Fluvial Bryophytes of Mediterranean Europe:

exploring the connection between core species, climatic regions and ecological determinants

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Introduction

Fluvial networks are structured across a spatial hierarchy of environmental factors, where variables acting at higher spatial scales, such as climate and geological setting, are major species occurrence ecological determinants interacting with lower spatial scale factors such as discharge and water quality or geomorphologic structure. Rivers in Mediterranean-climate regions are characterized by extremely variable annual and interannual discharge regimes, presenting seasonal and predictable floods and droughts to which faunal and floral species have adapted through their evolutionary processes. Therefore, it is assumed that fluvial communities composition between Mediterranean lotic systems may exhibit great similarity. Nevertheless, this idea has never been tested for bryophyte's communities in the Mediterranean Europe since the assessment of compositional differences between communities from different fluvial regions should be achieved using biologic and environmental field data from standardized surveys, and, until the beginning of the XXI century, this dataset was not available for bryophytic composition. Therefore, we aimed to explore the compositional segregation of bryophyte communities across three Mediterranean regions using biologic and environmental field data from standardized pan-European surveys available after the implementation and intercalibration processes of the EU Water Framework Directive.

Methods and results

Patterns of bryophyte assemblages

I. First, we used floristic data collected for intercalibration purposes under the European Union Water Framework Directive and data from River Habitat Survey of 474 Mediterranean stream sites in Mediterranean Europe Climatic Areas, namely: (i) 99 sites from Mediterranean South, (ii) 246 sites from Mediterranean North, and (iii) 129 sites from Mediterranean Mountains (fig. 1 and fig. 2). In order to compare bryophyte assemblages between Mediterranean climatic regions and identify indicator (core) taxa we performed: a Two-way Indicator Species Analysis (**TWINSPAN** classification; CAP 3.1), a One-way Analysis of Similarity (**ANOSIM**) between groups obtained in the TWINSPAN classification, and a Similarity Percentage Analyses (**SIMPER**; PRIMER 6).

Figure 2. Typical aspect of Mediterranean riverscapes. Rivers in mediterranean climatic regions are physically, chemically, and biologically influenced by seasonally predictable flooding and drought events.

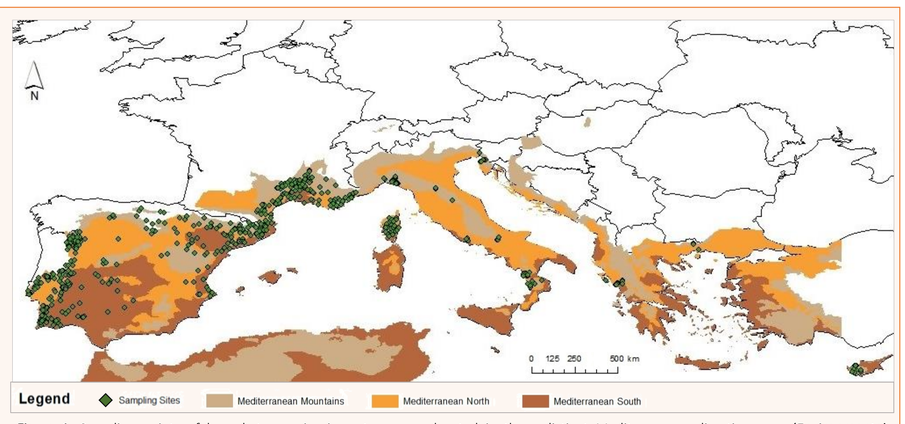


Figure 1. Sampling points of bryophyte species in watercourses located in three distinct Mediterranean climatic areas. (Environmental Stratification of Europe; Metzger et al. GEB 14: 549-563).

