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*Primary Research Paper*

# Seasonal and spatial distribution of stoneflies in the Chubut River (Patagonia, Argentina)

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## Abstract

Longitudinal and seasonal distributions of Plecoptera species were examined along the Chubut River in the Patagonian Precordillera and Plateau, Argentina. Chubut River ( > 1000 km) is the largest river in the area and the hydrological regime is modified in the lower section by an artificial reservoir (Florentino Ameghino Dam). Quantitative samples were collected in 13 sites in the higher, middle, and lower sections of the river basin. Sites were visited four times during 2004, and a total of nine species and 5772 individuals were collected in the study. Plecoptera richness decreased dramatically from the headwaters to the mouth of the river system. Two species, *Antarctoperla michaelseni* and *Potamoperla myrmidon*, were able to live below the impoundment but they were not abundant. *Notoperlopsis femina* and *A. michaelseni* abundances were higher in summer than in the other seasons, while *Limnoperla jaffueli* peaked in spring. Species–environmental relationships were examined using Canonical Correspondence Analysis and six independent variables were identified as the major factors structuring stoneflies assemblages. First axis was highly related to environmental variables reflecting the hydro-geological and land use gradients in the basin (conductivity, total suspended solids, periphyton Chlorophyll *a*). Second axis was more related to variables that changed seasonally (wet width, water temperature and soluble reactive phosphate).

## Introduction

Lotic insects, including stoneflies, are subject to both natural and man-induced disturbance and change (Resh et al., 1988). Natural factors such as temperature, elevation, latitude, substrate type, discharge, and current velocity are related to geology, climate, and vegetation of a particular region are primary factors determining stoneflies distribution (Ward, 1992; Morse et al., 1993; Malmqvist, 1999). On the other hand, humans have impacted, and are impacting, the river faunas in several significant ways: introduction of exotic species, impoundment construction (reservoirs), sedimentation processes (road construction, deforestation), toxic substances releases (industrial effluents, fertilizers), and organic enrichment (agriculture, urbanization). Among studies that explain how these impacts are affecting aquatic communities, Plecoptera appears as one of the most sensitive groups of organisms. Stoneflies have been used in biomonitoring organic pollution (Metcalfe, 1989), and also as part of the EPT groups assessing logging effects, deforestation and pasture conversion (Scarsbrook & Halliday 1999; Harding et al., 2000). Some Plecoptera species are also affected by river regulation (Brittain, 1991), and stonefly richness decreases when the habitat diversity is diminished (Landa et al., 1997).

Plecopteran fauna in the Patagonia ecoregion is rich and diversified, in the Argentinean side there are six different families represented (Illies, 1969).

Since stoneflies are more abundant and common in the Subantarctic Forest, most of the studies on the group have been focused in the Cordillera (Andean-Humid and Sub-Andean Sub-humic biozones). Spatial distribution of Plecoptera across altitudinal gradients has been well described in mountainous areas (Albariño, 1997; Miserendino & Pizzolon, 1999) and stonefly responses to organic enrichment have also been studied (Miserendino & Pizzolon, 1999). However, landscape approaches to explain lotic insects distribution are scarce (Miserendino, 2001), and studies on aquatic insects in the Patagonian Plateau have been practically neglected (Wais, 1984, 1987). Chubut River is certainly the most important watercourse in the Province. The basin is subject to multiple activities/uses, including agriculture, cattle raising, irrigation and river regulation. This river provides a unique opportunity to study the longitudinal distribution patterns of stoneflies and their environmental relationships.

The aims of this study were to: (1) analyze stonefly species distribution and (2) identify those key variables that influence Plecoptera community patterns along a large Patagonian river, from the upper tributaries to the outlet in the Atlantic Ocean.

## Study area

Chubut River flows from the West to the East of the Patagonia ecoregion and drains to the Atlantic Ocean. The Chubut basin (25,225 km$^2$) covers two main biozones: the Extra-Andean oriental and Extra-Andean occidental (Del Valle et al., 1995; Paruelo et al., 1999). Geomorphologic features and local climatic characteristics allowed us to divide the basin in three areas. The upper basin (7000 km$^2$) is characterized by a strong rainfall gradient (500–100 mm y$^{-1}$) and near the Cordillera shows the lowest air temperatures (mean annual temperature 8.5 °C). The middle basin (12,000 km$^2$) is the driest area with $\leq$ 150 mm y$^{-1}$ rainfall and 13.2 °C mean annual temperature. The lower basin, the regulated section of the river, has the smallest area 6000 km$^2$ being the rainfall $\geq$150 mm y$^{-1}$ (Coronato & del Valle, 1988). Dominant orders of soils in the basin are aridisols, entisols and vertisols (del Valle et al., 1998), characteristic of the arid and semiarid areas of Patagonia. Most of the river is located in the Patagonian Steppe, where the scarce precipitation in the Patagonian Plateau causes the dominance of xerophytic vegetation. *Mulinum spinosum* Pers., *Stipa* spp., *Colletia spinosissima* Gmel., *Adesmia campestris* (Rendle) Rowlee, *Larrea divaricata* Cav., *Fabiana imbricata* Ruiz et pav, and *Chuquiraga avellanedae* Lorentz represent the herbaceous-shrub-like steppe (Tell et al., 1997). In several sections of the river at the upper and middle basins, the riparian corridor has been completely invaded by the exotic *Salix fragilis* L., in some lower sections the native *S. humboldtiana* Willd is also present.

