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Short-Term Ecological Implications of the Diversion of a Highly Polluted Lowland River: A Case Study

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Many of the responses of a river to channel changes cannot be predicted by theory alone and thus documented case studies are an important means for evaluating impact of the management maneuvers. Moreover, the increasing pollution problems in areas with rapidly growing populations of developing countries are complicated by the complex interaction with channel changes (Dudgeon 1992). In this paper we present a case study of an engineering practice for flood control of the Reconquista River. The entire flow of this highly polluted lowland river was diverted through a relief channel by means of an impoundment (Fig. 1). As a result, the Luján River received the entire discharge of the Reconquista River upstream of its natural confluence. Even though there are water quality studies for the Luján (del Giorgio et al. 1991) and Reconquista rivers (Loez and Topalián 1999), it is only recently that information on the lower reach of the River Luján and some of its tributaries, including the Reconquista relief channel have been published (O'Farrell et al. 2002). The aim of this work is to assess the impact of the management practice performed on the abundance and species composition of planktonic diatoms as related to the variation of physical and chemical parameters.

MATERIALS AND METHODS

The Luján River is a lowland watercourse that rises in the North West of Buenos Aires (59° 37' W, 34° 43' S), joins the River Paraná Delta and discharges to the Río de la Plata Estuary (Fig. 1). The inferior reach receives high concentrations of industrial outflows and urban wastewaters by its tributaries; the most important one is the Reconquista River, considered the second most polluted river of Argentina (Loez and Topalián 1999). During the 1970's, as a flood alleviation measure, a 7.5 km relief channel (Aliviador Channel) was constructed approximately 5 km upstream of its confluence with the Luján River. On 5/8/2000 the entire flow of the Reconquista River was diverted by means of an impoundment (Fig. 1).

Samples were collected monthly before (May, June, July 2000) and after (August, September, October 2000) the flow diversion, at three sites: one at the

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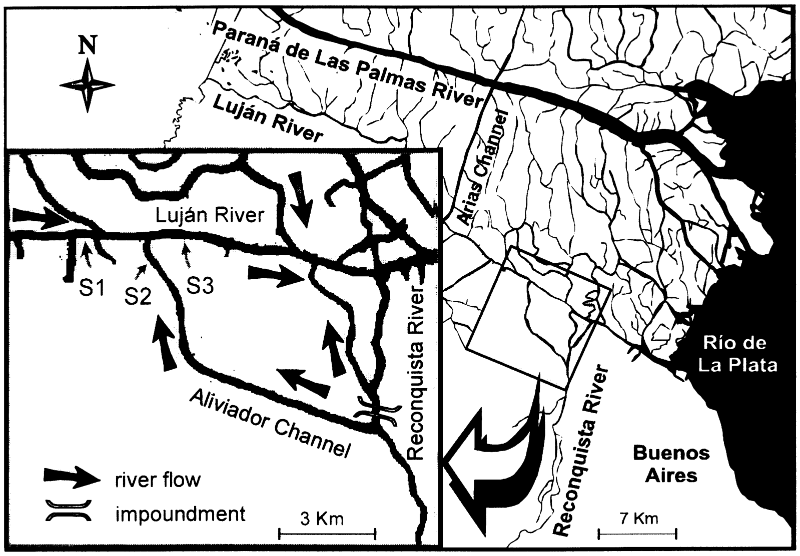

Figure 1. Location of the sampling sites in the Lower Luján River (S1 and S3) and the Aliviador Channel (S2).

Reconquista relief channel (S2) and the other two on the main channel of the Luján River, upstream (S1) and downstream (S3) of the point of discharge of the Aliviador Channel. The following variables were measured *in situ*: transparency, temperature, pH, dissolved oxygen and conductivity. Chlorides, sulfates, ammonia, nitrates, phosphates, total nitrogen and phosphorus, sodium, potassium, magnesium, calcium, and suspended solids concentrations were determined as previously described in O´Farrell et al. (2002). Phytoplankton surface samples, collected in 300 ml plastic flasks, were mineralized and diatoms mounted onto microscope slides following standard procedures for their analysis (Battarbee, 1986). Permanent slides for light microscopy of studied material were prepared with Naphrax®. Diatom concentration was determined by the "aliquot" method using a known volume of suspension when preparing the permanent preparations. Species ecological requirements were based on data of De Wolf (1982) and Van Dam et al. (1994).

