Experimental floods in Switzerland

Master Thesis

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von

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CONTENT

ABSTRACT

The river Spöl in eastern Switzerland flows through the Swiss National Park. The river here is fragmented by two reservoirs, resulting in two flow-managed sections: the upper and lower Spöl separated by Ova Spin reservoir. Environmental high flows (e-flows) have been implemented since 2000 to improve the ecological integrity in these sections of the river. While the upper Spol resembles an alpine stream with canyon like structures and large rocks, the lower Spol contains gravel sediments strongly influenced by tributary influxes from the Clouzza valley. As an indicator for biotic changes in the river, stream macroinvertebrates have been monitored in both sections over the last 18 years. Both stretches have shown major changes in macroinvertebrate assemblages resulting from the e-flows, although being somewhat different in each stretch. For example, the density of the common crustacean *Gammarus* decreased in the upper part while increasing in the lower Spöl. Nevertheless, the number of taxa increased in both sections over time. Additional habitat measures of the riverbed also detected differences in each site of the river as shown, for example, in cross-sectional profiles recorded over time in each section.

In the second chapter, I analyzed the drift patterns of MZBs over three separate e-floods in three different streams in Switzerland. These different e-floods are distinguished by their flow magnitude, duration, and season within the year. We investigated how the flow magnitude correlated with MZB' drift and seston. In particular, we studied if there were general discharge thresholds for the drifting of MZB. Moreover, the effects of the floods were investigated using the periphyton of stones and MZB density before and after the floods. Most of the invertebrates in the drift were in the first hour of the floods. There were as well some differences in the taxonomic groups. Trichopterans were the most resilient group of the EPT-taxa.

CHAPTER 1: LONG-TERM RESPONSE OF MACROZOOBENTHOS TO ENVIRONMENTAL FLOODS

Introduction

The change in the flow regime of rivers is a consequence of human influences worldwide (Lehner et al., 2011). The five most relevant factors of streamflow are influenced at each level by humans. These factors are flow magnitude, the frequency of occurrence, the duration and timing of an event and the rise and fall rate of the event (Poff et al., 1997). The functions are dependent and vary in response to climate, topography, geology, land cover and position in the network (Poff & Zimmerman, 2010). Poff et al. (1997) postulated that "the ecological integrity of river ecosystems depends on the natural dynamic character". Humans are interacting through many direct and indirect actions such as urbanization, replacement of wetlands and forest for agriculture, and development of drainage systems; all influence the flow regime of a river. The general consequences for biodiversity of flow altered rivers are well known (Bunn & Arthington, 2002):

1. The altered flow changes the ecology of rivers at spatial and temporal scales.
2. Aquatic species evolved live histories according to the natural flow regime.
3. There is less longitudinal and lateral connectivity in the river.
4. There is a higher chance of introduction of exotic and introduced species.

In this thesis, the focus will be on reservoirs and environmental flows (e-flows). In the last couple of decades, the number of reservoirs has drastically increased. Worldwide, there are over 57,000 large dams (>15 m), which are mostly used for hydropower production (Day of Action Coordinator & International Rivers, n.d.). The residual water originating from the dam is often only a percentage of the natural flow and with an altered water chemistry (Uehlinger et al., 2003). The consequences are drastic at hydrological and ecological levels. It causes consolidation of the riverbed and a general accumulation of sediments (Döring & Hossli, 2014), thereby affecting many trophic levels. There is more algal growth, a change in the benthic community (Cazaubon & Giudicelli, 1999) and on the recruitment of fish (Robinson et al., 2004). In particular, many species adapted life cycles to these stochastic flow disturbances (Turner & Dale, 1998)(Lytle & Poff, 2004) and evolved life history traits (Knispel et al., 2006). In addition, river fragmentation can cause isolation of populations and an interruption in river connectivity. For instance, Merritt and Wohl (2006)showed a difference in riparian plant communities upstream and downstream of a dam. Furthermore, the number of Ephemeroptera and Diptera (without Simuliidea) compared to natural streams in fragmented streams decreased. Monaghan et al. (2005a)showed that dispersal of Ephemeroptera is affected between stream fragments.

In order to restore river ecosystems, e-floods (e-flows) have been conducted. In the last few decades, the application of e-floods have gained popularity. These floods were mostly conducted in order to protect the natural resource and endangered species of a river (Olden et al., 2014). Nevertheless, there is a tension field between the different stakeholders. The society, politics and management of a dam have often other objectives regarding the river ecosystem. Gillespie et al. (2015) analyzed 76 studies on e-floods. They showed that the turbidity of the river increased with flow magnitude, electrical conductivity decreased and there was no change in river temperature. However, they could not detect any relationship between flow magnitude and macrozoobenthos (MZB). The review of Poff and Zimmermann (2010) suggested that there is a negative relationship between flood magnitude and fish abundance. Nevertheless, these reviews only examined single flood events on a global scale. Gillespie et al. (2015) proposed the importance of the site as a specific factor. For instance, a long-term study of 10 years with 1-2 e-floods per year at the Spöl river in Switzerland showed a MZB-flood magnitude relationship. Even more, the MZB assembly changed into a more resilient MZB composition (Robinson, 2012). Considering the high cost of an e-flood, there is a strong need of long-term data.

MZB may be considered as keystone species in a river ecosystem and are applied as indicators of water quality in running waters, the mentioned monitoring project at the Spöl was started in 1999 on the two dam regulated sections of the river (upper and lower Spöl). The main objective of this study was to examine the effects of one to two e-floods per year over

Introduction

15 years on the MZB assemblages and taxa richness in each section. Based on the different sediment properties, there should a more sensitive response over the years in the upper than the lower Spöl.

Material and Methods

1.1 Study site

The river Spöl is situated in the central massive of the central Alps and originates from Punt dal Gall reservoir on the border with Italy (Figure 1). *Picea excelsa* and *Pinus mugo* are the most abundant trees in this area, whereas the alder (*Alnus incana*) is more common in the riparian margin. The lower reservoir is ca. 5 km downstream of the canyon like valley. For the long-term Macrozoobenthos study, the upper Spöl sites (Table 1) were situated 400 m below the Livigno reservoir (coordinates: 46°37′ N, 10°11′ E). The elevation is 1690 m a.s.l. with a slope of 0.9% and a channel width of 10-12 m. At Punt Periv, 2.3 km downstream of the Livigno reservoir (coordinates: 46°38′ N, 10°11′E), the altitude is 1660 m a.s.l. and the slope is 1.3 % with a channel width ca. 10 m. The lower Spöl study sites are 300 m below the Cluozza (coordinates: 46°41' N,10°06' E) inflow and on the other hand 5 km below Ova Spin reservoir (coordinates: 46°68′ N,10°14′ E). The altitudes are 1500 and 1480 m a.s.l. with slopes from 1.1 and 1.5 %, respectively. The substrate in the upper river consists of stones and boulders, while the lower part is covered with gravel and smaller stones.

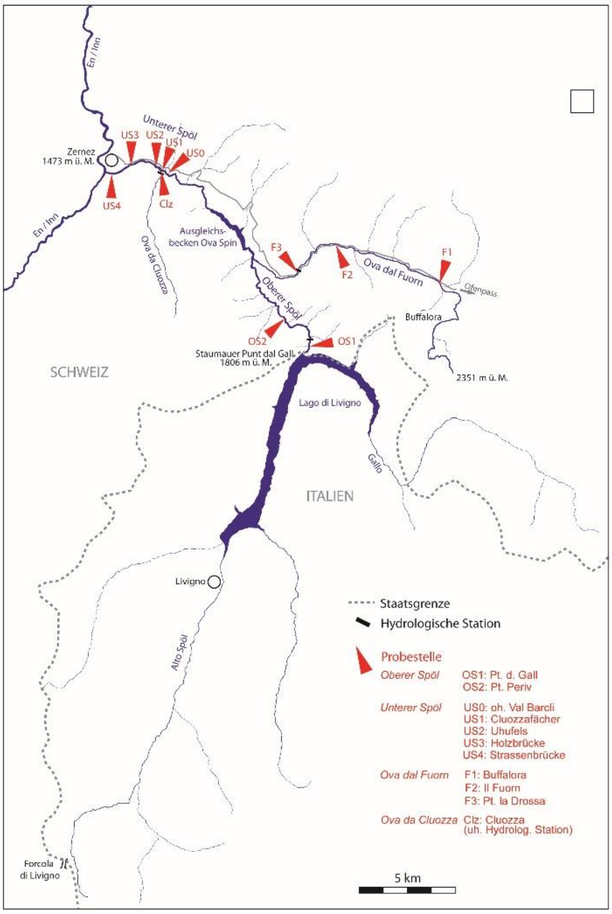

Figure 1: Map of study site, showing the study sites OS1 and OS2 in the upper spöl and USP2 and USP3 in the lower Spol. Map provided by Johannes Ortlepp.

According to Scheurer and Molinari (2003), the discharge of the upper Spol (Figure 2) was 6 to 13 m^3/s with maximum peaks of 120 m^3/s. After building the dam in 1970, the residual flow fluctuated in summer from 2.5 m^3/s to 0.55 m^3/s in winter. There were two flushes implemented in 1979 and 1990 with the peak of 35 m^3/s and also in 1985 at 10 m^3/s. In 2000, the residual flows changed from 1.45 m³/s to 0.55 m³/s depending on season. In order to improve the ecological conditions, the experimental flood program was initiated in 1999 by the power company (Engadiner-Kraftwerke). There were 5 separate floods in a pilot phase from July 2001 to August 2002 (with length of 9.5 to 11.8 h and peak discharge from 12 to 44 m³/s). After 2002, there were two floods per year with a higher peak during summer, and in autumn there was a minor flood. The flood durations ranged from 7 to 9.3 h. Due to a discharge accident in 2013, there was only one large flood.

The macrozoobenthos community was mostly dominated before the experimental floods with 8000 to 15000 individuals/m² of *Gammarus fossarum* (Uehlinger et al., 2003). The peak flows of the lower Spol happened four times in 2000 and 2001, always at 15.9 m³/s with a duration of 11.5 h. Since 2002, the floods have been shorter and only once per year with a discharge ranging from 25 to 50 m³/s. The residual flow ranges from 0.9 m³/s in summer (May-September) to 0.3 m³/s in the remaining year.

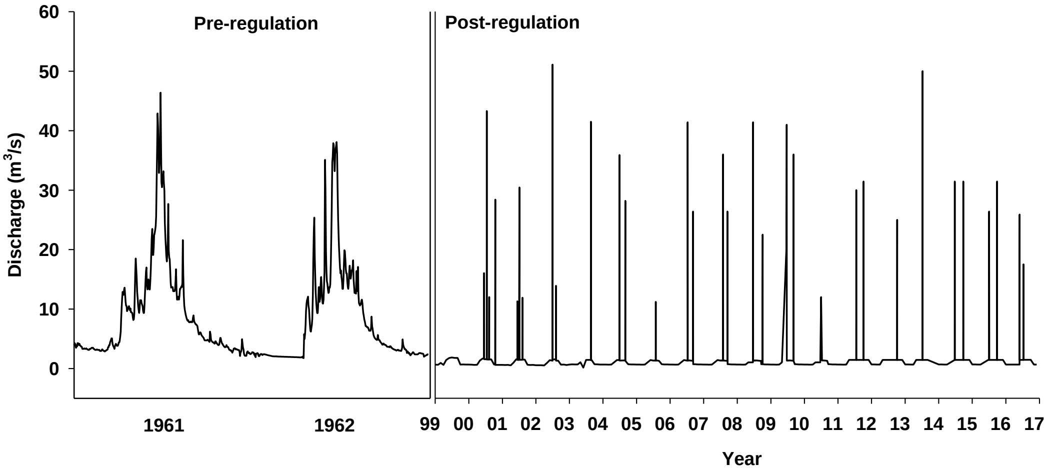

Figure 2: Discharge in m³/s in the upper Spol.

Table 1: Characteristics of the long-term (1999-2014) macrozoobenthos study sites.

Parameter	upper Spol		lower Spol	
Site	OS1	OS2	USP2	USP3
Altitude at study sites (m a.s.l.)	1690	1660	1500	1480
Channel slope (%)	0.9	1.3	1.1	1.5
Channel width (m)	11	10	8	15

1.2 Sampling Methods

Macrozoobenthos

The long-term monitoring started in November 1996. Each site was visited in summer and in autumn. Each sample consisted of three subsamples in runs, riffles and the margin of the river with an area 0.09 m^2 each (total 0.27 m^2). The samples were taken by kick-sampling with a net of 200 μm mesh and preserved in Ethanol. The sampling, determination and counting of the macrozoobenthos was performed by the Hydra-office (Constance, Germany).

Transect Profiles

Upper Spol

In 1999, transect profiles were set up and marked (Punt dal Gall (PDG) and Punt Periv (PP), (App. Table 2, App. Table 3). Several measurements were made from 1999-2001 before and after an e-flood. A later measurement of the transect profiles were made in 2014 in PDG and PP.

Lower Spöl

In 2000, the set up and labeling of transects at USP1A, USP1B, USP2 and USP_Uhu was performed. There were several transect measurements from 2000-2002 performed. In 2013, there were additional measurements performed.

1.3 Analysis

Macrozoobenthos

To examine the shift in assemblage structure, nonmetric dimensional scaling (NMDS) was applied using taxa densities and relative abundances based on 35 (OS1), 31 (OS2), 38 (USP2) and 37 (USP3) sampling visits over the study period.