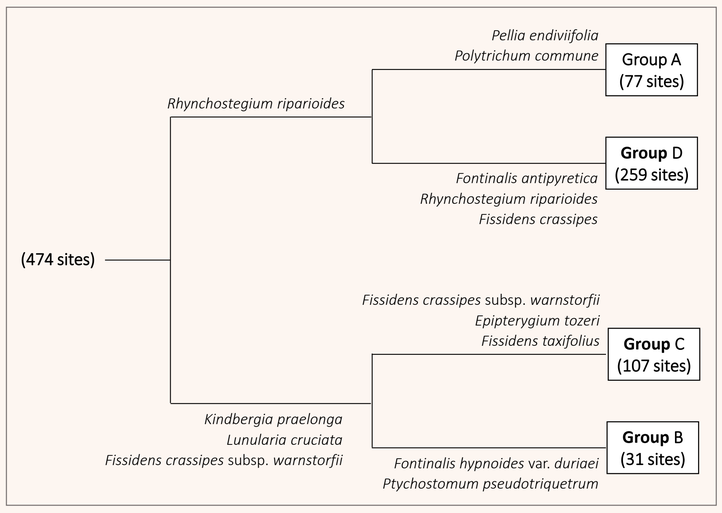


Figure 3. Summary dendrogram derived from TWINSPAN classification of the 474 sampling sites in the studied Mediterranean climatic areas. For each dichotomy, the bryophyte *taxa* used to divide the TWINSPAN groups are indicated.

TWINSPAN classification revealed four distinct groups after two divisions (fig. 3), which do not strictly separate sites according to climatic regions, indicating other underlying ecological compositional determinants.

Table 1. Pairwise ANOSIM tests of differences in bryophyte assemblages between TWINSPAN groups (Global R = 0.436, p < 0.001); * p < 0.001.

TWINSPAN groups	*R* Statistic
A - D	0.3*
A - B	0.541*
A - C	0.582*
D - B	0.506*
D - C	0.498*
B - C	0.221*

Results from both ANOSIM and SIMPER analysis (table 1 and 2) validated the groups created by TWINSPAN, as well as the indicator taxa of each group.

Table 2. Results of SIMPER analysis for bryophyte species composition of stream sites within each TWINSPAN group (A-D) (*Asim* = average similarity of sampling sites in the group; *Av.abund* = average abundance; *Co%* = percentage of the contribution of species for similarity of the group).

Group A (Asim: 20.95)			Group B (Asim: 28.94)		
Species	Av.abund	Co (%)	Species	Av.abund	Co (%)
Pellia endiviifolia	0.71	40.54	*Fontinalis hypnoides* var. *duriaei*	0.71	44.89
Polytrichum commune	0.44	15.91	*Lunularia cruciata*	0.55	21.78
Marchantia polymorpha	0.36	12.27	*Kindbergia praelonga*	0.42	12.46
Group C (Asim: 22.07)			**Group D (Asim: 21.05)**		
Species	Av.abund	Co (%)	Species	Av.abund	Co (%)
Kindbergia praelonga	0.58	31.96	*Rhynchostegium riparioides*	0.65	50.86
Lunularia cruciata	0.52	26.35	*Leptodictyum riparium*	0.37	15.74
Fissidens crassipes subsp. *warnstorfii*	0.44	18.33	*Fontinalis antipyretica*	0.31	9.49

Environmental factors

- **II.** To study the influence of enviromental factors on bryophyte assemblages we performed a canonical correspondence analysis (CCA; CANOCO 5) with forward selection of environmental variables to explore the influence of environmental factors on bryophyte assemblages.
- Each TWINSPAN group corresponds to a distinct community dominated by a different assemblage of bryophyte species, presenting different and recognizable ecological preferences.
- The CCA ordination supports the segregation of TWINSPAN groups and the heterogeneity of the climatic groups (Figure 4). The first axis reflects a climatic and stream water pH gradient, represented by bryophyte communities from more alkaline streams in drier conditions to those characterizing more acidic watercourses with greater rainfall. The second axis is mainly related with an altitudinal gradient (fig. 4).
- Bryophyte communities A and D are usually found in the climatic area corresponding to the Mediterranean Mountains (fig 5a), in watercourses with moderate alkalinity (fig 5b), while communities B and C are more commom in the Mediterranean North and South (fig 5a), in more acidic streams (Fig. 5b).

