Geomorphological and Seasonal Effects on Macroinvertebrate Populations in Chilean Southern Patagonia

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Directed Research

8 December 2022

Abstract

We studied the effects of geomorphology and seasonality on macroinvertebrate species richness in 17 rivers within the Ultima Esperanza Province of southern Patagonia. We compared collected counts of macroinvertebrate morphospecies from both fast and slow-moving water sites with riverbed substrate size, percent vegetation, discharge, and seasonality. Using an OLS model, our findings indicate that geomorphology has a significant effect on species richness, however, different geomorphic variables impact the species richness of slow water sites, fast water sites, and all sites combined. Furthermore, seasonality proved to have the most significant effect on species richness across sites. Future investigations would benefit from expanding the seasonality model as well as the sample size.

Introduction

The health and function of a riparian ecosystem is directly tied to its macroinvertebrate community structure (Elgueta, 2020). Macroinvertebrates are excellent indicators of stream health, as they are highly sensitive to environmental changes such as temperature, pollution, vegetation, and substrate type (Fierro et al., 2015; Wallace, 1996).

Here, we focus on the riverbed substrate size and material and its impact on macroinvertebrate species richness. Substrate type impacts the ability of organic matter, such as vegetation, to grow and thus the ability of macroinvertebrates to establish a sustainable colony (Rempel et al., 2000). Substrate size further affects substrate stability and microtopography, which in turn impacts macroinvertebrate ability to move, find shelter, and locate food (Rice et al., 2001). Previous research has shown that higher substrate roughness retains higher amounts of organic matter and thus creates microhabitats suitable to host macroinvertebrate communities (Rempel et al., 2000).

Riverbed substrate material also functions as a proxy for multiple variables affecting river health. Substrate material is linked with land-uses that alter flow regime, creating seasons of extremely high and extremely low flow and can result in lower macroinvertebrate abundances in highly anthropogenic zones (Fierro et al., 2015). Furthermore, substrate size and material can help inform us on the water source of the river – glacial, lake, precipitation – as well as how far the particular site is from its water source.

By looking at substrate size and composition of multiple riparian ecosystems, we aim to better determine its effects on macroinvertebrate biodiversity and overall riparian health. In this paper, we investigate the effects of riparian geomorphology on macroinvertebrate species richness in riparian ecosystems. We hypothesize that riverbed substrate size and composition significantly impact species richness of macroinvertebrates in riparian ecosystems.

Methods

Macroinvertebrate sampling

Ten sites from seven separate streams were chosen from the Ultima Esperanza Province in southern Chile (*Table 1, Figure 1*). When possible, each stream site was separated into three fast water and three slow water subsites. If the stream site only exhibited slow moving water, four total subsites were chosen. At each subsite, the kick net method was used for one thirty second increment. Macroinvertebrates were removed from the net and placed in jars of 70% isopropyl alcohol according to site and water speed.

Streambed sediment sampling

At each site, the streambed substrates were categorized into five types based on size: boulder, cobble, pebble, sand, and silt (*Table 2*), as well as presence of vegetation. The streambeds were surveyed by the percent coverage of each type of substrate. Length and width of up to 40 boulders, cobbles, and pebbles were measured to determine an average size of each at each site.

Macroinvertebrate analysis

Macroinvertebrate samples were categorized at the site and subsite level by morphospecies. The species richness, species abundance, and Shannon's Index of species diversity were calculated at each site and subsite.

Streambed sediment analysis

For each site, the surface area of each sediment sample was calculated, and those values were averaged by sediment type present at each site. These averages were transformed on a log_{10} scale to normalize the data and were multiplied by the percent of the site occupied by that substrate to determine a fixed amount of streambed area covered by each substrate.

GIS sourced supplementary data

Average air temperature data was collected from *WorldClim* for each site (Fick & Hijmans, 2017). Discharge, upland area, and river order data was collected from *HydroRIVERS* for each river (Lehner & Grill, 2013).

Statistical Analysis

Field data collected this semester was supplemented with data collected from the previous semester. Variables were transformed on a log_{10} scale to normalize data when necessary. A stepwise comparison was used to determine significance of the effects of the aforementioned variables on species richness, species abundance, and Shannon's Index of species diversity.