Since I was interested in the influence of the e-floods on macrozoobenthos of the river Spöl, the Shannon index of species diversity was calculated for each monitoring event and location. This index takes into account not only the number of different species present but also their relative abundances and can therefore serve as a proxy for biodiversity. It was set as the outcome variable of the analysis. To assess how macrozoobenthos diversity was affected by flooding and how long after a flood a possible effect might still be noticeable, the time lapse since the last flood was determined for every monitoring event and set as a fixed effect. Moreover, flood magnitude and duration were also set as fixed effects to assess their influence on the river's macrozoobenthos. Since these three variables are at different scales, they were normalized before creating the model. Location (lower/upper Spöl), site (USP1, USP2, OS1, OS2) and date of the monitoring event might also affect the outcome but are not relevant to our research question, which is why they were set as random effects.

Some analytical difficulties were encountered with the very early monitoring events, which took place several years before the first artificial flood was produced and therefore had no measurements for any of the fixed effects. The problem was handled by setting their flood magnitudes and durations to 0 and adding a very high number (350 days) as the time lapse since the last flood as an approximation for the absence of flooding events. Statistical analyses were performed using R Studio (R version 3.1.2) and the packages "vegan", "nlme". Since the data set includes random as well as fixed effects, a linear mixed-effects model was created, with site added to the model as being nested within location. The plot diagnostics showed the model to suit the data adequately. ANOVAs were then conducted to test for variation in macrozoobenthos diversity with respect to time lapse, magnitude and duration of each flood.

Transect

The differences in the riverbed profile were calculated by Image J (Schneider, Rasband, & Eliceiri, 2012). Sites in the upper Spöl had a sample size of 47 (PDG) and 51 (PP), whereas sample size in the lower stretch (USP) was 12.

To examine differences between sites with regard to area differences, an ANOVA was performed. The graphs and statistical analysis were performed in R Studio.

Results

1.4 Community Assembly

Upper Spol

After the first flood in 2000, the taxa number and density experienced a short-term decrease, but with a fast recovery (Figure 3). The density from 10,494 individuals/m^2 in 1999 decreased to 9407 individuals/m^2 in 2000-2001. Nevertheless, the density recovered from the altered flow regime in 2003 and showed a pattern with some yearly but stable variation. Within the different taxa, the abundances showed different patterns. For instance, *Gammarus fossarum* showed before the first three flood events a relative abundance of 87% of the total MZB individuals After the flows in 2000, the abundance dropped from 71% to 14% in 2001. After a recovery, the relative abundance reached the level of 2000 in 2008. But two major floods 2009 and 2010 decimated the abundance of *Gammarus* again, whereas *Protonemura* sp. increased up to 25% in 2009 and 2010. The Orthocladiinae only showed a decline after the sediment accident in 2013. Also new taxa colonized the two sites: in 2012, *Rhynchelmis limosella* appeared at both sites and as well as *Stylodrilus* sp. in 2003.

Lower Spol

The lower Spol MZB density showed less variation during the year. Nevertheless, the taxa number increased. Equally to the upper Spol, the density of *Gammarus fossarum* was reduced after the first and large flood in 2009 and *Protonemura* sp. increased. As well, *Rhyacophila torrentium* density increased at both sites. Ephemeropterans such as *Rhithrogena alpestris*, *Rhithrogena degrangei*, *Rhithrogena grischuna* and *Rhithrogena puthzi* colonized the downstream site US3 first and after some years also site US2.

1.5 NMDS and Lme

The NMDS analysis, which was completed using log-transformed taxon densities, indicated a temporal shift in assemblage composition in both river systems (Figure 5). The upper Spol showed less change than the lower Spol. This pattern was also revealed in the Simpson index (Figure 6).

Results

Despite major changes in community assembly, the lme could not indicate a time lapse since the last flood (ANOVA, N=56, p=0.211), and flood magnitude (ANOVA, N=56, p=0.701) or duration (ANOVA, N=56, p=0.946) initiated no detectable shift in the values of the Shannon index of species diversity. Also, no interactions were found between any of the fixed effects (time lapse since the last flood, magnitude and duration).

1.6 Transect measurements

The transect measurements showed differences during the measurement periods (Figure 7). Interestingly, the area difference of the profiles did not increase with time but differed among sites.

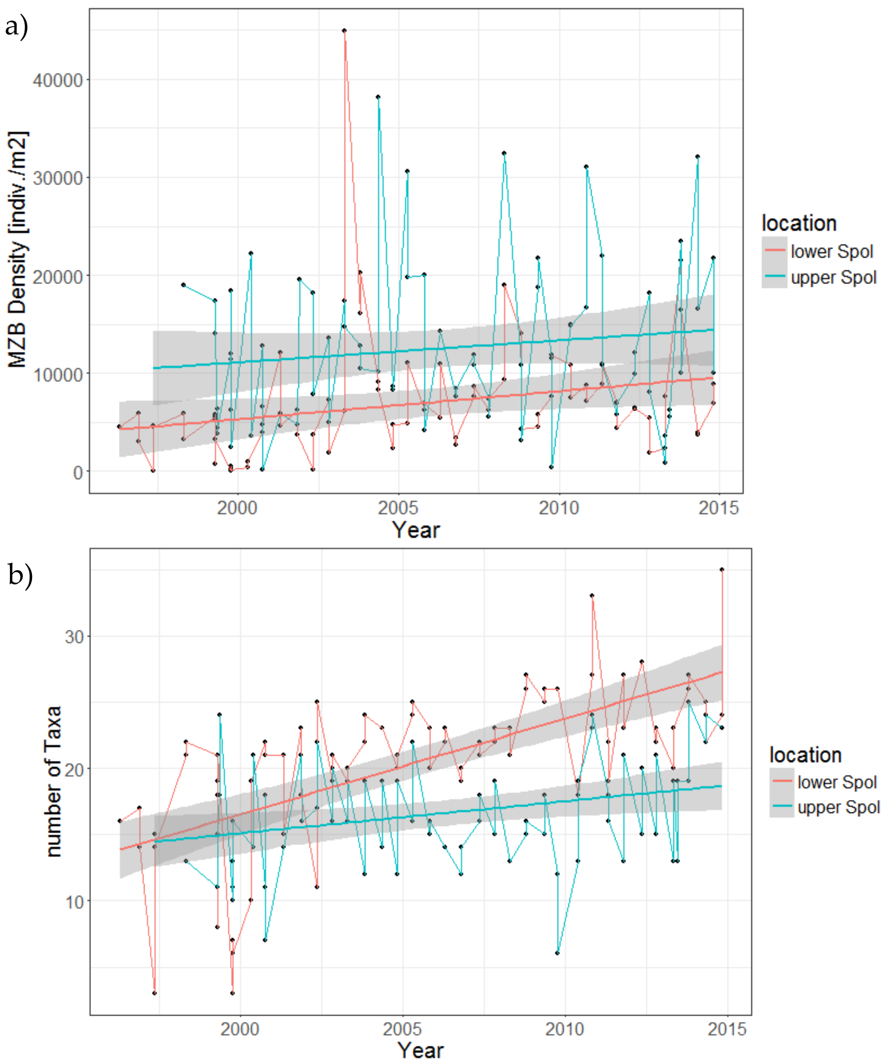

Figure 3: a) Mean MZB density in the lower and upper Spol. b) Mean number of taxa in the lower and upper Spol. The grey bars indicating standard error.

Results

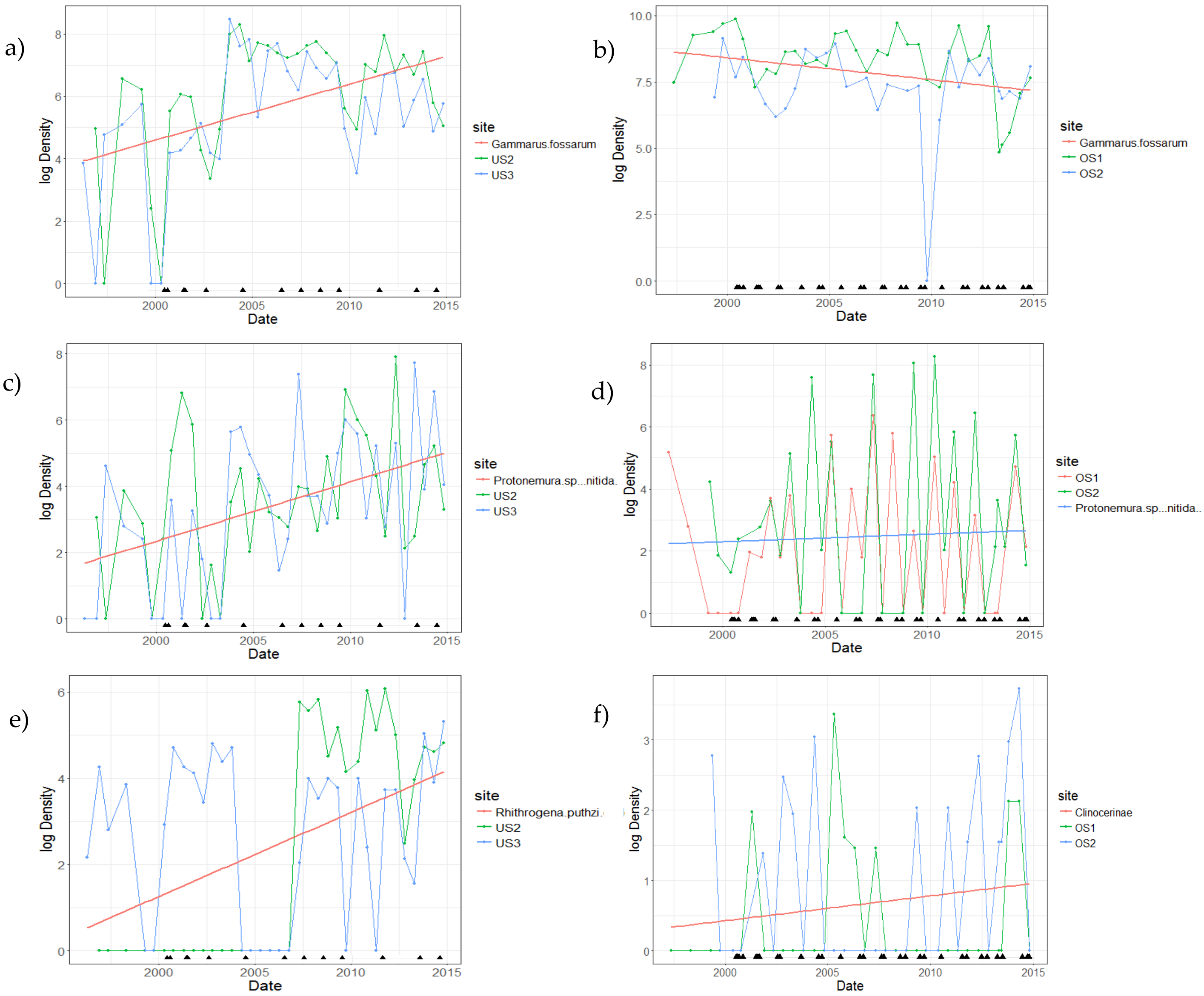

Figure 4: a-b) Log-transformed Gammarus fossarum *density in the lower and upper Spol. c-d) Log-transformed* Protonemura nitida *density in the lower and upper Spol. e) Log-transformed* Rhithrogena puthzi *density in the lower Spol. f) Log-transformed Clinocerinae density in the upper Spol.*

Results

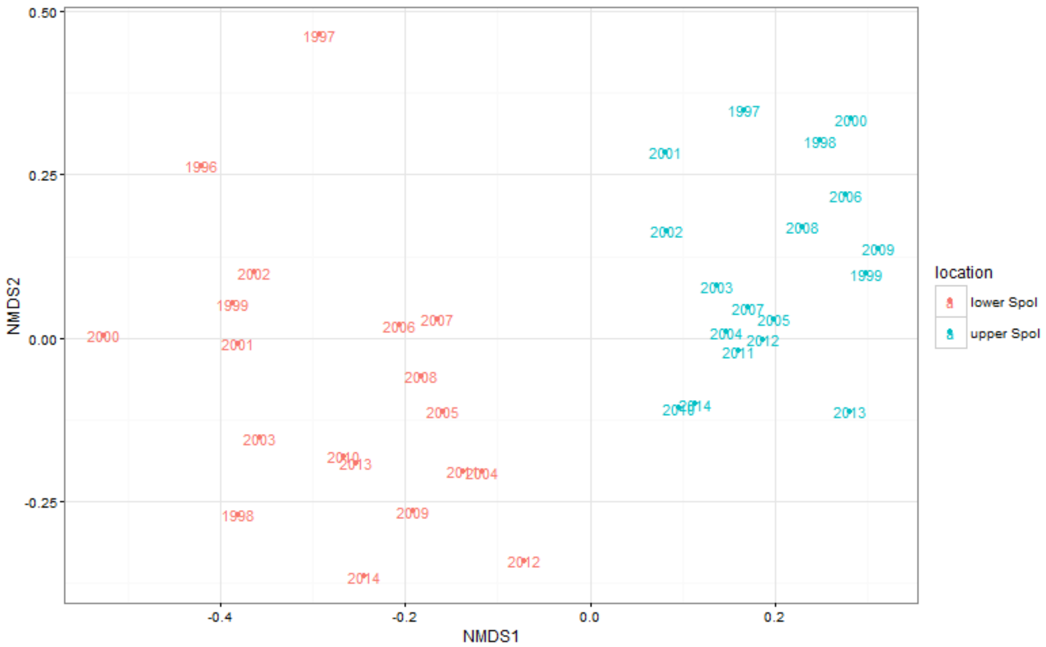

Figure 5: NMDS plot of the upper and lower Spol based on log-transformed densities.