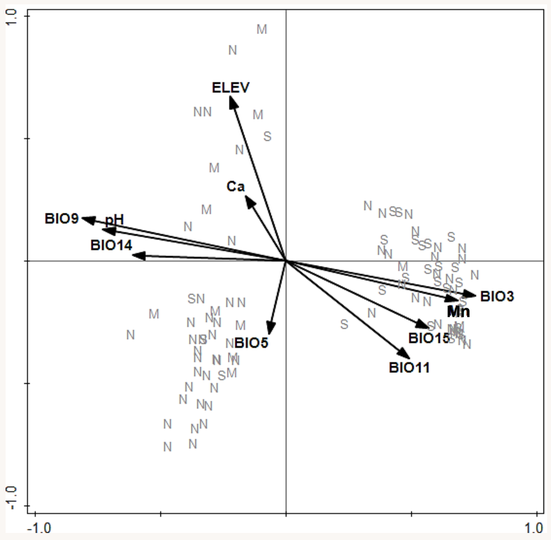


Figure 4. Canonical Correspondence Analysis (CCA) ordination plot representing the Mediterranean stream sites studied and environmental variables (**ELEV** – elevation; **Ca** – calcium concentration; **BIO9** - mean temperature of driest quarter; **BIO14** - precipitation of driest month; **BIO5** - max temperature of warmest month; **BIO11** - mean temperature of coldest quarter; **BIO 15** - precipitation seasonality; **Mn** – manganese concentration; **BIO3** - isothermality). Only the 10 most influential variables obtained through forward selection procedure are represented; **N- Mediterranean North sites; S: Mediterranean South sites; M: Mediterranean Mountainous sites (See Figure 1);**

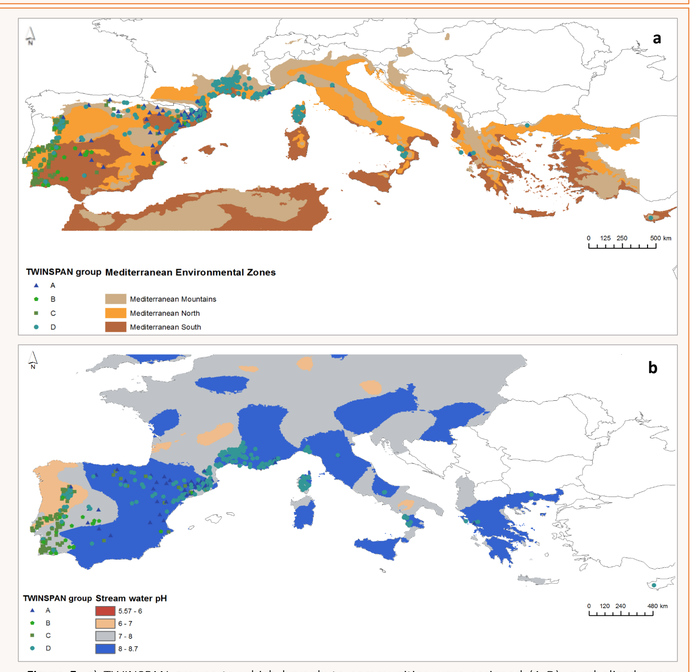


Figure 5. a) TWINSPAN groups to which bryophyte communities were assigned (A-D), symbolized over different mediterranean climatic areas (a) and stream water pH (b).

Community distribution modelling

III. To better understand the distribution of the TWINSPAN groups, we used a "assemble first, predict later" community level modelling approach. We used the site groups obtained in the TWINSPAN analysis and Species Distribution Modelling techniques to model the distribution of the main Mediterranean fluvial bryophyte assemblages found.