The adjacent land management is mainly agricultural, with extensive livestock in the upper and middle sections, and predominantly farms and industries in the lower section. Chubut Province produces 4,000,000 sheep per year. In the section between Paso de Indios and Rawson, a typical cattle farm has between 300 and 500 sheep every 2500 h. From Paso the Indios to the Cordillera the increases and ranges between 400 and 650 sheep every 2500 h (Rimoldi, pers. com.). In the middle basin, anthropogenic activities in the last century (overgrazing, wood collection) have accelerated land cover degradation in the adjacent zones, and broad areas exhibit extreme land degradation as is shown by the status of desertification that ranges from moderate to very severe (del Valle et al., 1998). This situation resulted in low productivity of the land and landowners have recently started to cultivate potatoes, corn, and alfalfa. Therefore, various segments of the river are used for watering, particularly during the low water period in summer. For example, in the agricultural middle valley, 2,000,000 l per hectare are pumped from the Chubut River for water supply in the alfalfa fields (800 h approximately). No fertilizers or herbicides are used and water returns into the river by natural gravity (Luque et al., 2000). Main cities next to the river in the lower basin use water from the Florentino Ameghino Dam mainly as potable water supply and irrigation via a channel network in the lower valley. Chubut River outlet is on the estuary next to Playa Union town.

Thirteen sampling sites were established within the river system (Fig 1), LA (Lepá River) and AM

(Madera Stream) were located on upper tributaries, site EM was placed on the Chubut River next to the locality of El Maitén (3500 inhabitants), and FO on the Chubut River further downstream. Le (Lepá River) was located by the side of Gualjaina City (1000 inhabitants) and LG further down after Gualjaina River joins Lepá River. To assess possible changes in response to land use on the upper and middle basin, four sites on the Chubut main channel were established: PP, PB, VA, and LP, the sampling site LP was next to the rural town of Las Plumas (500 inhabitants). DA was placed just below the impoundment. D2 and EE were located in the more developed lower Chubut River basin; in which the cities Gaiman, Trelew, and Rawson together comprises more than 250,000 inhabitants. This corresponds with the most urbanized area since 77% of the Chubut Province population is concentrated on the coast.

## Materials and methods

### *Field methods*

A total of 13 sites were sampled in February, May, September, and December of 2004 (Fig. 1). Stonefly larvae were collected taking three quantitative replicates on run/riffles sections with a modified kick net sampler (surface of the frame: $0.25\ m^2$, 250 $\mu$m pore size) (Hauer & Resh, 1996). Samples were fixed with 4% formaldehyde solution. A total of 156 replicates were analyzed. At the laboratory samples were sorted out under 5× magnification and then stored in 70% ethyl alcohol. Species were identified using available keys (Illies, 1963; Fernández & Domínguez, 2001).

Substrate composition was estimated as percentage of boulder, cobble, gravel, pebble, and sand using a $1-m^2$ grid (Gordon et al., 1994).