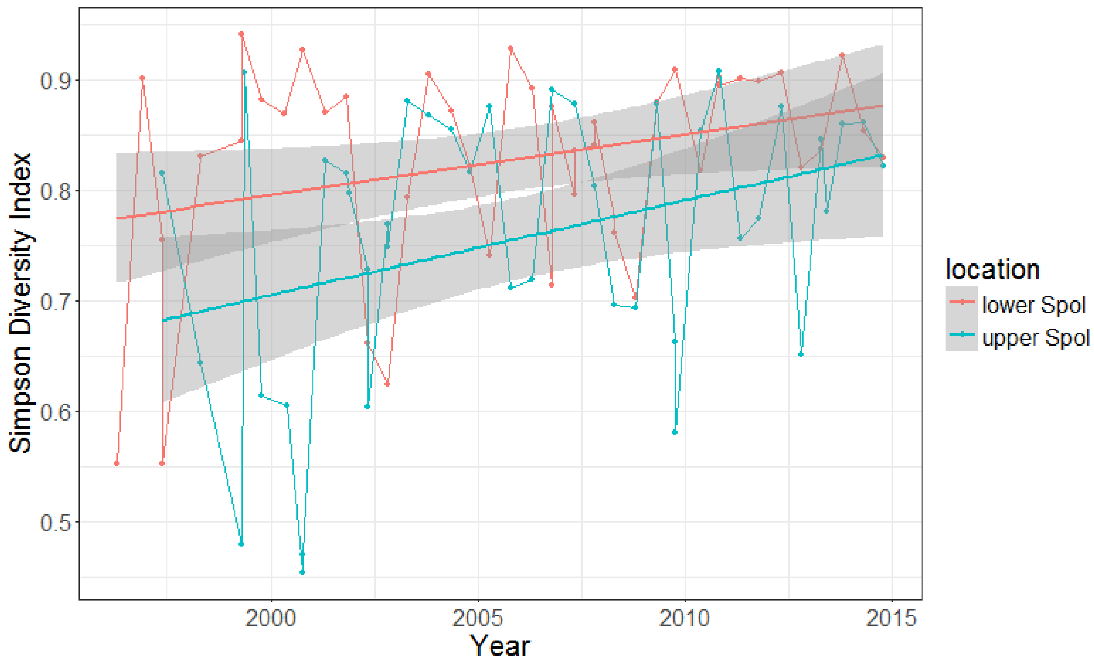

Figure 6: Simpson index of macroinvertebrates in the upper and lower Spol.

Results

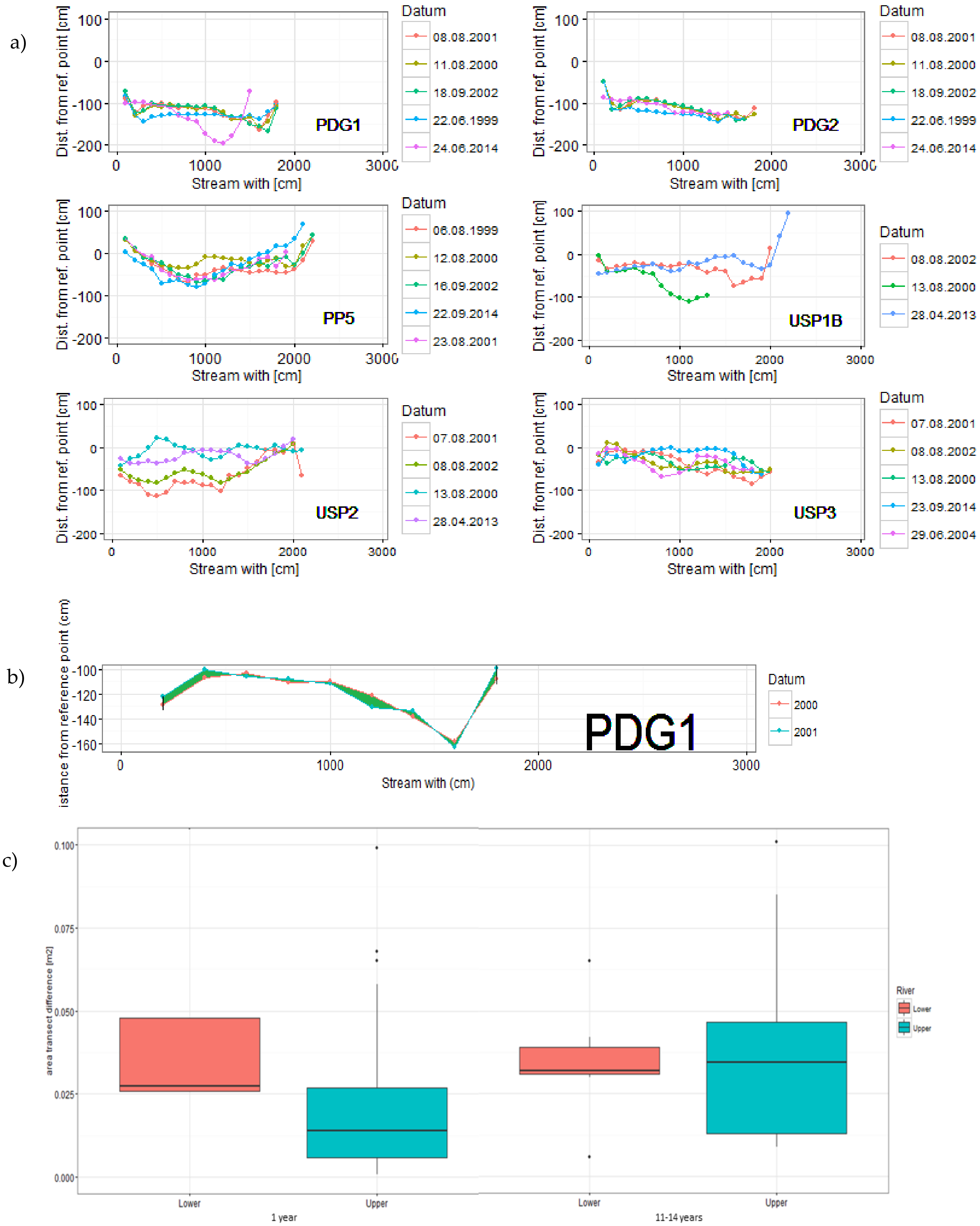

Figure 7: a) Selection of some river transect profiles measurements. b) Measurement of the differences in the area between two profiles. c)The measured aerial difference of the upper and lower Spol within one year and more than 11 years.

Discussion

In order to identify the effects of e-flows to the MZB community and river profiles, a 17- year study was conducted at the river Spöl. The two river sections experienced different amount, magnitude and frequency of high flow events. Due to different sediment properties, inflow and flow management, we expected different effects in terms of MZB abundance and density in the two river stretches. In contrast to expectations, the lower Spol showed a greater shift in community assembly and more colonization of new taxa. The transect differences in the profiles were more site dependent than with river section.

The upper Spol showed more properties of an alpine river and should be therefore more sensitive (Hannah et al., 2007) to changes than the lower Spol (the discharge and sediment input is also dominated by the inflow of the Culozza river). By examining the colonization of new species in the lower Spol, new taxa such as *Rhithrogena alpestris* were first detected in the downstream site (US3). This is an indication for the spread of the population from the lower part or even the Inn. Trait analysis from Buffagni et al. (2009) showed in their book the sediment preference of *Rhithrogena alpestris* as mesolital. It could also indicate an increase in fine sediment. Therefore, e-floods may have had a positive effect. Moreover, the upper Spol is more isolated (Monaghan et al., 2001) from other tributaries and is located between two storage reservoirs. Caudill (2003) showed with the measuring of stable isotopes, that dispersal between communities is not well understood and therefore the effects difficult to show.

However, the upper Spol experienced more frequent and higher flushes than the lower Spol. For instance, only the upper Spol MZB density changed at the start and the greater flows in 2009 and 2010 only reduced *Gammarus* sp. and increased the *Protonemura* sp. population. Because of the sediment impact from tributaries, the degree of consolidation could have been greater in the lower Spol. With the e-flows, fine sediment could be redistributed and generate habitats for MZB.

Nispel & Ubini (2015) detected in the National park 34 stonefly taxa, whereas only a few taxa were determined in the whole study area of the Spol. The most abundant were *Leucta sp*. and *Protonemura nitida*. The *Leuctra* spp. and *Protonemura nitida* are mostly eurytherm (Graf et al., 2009), while the other taxa favor cold temperatures and showed higher abundances in springs and brooks (Nispel & Ubini, 2015). This pattern of abundance reveals the higher temperature of the reservoir water in the river. *Isoperla rivulorum* was the only taxa which prefers cold water that was able to colonize a new site (OS1) after the higher flow in 2009 and had increasing abundances at the other sites.

The profile measurements showed a difference within sites more than in the time span or the river stretch (upper/ lower Spol). These results resemble the dynamic river system with the location of sediment being dependent on many variables besides flow.

This long-term study showed the shift in community assembly in two different rivers. Even though the lme analysis did not show that the experimental floods have an influence on the diversity of MZB. The colonization and the positive reaction of the *Protonemura* sp. suggested that a higher magnitude flow in both rivers may be influential on population abundances. Especially in the lower Spol, the measurement of transect profiles before and after each flood would be of interest, despite the accumulation of sediment at the lowest downstream sample site US3. These data also show, the need of annual floods. Townsend et al. (1997) demonstrated the shift in the benthic composition favors generalist taxa tolerant of unstable conditions. But the resilience of taxa and tend to shorten the effect on the invertebrate community (Matthaei, Arbuckle, & Townsend, 2000).

CHAPTER 2: DRIFT PATTERNS DURING E- FLOWS

Introduction

The flow regime is one of the most important parameters for all kinds of streams. It has been shown that the flow regime effects the benthic communities (Resh et al., 1988) and the stream's hydrology massively. However, the extensive use of freshwater with urbanization, agriculture, and the building of hydropower plants regulate the natural flow regime of streams. The observed consequences are often an altered flow regime and a lower discharge within the stream. In particular, a decrease of the stream's flow velocity, depth and wetted width have been observed (Dewson et al., 2007). On the other hand, the sediment deposition (Wood & Armitage, 1999) and temperature (Meier et al., 2003) increases lead to a higher algal biomass and a decreased habitat diversity within a given stream. In turn, the invertebrate community (macrozoobenthos) changes in terms of their composition, abundance and diversity (Cazaubon & Giudicelli, 1999). The review of Dewson et al. (2007) shows, however, no clear result in the macrozoobenthos' (MZB) density, but a decrease in the general taxonomic richness of the stream. The invertebrates are assumed to select habitats most suited to their requirements (Suren & Jowett, 2006). Hence, during long lasting reduced flow, invertebrates which prefer fast flowing water will decrease. Other invertebrates, which prefer slow flowing water, such as midges, snails and oligochaetes will increase (McIntosh et al., 2002). As introduced in Chapter 1 (S.2), environmental-flows (e-flows) can be used to mitigate the unwanted effects of altered flow regimes. E-flows are considered especially useful in residual flows to restore the ecological integrity of the river ecosystem (Poff et al., 1997). In general, a flood is described by Lake (2000) as a "pulse disturbance" and is characterized by its magnitude, duration, frequency, timing and the rate of change (Poff et al., 1997).

During an artificial flood, drift, which is defined as ''the downstream transport of aquatic organisms in the current', is increased (Brittain & Eikeland, 1988). The invertebrates experience catastrophic drift during a flood and are carried away passively. Therefore, floods are often related with an increase in drift density (Poff, Decino, & Ward, 1991). The process of drift can be divided into three phases: the departure from the substratum, the movement through the water column and the return to the substratum (Ciborowski, 1987). The invertebrates also adapt to the flow impulses and therefore floods can be considered as an ecoevolutionary force (Lytle & Poff, 2004). Indeed, studies have shown different drift patterns among different MZB taxa (Palmer et al., 1992). These were mostly in response to the discharge within streams (Crisp & Robson, 1979), duration of the flood and the particular substrate from which the invertebrates departed (Gibbins et al., 2005). In particular, Bruno et al. (2016) found that Chironomidae and *Baetis* spp. are highly susceptible to displacement, while net-spinning caddisflies, Simuliidae and Hydrachnidia are more resilient towards high flows.

In this study, we assessed the drift patterns of MZBs over three separate e-floods in three different streams in Switzerland. Thereby, we used three different kinds of e-floods. These different e-floods are distinguished by their flow magnitude, duration, and season within the year. We investigated how the flow magnitude correlated with MZB' drift and seston. In particular, we studied if there are general discharge thresholds for the drifting of MZBs. Moreover, effects of the flood were investigated using periphyton of stones and MZB density before and after each flood.

Methods

1.7 Study site

Sarine

The Sarine River rises from Sanetsch (2252 m a.s.l.). The climate is pre-alpine with an average temperature of 7.1 °C and average annual rainfall of 1200mm. The Sarine has an average slope of 1.0% (Mendonça Santos et al., 1997). The Sarine is fragmented by several hydropower dams. The largest hydropower reservoir is situated in Rossens with a surface of 9.4 km^2 and a volume of 200 million m^3. It was constructed in 1948. Figure 8 shows the discharge before and after the dam construction (Ribeiro et al., 2014). Our sampling point was located 11.5 km below the Rossens reservoir (570 m a.s.l., 46°45′51.317″N 7°06′52.845″E). The e-flow reached a maximum discharge of 255 m^3/s for 3 hours on 14-15. September 2016.

