Relationship between Morphology and Terrestrial and Aquatic Invertebrate Assemblages:

A case study at the Bünz (CH)

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Contents

Index of Figures

Index of Tables

1 Summary

River channelization affects the biotic assemblages associated with a river. The biodiversity along channelized rivers has decreased because of a loss in habitat diversity. Further, the connection between the river and its riparian zone is disrupted by concrete training elements. This lateral connectivity is crucial because many energy transfers occur in this zone. Because of the growing awareness of the consequences of river degradation, restoration efforts have gained in importance over the last decades.

The aim of this study was to evaluate the relationship between different morphological parameters and the terrestrial and aquatic adult invertebrate assemblages along a river.
The Bünz, a small Swiss midland stream, was an excellent study system because it presents a broad range of sites in different morphological states. The river was almost completely channelized in the beginning of the last century and today many restoration projects have been completed or are in progress. Additionally, a floodplain that was naturally created by a large flood is also found on the river.

The morphological and biological differences between the sites could be shown and it became clear that the restored and near-natural sites are in a better morphological condition than the channelized section. Some correlations between morphology and biological parameters as well as the correlation between emerging aquatic insects and riparian predators were apparent. The results suggest that an improvement in morphology can have positive effects on invertebrate assemblages associated with a river. The good performance of the floodplain site indicates that nature is capable, if enough space and time is provided, to reestablish more natural conditions in regulated rivers. This approach could be a good supplement to usual river restorations and also help reduce costs.

1 Zusammenfassung

Die Kanalisation von Fliessgewässern beeinträchtigt die assoziierten biologischen Lebensgemeinschaften; mit dem Verlust von Habitatsdiversität nimmt die auch Biodiversität entlang von kanalisierten Flüssen ab. Zusätzlich schränken die lateralen Verbauungselemente die Konnektivität zwischen den aquatischen und terrestrischen Habitaten ein. Diese Verbindung ist jedoch äusserst wichtig, da natürlicherweise ein grosser Energieaustausch zwischen diesen Habitaten stattfindet. In den letzten Jahrzehnten rückten die ökologischen Konsequenzen solcher Flussverbauungen zunehmend ins Bewusstsein der Verantwortlichen und Flussrenaturierungen gewannen an Wichtigkeit.

Das Ziel dieser Studie war die Zusammenhänge zwischen der Morphologie und den aquatischen und terrestrischen Lebensgemeinschaften entlang eines Flusses zu zeigen. Die Bünz, ein kleiner Fluss im Schweizer Mittelland, präsentierte sich als ideales Studienobjekt, da hier ein breites Spektrum an morphologisch unterschiedlichen Abschnitten vorhanden ist. Zu Beginn des letzten Jahrhunderts wurde der Fluss beinahe komplett kanalisiert; in jüngster Zeit wurden verschiedene Renaturierungsprojekte durchgeführt, einige sind noch im Gange. Zusätzlich wurde im Jahre 1999 durch ein extremes Hochwasserereigniss eine Aue geschaffen.

Die morphologischen und biologischen Unterschiede zwischen den einzelnen Untersuchungsabschnitten konnten gezeigt werden; die natürlichen und renaturierten Stellen sind in einem deutlich besseren morphologischen Zustand als die kanalisierte Stelle. Korrelationen zeigten sich einerseits zwischen gewissen morphologischen und biologischen Parametern und andererseits zwischen der Dichte der emergierenden aquatischen Insekten und der Dichte der räuberischen Uferarthropoden. Diese Resultate weisen darauf hin, dass eine Verbesserung der Flussmorphologie vermutlich positive Effekte auf die Lebensgemeinschaften der Invertebraten nach sich zieht. Das gute Abschneiden des Untersuchungsabschnittes in der Aue führt zum Schluss, dass die Natur durchaus fähig ist, selbst wieder naturnahe Bedingungen herbeizuführen wenn genügend Zeit und Platz zur Verfügung gestellt werden. Dies könnte eine wertvolle Ergänzung zu gängigen Renaturierungsmethoden sein die hilft, Kosten zu reduzieren.

2 Introduction

Natural river corridors consist of diverse landscape elements and therefore provide a broad range of different habitats (Ward et al., 2002). This heterogeneity leads to high levels of biodiversity in riverine landscapes (Ward, 1998). Unfortunately, almost all river corridors in Europe were regulated before the science of river ecology was developed (Ward et al., 2001). We now know that alterations in river morphology can have widespread impacts to associated habitats (Paetzold et al., 2005). Channelization and stabilization of riverbanks affect the connection between the river and the riparian zone. The resulting disruption of these two habitats has severe impacts on aquatic and terrestrial biotic communities along the river.

In the last decades, society began addressing the ecological consequences from the degradation of many riverine ecosystems. Interest in stream restoration has increased and many projects have been or are being completed, and developed for the future (Lake et al., 2007). Additionally, public awareness of ecological processes occurring in rivers has increased, and responsible stakeholders are switching from solely engineering solutions to ecologically-based activities (Palmer et al., 2005). For example, the awareness of lateral connectivity has gained in importance and riparian zones are now integrated part of river ecosystems and thus considered in planning river restorations (Lake et al., 2007).

Following Naiman et al., (1993), natural riparian zones are among the most diverse and dynamic biophysical ecotonal habitats. They consist of a diverse mosaic of landforms and act as an interface between terrestrial and aquatic biotopes. Numerous aquatic-terrestrial interactions, including crucial energy flows, occur in this zone. Aquatic and terrestrial invertebrate communities along a river are interdependent and the change in abundance on one side can directly influence the other (Marczak and Richardson, 2007). Rivers and their riparian zones are closely linked by reciprocal flows of invertebrate prey (Baxter et al., 2005), and the largest part of the riparian fauna is predaceous (Hering and Plachter, 1997). Predation by riparian arthropods, e.g. ground-dwelling beetles on emerging insects, is an important pathway of energy transfer from aquatic to terrestrial foodwebs (Paetzold et al., 2005; Iwata, 2007). Reciprocally, the input of terrestrial arthropods, via in-fall and drift, transfers terrestrial energy to aquatic habitats, for example, as prey for fish (Allan et al., 2003).

In this study, terrestrial and aquatic adult invertebrate assemblages were investigated along a river with sites of different morphological condition. The aim of the study was, firstly, to show the morphological differences between natural, human-affected and restored sites. Further, terrestrial and aquatic adult invertebrate assemblages were examined at these sites and then relations between emergence, riparian predators and terrestrial inputs were identified, and correlations between morphological and biotic parameters tested.

The following hypotheses were tested:

I: The ecomorphological state will differ between the different sites. Sites affected by human activities will be in a worse morphological state than natural or restored sites.

II: Differences between sites and season will be apparent in the terrestrial and aquatic adult invertebrate assemblages.

III: There will be a relationship between the emergence of aquatic insects, riparian predators, and input of terrestrial invertebrates into the river at the different sites.

IV: Measured biotic parameters will correlate with the morphological characteristics of the different sites.

3 Material and Methods

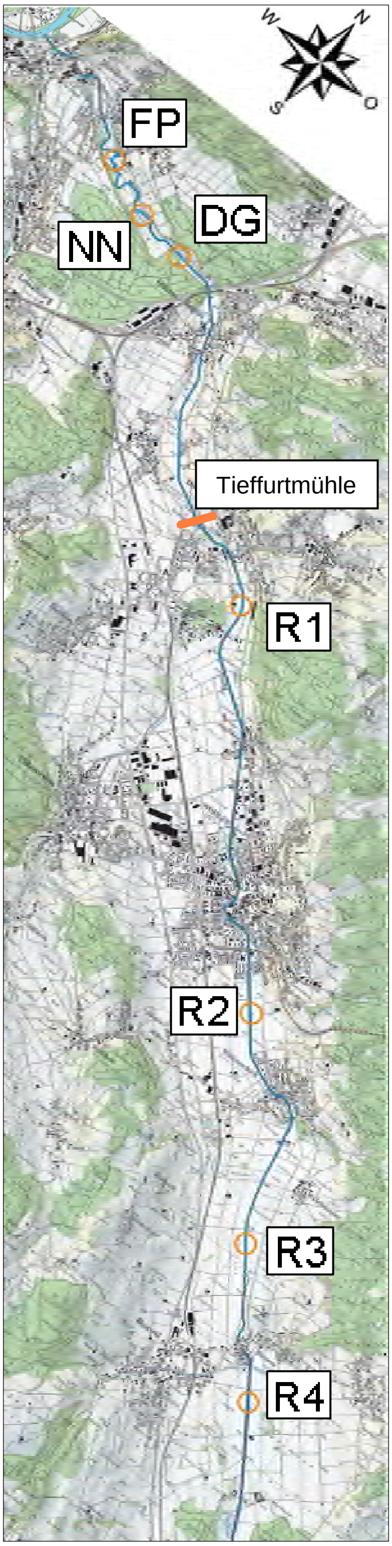

Figure 1: The seven study sites along the Bünz. Flow direction is from SE to NW.

3.1 Study system

The River Bünz is a small midland stream about 25 km long and has a yearly average discharge of ca.1.5 m^3/s at Othmarsingen. In its natural state, it was a slow meandering river due to the low slope. Because it required large areas that were periodically flooded, a large length of the river was channelized around 1930 to claim space for agriculture and human settlement. Only a part of the downstream section was left in a near-natural state. In this part, the riverbanks were stabilized to keep the river in its channel. In the last five years, multiple restoration projects were completed along the river in the formerly channelized part. In the near natural section, an extreme flood event created a floodplain in the year 1999 (Burger, 2007). A small hydropower plant that is privately owned hydrologically influences the downstream part of the river by periodic releases.

3.2 Study sites

Seven sites with different morphological conditions were chosen along the river (Figure 1). A near-natural site and a channelized site reflect the state of the river before the morphological changes took place. Five other sites, namely the newly created floodplain and four sites that were formerly restored reflect the new morphological conditions (Figure 2). The length of the investigated reach in each study site was 100 m.

