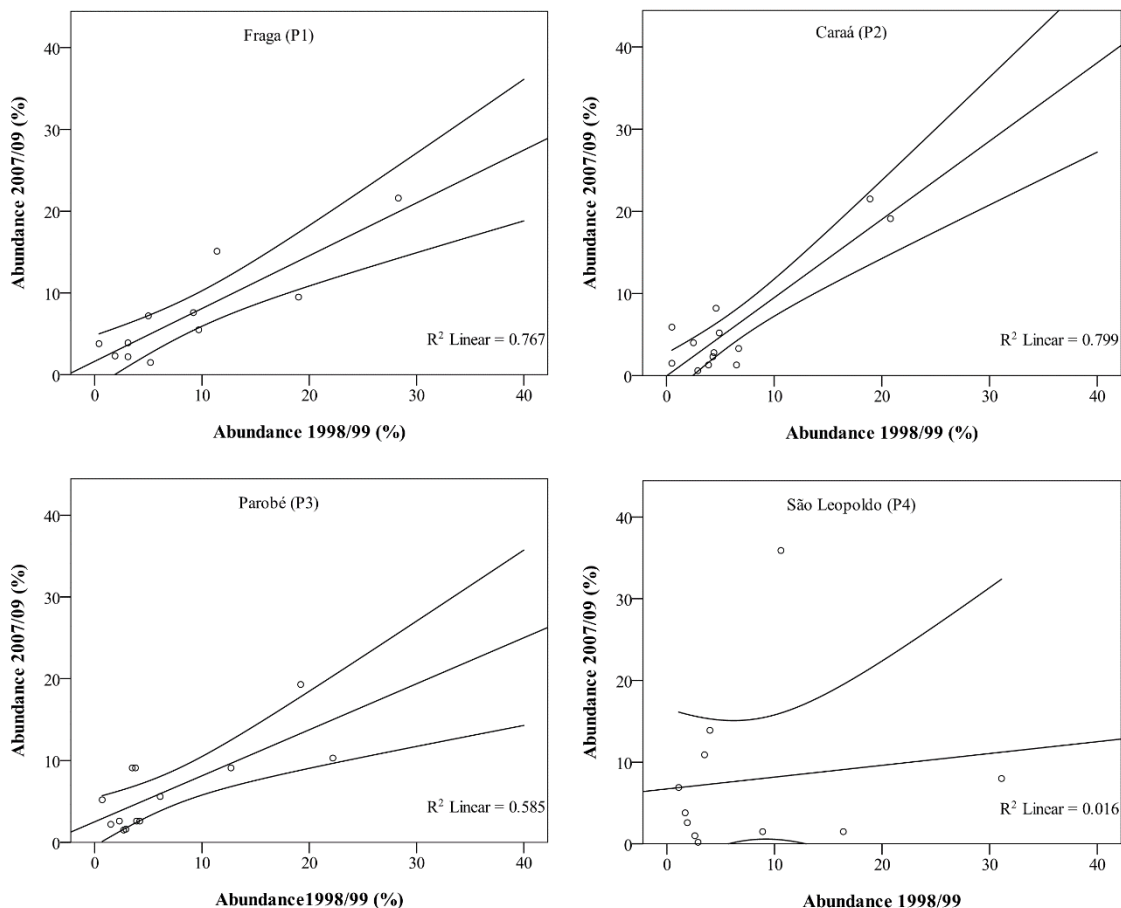
Figure 3. Spearman's rank correlation of species constancy in the 1998/99 and 2007/09 collections with 95% confidence interval.
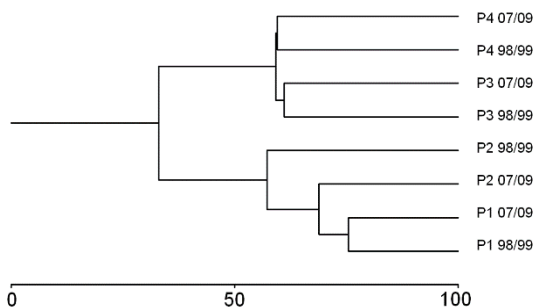

Figure 4. Bray-Curtis similarity of the studies 1998/1999 and 2007/09. P1=Fraga, P2=Caraá, P3=Parobé and P4=São Leopoldo.

between the 1998/99 and the 2007/9 collections. Richness increased in all sites by approximately the same amount and mean Shannon diversity values followed this tendency. An increase in species richness can be a community response to decreasing impact levels (Soto-Galera et al., 1998; Lima-Junior et al, 2006). However, increasing impact levels which occur when an aquatic system shifts from almost

pristine to very moderately impacted, may also increase species richness due to slightly higher nutrient input and, consequently, higher primary and secondary production (Mackey and Currie, 2000). This might have been the case in the headwaters. The increase of the trophic state may reduce intra- and interspecific competition, which, consequently, may increase species richness (Clarke and Warwick, 1994). During the ten-year interval that passed between the two studies, the former almost pristine headwaters received slightly increased nutrient loads due to some few new residential constructions, which probably discharge the outflow of the septic tanks indirectly into the river. The reason for richness increase in the lowland section remains mostly unexplained. It may indicate that the Sinos fish community is recovering, even under continuing press disturbance caused by frequent hypoxic conditions.