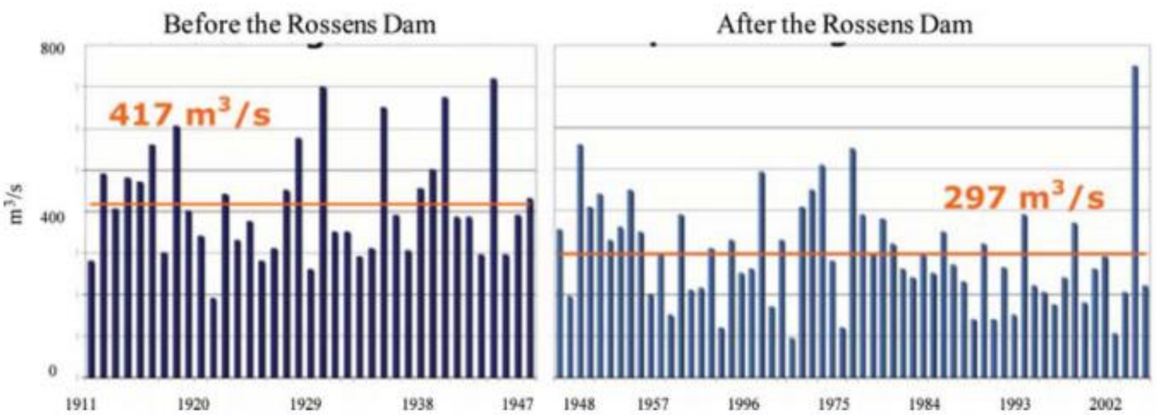

Figure 8: Annual peaks of the Sarine River from 1911 to 2007 in Fribourg (Swiss Federal Office for the Environment, 2007)

Spol

The location of the upper and lower Spol, the climate, vegetation and discharge are described in 1.1 Study site (S.5). The flood in the upper Spol reached a maximum of 30 m^3/s for 1.2 hours (30.05.2016), while the flood in the lower Spol lasted for 2.75 hours at a maximum of 25.9 m^3/s (08.06.2016).

Methods

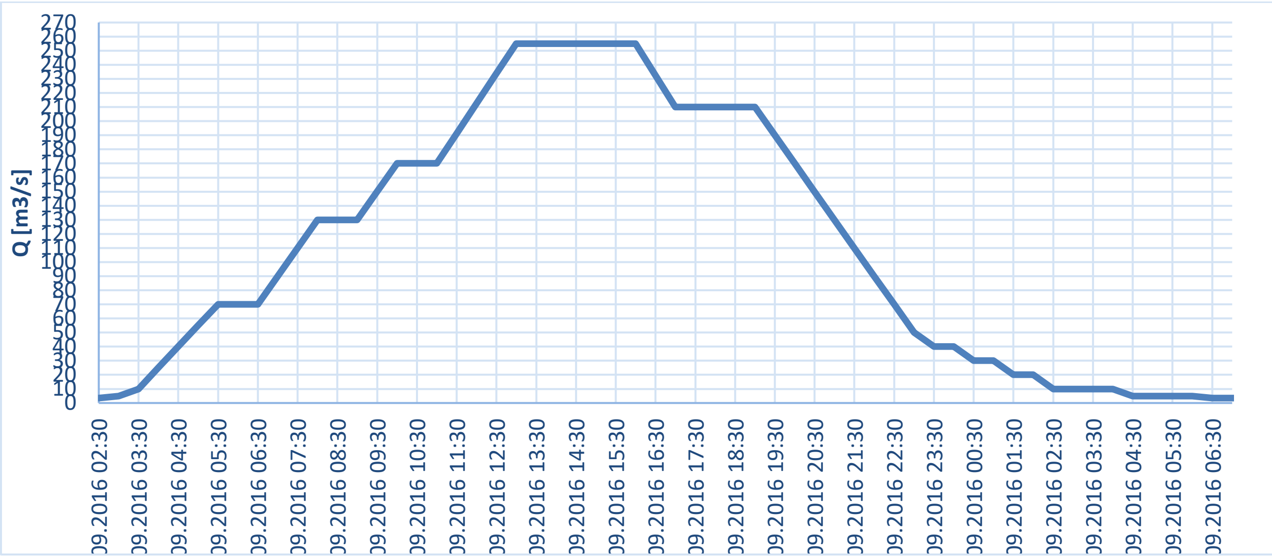

Figure 9: Expected hydrogram of the artificial flood of the Sarine.

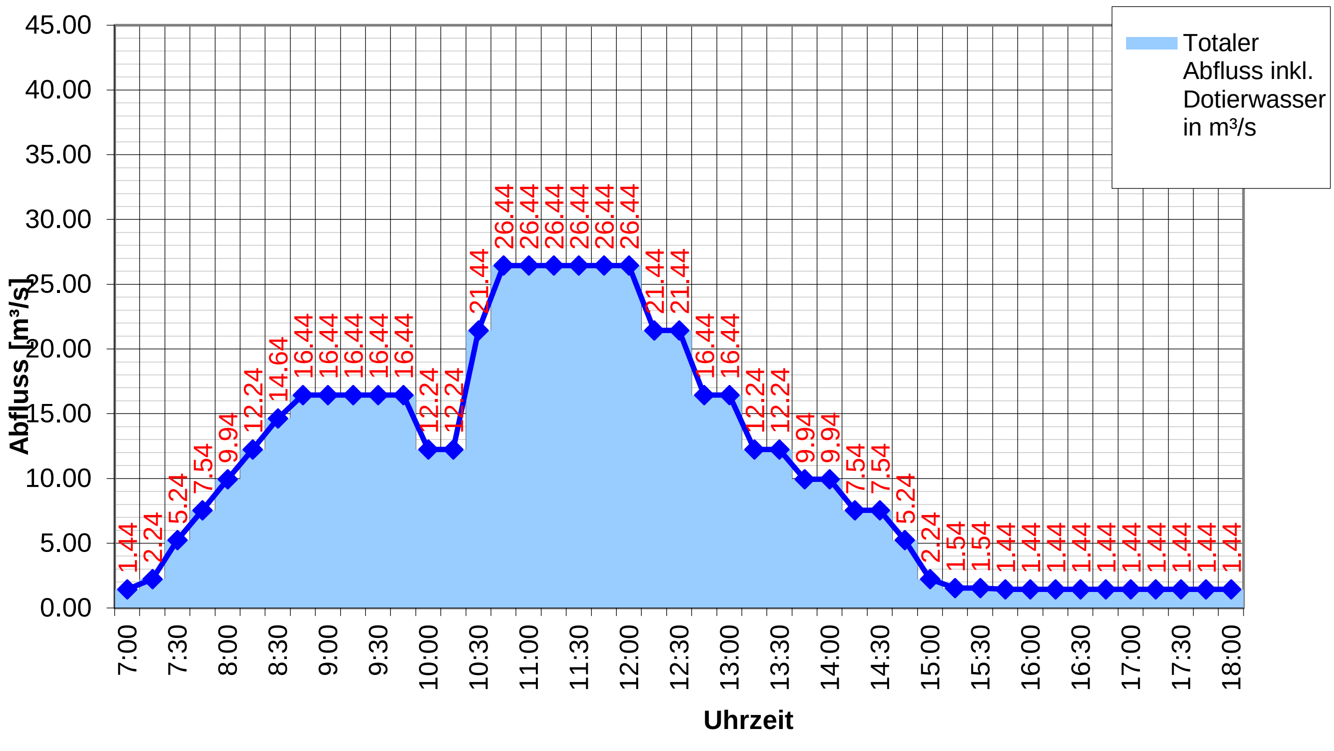

Figure 10: Hydrogram of the experimental flood of the upper Spol on 30 May 2017.

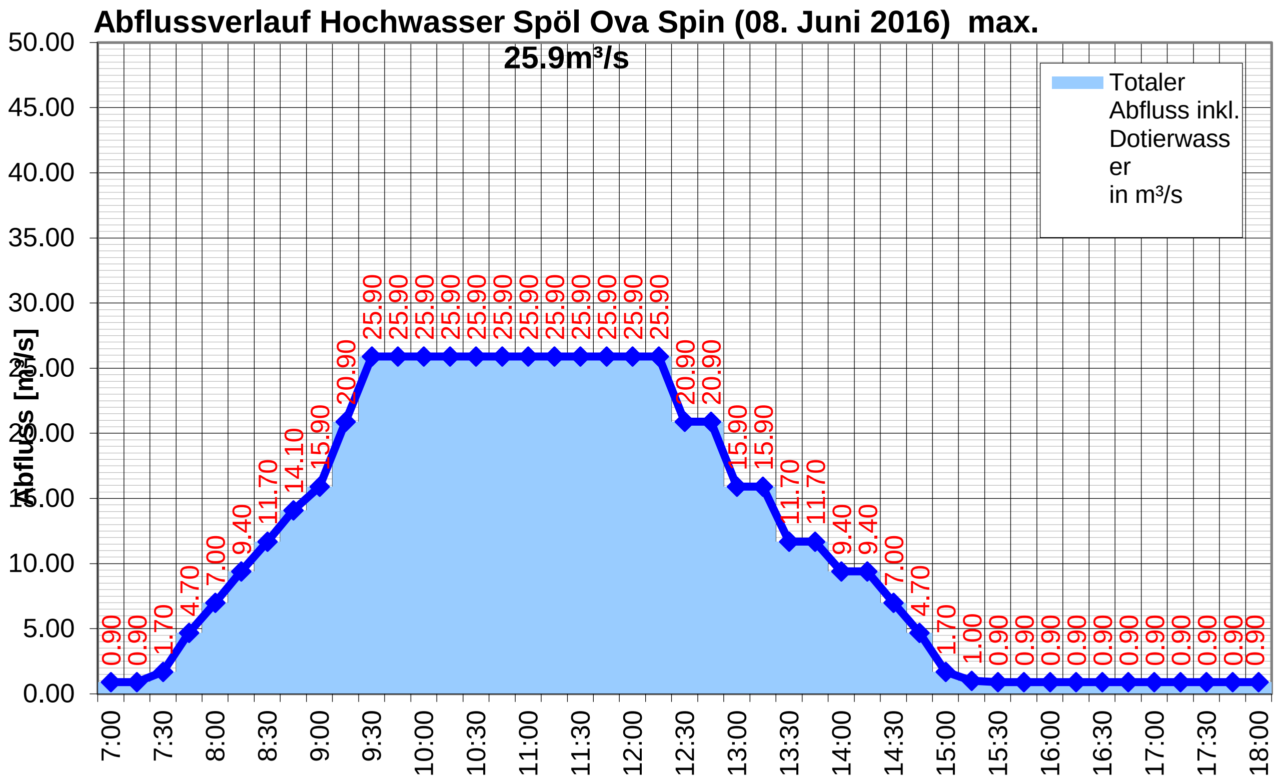

Figure 11: Hydrogram of the experimental flood of the lower Spol on 8 June 2017.

1.8 Sampling Methods

Measures collected during floods

Invertebrate drift and organic matter in transport (seston) was collected before, during and after each flood. The Spol samples were collected at 20- to 40 min intervals, resulting in 20 samples per flood. During the rise of the flood, more frequent samples were collected, whereas the sampling interval was increased later in the falling limb. Due to the long duration (28 hours) of the Sarine flood, the samples were collected in 30 min- to 7 hour intervals, resulted in 28 samples. All samples were taken using a 400-µm mesh nylon net attached to a 15 x30 cm frame and stored at -20°C. The sampling times were dependent on the amount of material and fluctuated from 30 s to 5 min. The invertebrates were handpicked from each sample, counted and determined in the laboratory. The remaining material was used for the ash-free dry mass (AFDM), which is used to determine the seston quantity. The AFDM of the samples was determined by first drying them at 60 °C, weighing, and then the samples were burned at 500 °C for 4 h and reweighed.

Methods

During each sample, velocity (MiniAir2 velocity meter) (Schiltknecht Ag, Gossau, Switzerland), pH (WTW pH3110, Weilheim, Germany), turbidity (nephelometric turbidity units; NTU) (Cosmos, Züllig AG, Switzerland) and conductivity (µS/cm at 20°C) (WTW LF340, Weilheim, Germany) was measured. Additionally, 0.5-L water sample was collected from the thalweg in a polypropylene bottle for analysis of nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonium (NH_4-N), soluble phosphorus (PO_4-P), dissolved organic carbon (DOC), and particulate organic carbon (POC). Each bottle was rinsed three times with sampling water before collecting the sample and was cold stored till analysis in the laboratory on the following day.

For the periphyton measurement, 5 rocks (cobble-size) were collected in plastic bags and stored at 20 °C. In the laboratory, the periphyton was removed with a wire brush into a basin with water. The rock was measured on the a-, b- and c axes. An aliquot of the water-periphyton suspension was filtered through a glass fiber filter (Whatman GF/F). The first filter was used for AFDM determination and was processed as the seston AFDM samples.

Before and after each flood, benthic macroinvertebrates were collected in riffle and run habitats. The samples were collected with a Hess sampler (0.045 m^2, 250- µm mesh, n = 3 samples). The samples were stored in a plastic bottle with 70 % EtOH. The invertebrates were handpicked in the laboratory, identified and counted.