For the multivariate analyses, rare species occurring in less than 3 % in all samples were removed without much influence in the analysis. Agglomerative classification of the 16 remaining species was performed on relative abundance data using correlation coefficient and unweighted pair group average linkage procedure. Stepwise multiple discriminant analysis of samples was performed, using arcsin-transformed relative abundance data to avoid departures from normality and within-group variance-covariance matrices inequality across groups. Ordination and identification of relatively homogeneous groups of samples based on physical and chemical data were performed using principal component analysis (PCA) and k-means cluster analyses, respectively (SPSS

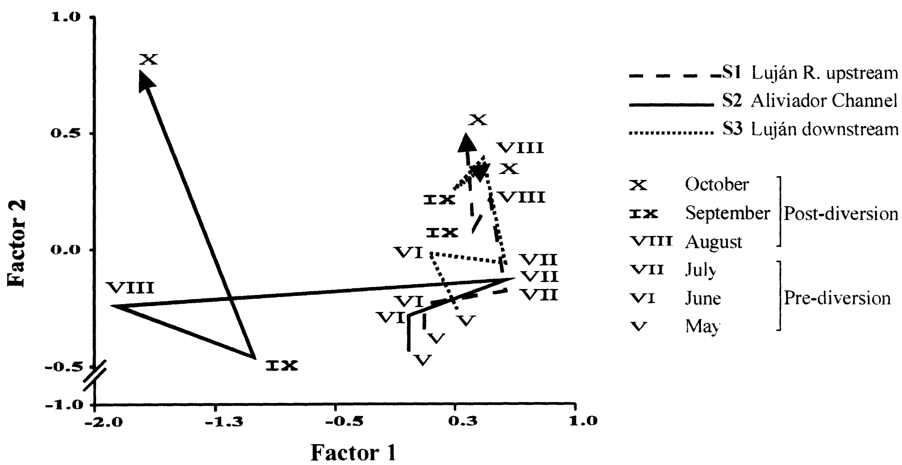

Figure 2. Samples ordination resulting from PCA. Lines show the temporal pattern for each sampling site.

software). Partial canonical correspondence ordination based on raw data was used to elucidate the relationships between diatom assemblages and environmental parameters, using dummy variables for coding the watercourses (Luján River and Aliviador Channel) and the management periods (pre and post diversion), and performing Monte Carlo permutations for significance testing (ter Braak & Verdonschot, 1995). A forward selection of the measured environmental variables was done to extract synthetic gradients not correlated with the above-mentioned covariables (Canoco software).

RESULTS AND DISCUSSION

The physical and chemical results obtained in the present study (May to October 2000) at S1 agree with the mean values presented for this reach of the Luján River by Tell et al. (2001) from October 1998 to October 1999. A further coincidence is referred to the phytoplankton composition previously described for this river stretch (O'Farrell et al. 2002). Thus, in order to assess the impact of the diversion of the Reconquista waters, we will consider the present registers for S1 as background information regarding both water quality and phytoplankton community.

Physical and chemical variables summarized in Table 1 show a deterioration of water quality at S2 after the diversion of the River Reconquista waters. The K-means cluster performed to classify samples into two group in order to test a possible management effect in the water quality of the system produced one cluster comprising the S2 August, September and October samples (Aliviador Channel post-diversion), and another cluster with the remaining 15 samples. Conductivity and dissolved sodium, and secondarily ammonia and dissolved oxygen showed the higher contribution to this group separation. The PCA, also performed with the abiotic variables, explained 71 % of the variance with the first two factors. The first axis was inversely correlated with conductivity and sodium and directly correlated with dissolved oxygen (57% variance explained). The second axis was inversely correlated with suspended solids and directly with transparency. The ordination revealed a temporal pattern common to the three sites for the pre-diversion months (Fig. 2). After the discharge diversion, the sites located in the Luján River followed a similar pattern, whereas the S2 pattern diverged along the first factor due to the strong conductivity increase associated with an abrupt oxygen decrease. The temporal tendency lines for each site illustrate different patterns for both courses. The S2 October sample is located in the upper left region of the ordination due to a marked decrease in suspended solids content. Thus, both the K-means cluster and the PCA revealed a difference before and after the diversion.