The effects of sample sites and sample period on abundance was not significant. The effect of sampling sites and investigation period on Shannon diversity was similar to rarefied richness. The headwater site Caraá displayed the highest values, the São Leopoldo the lowest. In general terms it seems that despite the long-term press disturbance by pollution the Sinos River still maintains

Table 1. Means and standard deviations of rarefied species richness, abundance and Shannon diversity of the 1998/99 and 2007/08 collections at sampling sites Fraga, Caraá, Parobé and São Leopoldo. Unrarefied richness values are given for additional information.

		Fraga	Caraá	Parobé	São_Leo
Rarefied Richness	1998/99	12.8 (2.5)	23.8 (1.3)	20.5 (5.3)	14.5 (10.2)
	2007/09	18.8 (1.8)	26.6 (2.2)	25.7 (4.3)	18.3 (1.9)
Richness	1998/99	12.8 (2.5)	23.8 (1.3)	20.5 (5.3)	14.5 (10.2)
	2007/09	19.8 (2.2)	29.0 (3.7)	29.0 (3.2)	22.5 (5.4)
Abundance	1998/99	195.3 (97.2)	260.5 (70.3)	312.8 (85.3)	245.5 (209.2)
	2007/09	253.0 (66.7)	235.8 (87.4)	292.0 (99.1)	361.8 (217.8)
Shannon Diversity	1998/99	2.1 (0.17)	2.6 (0.08)	2.1 (0.35)	1.7 (0.59)
	2007/09	2.3 (0.19)	2.5 (0.31)	2.5 (0.40)	1.9 (0.12)

Table 2. Comparison of mean rarefied richness, abundance and Shannon diversity of the sites P5 (Sapucaia) and P6 (Canoas) affected by the 2006 fish kills with the unaffected sites P4 (Parobé) and P5 (São Leopoldo). Unrarefied richness values are given for additional information.

		Affected Sites (P5 + P6)		Unaffected Sites (P4 + P5)
Rarefied Richness	mean	20.0		22.0
	s.d.	2.6		5.0
	t-value		−0.093	
	p		0.337	
	d.f.		10.6	
Richness	mean	26.6		25.6
	s.d.	5.5		5.3
Abundance	mean	587.4		326.9
	s.d	379.6		161.0
	t-value		1.787	
	p		0.096	
	d.f.		14.0	
Shannon Diversity	mean	2.22		2.24
	s.d.	0.3		0.4
	t-value		−0.104	
	p		0.919	
	d.f.		14.0	

considerable species diversity. However, rarefied richness is lowest and Shannon diversity second lowest in the most impacted lowland site of São Leopoldo. It appears likely that during the 10-years period between the first and the second collections the fish fauna is resistant to various anthropogenic influences that affected the river or on the way to recovery.

The observed differences in tested community parameters were relatively small. The analysis of species constancy confirms the stability of the pattern. R^2 values for the sites Fraga and Caraá show that stability is more pronounced at the less impacted headwater sites. At the lowland site São Leopoldo species rank correlations of the 1998/00 and 2007/09 collections were not significant. At this sites most species which were abundant in 1998/99 still were abundant

10 years later but their relative abundance changed. *C. voga*, the most abundant species in 1998/99 with 31.1%, dropped to 8% in 2007/09. *A. fasciatus*, with 10.6% in 1998/99, increased to 35.9%. The predator *Oligosarcus robustus* (Menezes, 1969) decreased from 16.4% to 1.5%, and *H. luetkenii* increased from 4% to 13.9%. It is not clear if these changes indicate long-term patterns of the food web or if they represent erratic changes in abundance.