1.9 Analysis

Data analysis

The drift, physical and chemical parameters were plotted against time. All plots were performed using the statistical program R (R Core Team, 2016). Measures of drift and seston during floods also allowed comparison of response patterns of living organisms to that of nonliving organic particles from floods. Plots of drift and seston against discharge revealed the different hysteresis patterns between early and later floods, and between floods of different magnitude. Plots of drift and seston against time of day revealed temporal concentration patterns in relation to flood timing between floods of different magnitude.

Results

1.10 Flood effects on stream benthos

The floods caused drift of the MZB. Although the three floods were in different seasons, had different discharge and were different in the duration and in different river systems, the increasing slope of the discharge provoked catastrophic drift in the first 30 min.

Upper Spol

Due to increased turbidity, the water discharge had to be reduced after 3 hours. Abundant genera such as *Gammarus* sp., *Baetis* sp. and *Protonemura* sp., and the family Chironomidae showed a large response in the first flow maximum of 16.24 m^3/ s (Figure 14). Caddisflies showed no specific response to the increased flow in discharge.

Lower Spol

The lower Spol had a maximum discharge of 25.9 m^3/ s. The highest amount of drift was measured in the increasing discharge slope at 11.7 m^3/ s (Figure 13). Similar to the upper Spol, *Gammarus* sp., *Protonemura* sp. and the family of Chironomidae all responded to the increase in flow by drifting (Figure 15).

Results

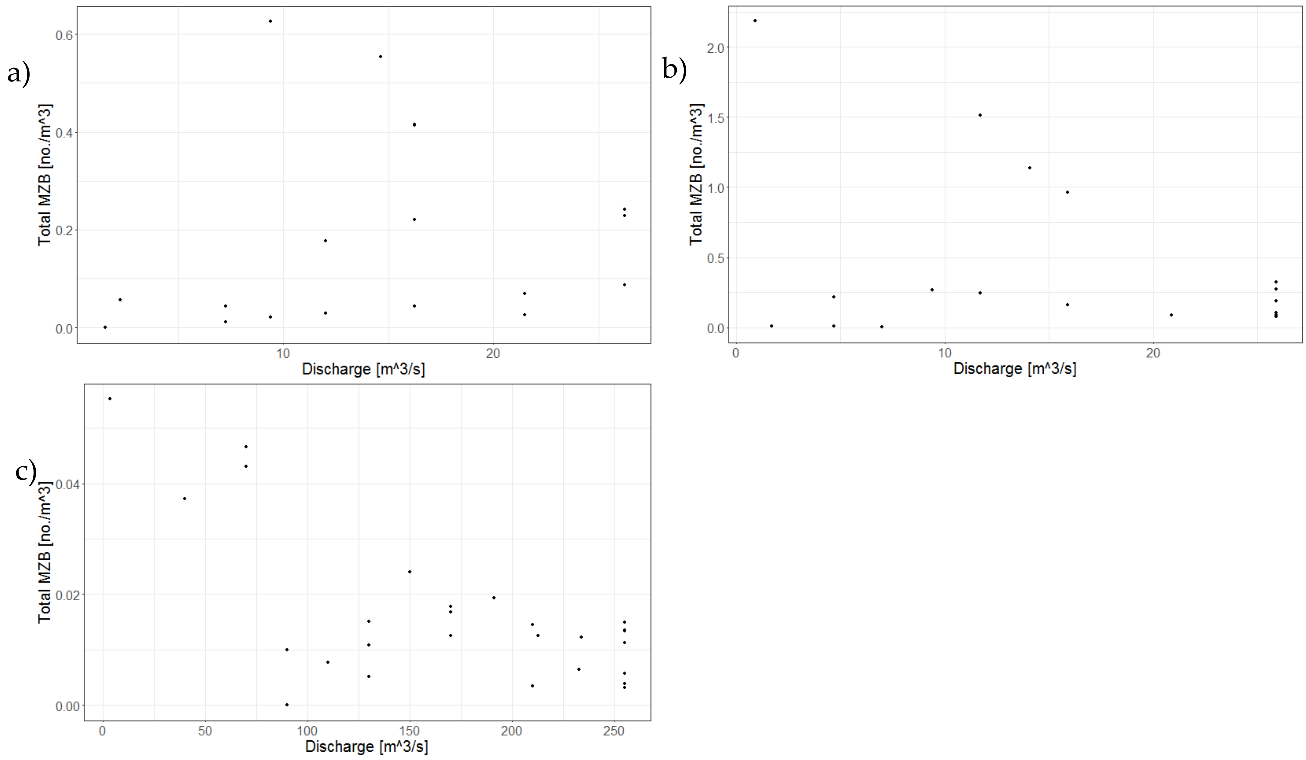

Figure 13: a) Upper Spol: Total MZB drift against discharge. b) Lower Spol: Total MZB drift against discharge. c) Sarine: Total MZB drift against discharge.

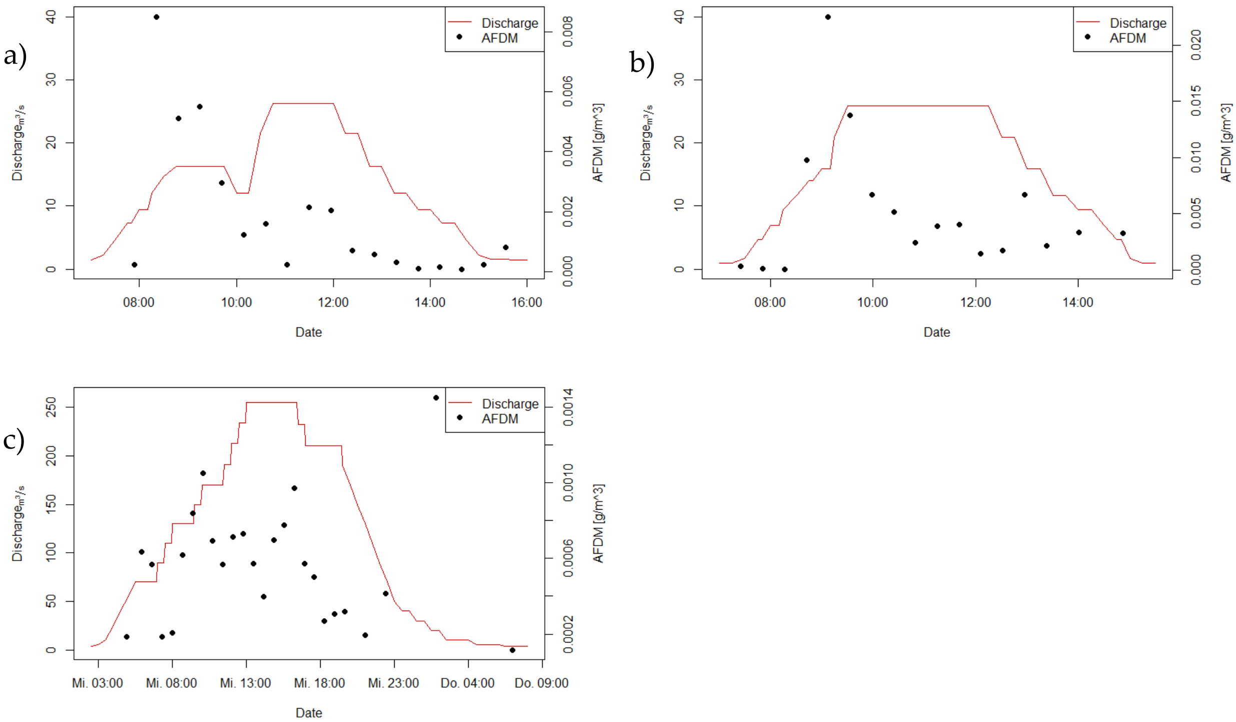

Figure 12: Discharge of the a) upper Spol, b) lower Spol and c) Sarine with AFDM of seston against the time.

Results

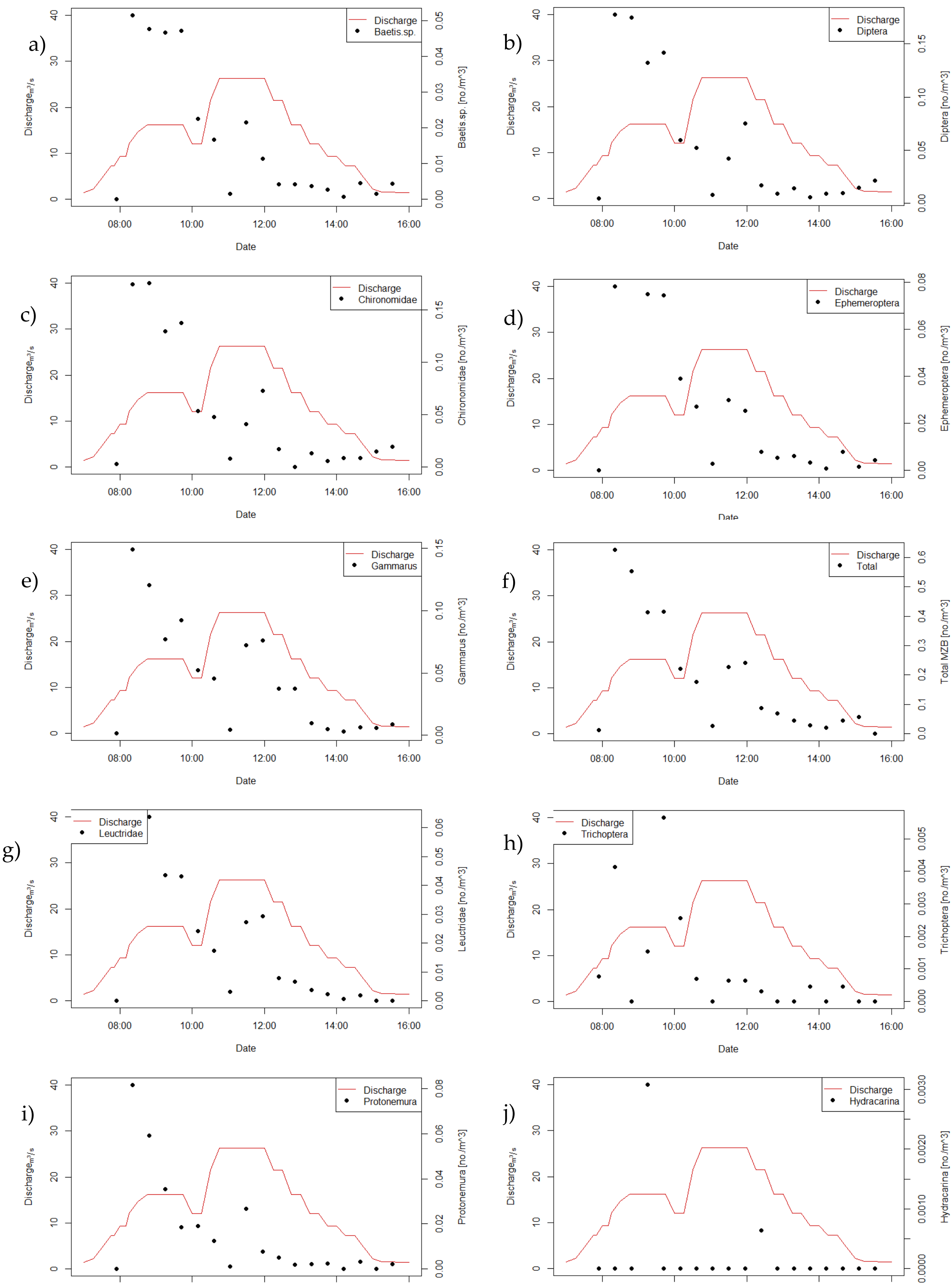

Figure 14: a-j) Discharge of the upper Spol with different Taxa or taxonomic groups against time.