The ionic charge balance at S2 after the diversion is basically influenced by the great occurrence of both sodium and ammonia, which most probably derive from organic matter degradation. These cations present similar evolution patterns after the diversion at S2. The relative increments for sodium, calcium, magnesium, chloride and sulfate concentrations by a factor of 5 and for ammonia content by a factor of 10 to 100, could be attributed to the industrial and sewage pollution from the Reconquista River. The occurrence of both sulphide and ammonia would be the cause of the decrease of dissolved oxygen concentrations leading to an increase in the environment reductive condition. Loez and Topalián (1999) have

Table 1. Mean and standard deviations of physical and chemical variables in the studied sites before (pre: May, June, July) and after (post: August, September, October) the diversion.

	S1 (Luján River)		**S2 (relief channel)**		**S3 (Luján River)**	
	pre	**post**	**pre**	**Post**	**pre**	**Post**
Number of samples	3	3	3	3	3	3
Channel depth (m)	4.8±3	4.7±0.4	1.7±1.1	1.9±0.5	7.1±0.6	6.0±1.1
Velocity (m seg^{-1})	0.3±0.5	0.36±0.1	0.03±0.4	0.09±0.1	0.15±0.2	0.51±0.01
Temperature (°C)	12.3±3.5	16.2±3.6	12.4±3.4	15.5±3.4	12.3±3.6	15.9±3
pH	6.8±0.2	7.2±0.1	6.7±0.3	7.1±0.3	6.7±0.3	6.6±0.3
Conductivity (µS cm^{-1})	325±59	259±64	325±75	901±378	320±23	310±356
Transparency (cm)	23±5	25±8	20±2	17±7	19±3	30±9
Susp. solids (mg l^{-1})	120±37	49±48	94±57	139±54	140±29	52±97
Diss. oxygen (mg l^{-1})	7.8±1.4	8.1±1.8	6.6±1.5	0.5±4.1	7.7±1	7.8±4.6
Ammonia (µg l^{-1})	269±381	88±344	400±373	5597±2911	313±33	475±2687
N-NO_3 (µg l^{-1})	283±72	380±72	317±75	496±119	184±108	334±678
P-PO_4 (µg l^{-1})	75±41	29±125	136±45	813±360	148±23	80±347
Tot. nitrogen (µg l^{-1})	934±322	3048±3431	1219±497	7966±1744	902±479	2890±2522
Tot. phosphorus (µg l^{-1})	88±33	132±134	189±42	1000±494	244±38	225±468
Cl^- (mg l^{-1})	23.0±6.3	21.4±7.3	23.2±6.8	49.5±36.9	22.7±9.3	23.0±37.2
$SO_4^=$ (mg l^{-1})	27.3±6.1	12.7±6.9	27.6±8.9	47.0±29.8	26.8±4	13.9±31.1
Na^+ (mg l^{-1})	68.3±17.7	65.0±20.7	69.6±19.5	253.5±148	69.1±10.8	69.1±137
K^+ (mg l^{-1})	4.2±1.6	3.0±2.7	5.5±1.7	11.4±6.1	6.0±0.2	2.9±5.9
Mg^{++} (mg l^{-1})	3.3±0.6	3.7±0.7	3.4±1.3	9.4±5	3.4±1.4	3.0±4.7
DQO (mg l^{-1})	20.7±4.6	11.3±3.6	61.0±2.9	41.0±16.3	23.0±4	14.0±12.1

registered such events in the past in the downstream stretch of the Reconquista River: oxygen levels near anoxia (0.4 mgl^{-1}) in coincidence with very high conductivity, chloride and ammonia concentrations and chemical oxygen demand after the input of an extremely polluted stream. Even though S2 is located in the Aliviador Channel, its water quality does not greatly differ from the sites located at the Luján River in the months previous to the flow diversion. Is there any external factor other than the polluted water input influencing the changes registered from August onwards? As far as the hydrological and weather variables (discharge, tides, winds, and temperature) are concerned, none of these appear to be producing such a shift in water quality and phytoplankton structure. Moreover, in spite of the rapid action of physical processes that would not allow the development of persistent or constant conditions (water mixing, water residence changes, particle entrainment and sedimentation), we found a consistent pattern of change.