In the 1998/99 study, 63 species were recorded at five sampling sites (Petry and Schulz, 2006). At the six sampling points of the current study, we identified 68 species, which is similar to what was registered almost ten years ago. The similarity dendrogram reinforces the view of general stability, since it joins the sample sites of the 1998/99 and 2007/09 study in the same clusters. Our results cannot

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estimate diversity change in relation to pre-disturbance conditions, because the composition of the undisturbed community is not known. Most probably the collective community properties decreased with the industrial and domestic sewage discharges in the decade of the 70s of the last century and the stabilised on a lower level. Schlosser (1990) observed that maximum longevity, maximum body size and age at maturity of fish species are associated with stream order. Higher stream orders tended to have larger and longer-lived fish species which mature at higher ages. In the Sinos River basin three longer-lived species occur, particularly in the higher order lowland sections: the freshwater dourado, *Salminus brasiliensis* (Cuvier, 1816), piava, *Leporinus obtusidens* (Valenciennes, 1837), and grumatã, *Prochilodus lineatus* (Valenciennes, 1837). According to fishermen all of them suffered population declines at the beginning of industrial and municipal pollution from about 1970 on. They appeared in very low abundances in 1998/99 and 2007/09 studies. The long-term pressure disturbances caused by sewage discharges probably caused the decline of these more K-selected species. The decrease of the large *O. robustus* in favour of small sized *H. luetkenii* at the São Leopoldo site may be seen as an indicator of this pattern. In the 2007/09 study the piava and grumatã were captured at the lowermost site Canoas (P6), which is located near the Jacuí river delta, a relatively undisturbed refuge or source area. At all other sites these species were absent or occurred in very low abundances. One dourado was captured at the headwater site Caraá. An adipose fin-clip identified the origin of this individual being from a restocking experiment. It seems that after the initial population decline of the most sensitive species a new stable state of the fish community of the Sinos River can be observed, although high sewage discharges and hypoxic conditions still continue.

The comparison of the sites affected by the 2006 pulse disturbance with the unaffected sites showed no significant differences in richness, abundance and Shannon diversity. One year after the fish kills three highly opportunistic species, *A. fasciatus*, *A. jacuiensis* and *C. voga* dominated the community with 51% to the total abundance at the affected sites. In the adjacent unaffected upstream reach they contributed only with 36%. These small sized species have high environmental plasticity and predominantly omnivorous or detrivorous feeding habits (Graciolli et al., 2003). Detenbeck et al. (1992) reviewed case histories of 49 sites and data on 411 recovery end points. They showed that collective community properties like species composition, richness and total density recovered within one year in 70% of the systems investigated. Recovery was enhanced by the presence of refuge or source areas. In the case of the affected sites in the Sinos River the adjacent delta of the Jacuí river in downstream direction and the unaffected upstream sites are possible source areas for recolonisation. Meffe and Sheldon (1990) proposed that recolonisation can be the result of seasonal long range movements, accumulative short range movements, agonistic interactions in the source areas resulting in displacements to the new

habitats, larval drift or *in situ* reproduction. The recolonisation process in the river reaches affected by the 2006 fish kill was not the result of *in situ* reproduction or larval drift, since one year after the fish kill most captured individuals were adults. Most probably the process was based on short or long range movements, favoured by the proximity of the relatively undisturbed Jacuí delta, which hosts source populations of *A. fasciatus*, *A. jacuiensis*, *C. voga* (Marques et al., 2007; Milani and Fontoura, 2007), and even more sensitive species like *P. lineatus* and *L. obtusidens* (Koch et al., 2000). The latter species are long distance migrators (Zaniboni-Filho and Schulz, 2003) and the others may perform short distance displacements. The resilience of the community affected by the fish kills and the observed stability of the fish community since the 1998/99 study are favoured by the relative integrity of morphological habitat structures. The Sinos River main stem is not channelled, no dams obstruct dispersal, movements and migrations and the lateral connectivity with floodplain structures like oxbows and wetlands is still functional. Aarts et al. (2004) observed that European fish communities are recovering very slowly from chemical pollution, because physical habitat structures are degraded in most rivers. The current Brazilian government projects the construction of sewage treatment plants in every municipality of the Sinos watershed. On the long-term these investments will increase water quality and may favour a fish community with a composition close to pre-disturbance conditions. A precondition for this positive perspective is the conservation of the morphological habitat integrity, which today is becoming under hard pressure.

5. Conclusions

1. The probable initial shift of the Sinos fish community from pre-disturbance conditions to permanent high pressure disturbance caused by chemical and organic sewage in the second half of the last century could not be documented by this study. But the comparison of 1998/99 and 2007/09 collection shows that during the period subsequent to a probable initial decline the Sinos fish community remains stable or is on the way to recovery.

2. Recolonisation of the river reach affected by the 2006 fish kill occurred within one year, mostly by opportunistic species through immigration from nearby source and refuge areas.

3. Resilience of the river reaches affected by the 2006 fish kill and the current stability of the communities at the other sampling sites is favoured by the still existing morphological habitat integrity.

4. At the moment river management focuses the increase of water quality by the construction of sewage treatment plants. These efforts should be accompanied by the conservation of the physical habitat structures.

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