Results

In fast water subsites, seasonality, percent vegetation cover, and cobble coverage of streambed proved to be significant with *p* values of 0.000, 0.054, and 0.006 respectively (*Table 3*). This model yielded a strong positive correlation with species richness, with an adjusted R^2 of 0.805 (*Table 4*). In slow water subsites, seasonality proved to be significant with a *p* value of 0.013 (*Table 3*). This model yielded a positive correlation with species richness, with an R^2 of 0.248 (*Table 4*). When all subsites were combined, seasonality, cobble coverage of streambed, and boulder coverage of streambed proved to be significant with *p* values of 0.001, 0.129, and 0.140 respectively (*Table 3*). This model yielded a strong positive correlation with species richness, with an adjusted R^2 of 0.501 (*Table 4*).

Discussion

Fast Water Model

In the fast water model, we see a significant strong positive correlation between macroinvertebrate species richness and seasonality, percent vegetation cover, and cobble cover of streambed. Seasonality can be explained by excess leaf litter in the autumn months resulting in the growth of shredders with adult emergence in late spring causing a decline in species richness (Cowan & Oswood, 1984). Previous research has shown that larger and rougher substrates, such as cobbles, can retain more organic matter, which creates ideal microhabitats for macroinvertebrate communities (Rempel et al., 2000). This build-up of organic matter also creates an environment in which vegetation can grow, adding to overall organic matter. These microhabitats, created by rough substrate and vegetation, also work to reduce hydraulic stress, allowing for the development of stable macroinvertebrate communities (Rempel et al., 2000), likely with higher levels of species richness. In addition, many macroinvertebrate species that are found in boulder and cobble substrates can also be found in smaller substrates; but have greater success in community formation when the streambed substrate is larger and more stable when exposed to changes in hydrological flow (Rice et al., 2001). This can explain the significant positive correlation between cobble coverage and species richness, as well as the lack of statistical significance in pebble coverage.

Slow Water Model

In the slow water model, we observe a statistically significant positive correlation between seasonality and species richness, and no other significant variables. The aforementioned impact of seasonality and leaf litter seen in fast flowing sites also applies to the slow model. In addition, slow moving sites are more likely to retain fallen leaves than fast moving sites, meaning there is a potential for an increase in organic matter in these sites (Cowan & Oswood, 1984). Furthermore, as with the fast water model, larger and rougher substrate positively correlates with species richness, due to its ability to provide shelter from changes in discharge (Rempel et al., 2000). It is reasonable to conclude that in slower moving sites, there is less of a necessity for refuge from sudden fast-moving water, and thus the type of substrate is less significant than other factors.

Combined Model

In the combined model, we observe a statistically significant strong positive correlation between species richness and seasonality, streambed cobble and boulder coverage. Many of the previously stated explanations for these correlations can also be applied to this model. In addition, substrate heterogeneity is an important factor in increasing species diversity (Duan et al., 2009; Rempel et al., 2000; Rice et al., 2001). This can explain the significance of both cobble and boulder coverage, as the range in size between the two sediment categories creates a heterogeneous environment (Table 2). While it may not have been deemed significant in the combined model, the heterogeneous substrate materials allows for a wider range of vegetation and thus an increase in organic materials which, as mentioned above, has a direct impact on the development of diverse macroinvertebrate communities (Rempel et al., 2000).

Discharge

Throughout all models, we noticed a lack of effect of discharge on species richness. This is contrary to previous research which has concluded that discharge is one of the most important factors determining macroinvertebrate community structure (Blaen et al., 2013; Rempel et al., 2000). Based on our findings, the exact reason for the statistical insignificance of discharge is still unknown, but there are potential explanations surrounding the region of study. Potential species richness of the study sites is relatively low, and thus is likely impacted less by discharge than by other environmental factors. Furthermore, we examined annual discharge as opposed to seasonal discharge. Given the impact of seasonality on biodiversity, it is worth investigating discharge as a seasonal variable in future.

Limitations

Our data, analysis, results, and interpretations are limited by the relatively small sample size, with only 17 fast sites, and 21 slow sites representing a total 14 different rivers. Standardization of data collection may have also created differences in the data, given differences in environmental factors and the collectors between collection seasons. A lack of standardization between semesters in identifying morphospecies may also have affected data collection.