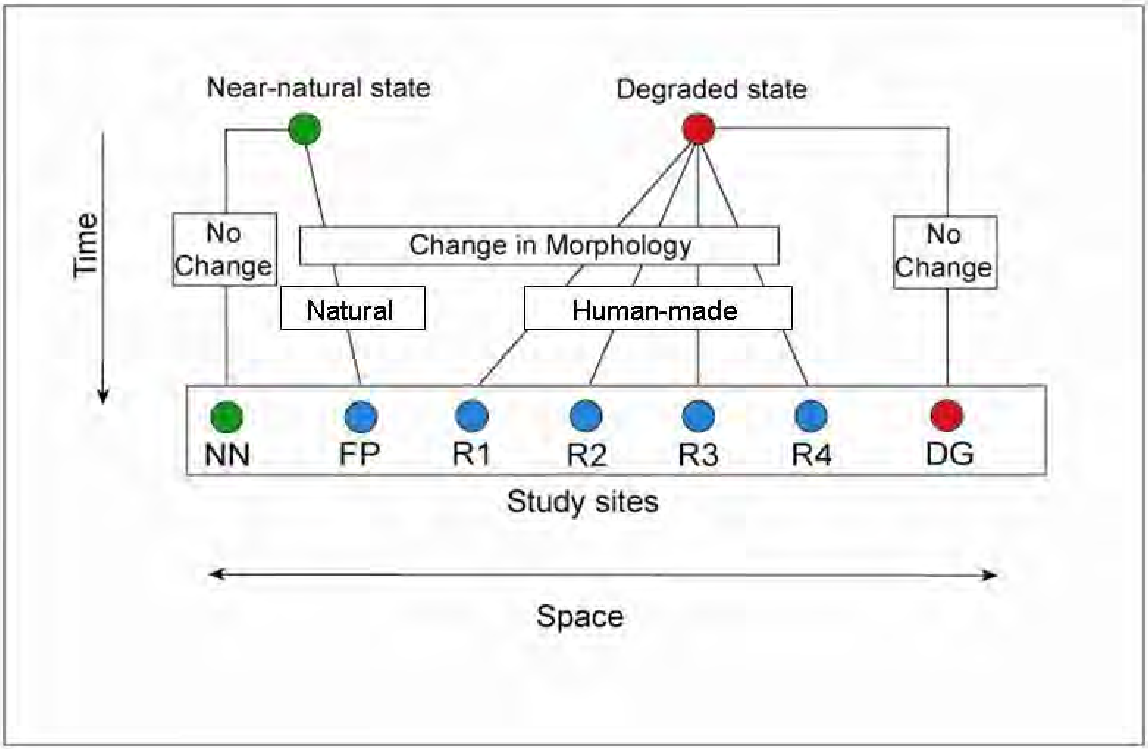

Figure 2: Schematic overview of the study design. Due to changes in morphology caused either by humans or natural events, the study system presents a broad range of morphologically different sites.

Description of study sites

1: Floodplain at Möriken (FP)

This site has never been channelized; only the river banks were trained. In 1999, a large flood removed the training elements and the river broke its banks and created a floodplain that is now protected as a floodplain of national importance. The riparian zone consists mainly of gravel banks with some shrubs and pioneer vegetation. A part of it has undercut slopes where agricultural land was removed. The riparian zone is bordered by agriculture, forest and settlements.

Figure 3: Site FP.

2: Near Natural site at Möriken (NN)

Like the floodplain, this site has never been channelized; only the riverbanks were trained. It preserved the same state for several decades. The riparian zone consists of various elements such as gravel banks, trees, shrubs, reeds and undercut slopes. On one side, the riparian zone is bordered by agriculture, on the other side by a slope to a road.

Figure 4: Site NN.

3: Degraded site at Möriken (DG)

This section, as is the rest of the river further upstream, was channelized around 1930 and the riverbanks trained with concrete elements connected by barriers on the riverbed at regular intervals. This site has never been modified since then. The riparian zone consists of a steep slope with high grass and is bordered on both sides by agricultural land.

Figure 5: Site DG.

4: Restored site at Dottikon (R1)

In the years 2005 and 2006, a 1.5 km section of the river was restored. The river was widened, and tree-trunks and large stones were introduced into the riverbed. The riparian zone is planted with typical shrubs and young trees. On one side, the riparian zone is bordered by a non-paved road, on the other side by a cow paddock.

Figure 6: Site R1.

5: Restored site at Wohlen (R2)

Here, only few changes were made; the training elements were removed and some larger stones added in the riverbed. The riparian zone is a slope with grass, trees and shrubs. On one side the riparian zone is bordered by a paved road for pedestrians and bikes, on the other side by agriculture.

Figure 7: Site R2.

6: Restored site downstream of Bünzen (R3)

This site was restored in 2007 and 2008, and the last efforts were finished shortly before the start of this study (February 2008). The river was widened, at some parts quite extremely, and it contains several little gravel islands. The riparian zone is planted with shrubs and young trees. Also, habitats with high grass and gravel banks occur. The riparian zone borders a gravel road and agricultural land.

Figure 8: Site R3.

7: Restored site upstream of Bünzen (R4)

This site was restored in 2005 and 2006. The riparian zone is partly quite steep and consists of high grass, shrubs and trees. Also, shrubs and young trees were planted. The riparian zone is bordered on both sides by a gravel road and agriculture.

Figure 9: Site R4.

For additional information see Table AIII-1, Appendix III.

3.3 Morphological measurements

Three methods were applied to characterize the seven study sites:

3.3.1 Ecomorphology

The ecomorphological state of each site was determined according to the new "Methods for the Investigation and Assessment of Running Waters in Switzerland (Modular Stepwise Procedure)" (Buwal, 1998). This is a standard method in Switzerland and groups the sites into four categories based on several morphological measurements.

I = natural / near-natural
II = little affected
III = highly affected
IV = non-natural / artificial

For sites NN, DG and R2, we had access to external data from the year 2001 (Source: Peter Berner, Abteilung für Landschaft und Gewässer, Kanton Aargau). The remaining sites were surveyed during summer 2008.

3.3.2 Indicators

Eleven Indicators that characterize river restoration success (Woosley et al., 2005) were used to evaluate the study sites. They all give a value between 0 and 1, where 0 represents the artificial condition and 1 the natural condition.

Indicator 11, Fish habitats: Gives information about the availability of different refuges for fish and their percentage of the whole water surface area.

Indicator 14, Variability in river width: Classifies into pronounced, limited or no variability in river width.

Indicator 21, Abundance of riparian arthropods: Is based on carabid beetle abundance.

Indicator 35, Quality and grain size distribution of riverbed substrate: Gives information on the percentage of the different grain size categories.

Indicator 36, Structure of the riverbed: Percentage of different structures as riffles, pools, etc. in the riverbed.

Indicator 37, Training of the riverbed: Estimates the percentage of river bed training and characterizes the training structure.

Indicator 42, Width and composition of riparian zone: Includes the mean width of the riparian zone and its composition, evaluating if it is appropriate for the river or artificial.

Indicator 44, Shoreline length: Compares the length of the shoreline to the length of the corresponding river section.

Indicator 45, Structure of the riverbank: Estimates percentage of training elements and number of different structures in areas without training elements.

Indicator 46, Training of the riverbank: Evaluates percentage and kind of training elements

3.3.3 Vegetation measurements

At each site, a sketch of the river and five meter width of each riverbank was drawn and all vegetation structures (Table AIII-3, Appendix III) were plotted. Additionally, the percentage of the total area of each vegetation structure was estimated. Four parameters to characterize the vegetation were evaluated. First, vegetation diversity was determined by counting the number of different vegetation structures occurring at each site. Secondly, vegetation heterogeneity was determined as the number of alternating structures summed up for both riversides. Furthermore, the Simpson-index and evenness for the vegetation structures were calculated (Equations can be found in Appendix III).

3.4 Biotic measurements

Three groups of arthropods were sampled:

1: Emerging aquatic Insects.

2: Terrestrial arthropod input into the river.

3: Riparian arthropod community.

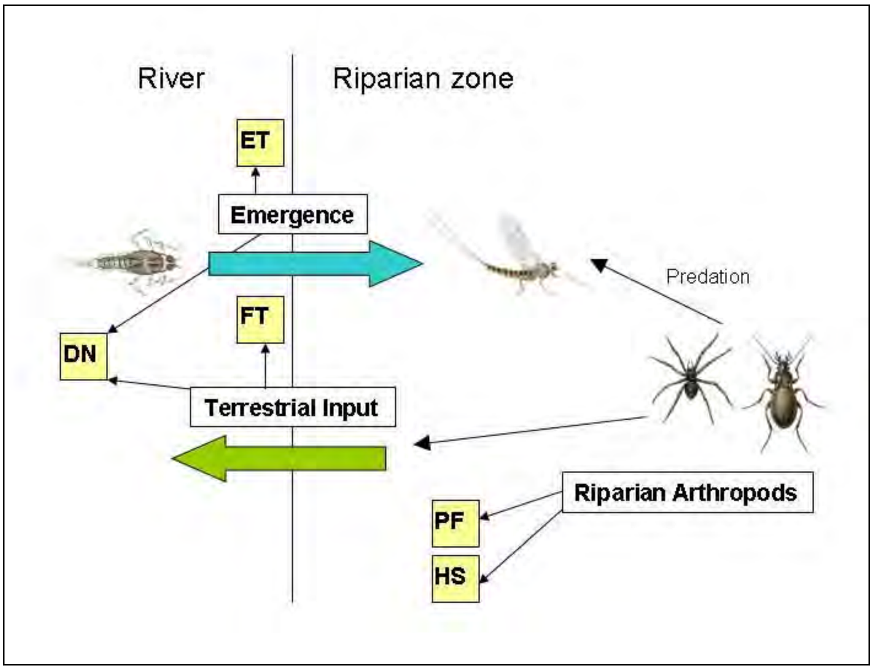

Figure 10: Schematic overview of the sampling methods. The picture shows the three sampled groups of invertebrates, their connection to the river and the traps used to sample them . ET=emergence trap, DN=drift net. FT=floating trap, PF=pitfall and HS=hand sampling

3.4.1 Sampling methods

To assess the biological diversity at each site, five different sampling methods were applied.

Emergence traps (ET): Pyramidal emergence traps (for detailed description see Paetzold, 2004), with an opening of 0.25 m^2 at the water surface, were placed on the river near the shoreline (Figure 12A). Emerging insects were collected in an elector head filled with 70% ethanol. On each sampling date, the traps were exposed for 24 hours.

Drift nets (DN): Drift nets with a mesh of 400 µm and a rectangular opening of 15 x 20 cm (Figure 12C) were exposed for 25 - 60 minutes. Flow velocity was measured at the mouth of each net to calculate the volume of water filtered.

Floating traps (FT): A pan (0.25 m^2) framed by styrofoam and containing water and one drop of detergent (Glycerin) up to a filling height of ca 5 mm was fixed near the shoreline to collect invertebrates falling into the water (Smock, 2006; Figure 12A). They were exposed for 24 hours on each sampling date.

Pitfalls (PF): Plastic bins, 0.12 m high and with a quadrate opening of 9.5 x 9.5 cm were dug into the ground near the shoreline (Figure 12C). They contained water with some dishwashing liquid and were exposed for 24 hours on each sampling date.

Hand samplings (HS): With a self-made exhauster and forceps (Figure 12D), arthropods were sampled in areas of 0.25 m^2 near the shoreline. Vegetation and large stones were partly removed.

Four sampling surveys took place during the season (Figure 11 and Table AIII-2, Appendix III) and for each trap method three samples were taken per site.