Results

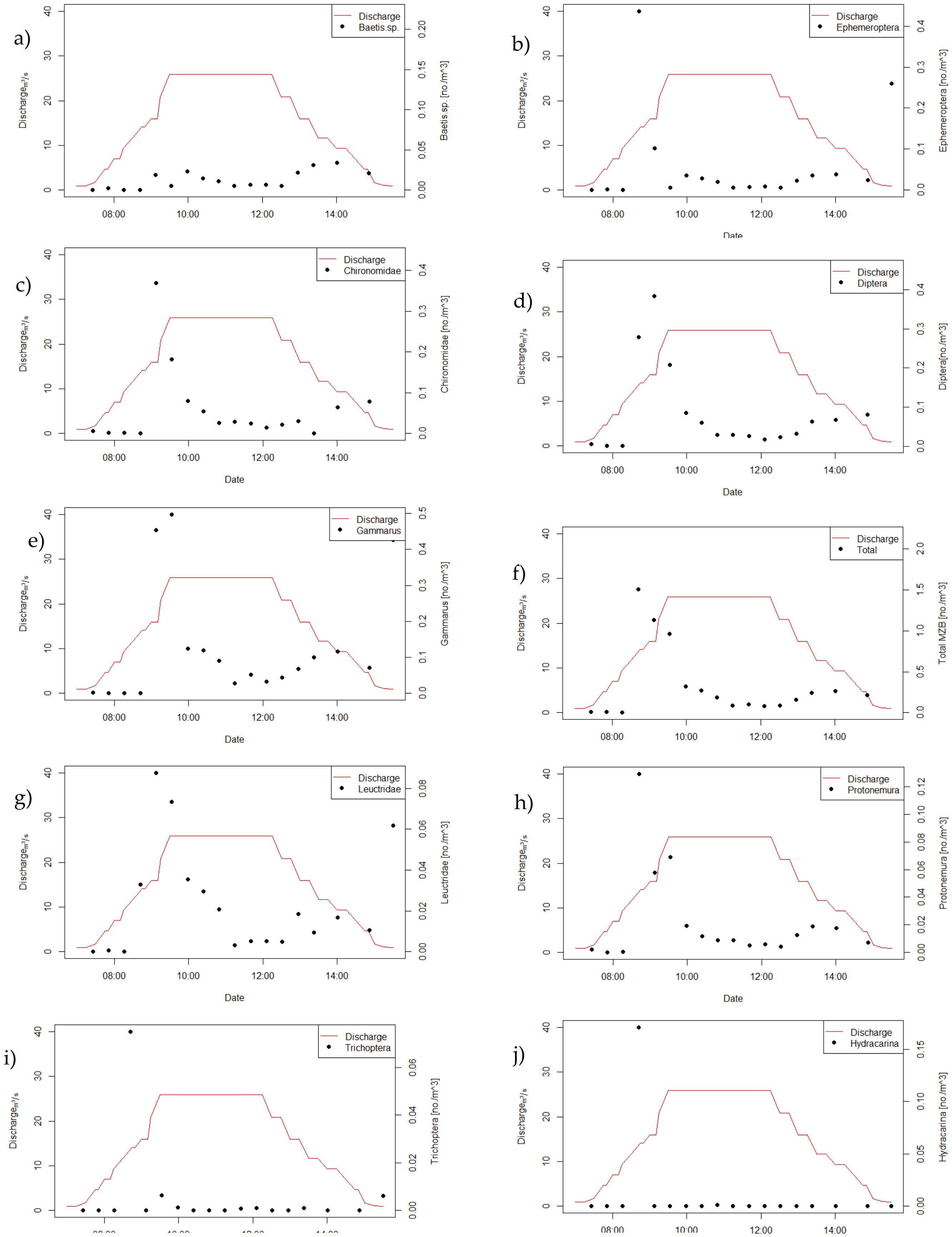

Figure 15: a)-j) Discharge of the lower Spol with different Taxa or taxonomic groups against time

Results

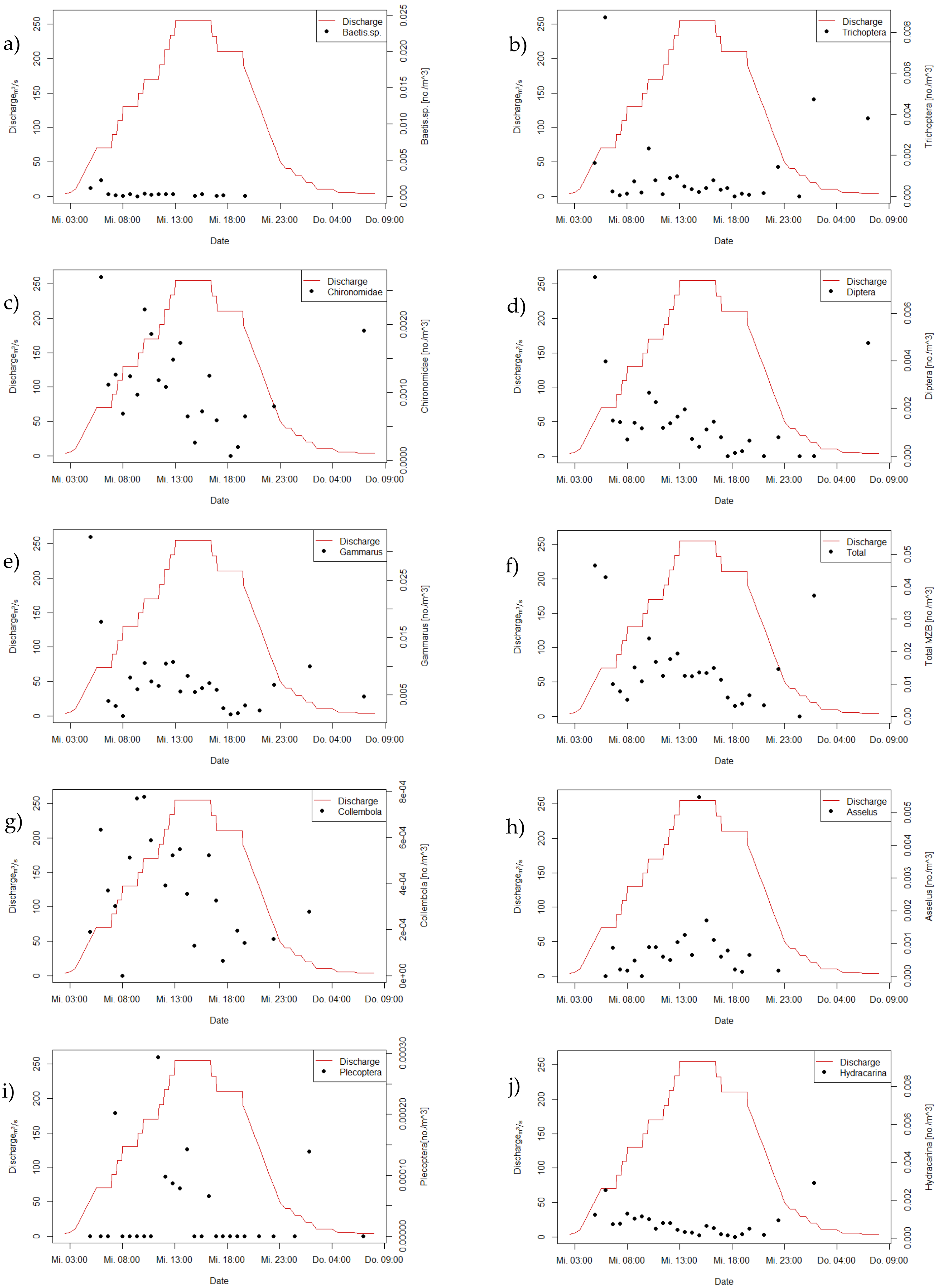

Figure 16: a)-j) Discharge of the Sarine with different Taxa or taxonomic groups against time.

Results

Sarine

With a maximum discharge of 255 m^3/s, the Sarine had the largest flood. From 0-75 m^3/s discharge, the highest drift was measured. The most abundant species of *Gammarus* sp. and Chironomidae were drifting at a discharge of 70 and 130 m^3/s, respectively (App. Figure 15). *Asselus* showed an increase of drift with the increase of discharge.

The Hess samples before and after the flood showed the effects of the flood to benthic invertebrates. In the Sarine, Ephemeroptera, *Gammarus* and Chironomidae was reduced over 50 %. Only the Trichoptera revealed to be more resilient towards floods.

1.11 Physico- chemical responses during the floods

The different parameters responded differently to changes in discharge. For all three floods, a decrease in conductivity and alkalinity occurred, while there were no patterns in the ammonium-N, nitrate-N and dissolved organic carbon (App. Figure 4- App. Figure 9). Total phosphorus and turbidity showed a response to the flood at the upper Spol. In the flood of the lower Spol, only a turbidity peak in the increasing discharge slope was detectable.

The AFDM of the drift samples increased with the increasing discharge in the beginning of the flood at all sites (Figure 12 and App. Figure 16). Remarkable is the high amount of organic material in the lower Spol compared to the two other stream systems. There were also differences in the responses of the three rivers in the amount of periphyton organic matter before and after each flood. While there was a great difference in the lower Spol and Sarine, only a small AFDM difference was observed in the upper Spol.

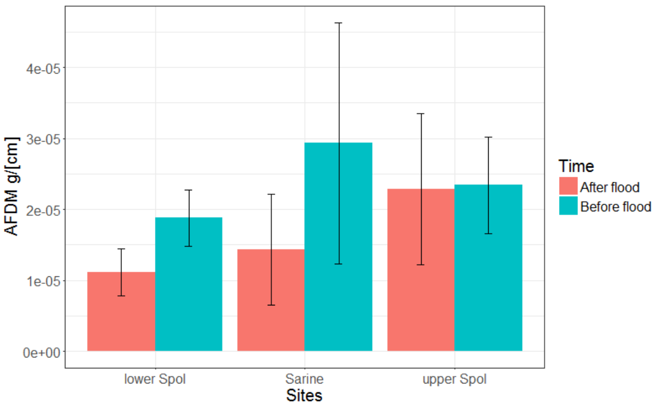

Figure 17: Periphyton AFDM of five random cobbles before and after food. The error bars indicate the standard deviation.

Results

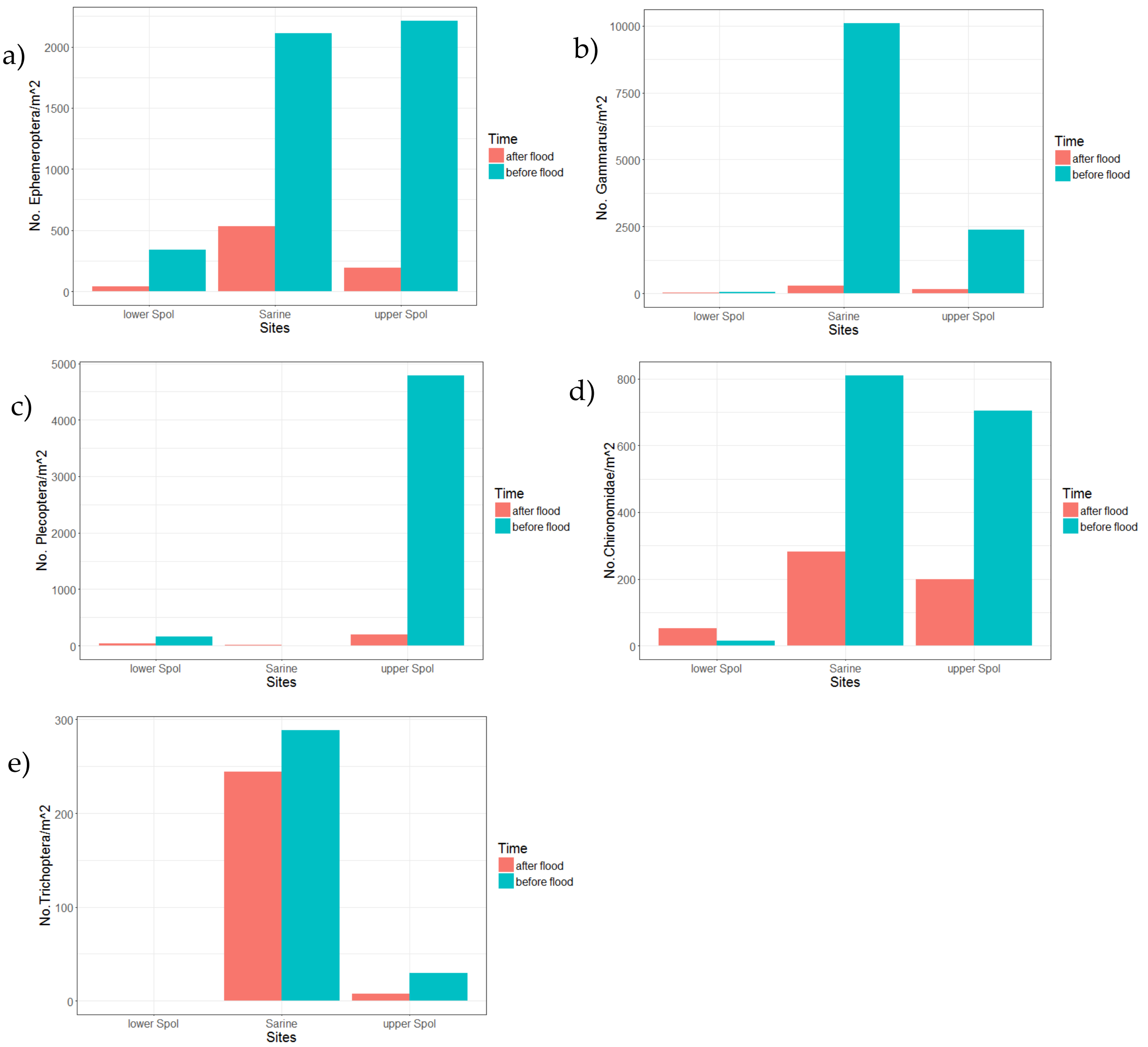

Figure 18: a) -e) Hess samples before and after the flood on the three streams: lower Spol, upper Spol and Sarine. The y axes indicate how many individuals per m^2 were collected.

Discussion

This chapter examined 3 e -flows of different magnitude, duration, location and timing. More specifically, the drift patterns of macroinvertebrates were investigated. It was shown that during the first hour of the flood, the number of invertebrates was highest in the drift samples. There was no clear dependency on the amount of discharge. The first drifting invertebrates may have been in the water column and be flushed by the increased discharge and the local velocity increase. This increase in flow can cause an increased shear stress and mobilize surface sediments (Robinson et al., 2004). Similar patterns have been found from Gibbins et al. (2010), Bruno et al. (2016) and Imbert & Perry (2000). They all observed that during the first 5-10 minutes, the drift rates increased, followed by a decrease. Additionally, they discovered taxonomic differences: flood sensitive taxa such as Chironomidae and Baetidae were less reduced in the drift compared to flood resistance taxa (for example Simuliidae). This pattern can be seen in the flood of the upper Spol where *Baetis* sp. showed a greater drift rate after 5 hours of the flood than the more flood resilient caddis flies. This pattern is also observed in the Hess samples of the Sarine: while other groups experienced a loss in density over 50%, the Trichoptera were more resilient. The tendency to drift also differs between species traits (Rader, 1997), such as shown in the two trichopterans *Hydropsyche guttata* and *Rhyacophila tristis*. *Hydropsyche guttata* had an initial drift at 70 m^3/ s, while *Rhyacophila tristis* had the most drift at 130 m^3/s. This pattern is also revealed in the current (flow) preferences of the two taxa (Graf, et al., 2008).