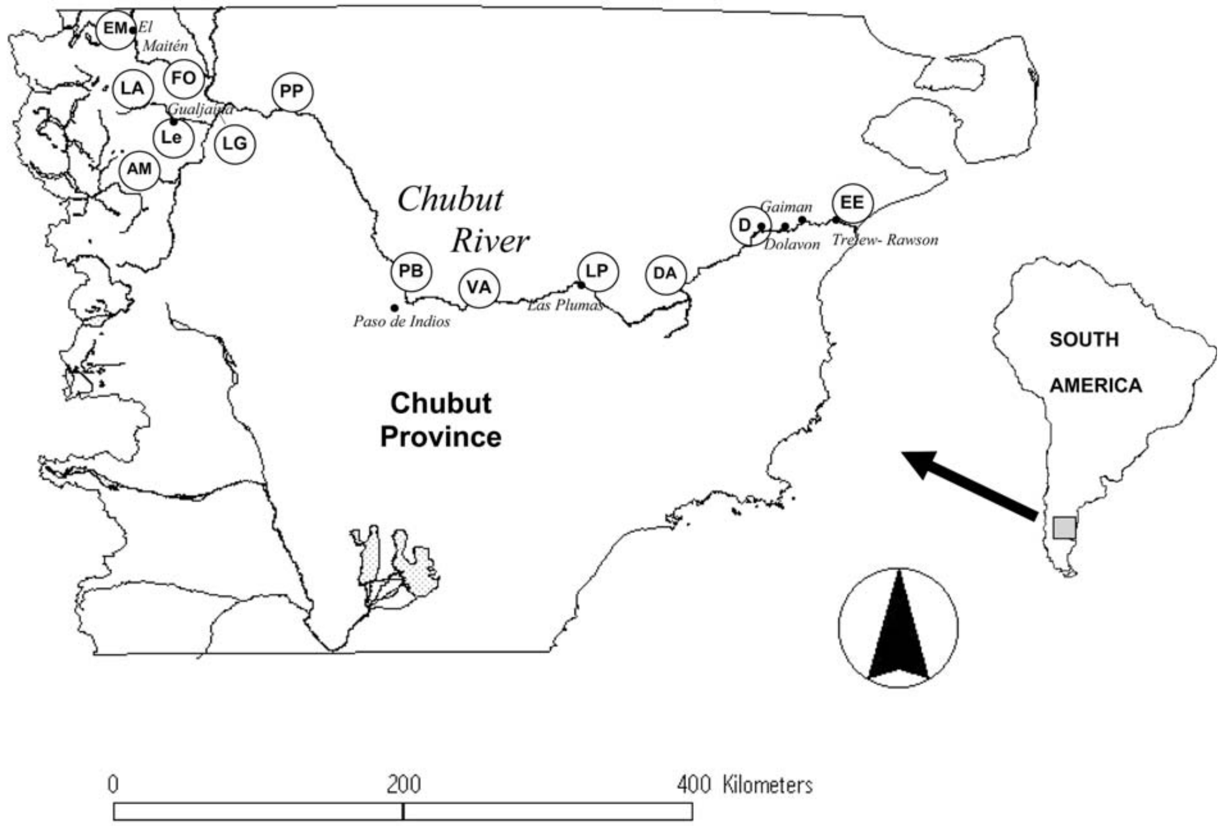

*Figure 1.* Study area showing the locations of the 13 sampling sites in the Chubut River, Patagonia Argentina. Names of the sites are in Table 1.

Stream order was obtained from Coronato & del Valle (1988). Average depth was estimated from five measurements along one transversal profile across the channel with a calibrated stick. Surface current speed was obtained by timing a bobber (average of three times) as it moved over a distance of 10 m (Gordon et al., 1994). At each site air and water temperatures were measured with a mercury thermometer ($-10/+60$ °C).

Water samples were collected below the water surface and kept at 4 °C prior to analysis. At the laboratory specific conductance, pH, total alkalinity, total suspended solids, and main nutrients were analyzed. Specific conductance was measured with a Horiba U2-probe, and pH with an ORION 720 SA meter, both at 20 °C. Total alkalinity (eriocrome black) was determined by titration with colorimetric end-point; total nitrogen (TN) and total phosphorus (TP) were determined on unfiltered samples digested with persulphate, nitrate plus nitrite nitrogen ($NO_3$–$NO_2$), ammonium ($NH_4$), and soluble reactive phosphate (SRP) were analyzed following APHA (1994).

Algal biomass (as Chlorophyll *a*) was determined by scraping algae from five rocks within a 20 m reach at each site. Samples (120 ml) were kept on ice in the dark until they were brought back to the laboratory and filtered onto GF/F filters. Chlorophyll *a* (Chl *a*) was extracted from filters in 90% acetone and the extract was measured spectrophotometrically (Wetzel & Likens, 1991).

### *Data analysis*

Principal Component analysis (PCA) on log $(x+1)$ transformed data was used to examine variation in physical and chemical parameters across sites in the entire basin. The PCA is a method of breaking down or partitioning a resemblance matrix into a set of orthogonal axes (linear model). This method used within of its intended limits is a valuable procedure to detect structure in the relationships between variables (Ludwing & Reynolds, 1988).

Canonical Correspondence Analysis (CCA) was performed using the package CANOCO (ter Braak & Smilauer, 1999) to assess the relationships between stonefly assemblages and environmental variables. We included the basin and reach descriptors and land-use related variables in the analysis. The CCA is a direct gradient analysis that assumes a unimodal model for the relationships between the response of each species to environmental gradients and ordination axes are linear combinations of the environmental variables (ter Braak, 1986). Variables (except pH and Chl *a*) and species density were transformed as log $(x+1)$, prior to analysis. Also, variables that covaried with other measured variables (Pearson correlation coefficient $r > 0.65$; $p < 0.01$) were removed prior to CCA. Thus, channel dry width and stream order were omitted in the analysis as they covaried with channel wet width and elevation respectively. To extract a reduced set of variables, covariable environmental factors were excluded if the variable inflation factor was greater than 10 (ter Braak & Smilauer, 1998). A Monte Carlo permutation test (9999 permutations) was used to verify the significance of the model.

## Results

### *Environmental features of the Chubut River*

River orders ranged from 3 to 6 and elevation of the sites was between 4 and 936 m.a.s.l. Substrate size was similar at most sites and mainly comprised boulders, cobbles, and pebbles (Table 1). Sites PB, VA, and EE had more sand in the substrate composition than the other sites. Water temperature ranged from a minimum of 5 °C in May to a maximum of 22.2 °C in February (Table 1). Maximum current velocity recorded was 2.1 m $s^{-1}$ during February (FO) and the minimum was 0.2 m $s^{-1}$ also in summer (LA), at that section the river suffered water abstraction for irrigation.

Chemical and physical data provided a clear distinction among the upper catchment sites and those on the middle and lower catchments as is shown in the PCA ordination graph (Fig. 2). Samples taken in the upper basin and tributaries (AM, LA, FO, EM, Le, and LG) were placed on the upper and lower left quadrants, those from the lower basin (DA, D and EE) were positioned in the upper right quadrant, and samples from sites on the middle basin (PB, VA and LP) were plotted on the lower right quadrant. First three factors accounted for most of the variation in the data set