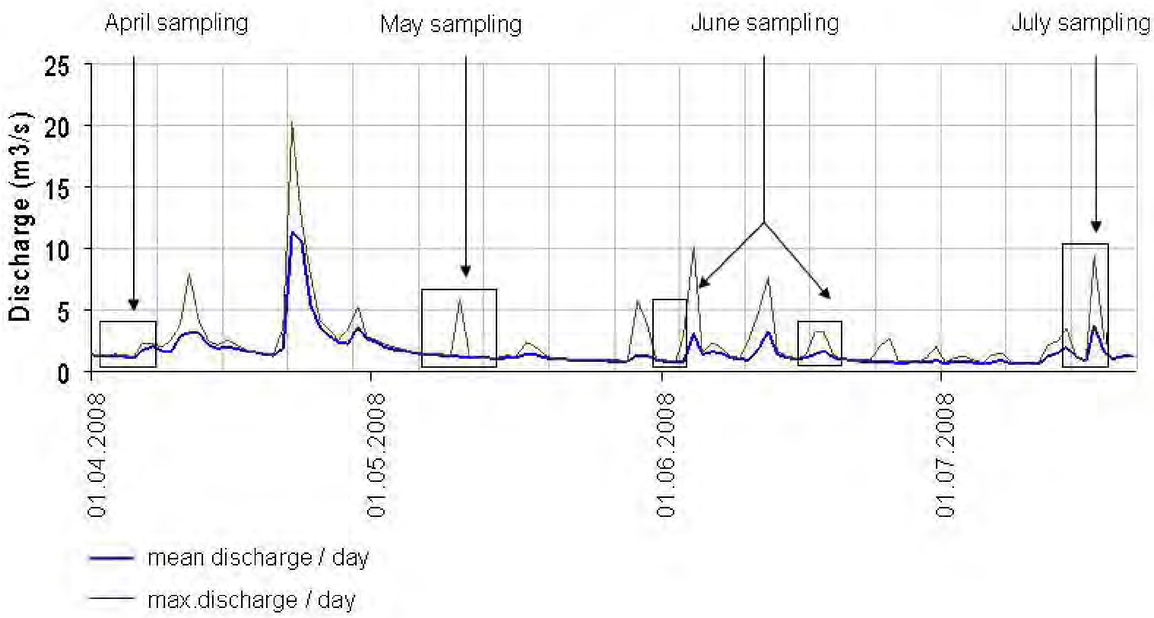

Figure 11: Discharge during sampling surveys. The values are from the measurement station in Othmarsingen. The peak of maximum daily discharge during the May sampling is only relevant for the lower three sites because it is caused by a flushing of the power plant Tieffurtmühle.

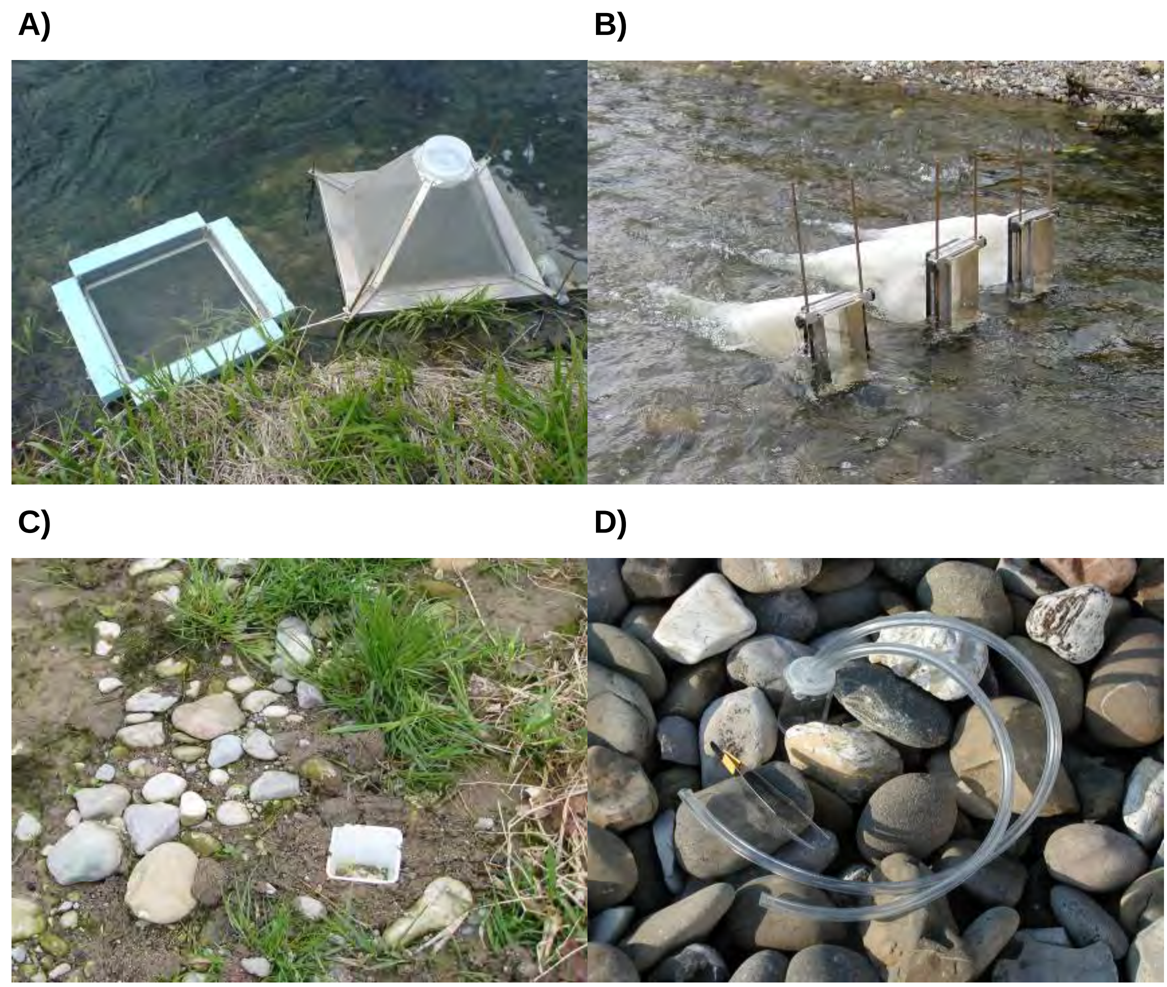

Figure 12: The different trap types. The photos show A) an emergence trap and a floating trap, fixed near to the shoreline, B) drift nets in the middle of the river, C) a pitfall trap dug in the ground near the shoreline, and D) a self-made exhauster and a forceps to collect riparian arthropods

In the field, samples were sieved through 63 µm mesh and preserved in 70% ethanol. In the lab, collected organisms were identified to different taxonomic levels. For each sampling date, site, and trap, four parameters were evaluated, namely the abundance, taxonomic richness, Simpson-index, and evenness. The abundance gives the total number of organisms, the taxonomic richness the number of different taxa found per sample. Simpson-index and evenness give information about biodiversity and distribution of taxonomic composition.

3.5 Analysis of data

The parameters of the morphological measurements were analyzed using a Principal Component Analysis (PCA) and the results presented in a scatter plot to evaluate differences between the sites.

The influence of site and sampling date on the biotic parameters was tested by ANOVA (linear model $x \sim$ site * date) using the statistical program R (version 2.4). This analysis was done for each trap type. To assure a normal distribution of the data, the values were log transformed.

To determine relationships between the biotic and morphological parameters, a correlation test was done using the program SPSS for each trap type.

To identify connections between insect emergence, riparian predators and terrestrial inputs, a Pearson correlation test was done between the abundance of emerging insects from the emergence traps and the abundance of spiders (all families), rove beetles (Staphilidae), ground beetles (Carabidae) and riparian predators (the preceding three groups together) from the pitfall traps and the terrestrial invertebrates in the floating traps.

4 Results

4.1 Morphology

The results of the ecomorphology, indicators and vegetation measurements are summarized in Table 1. All sites are in a better ecomorphological category than the channelized section, except for site R2. For every single indicator, DG had the lowest values, but the other sites performed similarly at times. This finding is also apparent when we compare the mean indicator values (Figure 13). Vegetation diversity was lowest at site DG, which had only two different vegetation structures that occured in only three patches. The other sites all had clearly higher values.

On the PCA plot (Figure 14), we see a clear separation of DG from the other sites along the x-axis, which explained 57% of the total variance. Factor 1 correlates with several morphological parameters, for example, width and composition of the riparian zone, structure of the river bank, and training of the riverbank (Table 2). The y-axis, which explains 25% of the variance, separates the sites FP and NN from the others.
The results for all indicators (besides indicator 21 and indicator 44) were analyzed by Stäheli, (2008) following the methods proposed by Woosley et al., (2005).

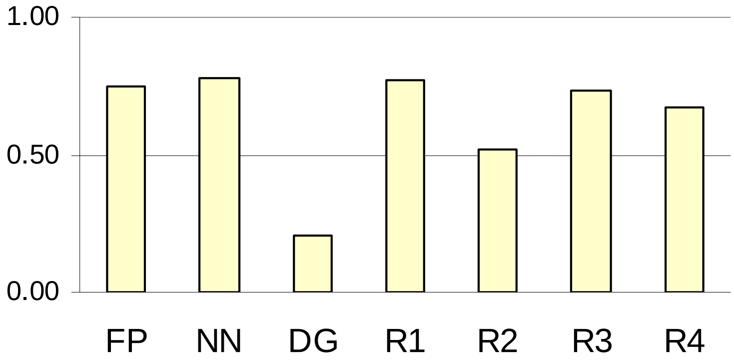

Figure 13: Means of indicator values for each site.

Table 1: Summary results of morphological measurements. The colors for the ecomorphology are based on BUWAL (1998).