The physico-chemical response showed no clear patterns. Only conductivity and alkalinity had a negative response in all three floods with increasing discharge. This observation is according to our expectations because water for the floods is derived from reservoir water and had therefore more stable conditions.

This results indicate the complexity of response of flood events of benthic invertebrates. There is, on the one hand, behavior and morphological traits (Rader, 1997) that play within these results and, on the other hand, mechanical and hydrological aspects (Musilová et al., 2015) that interfere with community assembly of the invertebrates before and during a flood. There have been diverse approaches to learn more of drift related patterns. There were measurements of drift in artificial stream studies from Ciborowski (1987), velocity manipulations in natural rivers (Gibbins et al., 2010) and drift measurements during e- flows

(Robinson, 2012). Still there is a lack of knowledge in the mechanisms of the benthic drifting invertebrates (Hieber et al., 2003).

In this study, I could confirm known drift patterns of benthic invertebrates. However, I expected a stronger response pattern with increases in discharge magnitude. More specifically, I expected more drift of Simulidae in the Sarine flood. These observations could have many reasons, first there was a sampling limitation during the flood. We could only take samples (due to safety reasons) from the river side during the flood. Another reason could be that Simulidae are even more resilient to floods than we expected. Additionally, the sampling point in the Sarine was about 11.5 km downstream the hydropower dam. The discharge was probably less intense than in the hydrogram displayed and must be looked at with caution.

For further investigation, I would suggest a smaller sample interval during the increasing stage of a flood. Furthermore, the sampling points were at least 2 km below the dam. This may cause temporal and magnitude differences in the hydrograms at the power station. To be more accurate, it is necessary to have the actual discharge at the sampling points.

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I thank Johannes Ortlepp and Ute Murle from the HYDRA office were supporting me with the long- term data from the Spol.

STATEMENT OF AUTHORSHIP

I declare that I have used no other sources and aids other than those indicated. All passages quoted from publications or paraphrased from these sources are indicated as such, i.e. cited and/or attributed. This thesis was not submitted in any form for another degree or diploma at any university or other institution of tertiary education.

Zurich, 31th March 2017

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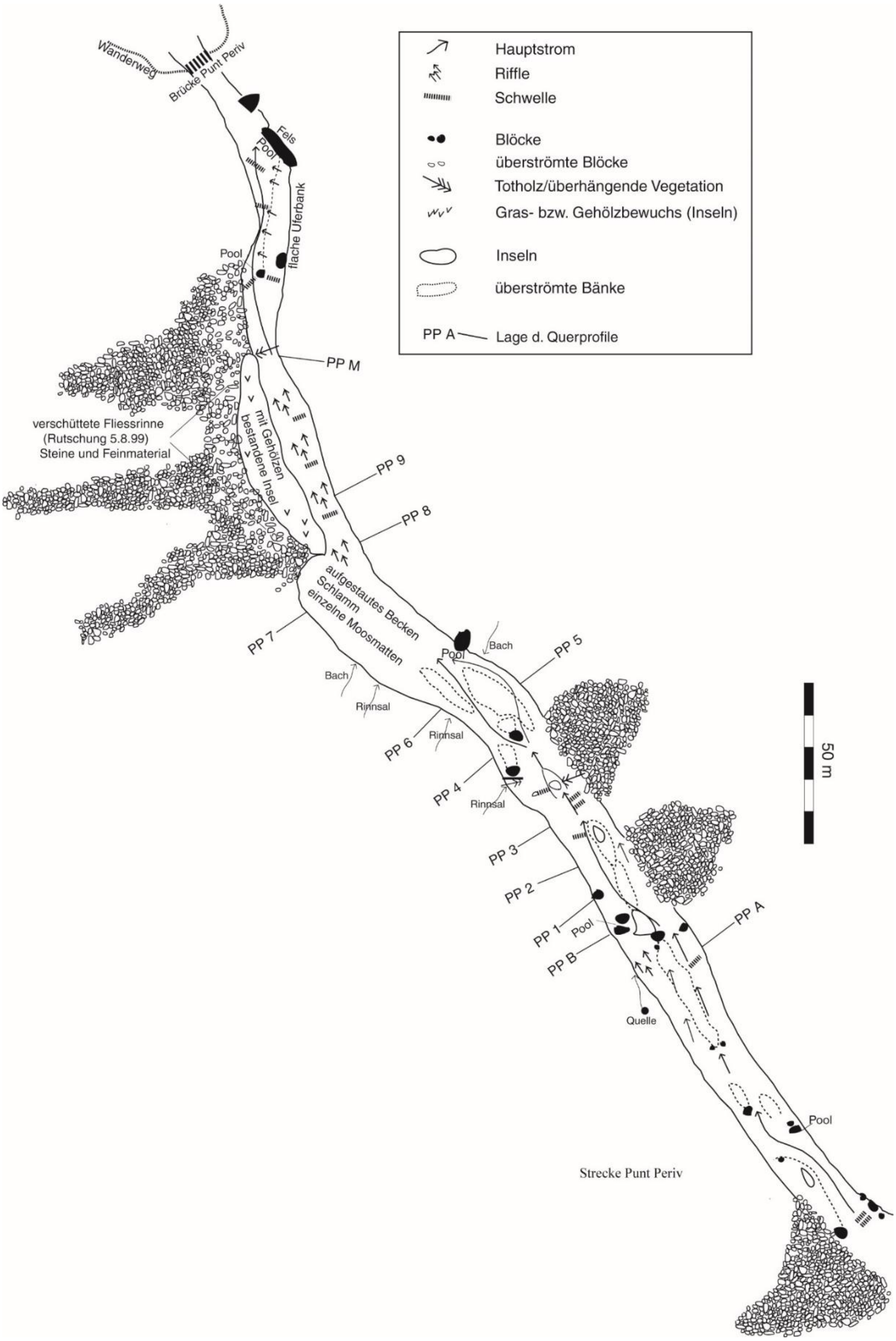
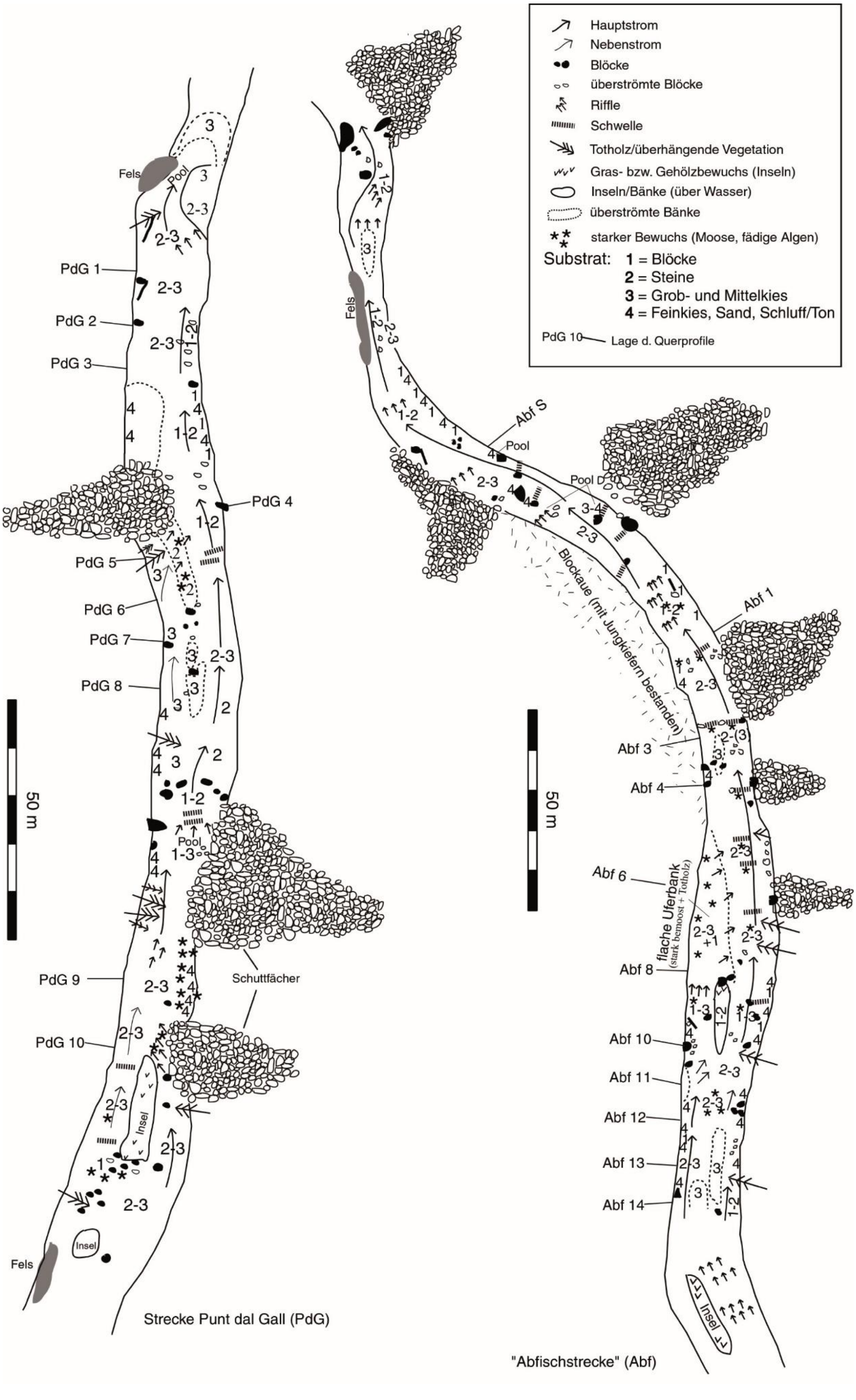
APPENDIX

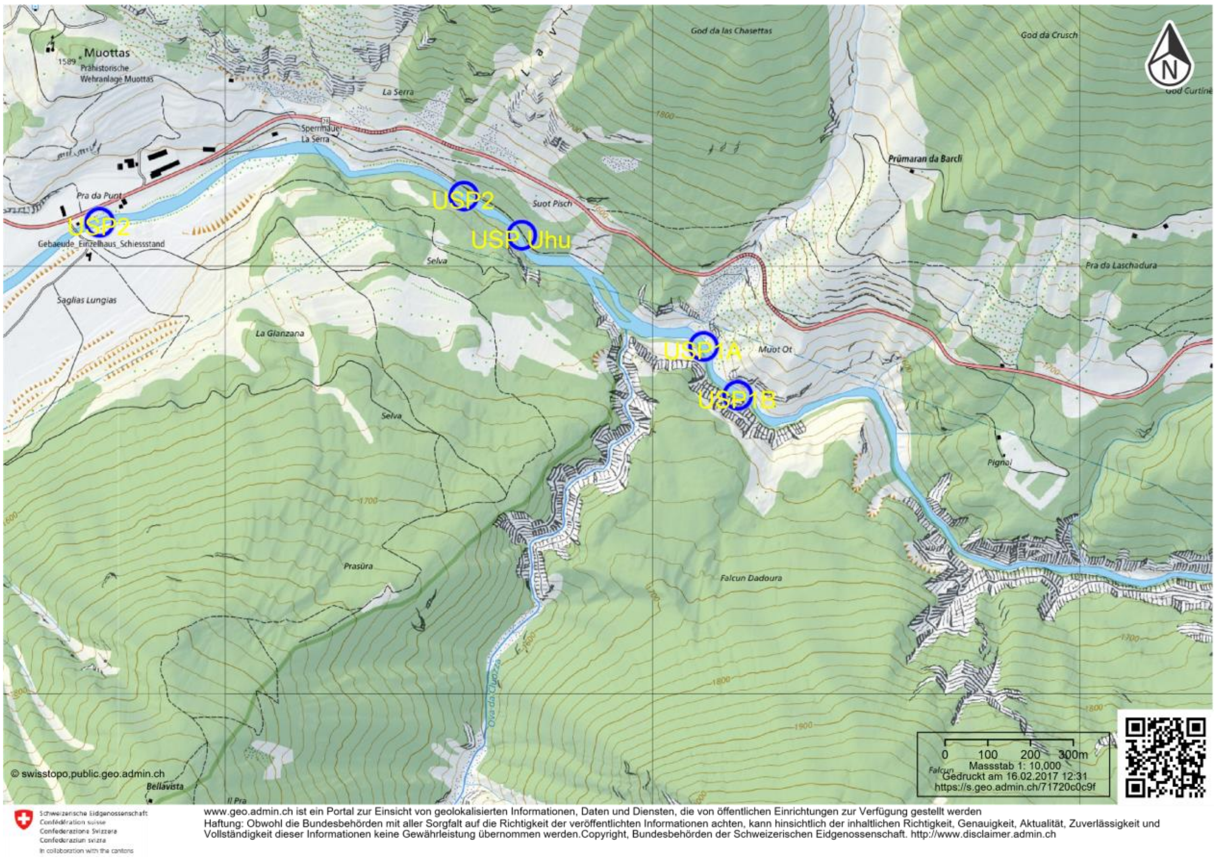
Appendix Methods- Chapter 1



App. Figure 1: Map of the transect measurement sites at Punt Periv. Provided by J. Ortlepp, Hydra.