*Table 1.* Environmental features measured at 13 sampling sites on the Chubut River basin, Patagonia, Argentina. Mean values ± SD ($n = 4$). T – tributary, MC – main channel. B – boulder, C – cobble, P – pebble G – gravel, S – sand, c – coarse, f – fine. Ch – Chubut River. Land use codes: Cr – cattle raising, U – urban, A: – agriculture, R – flow regulation

| Sites codes | River location | Main land use | Altitude (m.a.s.m.) | Stream order | Dry width (m) | Mean Wet width (m) | Depth (min–max) (cm) | Velocity (min–max) ($m\ s^{-1}$) | Water temperature (min–max) (°C) | Substrate type |
|---|---|---|---|---|---|---|---|---|---|---|
| AM | Madera Stream (T) | Cr | 936 | 3 | 12 | 8.5 ± 8 | 8–19.2 | 0.3–1.7 | 4.5–20 | C/P |
| LA | Lepa River (T) | Cr | 829 | 4 | 20 | 2.7 ± 3 | 17–40 | 0.2–1.2 | 5–20 | B/C |
| EM | Ch (MC) El Maitén | U | 702 | 4 | 100 | 51.7 ± 39 | 38–45 | 1.2–1.7 | 5–17 | C/P |
| FO | Ch (MC) Fofo Cahuel | Cr | 500 | 4 | 80 | 52.5 ± 24 | 36.6–45 | 1.1–2.1 | 8–21.4 | P/G |
| Le | Lepa River (T) Gualjaina | U | 518 | 5 | 100 | 32.4 ± 20 | 27.2–45 | 0.3–1.6 | 9–21 | P/G |
| LG | Gualjaina River (T) After Gualjaina | Cr | 476 | 6 | 50 | 30.5 ± 16 | 32.8–45 | 1–1.4 | 7–22.2 | P/G |
| PP | Ch (MC) Piedra Parada | Cr | 440 | 5 | 200 | 105 ± 65 | 45–53.7 | 0.9–1.2 | 7–21.4 | C/P |
| PB | Ch (MC) Paso Berwyn | Cr/A | 308 | 5 | 160 | 125 ± 56 | 23–45 | 0.5–1.6 | 6–21.4 | C/P/S |
| VA | Ch (MC) Los Altares | Cr/A | 243 | 6 | 200 | 117 ± 58 | 30–45 | 0.8–1.2 | 7–21.6 | P/G/S |
| LP | Ch (MC) Las Plumas | U | 158 | 6 | 300 | 215 ± 23 | 19.6–45 | 1.7–1.9 | 7–20.7 | B/C |
| DA | Ch (MC) D. F. Ameghino | R | 74 | 6 | 70 | 64 ± 5 | 45–60 | 0.7–0.9 | 8–15.5 | C/P |
| D | Ch (MC) 28 de Julio | R-U | 32 | 6 | 40 | 35 ± 4 | 46.7–60 | 0.9–1.4 | 8–18.1 | cG |
| EE | Ch (MC) Estuario | U | 4 | 6 | 160 | 151 ± 2 | 33–60 | 0.8–1.1 | 9–21.1 | fG/S |

(66.2% of total variation). The PC1 (39.6% of total) consisted in water chemical variables and physical attributes of the sites (i.e., high positive loadings by conductivity, SRP, TSS, and $NO_3$; negative loading by elevation) and PC2 (13.3% of total) consisted mostly of physical variables (i.e., high negative loadings by elevation and river wet width).

Conductivity in the middle basin increased from 99.2 to 189.5 $\mu S\ cm^{-1}$ from FO to LP, and reached 1528 $\mu S\ cm^{-1}$ at EE, at this site consistent with the ocean proximity. The TSS values were higher at PB, VA, LP, and EE than the rest of the sites. However, an increase in TSS values was observed on the Chubut main channel sites, starting at FO, near to the point where Fita-Michi River connects from the North. Parent rocks at this section (Collon Cura Formation) are dominated by tuffs, which are friable material. These particular rocks in contact with the water can easily produce clay sediments. The highest mean values of $NH_4$ and $NO_3$ were observed at EE, which probably reflected the important industrial and urban development in the area (Table 2). Several post-impoundment changes in the environmental parameters were observed when comparing mean values on LP (non-regulated) with DA (regulated); $NO_3$, SRP and Chl *a* increased, while $NH_4$, TP, and TSS decreased (Table 2).

### *Stonefly distribution and seasonal patterns*

Nine Plecoptera species were collected but just four of them were frequent and abundant along the system. Plecoptera species decreased from the upper basin to the lower basin sites. Regarding to the relative abundance of the species, *Notoperlopsis femina* was dominant at AM, LA, Le, LG. *Limnoperla jaffueli* peaked at EM, while *Potamoperla myrmidon* predominated at FO, and in all the study sites from PP to D. Mean total stoneflies density ranged from 0 ind $m^{-2}$ (EE) to 297 ind $m^{-2}$ (FO), and they were practically absent below the impoundment (DA) (Table 3).

Most of the species were very abundant in February, *N femina* and *Antarctoperla michaelseni* abundances were higher in summer than in the rest of the seasons, while *L. jaffueli* peaked in spring, being also recorded in December (Fig. 3).

### *Environmental relationships*

The CCA ordination showed a strong relationship between Plecoptera species distribution and the measured environmental variables. The environmental variables selected in the analysis are represented in the figure by arrows, which point in the direction of maximum change in the value of the associated variable (Fig. 4). The species–environmental correlation were: 0.87, 0.86 and 0.62 for the first, second, and third axis, respectively (Table 4), suggesting a close relationship between the environmental variables selected. The Monte Carlo test of significance of canonical axes (to judge the significance of that relation) produced significant values for all the axes (Table 4). The strongest explanatory factors were physico-chemical variables, but only 37.2% of variation in the species data was accounted for by the environmental variables measured (Table 4). The main environmental gradient (axis 1) was determined by conductivity, Chl *a* biomass, and total suspended solids. The triplot displayed in Fig. 4 highlights the existence of a hydro-geological and land use gradient along CCA axis 1. Thus conductivity, total suspended solids were negatively related, and Chl *a* was positively related with the first axis. Samples on the upper and lower left quadrant were from sites with less diluted waters and higher total suspended solids contents, whereas samples on the upper and lower right quadrants were from sites with more diluted waters, minor suspended solids contents but more Chl *a* biomass.