	FP	NN	DG	R1	R2	R3	R4
Ecomorphology Level F	I	II	III	II	III	I	II
Fish habitats Indicator 11	0.10	0.25	0.10	1.00	0.25	0.10	0.25
Variability of river width Indicator 14	0.80	0.58	0.00	0.91	0.33	1.00	0.44
Abundance of riparian arthropods Indicator 21	0.75	1.00	0.50	0.75	0.50	0.50	0.75
Quality/grain size of riverbed substrate Indicator 35	0.25	0.75	0.25	0.50	0.25	0.75	0.75
Structure of the riverbed Indicator 36	1.00	1.00	0.00	0.50	0.25	0.50	0.25
Training of the riverbed Indicator 37	1.00	1.00	0.33	1.00	1.00	1.00	1.00
Width and composition of riparian zone Indicator 42	0.84	0.36	0.30	0.62	0.33	0.92	1.00
Shoreline length Indicator 44	1.00	0.86	0.61	0.69	0.67	0.79	0.64
Structure of the riverbank Indicator 45	0.75	1.00	0.00	0.75	0.63	0.75	0.63
Training of the riverbank Indicator 46	1.00	1.00	0.00	1.00	1.00	1.00	1.00
Discharge (m^3/s)	1.91	1.75	1.54	1.30	0.71	0.68	0.37
Vegetation diversity	6	10	2	7	5	7	7
Vegetation heterogeneity	16	20	3	24	11	24	17
Simpson-Index vegetation	0.25	0.16	0.62	0.21	0.41	0.40	0.22
Evenness vegetation	0.23	0.17	0.63	0.21	0.42	0.41	0.23

Results

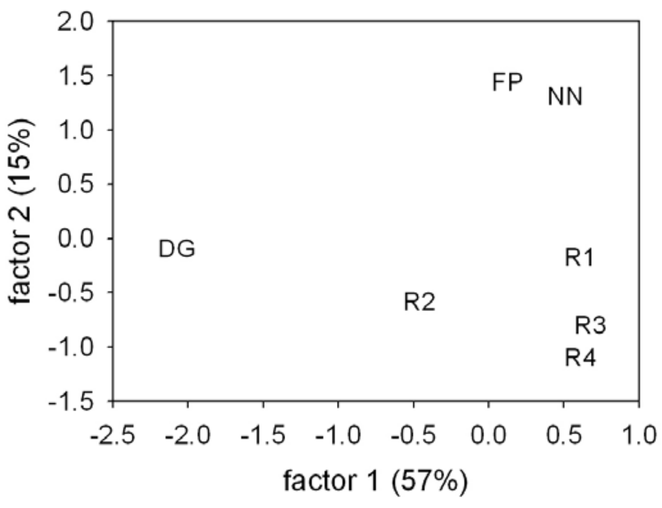

Figure 14: PCA plot, based on the results from the morphological measurements. Significant parameters for each axis are found in Table 2.

Table 2: Output from the PCA analysis. All values over 0.70 were considered to be significant for the corresponding axis.

	factor 1 57%	factor 2 15%
Ecomorphology Level F	-0.68	-0.27
Fish habitats Indicator 11	0.52	0.61
Variability in river width Indicator 14	0.40	**0.79**
Abundance of riparian arthropods Indicator 21	0.34	-0.11
Quality and grain size of riverbed substrate Indicator 35	**0.82**	0.13
Structure of the riverbed Indicator 36	**0.70**	-0.22
Training of the riverbed Indicator 37	0.58	**0.80**
Width and composition of riparian zone Indicator 42	**0.92**	0.04
Shoreline length Indicator 44	0.63	-0.27
Structure of the riverbank Indicator 45	**0.90**	0.32
Training of the riverbank Indicator 46	**0.92**	0.04
Discharge (m^3/s)	-0.25	**0.92**
Vegetation diversity	**0.87**	0.28
Vegetation heterogeneity	**0.94**	0.01
Simpson-index vegetation	**-0.86**	-0.33
Evenness vegetation	**-0.84**	-0.37

4.2 Biotic assemblages

4.2.1 Abundance and diversity

The ANOVA showed for all five sampling methods a significant influence of sampling date on abundance, taxonomic richness, Simpson-index and evenness (Table 3, Figure 15-19). For all trap types, except emergence traps, the site effect on abundance and richness was significant. For hand samplings and drift nets, the site effect was also significant for Simpson-index and evenness. A post hoc (Tukey) test was done to evaluate significance of differences between measures. These tables can be found in Appendix II. Complete taxa lists are in Appendix I.

Table 3: ANOVA table. F-values and p-values of the ANOVA of the linear model x～ site * date where x was abundance, richness, Simpson-index or evenness.

		Abundance		**Richness**	
		F-value	p-value	F-value	p-value
PF	date	13.21	< 0.001***	68.99	< 0.001***
	site	17.23	< 0.001***	4.79	0.03*
	date*site	19.51	< 0.001***	1.2	0.28
HS	date	57.79	< 0.001***	77.68	< 0.001***
	site	4.8	0.03*	18.05	< 0.001***
	date*site	0.31	0.58	3.49	0.07
ET	date	27.98	< 0.001***	59.09	< 0.001***
	site	1.94	0.17	1.86	0.18
	date*site	1.38	0.24	5.53	0.021*
FT	date	14.15	< 0.001***	68.99	< 0.001***
	site	9.29	0.003**	4.79	0.03*
	date*site	0.81	0.37	1.2	0.28
DN	date	57.79	< 0.001***	77.68	< 0.001***
	site	4.8	0.03*	18.05	< 0.001***
	date*site	0.31	0.58	3.49	0.07 .

		Simpson-Index		**Eveness**	
		F-value	p-value	F-value	p-value
PF	date	37.07	< 0.001***	57.78	< 0.001***
	site	0.28	0.6	0.06	0.80
	date*site	5.42	0.02*	5.11	0.03*
HS	date	9.42	< 0.001***	33.09	< 0.001***
	site	4.27	0.04*	10.55	< 0.001***
	date*site	0.34	0.56	0.15	0.7
ET	date	13.87	< 0.001***	19.8	< 0.001***
	site	0.07	0.80	0.04	0.85
	date*site	3.96	0.50	4.68	0.03*
FT	date	64.52	< 0.001***	83.89	< 0.001***
	site	0.23	0.64	1.53	0.22
	date*site	0.58	0.45	0.1	0.75
DN	date	9.42	0.003**	33.09	< 0.001***
	site	4.27	0.04*	10.55	0.002**
	date*site	0.34	0.56	0.16	0.7

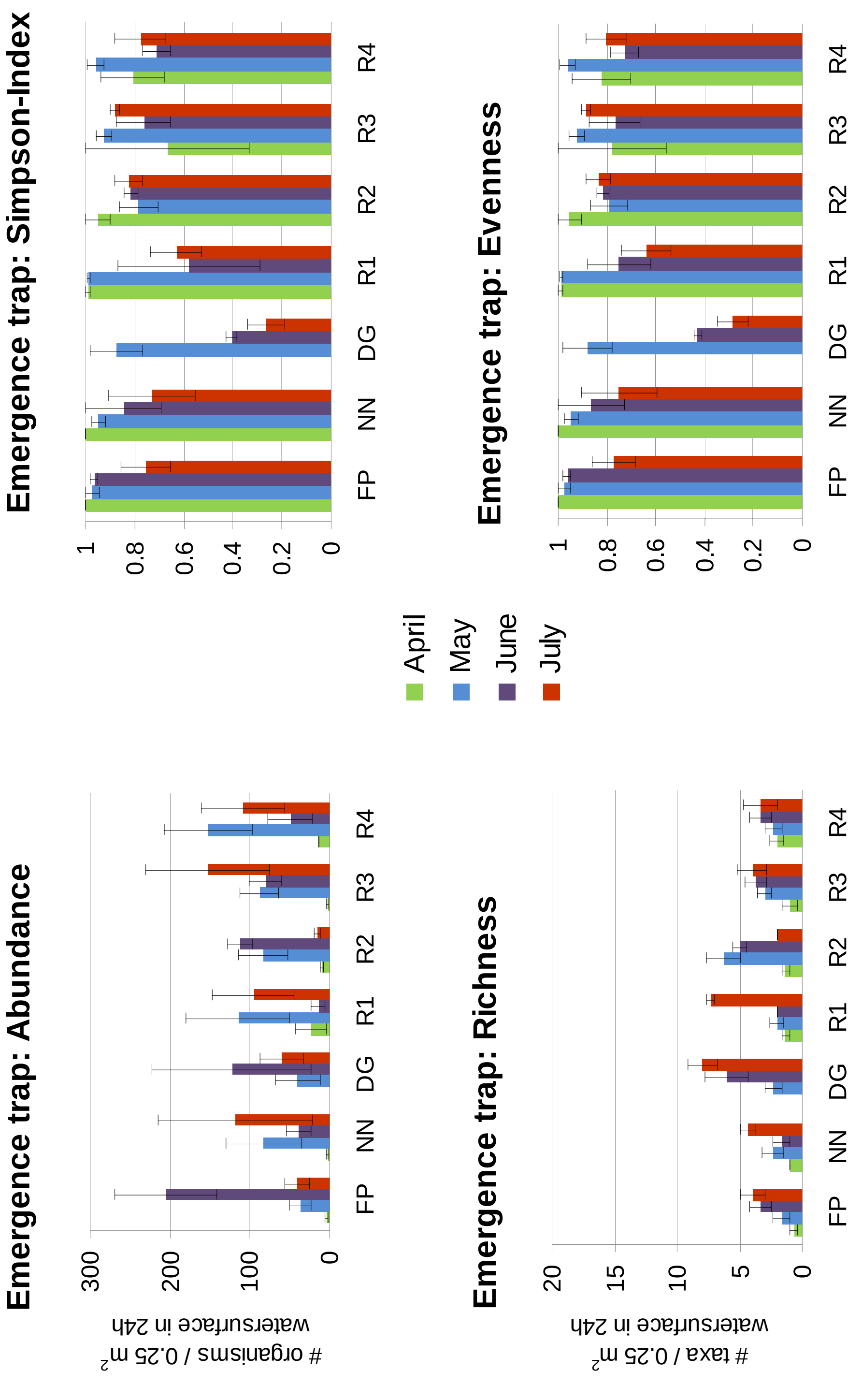

Figure 15: Results of biotic measurements. Means and standard errors of the abundance, richness, Simpson-index and evenness for emergence traps for each site and sampling date.