Conclusion

Our findings partially supported our hypothesis that streambed sediment size has an effect on macroinvertebrate species richness. Both the fast water and combined models supported our hypothesis. The fast water model found a correlation between cobble streambed cover and macroinvertebrate species richness, while the combined model found a correlation between boulder streambed cover and macroinvertebrate species richness. In addition, both models found a correlation between vegetation cover and species richness, which is directly related to substrate size and type. Our hypothesis was not supported by slow water sites, as it did not show significant correlation between any sediment size and species diversity. Our hypothesis did not account for the variable of seasonality, which proved to be significant in all three models.

As mentioned, streambed sediment size serves as a proxy variable for multiple other variables, including anthropogenic land-use and flow regime. By looking at the results from our investigation, we can extrapolate that both land-use and flow regime impact macroinvertebrate species richness, which is a strong indication of riparian ecosystem health. Furthering this project, we would aim to develop a more clear link between land-use and sediment type to better understand this extrapolation.

Further investigations in this topic should include continuing to collect seasonality data, as we were working from one set of autumnal data and one set of spring data. In addition, continuing to track the lack of effect of discharge on species richness will provide further explanation for this trend. Finally, increasing the range of sites will help create a map of riparian species richness in the Ultima Esperanza Province that can be used to make conclusions of the larger implications of geomorphology in these ecosystems.

Figures

Table 1

Sample site descriptions

Site Code	Month Sampled	Name	Latitude	Longitude
F1	04-2022	Arroyo Picana	-51.35619	-72.43239
F2	04-2022	Río Tres Pasos	-51.44814	-72.48733
F3	04-2022	Río Ascencio Glacial Tributary	-50.95294	-72.92281
F4	04-2022	Río Ascencio Tributary	-50.95589	-72.91222
F5	04-2022	Río Ascencio	-50.957	-72.91192
F6	04-2022	Río Ascencio	-50.97667	-72.88253
F7	04-2022	Río Nutria	-51.24894	-73.01175
F8	04-2022	Río Ventisquero	-51.40964	-72.79472
F9	04-2022	Río Prat	-51.50522	-72.69808
F10	04-2022	Río Hollenberg	-51.907	-72.44667
F11	04-2022	Río Tranquílo	-51.81678	-72.16147
S1	11-2022	Pingo Salvaje 1	-51.530043	-72.594675
S2	11-2022	Pingo Salvaje 2	-51.534448	-72.599985
S3	11-2022	Pingo Salvaje 3	-51.53851	-72.596933
S4	11-2022	Río Rincon	-51.315165	-72.831017
S5	11-2022	Río Nutria 1	-51.245561	-73.014301
S6	11-2022	Río Nutria 2	-51.24929	-73.01077
S7	11-2022	Río Ventisquero	-51.407525	-72.79105
S8	11-2022	Laguna Sofia Outlet	-51.505254	-72.698267
S9	11-2022	Río Primero	-52.204967	-72.465984
S10	11-2022	Cypress Peatland Runoff	-52.18383	-72.50446

Table 2

Sediment classification

Diameter (cm)	Size
<20	Boulder
<6.5-20	Cobble
0.1-6.5	Pebble
0.001-0.1	Sand
0.00039-0.001	Silt
>0.00039	Clay