The second axis showed an environmental gradient associated mainly with factors that changed seasonally, as shown by strong correlations with wet width, water temperature, and also with the soluble reactive phosphate concentration.

The triplot illustrates the position of the stoneflies species along the same gradients. *L. jaffueli*, which peaked on September at EM, FO, was positioned on the lower right quadrant, those sites showed high values of Chl *a* at that month. *P. myrmidon*, was placed on the lower left quadrant, the species peaked in FO, PP, LP, PB (middle basin sites) in February, coincident with higher

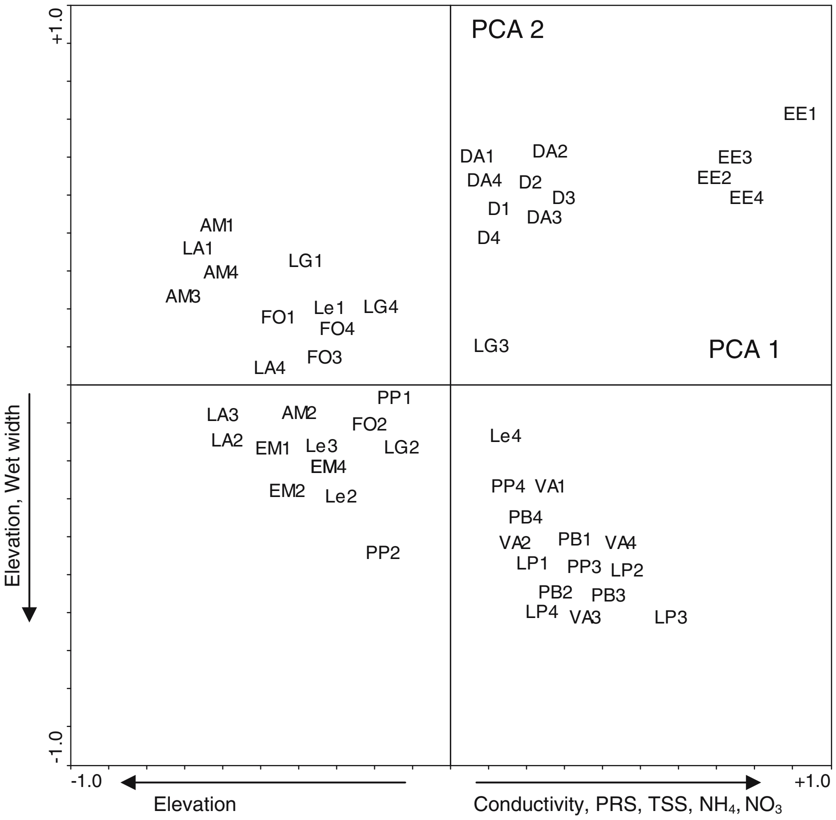

*Figure 2.* Ordination of sites according to PCA on the environmental variables measured at 13 sites on the Chubut River basin during 2004. February (1), May (2), September (3), and December (4).

*Table 2.* Range of chemical and biological variables measured on the upper (AM, LA, EM, FO, Le, LG, PP), middle (PB, VA, LP), and lower (DA, D, EE) basin sites of the Chubut River, Patagonia, Argentina. Data correspond to four sampling dates (February, May, September, and December 2004)

| | Range | | |
|---|---|---|---|
| | Upper | Middle | Lower |
| pH | 7.1–8.3 | 7.3–8.2 | 7.3–8.1 |
| Conductivity ($\mu$S cm$^{-1}$) | 42–308 | 141–275 | 177–2,960 |
| Total alkalinity (meq l$^{-1}$) | 0.11–3.39 | 1.45–2.05 | 1.52–1.94 |
| Total Nitrogen ($\mu$g l$^{-1}$) | 13.6–387.8 | 154.5–511 | 150.1–695.9 |
| Nitrate plus nitrate–nitrogen ($\mu$g l$^{-1}$) | 6.9–81.2 | 8.5–23.2 | 7.3–229.4 |
| Ammonia ($\mu$g l$^{-1}$) | 1.9–42.8 | 9–72.6 | 3.3–176.3 |
| Total phosphorus ($\mu$g l$^{-1}$) | 6.5–44.1 | 42.5–126.2 | 28.7–94.1 |
| Phosphate Reactive Soluble ($\mu$g l$^{-1}$) | 3.1–11.6 | 3–22.1 | 8.3–43.8 |
| Chlorophyll *a* (mg m$^{-2}$) | 0.01–8.5 | 0.7–5.45 | 1.3–17.59 |
| Total suspended solids (mg l$^{-1}$) | 0.2–27.8 | 20.9–171.1 | 2.1–55.3 |

temperatures and TSS values. *A. michaelseni* and *N. femina* were species more characteristics from upper sites on the Chubut river and tributaries (AM, EM, LA, and Le). They appear mostly in May; both species were placed on the upper right quadrant in the triplot.