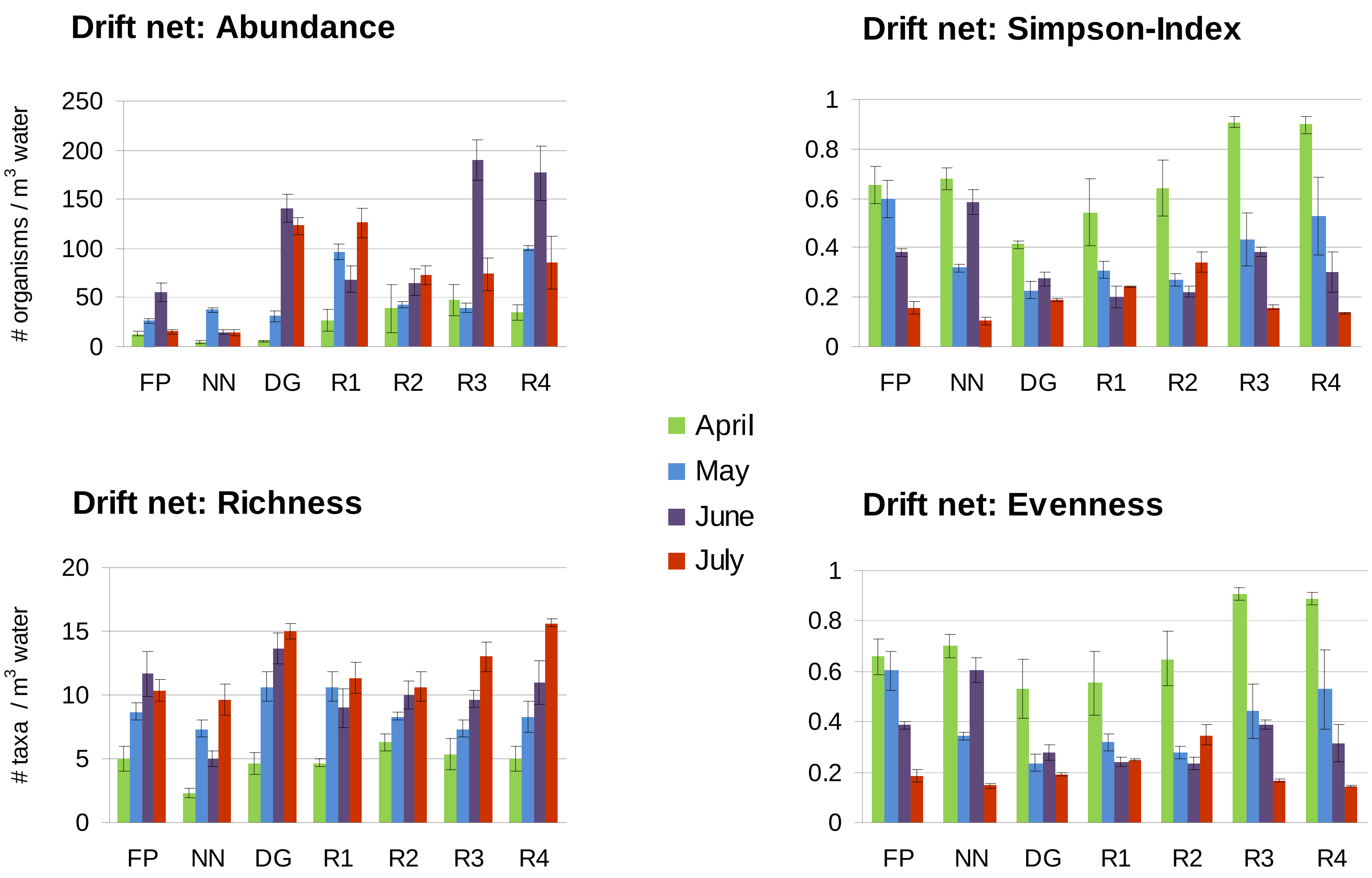

Figure 16: Results of biotic measurements. Means and standard errors of the abundance, richness, Simpson-index and evenness for drift nets for each site and sampling date.

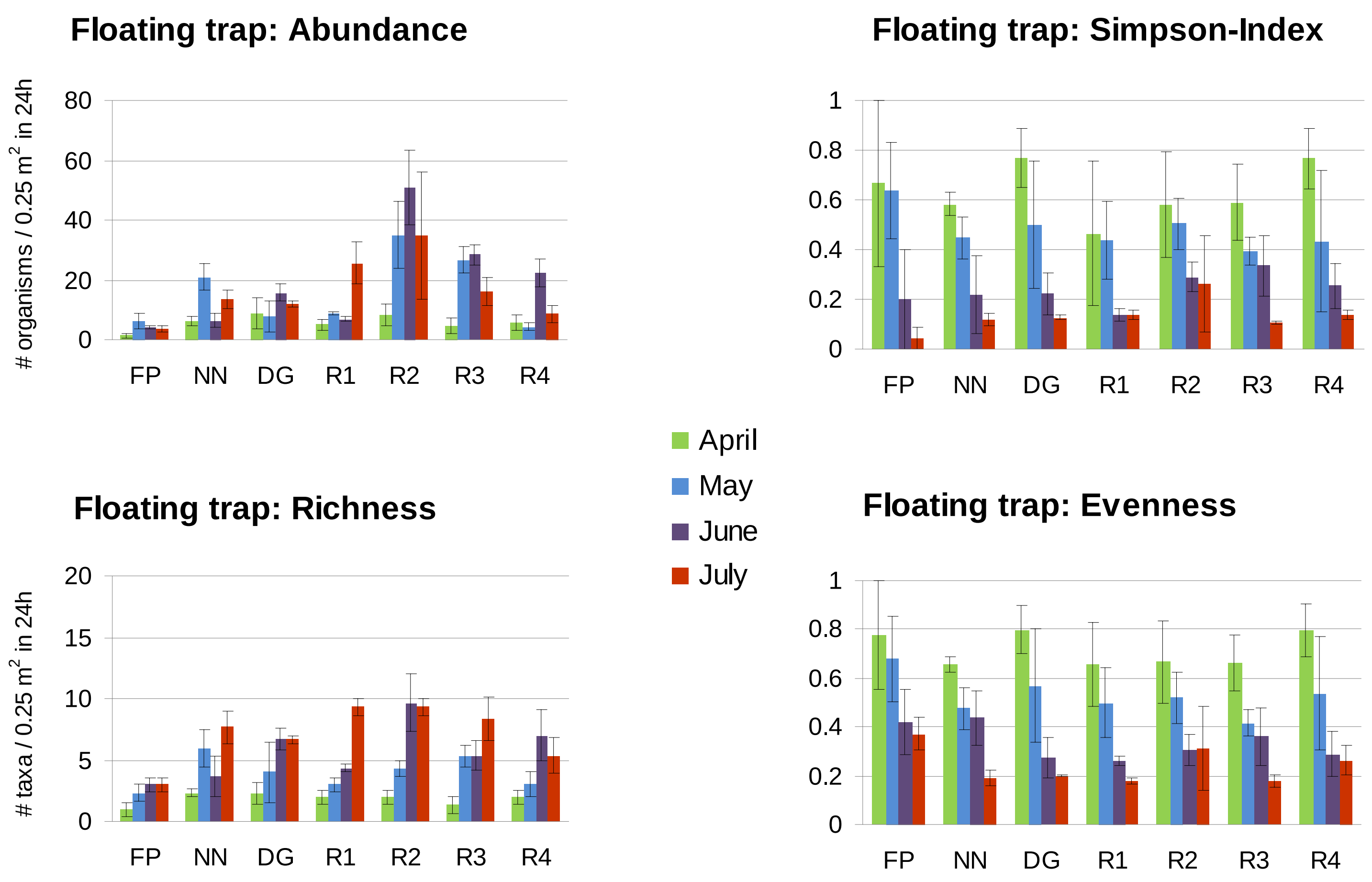

Figure 17: Results of biotic measurements. Means and standard errors of the abundance, richness, Simpson-index and evenness for floating traps for each site and sampling date.

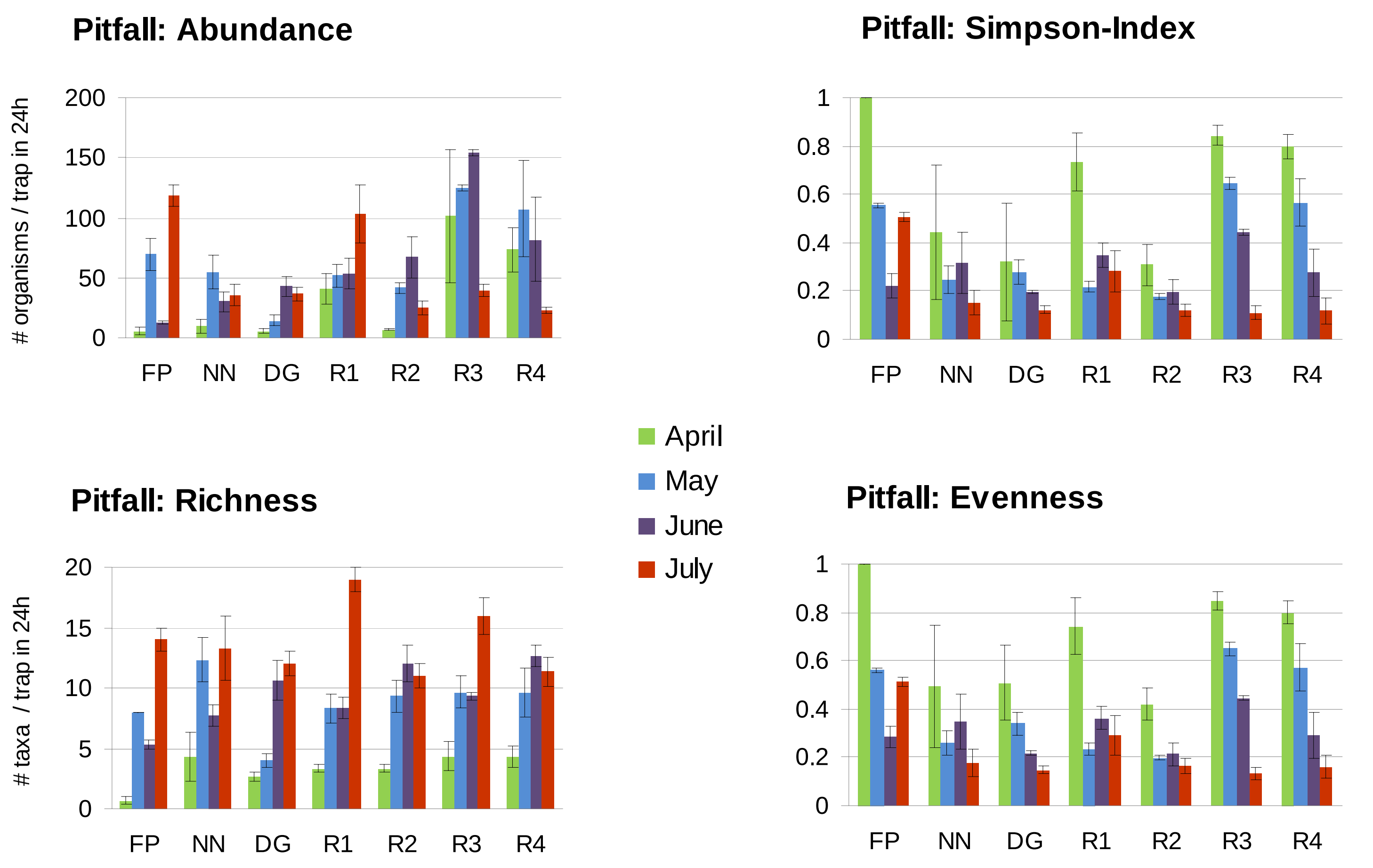

Figure 18: Results of biotic measurements. Means and standard errors of the abundance, richness, Simpson-index and evenness for pitfalls for each site and sampling date.