Figure 1
Sample site locations

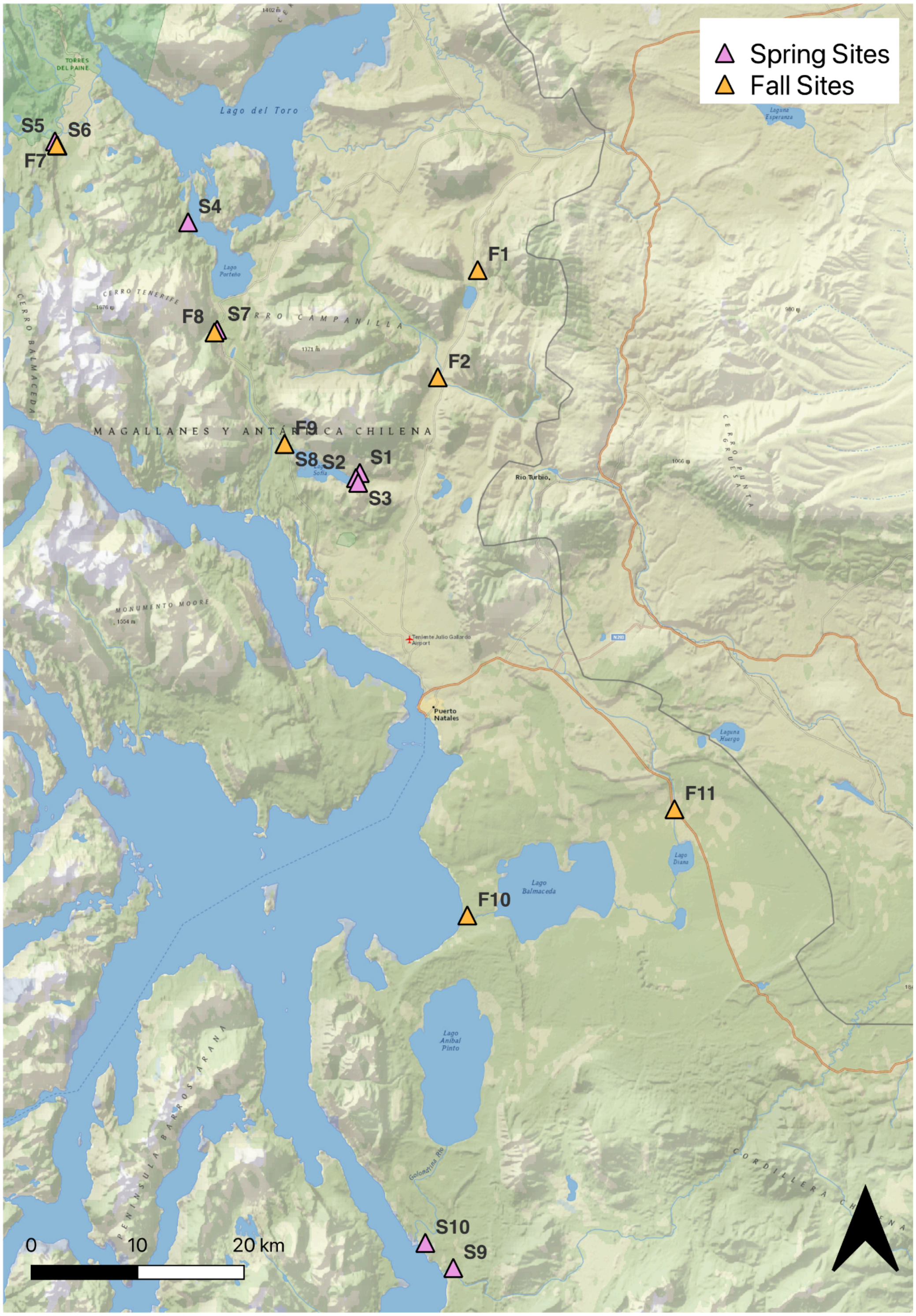

Table 3

Results from OLS Models Predicting Species Richness

Significant Variables	**p-value**		
	Fast	**Slow**	**Total**
Seasonality	0.000	0.013	0.001
Percent Vegetation Cover	0.054	*not significant*	0.129
Cobble Streambed Cover	0.006	*not significant*	*not significant*
Boulder Streambed Cover	*not significant*	*not significant*	0.140
Observations	17	21	21
Adjusted R²	0.805	0.248	0.501

Table 4

Parameter Estimates from OLS Models Predicting Species Richness

Significant Variables	**Beta (St. error)**		
	Fast	**Slow**	**Total**
Seasonality	0.359*** (0.055)	0.269** (0.098)	0.418*** (0.102)
Percent Vegetation Cover	0.003* (0.001)		
Cobble Streambed Cover	0.187*** (0.056)		0.669 (0.416)
Boulder Streambed Cover			-0.468 (0.300)
R	0.920	0.534	0.764
Adjusted R²	0.805	0.248	0.501
F Statistic	20.311	7.586	7.014
p value	0.0001	0.0126	0.0036
AIC	-19.6572	0.6175	-7.2175
AIC Min	-19.6572	0.6175	-7.2175

Note: *p<0.1, **p<0.05, ***p<0.001

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