## Discussion

The results suggested that stonefly communities in the basin, which were highly influenced by hydrogeological features, were less affected by the impoundment. Although, a strong reduction in stonefly density was noticed at DA, species richness values remained similar to those above the reservoir. Natural factors such as geology and agricultural land use in the arid area resulted in high TSS and TP values in the Chubut middle basin. The SRP values were higher in the lower basin in concurrence with a more urbanized and developed area. In spite of the high total phosphorous concentration in the middle basin, periphyton Chl *a* was not consistent with TP concentration ($r_{\mathrm{TP}} = 0.24$, ns), mean values of this nutrient showed a high correlation with TSS

*Table 3.* Relative abundance (%), total species richness and mean density ($n = 12$) of stonefly species along the Chubut river during the study (2004)

| | AM | LA | EM | FO | Le | LG | PP | PB | VA | LP | DA | D | EE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Austroperlidae | | | | | | | | | | | | | |
| *Klapopteryx kuscheli* Illies | 0.5 | | | | | | | | | | | | |
| Gripopterygidae | | | | | | | | | | | | | |
| *Notoperla* sp. | 1 | 18.7 | | | | | | | | | | | |
| *Notoperlopsis femina* Illies | 43 | 42.7 | 20.2 | 3.6 | 50.1 | 56.7 | 7.7 | | | | | | |
| *Antarctoperla michaelseni* Klapálek | 36.5 | 17.7 | 1.6 | 3.8 | 30.3 | 13.3 | | | | 0.8 | | 26.8 | |
| *Limnoperla jaffueli* Navás | 4.9 | 8.6 | 67.1 | 6.7 | 1.8 | 0.6 | | | 9.1 | | | | |
| *Potamoperla myrmidon* Illies | 8.3 | 2.8 | 0.8 | 85.6 | 17.7 | 29.3 | 92.3 | 100 | 90.9 | 99.2 | 100 | 73.2 | |
| *Chilenoperla semitincta* Illies | | | 0.2 | | | | | | | | | | |
| *Aubertoperla illiesi* Froehlich | 5.6 | 9.2 | 10 | | | | | | | | | | |
| Perlidae | | | | | | | | | | | | | |
| *Kempnyella genualis* Navás | | | 0.2 | 0.1 | | | | | | | | | |
| Plecoptera richness | 7 | 6 | 7 | 5 | 4 | 4 | 2 | 1 | 2 | 2 | 1 | 2 | 0 |
| Mean Plecoptera abundance (ind m$^{-2}$) | 136 | 36 | 163 | 297 | 252 | 238 | 241 | 131 | 135 | 232 | 1 | 62 | 0 |

($r_{TSS} = 0.80$; $p < 0.001$) suggesting that much of the phosphorous at this section was bound to suspended material. Additionally, it is probable that an increase in TSS at the middle section dramatically limited the transparency. However, significant correlations among mean values of Chl *a* and other nutrients were obtained ($r_{NO3–NO2} = 0.78$; $r_{NH4} = 0.63$, $r_{TN} = 0.57$, and $r_{SRP} = 0.63$ $p < 0.001$; $n = 13$), and in a multiple regression model inorganic dissolved nitrogen and SRP explained 80% of primary production. The decrease in suspended solids and TP downstream of the reservoir is in