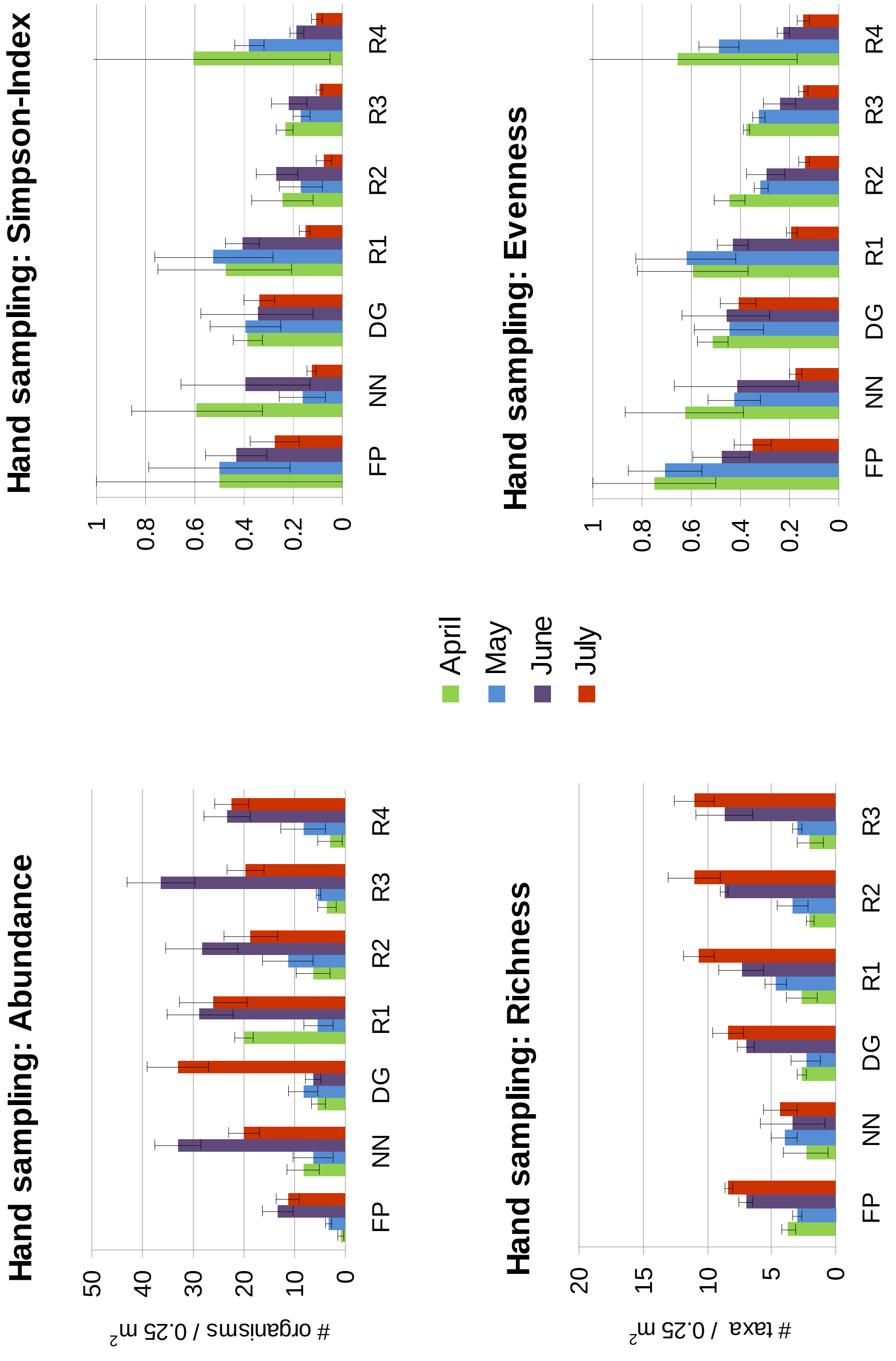

Figure 19: Results of biotic measurements. Means and standard errors of the abundance, richness, Simpson-index and evenness for A hand samplings for each site and sampling date.

4.2.2 Correlations

Significant correlations were found between the emerging insects and the abundance of riparian spiders (p= 0.009), rove beetles (p= 0.028) and the total abundance of the most important riparian predators (spiders, rove beetles and ground beetles) for the combined data for all sites (complete correlation table is found in Appendix II).

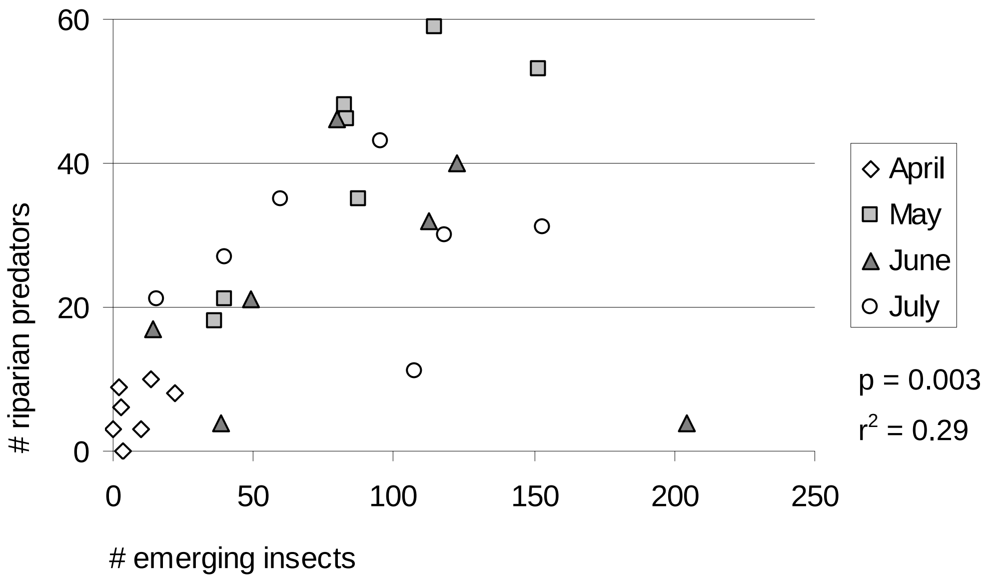

Figure 20: Correlation between insect emergence and riparian predators.

4.3 Correlations between morphology and invertebrates

In several cases interesting correlations between morphological parameters and results for single taxa were found (Figure 21). These graphs show positive correlations between a biotic and morphological parameter, except for graph B which shows a negative correlation between factor 1 from the PCA analysis and the abundance of mayflies (Ephemeroptera) in the emergence traps. Factor 1 was included in this analysis because it combines many morphological parameters. The complete correlation table is found in Appendix II.

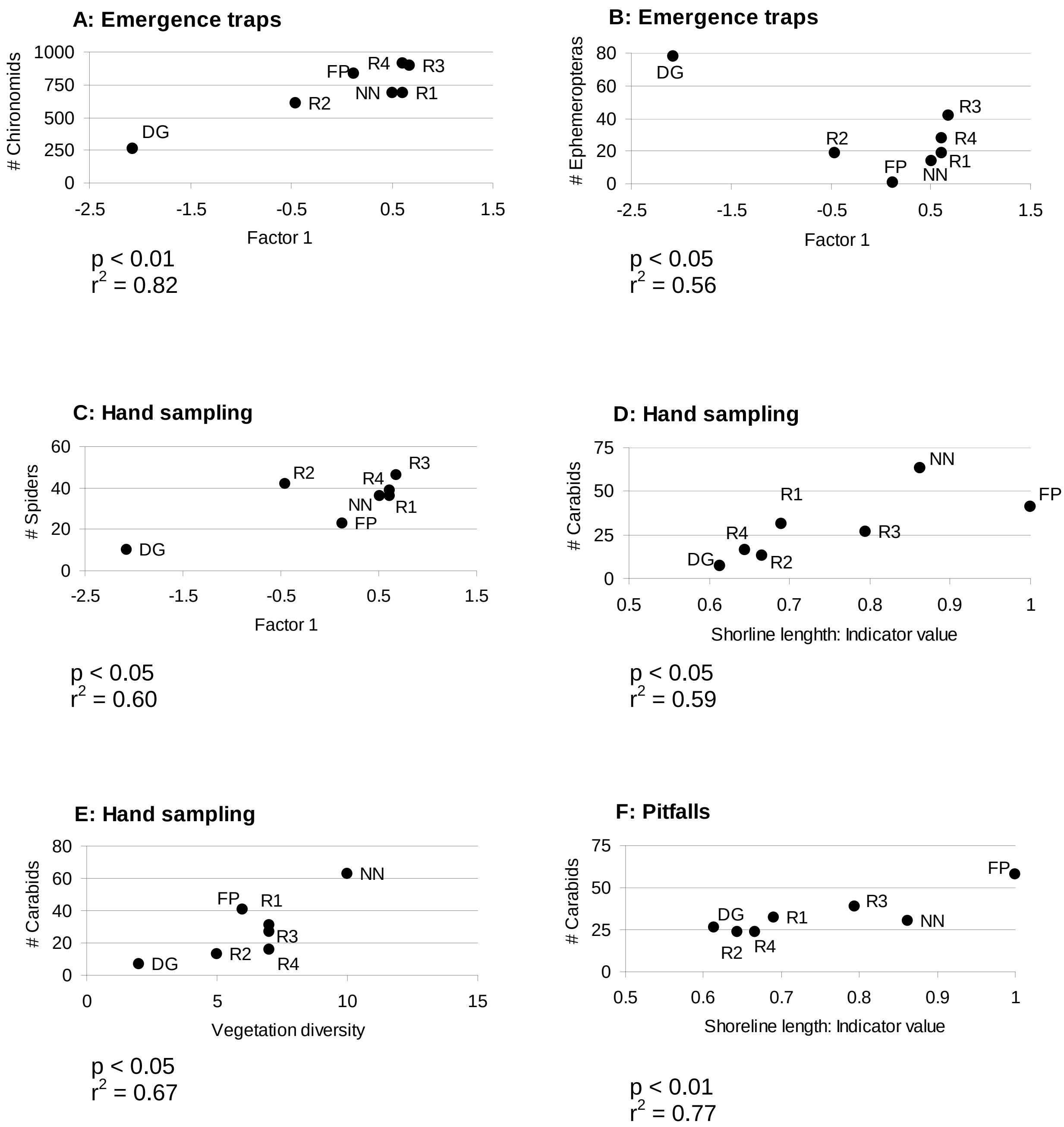

Figure 21: Correlations between morphological and biological parameters.