Forty-one diatom genera, which comprised 230 infrageneric taxa, were identified. The most abundant taxa are shown in Table 2. Marked changes were registered

Table 2. Relative abundance of dominant taxa (> 3 % in at least one sample) in the studied system between May and October (V to X) 2000.

	S1 (Luján River)						S2 (relief channel)						S3 (Luján River)					
	V	VI	VII	VIII	IX	X	V	VI	VII	VIII	IX	X	V	VI	VII	VIII	IX	X
ACHDEL	0	0.2	0	0	0	0	0	0	0	1	2.6	0.3	0	7.2	0	0.5	0.5	0.6
AULAM	1.5	0	15	3.6	1.7	14	2.2	4	5.5	2.3	1.2	3	2.2	5.5	11	12	12	12
AULGRG	7.8	3.6	26	6.1	12	20	7.6	7.6	15	5.4	4.3	5.2	6.1	6.5	27	21	15	22
AULGRA	2	4	3.6	6.2	11	5.4	1.3	4.9	5.4	1.9	1.8	1.2	1.7	2.8	4.5	4.4	3	8
COCDIS	0	0.1	0.1	0	0.3	0	3	1.6	2.2	16	15	4.2	0.5	1.6	0.2	1.7	1.2	0.5
CYCLIT	0	0	0.1	0	0	0.1	0	0.4	0	6.3	3.4	1.6	0.2	0.5	0.1	1.1	0.6	0.1
CYCMEN	8.3	2.6	8.9	4.8	12	13	8.4	12	8.8	0.6	0.8	12	14	5.7	15	8.1	12	14
DIMMIN	0	0.5	0	0	0	0	0	0.4	0.3	4.1	5.2	2.6	0.1	0.5	0.1	1	1.5	0.2
FRAPIN	4.3	7.2	4	0.5	1.5	1.6	2	0.1	0.5	1.9	0.7	1.2	0.9	2.4	0.7	1.2	1.6	1.9
FRACOC	13	25	4.9	1.7	0.2	1.7	6.8	29	4.6	1.3	0.9	1.2	16	12	2.3	3.7	1.7	2.6
FRACOV	4.4	10	2	0.6	0.7	1.5	2.2	5.6	3.1	3.4	0.9	0.8	3.2	4.4	0.4	2.2	0.1	2.6
HYASCO	0	0	0	0	0	0.1	2.8	3.2	1.4	20	25	18	1.1	1.6	0.5	5.2	5.7	0.6
NITPAL	11	7.1	0.8	2.2	6.6	0	15	2.1	2.3	0	0.2	0.3	4.2	2.3	0.5	0	0	0
NITUMB	4.8	0.2	0.4	0	2.5	1.3	2.2	0.2	0.6	0	1.1	5.6	3.3	0.6	0.2	0.2	2	1.1
PARSUL	0.1	0.1	0.1	0.1	0	0.5	1.4	2.3	0.5	9.3	9.2	6.7	0.7	1.1	0.6	3.2	4.3	1.5
S-CENT	1.8	5.7	1	51	9.1	0.9	0.8	0.2	10	0.6	0	0.9	1.1	0.3	1.6	0.6	0.5	0.1
Cells ml^{-1}	67	164	32	251	114	18	23	28	10	96	143	8	52	84	25	9	14	39
N. of species	63	90	103	42	95	76	67	76	79	47	56	65	77	81	80	78	66	68
Diversity	4.6	4.5	4.5	2.7	4.8	4.3	4.7	4.2	4.9	4.1	4.1	4.7	4.7	5	4.2	4.7	4.6	4.2