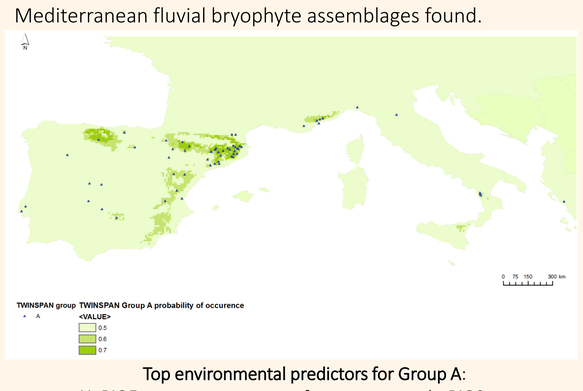
We modelled the distribution of the groups using biomod2 ensemble forecasting package in R environment.
The environmental predictors used in the modelling procedure were selected from the 10 most important variables influencing bryophyte assemblages identified in the CCA analysis.

We utilized the following **modelling algorithms**: Random Forest, Artificial Neural Networks Multiple Adaptive Regression Splines, MAXENT and Classification Tree Analysis.

Only models with an AUC evaluation score ≥ 0.7 were included in the ensemble forecast.

The ensemble predictions were obtained using the weighted mean of probabilities, which means that models with greater AUC scores had more importance in the ensemble.

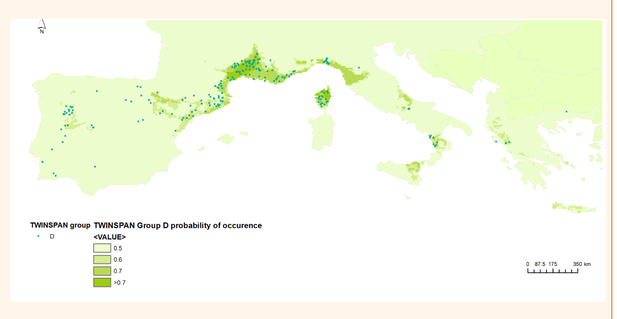
The maps shown correspond to modelled probability of occurrence of each group for Mediterranean Europe.



Top environmental predictors for Group A:
pH; **BIO5** - max temperature of warmest month; **BIO9** - mean temperature of driest quarter; **BIO 15** - precipitation seasonality; **Mn** – manganese concentration; **BIO14** - Precipitation of Driest Month.

Top environmental predictors for Group B:
BIO5 - max temperature of warmest month; **BIO11** - mean temperature of coldest quarter; **Mn** – manganese concentration; **Ca** – calcium concentration; **ELEV** – elevation.

Top environmental predictors for Group C:
BIO5 - max temperature of warmest month; **Ca** – calcium concentration; **Mn** – manganese concentration; **ELEV** – elevation; **BIO11** - mean temperature of coldest quarter.



Top environmental predictors for Group D:
BIO11 - mean temperature of coldest quarter; **BIO5** - max temperature of warmest month; **ELEV** – elevation; **BIO9** - mean temperature of driest quarter; **Ca** – calcium concentration.

Main conclusions

Bryophyte assemblages

- Bryophytic composition reveals that sites of different mediterranean climatic zones share hydrologic and geomorphologic features, creating niche for shared core taxa and other region-specific taxa responsible for each region singularity.

Environmental factors

- Even at spatial scales as big as the Mediterranean stream water chemistry, namely pH, plays a key role in shaping the distribution of fluvial bryophytes.
- The climate also shapes the distribution of these communities, in this case the key factor is the maximum temperature in the driest and/or warmest months.

Community distribution modelling

- The spatial distribution obtained for each community reflect the combined spatial patterns of water chemistry and climate.
- Low predicted probability of occurrence in sites with a recorded presence can be related with differential responses to environmental factors of the species that constitute each community.

Nigel Holmes, Poland in 2007 (photo by Paul Raven)

Acknowledgements:

***We dedicate this poster to Nigel Holmes, author and colleague and an authority on river plants and the biggest influence on river conservation and restoration in the UK. By demonstrating the importance of macrophytes as ecological indicators, he transformed the way that rivers were assessed both in Britain and across other parts of Europe. He will be sorely missed and fondly remembered by his many colleagues and friends for his inspiration, boundless energy, compassion, kindness, humour and youthful enthusiasm. He was in every sense a colossus who shaped modern-day river management.**

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