5 Discussion

5.1 Morphology

A historical or a natural reference site is missing in the Bünz; therefore, no statements can be made about how near the restored sites are now to their former natural state. But this was not really the goal of the restorations because the achievement to a natural state is not possible under todays conditions in this intensely farmed and densely inhabited Swiss midland (Woosley et al., 2005). The situation at the channelized site DG can be considered the worst state of the river except where it flows inside towns and if it is entirely within a culvert. All the restored sites (R1 to R4) were once in a state very near to this situation at DG. Therefore, it seems reasonable to compare the restored site to the degraded site and assess a positive divergence of the morphological values from these evaluated for site DG as an improvement. Stäheli (2008), who worked with the same data, analyzed the data by using site DG as a degraded reference. This approach is adequate if natural references are missing and the degraded state is of interest to evaluate deficiencies of a system (Rohde, 2004). Stäheli (2008) could show that all sites performed better compared to the degraded reference. The best site was FP, which is a special case compared to the rest because the morphological state here is caused by a natural event; it can be called a “restoration by nature”. Here the river also has the possibility to change its course, which allows a certain dynamic that is characteristic of natural river corridors (Ward et al., 2002). The relatively low ranking of NN in this analysis can be explained by the fact that the width of the riparian zone, which is an important quality measurement, is quite low at this site. It is evaluated regarding the width of the river itself, which is much wider at NN than in the more upstream restored sites and requires, therefore, an accordingly wider riparian zone. A wide riparian area is not possible because of the land tenure of the neighboring area, which is used as agricultural land.

In this study, several additional morphological measurements were used from those in Stäheli (2008). First, two indicators were included in the analysis that give information about the riparian zone, namely shoreline length (Indicator 44) and the density of riparian arthropods (Indicator 21). Shoreline length reflects the morphological complexity of a river section that is characteristic for a natural river system (Woosley et al., 2006). This indicator showed quite high values at sites NN and R3. These two sites meander more than the other sites and contain one or several little islands. For Indicator 21, the maximum could be reached at NN, while the lowest values were found at DG, R2 and R3. The reason for this result may be the low habitat heterogeneity and steep riparian zone at DG and R2. At site R3, the time factor may play an important role as restoration at this site was finished some months before this study. Further aspects of correlations between morphology and riparian arthropods are discussed in paragraph 5.3.2.

Secondly, the riparian vegetation was investigated. Here, we clearly see one of the main deficiencies of the channelized section. Only two vegetation structures were found, and on one river side only one structure is present (Figure 5). Habitat heterogeneity of the riparian zone that is crucial for biodiversity (Ward, 1998) is therefore very low. Here again, the natural site (NN) performs well. One reason may be the long time period of no change that allowed the development of diverse vegetation. This leads to the assumption that restored sites that are relatively young can reach their full potential only after some years.

In conclusion, it can be said that all sites are in a better ecomorphological state than the channelized section (DG). The PCA-plot (Figure 13) shows a clear separation of site DG from the other sites along factor 1. Factor 1 is highly correlated with several parameters such as, e.g., vegetation diversity (Table 2). Site R2 was placed between DG and the others. At this site, little restoration effort was made, and only the training elements were removed. Regardless, a positive effect is still apparent. As the riparian zone is quite narrow and steep at this site, the rehabilitation potential is low, and the river had little chance to expand. Based on the good performance of the floodplain (FP), which was actually restored naturally, it can be assumed that the removal of lateral training elements and additional availability of space for the river to expand can allow good restoration success at low efforts and costs.

Hypothesis I: The ecomorphological state will differ between the different sites. Sites affected by human activities will be in a worse morphological state than natural or restored sites.

This hypothesis can be accepted because morphological differences between sites are apparent. It could be showed that site DG, which was heavily affected by humans, is in the worst morphological state of all the sites.

5.2 Biotic assemblages

5.2.1 Abundance and diversity

Data analysis was done for each trap separately because of the different sampling approaches. For all traps, the biotic assemblages showed significant differences between the different sampling dates. This corresponded to initial expectations based on the knowledge of seasonal changes in biotic community structure at one place. Thus, it is important to collect several dates to cover the entire taxonomic phenology (e.g. Dineen et al., 2007).

Samples from the **emergence traps** showed no site effect, and only seasonal changes were apparent. No clear trend or seasonal peak was obvious. The main taxa in the samples were dipterans, the most frequent family the chironomids. Similar results by sampling emerging aquatic insects were found by Judd (1962).

The **drift net** samples showed large seasonal differences, but no clear seasonal peak was apparent. A reason could be that the sampling was not always done at the same time of day. The 24 hour drift net survey (Appendix III) showed large diurnal changes and in addition, the single data surveys spanned about one week and the weather conditions sometimes changed. Site effects were most pronounced in summer (June and July); for example, R3 and R4 showed significantly the greatest abundance in June. There were no sites that showed a clear greater or lower abundance in drift. It is possible that other factors may have produced these effects.

Regarding the results of the **floating traps**, two findings are interesting. Firstly, sites FP and DG were the only ones that showed no seasonal changes. Secondly, site R2 had always the highest abundance of terrestrial inputs; in June it differed significantly from all the other sites except for site R3. Sites FP and DG had the lowest canopy coverage, site R2 the highest. For terrestrial inputs, the vegetation type, coverage and succession state were important, and the terrestrial input changed with the seasonal change in vegetation (Wipfli, 1997). Thus, if almost no vegetation exists that can provide invertebrate input, no changes in input abundance or composition can be expected. This confirms the importance of canopy for the abundance of terrestrial invertebrate input.

Site effects in the **pitfall** and **hand sampling** samples were only small, but if present mostly pronounced in summer. In June, site R3 had significantly the greatest abundance, and in July the sites FP and R1 had the greatest abundance. In the hand samples, the evenness at site DG was in July significantly higher than at all other sites except for FP , which differed from no other sites. To conclude, it can be said that in cases where site effects were apparent, restored sites either had significantly greater abundance or diversity or the degraded site had significantly lower abundance and diversity.

Hypothesis II: Differences between sites and season will be apparent in the terrestrial and aquatic adult invertebrate assemblages.

Hypothesis II can partly be accepted. Seasonal differences differed between sites and trap types, but generally the abundance and richness were higher in summer and, therefore, Simpson-index and evenness were lower. Site effects were apparent, but not in all trap types and they did not allow a clear ranking of the sites.

5.2.2 Correlations between aquatic and terrestrial communities

The existing correlation of riparian arthropods and aquatic insect emergence indicates a trophic connection of the riparian zone and the river because emerging insects are an energy source for riparian predators (e.g. Burdon and Harding, 2008). The terrestrial input was not correlated with these values. A reason for that could be that, on one side, the abundance of terrestrial input is highly influenced by the riparian vegetation (Wipfli, 1997) and, on the other side, the terrestrial input does not directly influence the aquatic insect population. It serves mainly as an important food source for fish (Allan et al., 2003).

Hypothesis III: There will be a relationship between the emergence of aquatic insects, riparian predators, and input of terrestrial invertebrates into the river at the different sites.

The third hypothesis can not completely be accepted because the terrestrial input does not correlate with the other factors.

5.3 Correlations between morphology and biology

5.3.1 Aquatic communities

In emergence traps, two significant correlations were notable. Firstly, the abundance of chironomids, which was the main taxon, in all emergence traps correlated significantly ($p < 0.05$) and positively with factor 1 from the PCA analysis that combines several morphological factors (Table 2). Additionally, chironomid abundance correlated with the indicators for training of the riverbank and riverbed (both $p < 0.05$). This indicates an enhanced emergence at sites with better morphological condition and fewer training structures on the riverbed or on the riverbank.

Secondly, factor 1 is significantly ($p < 0.05$) negatively correlated with the abundance of mayflies. The high abundance at site DG is especially notable. Here, the abundance is more than twice as high as at the other sites. This result is surprising because the data for macrozoobenthos (Stäheli, 2008) showed little difference between the sites in the abundance of mayflies. Two explanations are possible. First, there is the possibility that the mayfly larvae drift and then emerge at this particular site due to reasons that were not addressed in this study. The alternative explanation is that the type of emergence trap is not appropriate for this special case. When possible, traps were placed in a slow flowing part of each site. At DG, no such habitats were available and the flow velocity under the emergence traps was quite high. This kind of trap is usually not considered for fast flowing streams. It is also possible that adult aquatic insects use the trap as an ovipositioning place and end up in the elector head of the trap. This was showed by a study of Mundie, (1956) for the mayfly family *Baetidae,* which was actually the most abundant taxa in the emergence trap samples for this site.

5.3.2 Terrestrial communities

Carabid beetles and spiders are both characteristic species of river banks (Kunz, 2006). The apparent correlations of carabid beetles with the indicator for shoreline length and vegetation diversity, both reflect heterogeneity, as well as the correlation of spider abundance with factor 1 from the PCA analysis indicates that riparian arthropods are influenced by morphological factors and occur in higher abundance in morphologically intact or restored sites. This is supported by a study of Bosccaini et al., (2000) who showed that carabids are sensitive to environmental change and channelization. The shoreline length reflects the morphological complexity of a river section (Woosley et al., 2006). Complex and heterogeneous habitats influence the abundance of riparian arthropods. Thus ameliorations in morphology can have a positive influence on riparian arthtopods.

Hypothesis IV: Measured biotic parameters will correlate with the morphological characteristics of the different sites.

This hypothesis can be accepted because of above mentioned significant correlations.

5.4 Conclusions

Restoration clearly influenced the morphological state of the various sites in a positive way. The Bünz could be potential habitat for many organisms such as invertebrates and fish. Also, the floodplain site that was restored naturally and site R2 where only little restoration efforts were made, showed a positive change compared to the channelized site. Allowing the river to expand by removing lateral training elements and providing space may be a good approach as a supplement to usual restoration efforts and may help reduce costs.

A better morphological state or a greater availability of habitats does not instinctively lead to a more abundant or more diverse biotic assemblage. The physical structures alone do not bring back organisms into the system (Field of Dreams Approach, Hildebrand et al., 2005). In planning restorations, morphological and ecological processes should be considered (e.g. Kondolf, 1998). The connectivity with habitats where the target species pool is present is crucial for the recolonisation of restored habitats.

The recolonisation potential of the Bünz valley was never considered and may be a restriction. This may be a reason for the poorly pronounced site effects in biotic assemblages. Another reason could be that the restored sites are quite young and the biotic community could not yet use the full potential of existing ecological niches.

The correlations of some biotic parameters with measured morphological parameters suggest that an improvement in morphology can have positive effects on terrestrial and aquatic invertebrate assemblages.

The restoration efforts at the Bünz showed some positive effects on biotic assemblages and further restorations that connect the morphologically good habitats may move the system to a better ecological state. However it is not excluded that some restrictions exist that impede the river to come to its full potential.

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Appendix I: Taxa lists

The taxa lists can be found on the attached CD-Rom.

File names:

Table AI-1: Emergence traps:	ET taxalist.xls
Table AI-2: Drift nets:	DN taxalist.xls
Table AI-3: Floating traps:	FT taxalist.xls
Table AI-4: Pitfalls:	PF taxalist.xls
Table AI-5: Hand samplings:	HS taxalist.xls

Appendix II: Statistical output

Tables AII-2 - AII-11 can be found on the attached CD-Rom.