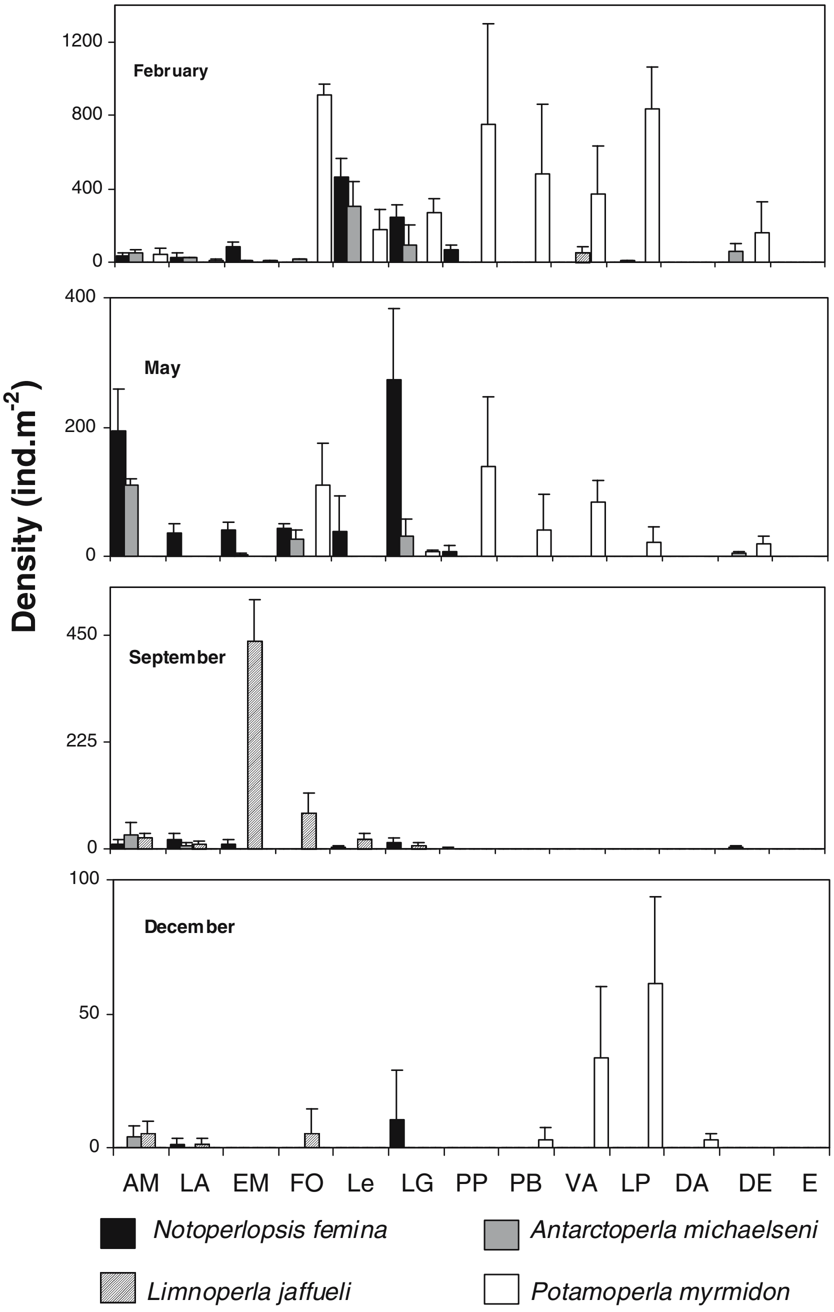

*Figure 3.* Seasonal density (ind m$^{-2}$) ± SD of the most important species of Plecoptera along the Chubut River and tributaries ($n = 3$).

agreement with one of the most common effects of impoundments (Ward & Stanford, 1982), which is the increase in Chl *a* as a consequence of higher water transparency (Ward & Stanford, 1990). Species that seem to take advantage of a high periphyton production were *L. jaffueli* and *A. illiesi*, as shown in Fig. 4. Both gripopterygids are herbivorous detritivores (Miserendino, 2000).

The serial discontinuity concept predicts that reservoirs placed in lower reaches of river systems could increase the biotic diversity (Ward & Stanford, 1982). Florentino Ameghino Dam did not affect much the stonefly richness even though density was at least locally reduced. The annual thermal range can be strongly diminished below impoundments in middle and lower reaches, and stoneflies seem to be very sensitive to thermal changes after river regulation (Miserendino & Stanford, 2004). DA had the lowest temperature comparing maximum water temperature among sites (Table 1). With the exception of *P. myrmidon*, it is possible that discharge fluctuation and lower water temperatures by hypolimnetic releases negatively affected the establishment of other stonefly species populations at DA. An interesting fact is that in February *A. michaelseni* was recorded above the reservoir at LP, then was absent at DA, and reappeared at D. Although the riparian corridor was similar and quite dense at both DA and D sites, maximum water temperature at D was 3 °C higher than at DA suggesting that this condition probably favored this species. Voelz & Ward (1990) reported gradients in faunal composition due to additions of invertebrate species downstream hypolimnetic release dams, reflecting changes in water temperature and food resources.

Stoneflies were completely absent from PB to LP in September. On the previous month, strong and continuous rains resulted in a historical record of discharge of the Chubut River (the highest of

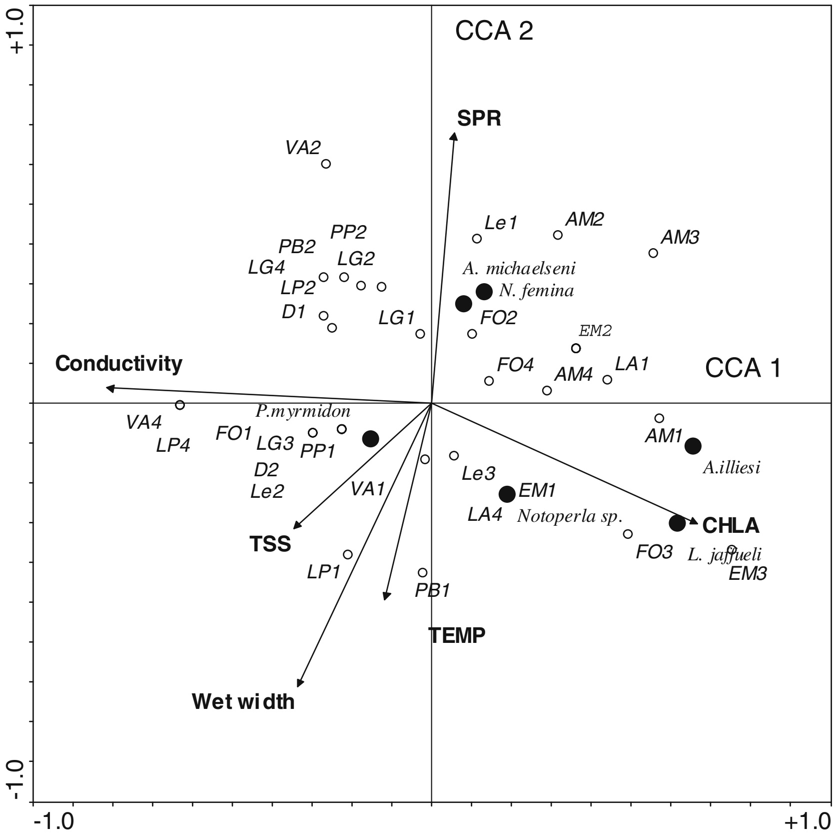

*Figure 4.* The CCA ordination diagram of sites, species and environmental variables. Full environmental variables and sampling sites names are in Tables 1 and 4. Filled circles indicate species, empty circles indicate sites.