ACHDEL: *Achnanthes delicatula*, AULAM: *Aulacoseira ambigua*, AULGRG: *A. granulata* var. *granulata*, AULGRA: *A. granulta* var. *angustissima*, COCDIS: *Cocconeis disculus*, CYCLIT: *Cyclotella littoralis*, CYCMEN: *C. meneghiniana*, DIMMIN: *Dimmeregramma minor*, FRAPIN: *Fragilaria pinnata*, FRACOC: *F. construens* var. *construens*, FRACOV: *F. construens* var. *venter*, HYASCO: *Hyalodiscus scoticus*, NITPAL: *Nitzschia palea*, NITUMB: *N. umbonata*, PARSUL: *Paralia sulcata*, S-CENT: small centrics

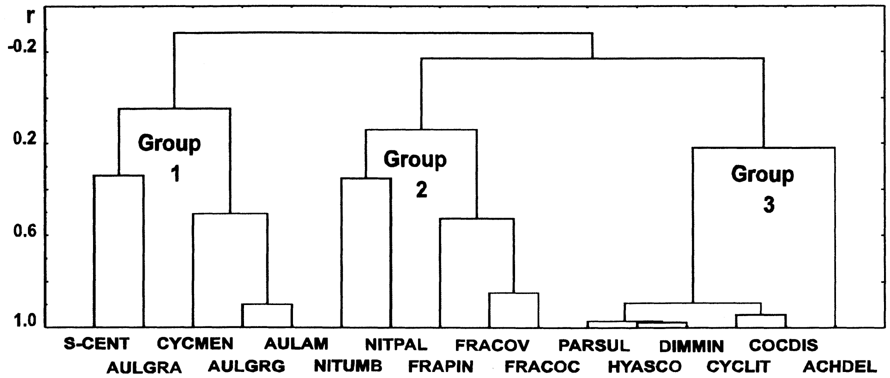

Figure 3. Dendrogram produced by the cluster analysis of dominant species (relative abundance >3% in at least one sample), r: Pearson correlation coefficient. Species codes are explained in the text.

after the discharge diversion in the structure of the diatom community from S2: specific richness decreased whereas abundance increased after the diversion. The typical planktonic centric species of the Luján River (*Cyclotella meneghiniana, Aulacoseira ambigua, A. granulata* var. *granulata, A. granulta* var. *angustissima*, dominated during July, September and October. In August, a group of small centrics prevailed; these included *Stephanodiscus parvus*, *Cyclostephanos invisitatus* and other forms smaller than 10 µm, which were impossible to identify to species level under light microscope. All the mentioned centrics constituted Group 1 in Fig. 3. Benthic and periphytic forms prevailed in S1 and S2 during May and June accounting for more than 65% of the diatom abundance. *Fragilaria construens* var. *construens, F. construens* var. *venter*, *F. pinnata, Nitzschia palea* and *N. umbonata* were the dominant species (Group 2 in Fig. 3). The greatest impact on the diatom structure at S2 was revealed by an increase in species tolerant to high conductivity: *Hyalodiscus scoticus*, *Cyclotella littoralis*, *Paralia sulcata*, *Dimmeregramma minor* and *Cocconeis disculus*, grouped with *Achnanthes delicatula* (Group 3 in Fig. 3).

The strong conductivity increase due to the pollution above described at S2 in the post-diversion period indicates that salinity stress could be a plausible explanation for the limitation of the development of many taxa and the prevalence of brackish species. The fact that the latter were only found in very low numbers during the pre-diversion period and that some of them were repeatedly recorded for the Río de la Plata (Ferrario and Galván 1989), points to salinity as a key factor in their distribution. Even though the recorded high conductivity levels were not a natural phenomenon during this event, these species apparently met favorable ecological conditions after the diversion. The scarcity of autoecological information on taxa from estuaries or shallow coastal environments (Sullivan 1999), implies our impossibility of grouping such species based on their pollution tolerances. The poor development of *Fragilaria* spp in the post-diversion period at S2 cannot only be explained in terms of salinity stress, as they are characterized as fresh-brackish