Correlation tables

Table AII-1: Correlation between riparian arthropods, emerging insects and terrestrial invertebrate input

		emerging Insects	spiders	carabids	staphylids	total riparian Insects	terrestrial Input
emerging Insects	Korrelation nach Pearson	1.000	0.483(**)	0.141	0.415(*)	0.535(**)	0.194
	Signifikanz (2-seitig)		0.009	0.473	0.028	0.003	0.322
	N	28	28	28	28	28	28
spiders	Korrelation nach Pearson	0.483(**)	1.000	-0.006	0.313	0.959(**)	0.277
	Signifikanz (2-seitig)	0.009		0.974	0.105	0.000	0.153
	N	28	28	28	28	28	28
carabids	Korrelation nach Pearson	0.141	-0.006	1.000	0.400(*)	0.226	0.202
	Signifikanz (2-seitig)	0.473	0.974		0.035	0.248	0.303
	N	28	28	28	28	28	28
staphylids	Korrelation nach Pearson	0.415(*)	0.313	0.400(*)	1.000	0.532(**)	0.597(**)
	Signifikanz (2-seitig)	0.028	0.105	0.035		0.004	0.001
	N	28	28	28	28	28	28
total riparian Insects	Korrelation nach Pearson	0.535(**)	0.959(**)	0.226	0.532(**)	1.000	0.393(*)
	Signifikanz (2-seitig)	0.003	0.000	0.248	0.004		0.038
	N	28	28	28	28	28	28
terrestrial Input	Korrelation nach Pearson	0.194	0.277	0.202	0.597(**)	0.393(*)	1.000
	Signifikanz (2-seitig)	0.322	0.153	0.303	0.001	0.038	
	N	28	28	28	28	28	28

Correlations between morphological and biological parameters:

File names:

Table AII-2: Emergence traps: ET corr.xls

Table AII-3: Drift nets: DN corr.xls

Table AII-4: Floating traps: FT corr.xls

Table AII-5: Pitfalls: PF corr.xls

Table AII-6: Hand samplings: HS corr.xls

Tukey tables

Output from post hoc (Tukey) tests:

File names:

Table AII-7: Emergence traps:	ET tukey.xls
Table AII-8: Drift nets:	DN tukey.xls
Table AII-9: Floating traps:	FT tukey.xls
Table AII-10: Pitfalls:	PF tukey.xls
Table AII-11: Hand samplings:	HS tukey.xls

Appendix III: Additional data

Site description

Table AIII-1: Site description

site	FP	NN	DG	
coordinates of end points of study reaches	E 08°12'04.2" N 47°24'23.8", E 08°12'09.2" N 47°24'23.2"	E 08°11'00.7" N 47°24'39.5", E 08°11'04.2" N 47°22'34.5"	E 08°19'51.0'" N 47°22'37.3", E 08°14'52.4" N 47°22'34.5"	
Ø discharge	1.91 m^3/s	1.75 m^3/s	1.54 m^3/s	
Ø river width	12 m	8.8 m	5 m	
last modification	1999	1930	1930	
type of modification	extreme flood event	stabilization of riverbank	channelization	
site	**R1**	**R2**	**R3**	**R4**
coordinates of end points of study reaches	E 08°11'33.8" N 47°24'27.8", E 08°11'37.6" N 47°24'28.4"	E 08°17'71.1" N 47°20'29.3", E 08°17'21.2" N 47°20'26.4"	E 08°18'42.2" N 47°19'09.2", E 08°18'44.3" N 47°19'06.7"	E 08°19'40.1" N 47°18'16.6", E 08°19'42.9" N 47°18'13.7"
Ø discharge	1.30 m^3/s	0.71 m^3/s	0.68 m^3/s	0.37 m^3/s
Ø river width	8.1 m	7 m	5.7 m	3.6 m
last modification	2005/2006	1995	2007/2008	2005/2006
type of modification	restoration	removal of training elements	restoration	restoration

Dates of data surveys

Table AIII-2: Sampling times and dates of the emergence traps, floating traps, pitfalls and hand samplings. The emergence traps, floating traps and pitfalls were exposed for 24 hours.

	April		**May**		**June**		**July**	
	date	time	date	time	date	time	date	time
FP	07.04.2008	13:45	13.05.2008	10:30	19.06.2008	10:00	16.07.2008	16:00
NN	07.04.2008	11:45	13.05.2008	11:45	16.06.2008	11:15	15.07.2008	15:00
DG	07.04.2008	10:00	13.05.2008	13:45	18.06.2008	13:00	15.07.2008	14:00
R1	03.04.2008	15:00	06.05.2008	14:00	16.06.2008	10:15	15.07.2008	13:00
R2	03.04.2008	11:35	06.05.2008	12:30	02.06.2008	10:40	14.07.2008	10:00
R3	02.04.2008	12:30	05.05.2008	10:50	02.06.2008	12:00	14.07.2008	10:55
R4	02.04.2008	10:10	05.05.2008	09:10	02.06.2008	13:50	14.07.2008	11:35

Equations

Simpson-index:

$$D = \sum_{i=1}^{S} \frac{n_i(n_i - 1)}{n(n-1)}$$

D = Simpson Index, n_i = # organisms of one taxa, n = # of all organisms

Evenness:

$$D = \sum_{i=1}^{S} p_i^2$$

D = Evenness, p_i = percentage of single taxa.

Vegetation measurements

Table AIII-3: The different vegetation structures included in the vegetation measurements.

	vegetation type
1:	no vegetation
2:	gravel with < 30 % vegetation cover
3:	gravel with > 30 % vegetation cover
4:	homogenous meadow, regularly cut
5:	meadow with additional herbaceous plants, regularly cut
6:	meadow with additional herbaceous plants, not cut
7:	single young shrub
8:	single shrub > 2m high
9:	composition of several different shrubs
10:	single young tree
11:	single tree
12:	composition of shrubs and trees, without under story
13:	composition of shrubs and trees, with understory

Table AIII-4: Percentage of the different vegetation structures at the different sites.

site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
FP	18	43	10	5		14		10					
NN	8	6	5	5		23		7	19		2		25
DG				75								25	
R1					33	15	7	4	25		6		10
R2		4			14	18		4					60
R3		9			61	13	7		3	3	4		
R4				4	35	12		12	6	5			26

24 hour drift net survey

Table AIII-5: Taxalist of the 24 hour drift net survey and the number of individuals found per single drift net.

	16:30			22:30			05:30			11:00		
	1	2	3	1	2	3	1	2	3	1	2	3
aquatic												
Diptera/Brachycera	7	3	3	2	2	4	1	2	2	8	1	3
Diptera/Nematocera	15	24	21	431	458	373	125	126	103	11	7	11
Trichoptera			1	3	6	3			1	1	1	1
terrestrial												
Acari								1				
Aranea			1			2				2	2	
Auchenorrhyncha		1	1	1								
Coleoptera/Carabidae						1				2		
Coleoptera/Staphylinidae	1	1									2	1
Coleoptera/Polyphaga	1	1	4		1							1
Collembola	2	2	2		3		1	1	3	1		1
Ephemeroptera	17	13	15	32	27	15	6	6	2	15	2	4
Heteroptera (Larvae)							1					
Heteroptera			1	1								
Hymenoptera/Chalcoidea	8	19	7	1	3	1	3	3	3	5	3	10
Hymenoptera/Formicidae	3	1	1			1	3	1		3	1	
Hymenoptera/Apocrita	1											
Psocoptera							2			1	1	
Sternorrhyncha/Aphidina	2	4	1	1		1	1			3	4	1
Thysanoptera	3	5	4	1	1					1		

Table AIII-6: Flow velocity, volume of filtered water and abundance of found organisms from the 24 hour drift net survey.

	16.07.2008 16:34 - 16-59			16.07.2008 21:38 - 22:03			17.06.2008 05:31 - 05:56			18.07.2008 10:44 - 11:09		
duration (s)	1500			1500			1500			1500		
depth (m)	0.12			0.12			0.12			0.12		
area (m^2)	0.018			0.018			0.018			0.018		
vel. (m/s)	0.53	0.7	0.84	0.58	0.66	0.83	0.65	0.74	0.84	1.14	0.85	0.66
filt. watervol. (m^3)	14.31	18.9	22.68	15.66	17.82	22.41	17.55	19.98	22.68	30.78	22.95	17.82
# organisms	60	74	62	473	501	401	143	140	114	53	24	33
# emerging org.	39	40	40	468	493	395	132	134	108	35	11	19
# terrestrial org.	21	34	22	5	8	6	11	6	6	18	13	14
# organisms/m^3	4.19	3.92	2.73	30.20	28.11	17.89	8.15	7.01	5.03	1.72	1.05	1.85
# emerging org./m^3	2.73	2.12	1.76	29.89	27.67	17.63	7.52	6.71	4.76	1.14	0.48	1.07
# terrestrial org./m^3	1.47	1.80	0.97	0.32	0.45	0.27	0.63	0.30	0.26	0.58	0.57	0.79

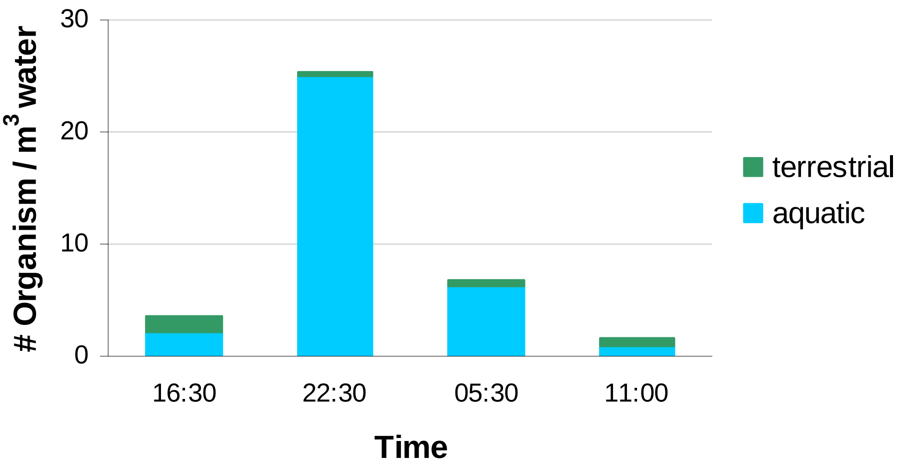

Figure AIII-1: Abundance of adult aquatic and terrestrial Arthropods of the 24 hour drift net survey.

Impressions of site FP


18.03.2008


31.08.2008


22.04.2008


12.10.2008


08.05.2008

Figure AIII-2: Some impressions of the floodplain site FP from spring to autumn 2008.