*Table 4*. Intraset correlation of environmental variables with the axes of CCA of Plecoptera species data in the Chubut river basin, Patagonia, Argentina. Codes for environmental variables in parenthesis

| Variable | Axis 1 | Axis 2 | Axis 3 |
|---|---|---|---|
| Conductivity | −0.71 | 0.03 | 0.12 |
| Total suspended solids (TSS) | −0.30 | −0.24 | 0.02 |
| Phosphate reactive soluble (SRP) | 0.05 | 0.51 | 0.34 |
| Chlorophyll a (CHLA) | 0.58 | −0.22 | 0.27 |
| Wet Width | −0.29 | −0.54 | −0.11 |
| Water temperature (TEMP) | −0.10 | −0.37 | 0.40 |
| Eigenvalues | 0.629 | 0.390 | 0.042 |
| Species-environment correlation | 0.87 | 0.86 | 0.62 |
| Cumulative percentage variance of species data | 23 | 37.2 | 38.7 |

$p$-values for Monte-Carlo Permutation testAxis1: $F=8.045$, $p< 0.03$.All canonical axes: $F=2.87$, $p< 0.009$.

the last 50 years), with the middle basin being the most affected by the flooding. This unusual expansion of the river on the floodplain dramatically increased TSS, TP, and SRP values, but also resulted in severe erosion and sedimentation reducing habitat availability. Stream invertebrates are adapted to strong currents, but few can persist under conditions of extreme and unpredictable flow fluctuation (Borchard & Statzner, 1990). Few months after the flooding, channel cleanup and dredging was carried out in some affected towns. In fact, our sampling of December was coincident with the dredging actions at Le (Gualjaina City). At that month, stoneflies were present at LA and LG, but absent at Le. Probably the local elimination of Plecoptera species was related with substrate removal during dredging.

In this study, altitude, stream order, substrate size, and topographic variables were not selected as major variables structuring stoneflies distribution. This is partially consistent with a previous study achieved in a river system in the cordillera in which best predictors of Plecoptera assemblages were variables related to river size (stream order, substrate size) and those associated with urban impacts (biochemical oxygen demand, conductivity and pH) (Miserendino, 2000). In the Chubut river system stonefly assemblages could be partly predicted by river size related variables (wet width), but land use variables (conductivity, nutrients level, TSS) also showed strong and significant correlations. Chl *a* was also selected in our CCA analysis indicating the important role of periphyton as food resource for Plecoptera in the system. In a study of 56 Swedish streams and rivers Malmqvist (1999) concluded that stonefly predatory species increased with river size, and non-predatory species increased with pH, distance from upstream lakes, but were negatively affected by sandy and silty substrates.

Catchment land uses and riparian vegetation play a strong role in structuring habitat features which in turn influence composition of invertebrate communities (Roth et al., 1996). Even though we ignore which was the situation of the middle Chubut basin prior to colonization, there is strong evidence that for more than a century overgrazing, wood cutting and inappropriate land uses on the arid area resulted in a severe land degradation process and loss of vegetation cover (del Valle et al., 1995). For example sites PB, VA, and LP are situated on the most degraded areas (very severe desertification status) compared to EM and FO sites (lightly to moderate desertification status) in the Chubut province (del Valle et al., 1998). The decrease in stonefly richness along the longitudinal river gradient could possibly correspond to natural causes, but this pattern was also consistent with an increase in TSS and nutrient contents and habitat impoverishment at the middle basin. Of all the recorded species, the small sized *P. myrmidon* seems to be the most ubiquitous and tolerant, existing in a wide range of ecological conditions. Seven Plecoptera species co-occurred at EM, at this site most nutrient concentrations were relatively low indicating good water conditions. Moreover, food availability was large from both terrestrial (riparian forest) and autochthonous sources as was shown by important values of Chl *a*. In medium sized rivers, retention of riparian forest can act improving instream habitats by buffering nutrient inputs, supplying allochthonous organic matter, and providing habitat for the terrestrial adult stages of insects with stream-dwelling larvae (Wiberg-Larsen et al., 2000).

Except for the sites below the dam, macrophytes were absent at most studied sites. According to the River Continuum Concept as the stream width/shoreline ratio increases from headwaters to the mouth, shading from riparian canopy declines enabling aquatic macrophytes to develop (Vannote et al., 1980). Again, total suspended solids strongly diminished transparency avoiding aquatic plant colonization on the river bottom at most reaches in the main channel.

The results of this paper are in agreement with a previous study carried out in the Chubut lower basin in which the authors concluded that there is a longitudinal gradient of eutrophication as revealed by physicochemical features and phytoplankton composition (Sastre et al., 1997). In some sectors of Europe stoneflies are being completely exterminated in potamal sections by gradual habitat fragmentation, pollution, and loss of biotopes after reservoir constructions (Landa et al., 1997; Küry, 1997). As a consequence of the increase in human development in the Patagonian provinces, there is a high demand of electrical power. There are plans to construct three new hydroelectric dams in Patagonia. This study shows a number of complex relationships between Plecoptera and the environmental variables along the Chubut River, and could be considered for management purposes in the future.

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