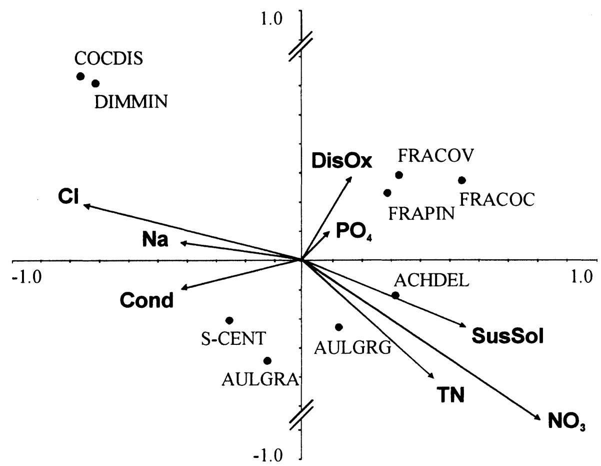

Figure 4. Species-conditional biplot based on a partial canonical correspondence analysis. Quantitative environment variables are indicated by arrows.

species (Van Dam et al. 1994). The oxygen depletion at S2 could explain the replacement of these species characterized by Van Dam et al. (1994) as having high oxygen requirements. In this sense Cooper (1995) asserts that, among others, *F. construens* is a good indicator of estuarine habitats that experience low detrimental anthropogenic effects, whether due to hydrology, current and tidal amplitudes, or direct human influence. Moreover, Muylaert et al. (1997) found that development and fate of phytoplankton assemblages in a freshwater tidal estuary were controlled by an oxygen gradient, in a similar way to our findings. The dilution potential of the Luján River downstream its confluence with the Aliviador Channel is critical in determining a reduction in pollutant concentrations.

The self-purification capacity of the Luján River after the diversion can be estimated from the comparison of S2 and S3 abiotic components concentration, as well as those from S1 that were established as background levels. Even though ammonia concentration diminished in S3 as compared to S2, it was still 5 times higher than at S1. Nevertheless, reductive conditions were almost the same at S1 and S3, and the PCA showed a similar pattern for both sites (Fig. 2). Moreover, the stepwise discriminant analysis selected a set of species that showed different ecological responses in the Luján River and the Aliviador Channel before and after the diversion. All pairwise comparisons between these sample groups resulted significant (p=0.008). *Fragilaria construens* var. *construens*, *F. construens* var. *venter, F. pinnata*, *Aulacoseira granulata* var. *granulata, A. granulata* var. *angustissima, Dimmeregramma minor, Cocconeis disculus, Achnanthes delicatula* and the group of small centrics entered this discriminant function explaining 95.2 % of the variance with a canonical correlation of 0.996.

Partial canonical correspondence ordination shows the relationships between the above-mentioned discriminant species and the selected environmental variables (Fig. 4). The first two axis account for 64.7% of the variance. The species–environment correlation with the first axis was 0.98. Abiotic factors were significantly correlated with the first axis (p=0.005). *Cocconeis disculus* and *Dimmeregramma minor* appeared correlated to those sites with high conductivity waters, characterized by elevated chloride and sodium concentrations as well as low nutrient contents. *Fragilaria* spp. were abundant at sites with high phosphate concentrations; there was a smaller peak at S2 in September that was related with dissolved oxygen increase. *Achnanthes delicatula* appeared closely associated to high suspended solids concentrations. The *Aulacoseira* spp. and the group of small centrics are displayed in an intermediate position regarding nutrient concentrations and most all other variables. Moreover, after the diversion the species composition at the Luján River was consistent to that registered in the Aliviador Channel. In this way, our results revealed that the altered ecological conditions at the Aliviador Channel still affected the diatom assemblage in the Luján River downstream the confluence of the two courses. Concluding, the hydraulic practice carried out as a flood alleviation measure resulted in a severe ecological degradation of the relief-channel with the consequent pollution diffusion downstream the Luján River.

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