App. Figure 2: Map of the transect measurement sites at Punt dal Gall. Provided by J. Ortlepp, Hydra.



App. Figure 3: Map of the transect measurement sites at the lower Spol ("Karten der Schweiz - Schweizerische Eidgenossenschaft - map.geo.admin.ch," n.d.).

Appendix Methods- Chapter 1

App. Table 1: Characteristics of Punt dal Gall transect measurement sites. Provided From J. Ortlepp, Hydra.

Profil	Lage/Beschreibung/Markierung	Koordinaten (CH-1903)					
		links			rechts		
		x	y		x	y	
PdG 10	am 1. grossen Schuttkegel von rechts Markierung links: auf Stein unter Kiefer Markierung rechts: auf Stein in Blockhalde	810985	167588	+- 3m	810998	167583	+- 4m
PdG 9	zwischen 1. (hier PdG10) und 2. Schuttkegel von rechts Markierung links: auf Block in kleiner Schutthalde Markierung rechts: Lärchenpflock	810986	167600	+- 3m	810998	167593	+- 3m
PdG 8	nach Bachverengung/Schwelle; im oberen Drittel der Aue rechts Markierung links: Block bei Kiefern Markierung rechts: auf Block	810993	167657	+- 4m	*811005*	*167655*	*+- 5m*
PdG 7	am unteren Ende der Aue rechts, Beginn der Rechtskurve Markierung links: auf Erle hinter gr. Block Markierung rechts: auf Stein unter Kiefer	810990	167666	+- 4m	*811000*	*167664*	*+- 6m*
PdG 6	wurde im Juni 2014 nicht mehr aufgefunden => keine Messungen mehr	*GPS schwankend*			811008	167674	
PdG 5	oberhalb Schuttfächer und Seitenbach von links; auf Höhe umgestürzter Kiefer links Markierung links: auf Erle Markierung rechts: auf Fels in Schutthalde	810989	167681	+- 4m	811006	167681	+- 3m
PdG 4	unterhalb Schuttfächer und Seitenbach von links; Bachverengung Markierung links: auf gr. Block (bachabgewandte Seite) Markierung rechts: blauer Punkt auf Block (=Fixpunkt für alle Profile)	810994	167687	+- 4m	811006	167691	+- 4m
PdG 3	auf Höhe der Hälfte der Aue links unterhalb Seitenbach Markierung links: auf Stein und Lärchen-pflock Markierung rechts: Block in Schutthalde	810983	167718	+- 4m	810998	167723	+- 4m
PdG 2	bei leichtem Anstieg des Weges, bei Felswand rechts; Ende Aue links Markierung links: Block in kl. Seitengerinne Markierung rechts: Felswand, bei kl. Kiefern	810986	167722	+- 3m	*GPS schwankend, Felswand*		
PdG 1	hier Weg direkt am Fels, Weg langsam absteigend Markierung links: auf Block links von gr. Fichte Markierung rechts: auf Felswand, unterhalb abgestorbener Weide	8109834	167736	+- 4m	810994	167741	+- 4m

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App. Table 2: Characteristics of the transect measurement sites at Punt Periv. Provided by J. Ortlepp, Hydra.

Profil	Lage/Beschreibung/Markierung	Koordinaten (CH-1903)			
		links		rechts	
		x	y	x	y
PP A	Markierung links: rot an kl. Stein bei gr. Kiefern Markierung rechts: rot an Fels ca. 21 m oh. PP B, ca. 3 m uh. Quelle links	810140	168538	810158	168553
PP B	bei 3 gr. Felsen im Bachbett Markierung links: an Kiefer, auf Höhe von mittl. Fels Markierung rechts: Lärchenpfosten und rot	810131	168561	810148	168570
PP 1	Markierung links: an Baumstamm Markierung rechts: Lärchenpfosten und Marke rot auf Block, uh. Anriss	810129	168568	810142	168577
PP 2	Markierung links: rot auf Stein unter abgestorbener Kiefer Markierung rechts: Felsplatte Ende Schuttkegel ca. 10 m uh. PP 1 (links gemessen)	810123	168577	810137	168587
PP 3	ca. 20 m uh. PP 2; oh. Schwelle mit gr. Fels Markierung links: rot auf Kiefer (links des Quellrinnsals) Markierung rechts: rot auf Block in Schutt-halde	810111	168597	810122	168608
PP 4	ca. 20 m uh. PP 3 Markierung links: rot auf abgestorbener Kiefer Markierung rechts: rot auf gr. Block in Schutthalde; unteres Ende des Anrisses	810097	168617	810113	168623
PP 5	ca. 10 m uh. PP 4 Markierung links: Lärchenpfosten Markierung rechts: rot auf gr. Block unter/seitl. von Kiefern	810092	168625	810110	168639
PP 6	ca. 14 m uh. PP 5, bei rechtem Seitenbach, ca. 10 m oh. Fels Markierung links: ca. 7 m oh. von fehlmarkierter Kiefer (durchgestrichene 6) Markierung rechts: rot auf Block	*GPS schwankend*		*GPS schwankend*	
PP 7	Ende **ehemaliges** Stillwasserbecken Markierung links: Kiefer oberhalb des Schuttkegels Markierung rechts: Lärchenpfosten bei liegender Stamm am Wildwechsel	*810030*	*168680*	*810050*	*168685*
PP 8	Ende Stillwasserbecken, ca. 10 m uh. PP 7 Markierung links: KEINE mehr (Schuttkegel); von links nach rechts 59° gg. N) Markierung rechts: rot auf Stamm			*810042*	*168713*

App. Table 3: Characteristics of the transect measurement sites at the lower Spöl. Provided by J. Ortlepp, Hydra.

USP 1B und **USP 1A** liegen in der Abfischstrecke oh. Cluozza-Schuttkegel (Lawinenholz-Strecke); oberes Streckenende: gr. Block in Bachmitte; unteres Streckenende: Blöcke in Bachmitte							
Fixpunkte USP1A+1B:							
Fixpunkt II gr., grauer Block links, ca. 40 m uh. Profil B							
Fixpunkt I heller Block auf linker Seite von Profil A (nach HQ z.T. unter Wasser)							
Profil	**Lage/Beschreibung/Markierung**	**Koordinaten (CH-1903)**					
		links			**rechts**		
		x	**y**		**x**	**y**	
USP 1B	am unteren Ende der Insel (uh. gr. Block am oberen Streckenende), **229°** Markierung links: ROT auf hellem Block (durch HQ z.T. holzbedeckt) Markierung rechts: ROT auf Block bei Felsnase (in bewachsenem Bereich oh. der mittleren, weiter nach unten reichenden Felsrippe)	805197	174685	+- 5m	805213	174698	+- 3m
USP 1A	oberhalb Mündung Val da Barcli, **260°** Markierung links: ROT auf hellem Block (nach HQ am 9.8.00 z.T. unter Wasser), hier auch Fixpunkt I Markierung rechts: Stamm (nach HQ 40 am 7.8.02 nicht mehr vorhanden) => neu auf dünnem Weidenstamm	805115	174789	+- 4m	805136	174800	
USP"Uhu" liegt unterhalb Cluozzza-Mündung und unterhalb Probestelle „Uhufels", bei markant ausge-waschenem Felsblock in Bachmitte							
Fixpunkt USP „Uhu": ausgewaschener Felsblock in Profil- bzw. Bachmitte, blaue Markierung							
USP „Uhu"	uh. Uhufelsen, bei markant ausgewaschenem Felsblock **241°** von rechts Markierung links: auf Fels (blau) Markierung rechts: auf Block + Baum	*keine GPS-Messung möglich*			804691	175065	+- 4m
USP2 liegt unterhalb Cluozza-Mündung, vor Linkskurve unterhalb 1. Galerie, an zweitem (von oben) Felsen links (1.Fels = Uhufels bzw. Amphibolitfels)							
ca. 8 m neben Weg, bei gr. Lärchen, Ufer: Lärchen + Erlen; **212°**							
Fixpunkt USP2: heller Block auf linker Seite von Profil (nach HQ z.T. unter Wasser)							
USP 2	Markierung links: auf hellem Block (nach HQ am 9.8.00 z.T. unter Wasser) uh. Fels, hier auch Fixpunkt Vorsicht: "fremde" blaue Markierungen am Fels ca. 8 m oh. unseres Profils!!! Markierung rechts: auf mehrstämmiger Erle im Uferbereich	804555	175157	+- 5m	804559	175167	+- 5m
USP3 liegt ca. 50 m oberhalb der Holzbrücke Zernez; von links nach rechts 345° gg. N							
Fixpunkt USP3: gelbe Markierung für Pegel auf linker Mauerkrone (Mauer unter der Brücke!)							
für die Einmessung wird die Latte ins Wasser gestellt und mit Theo abgelesen, zusätzlich wird die Höhe bis Mauerkrone (hier Fixpunkt) auf der Latte abgelesen, dieser Wert muss zum Theowert addiert werden!!							
USP 3	Markierung links: keine, ca. 5 m uh. Erlen-Hauptstamm (schiefwachsende Erle); Mai 2011: neue Markierung auf flachem, weissem Block in Uferbank Markierung rechts: Block + Baum **345°** von links nach rechts	803703	175090	+- 3m	803698	175112	+- 4m

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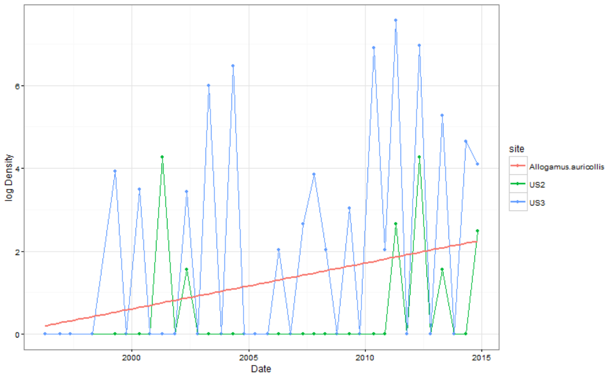
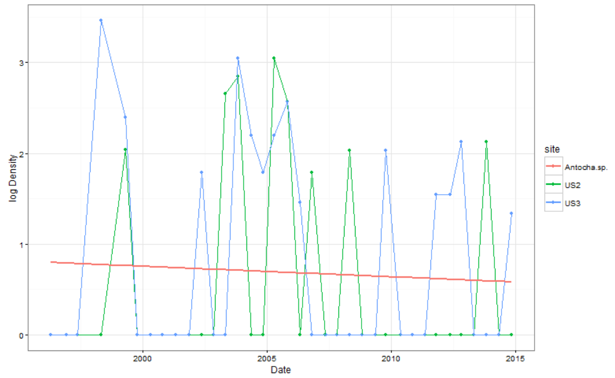
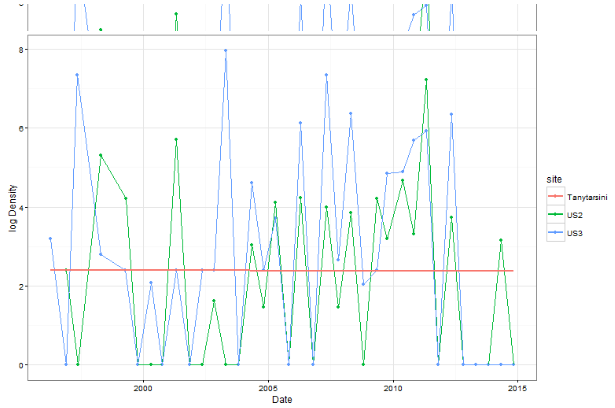
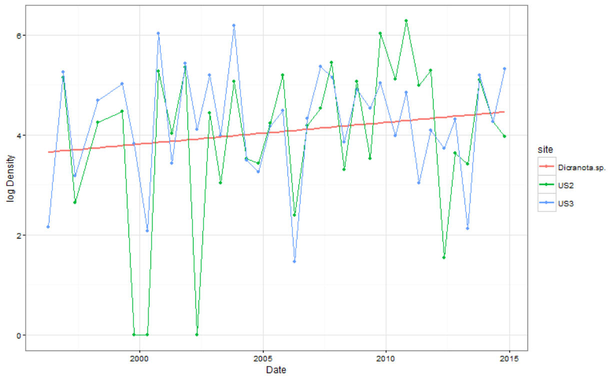
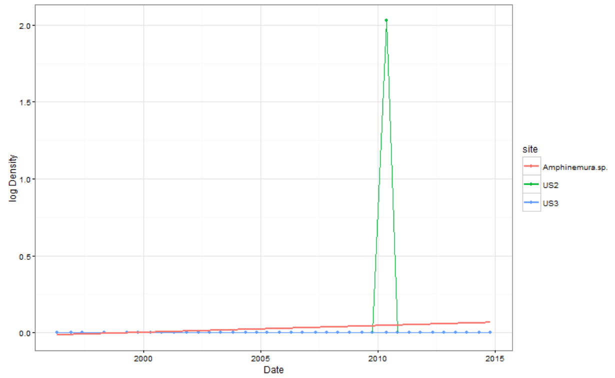
Log-transformed macrozoobenthos density of the lower Spol

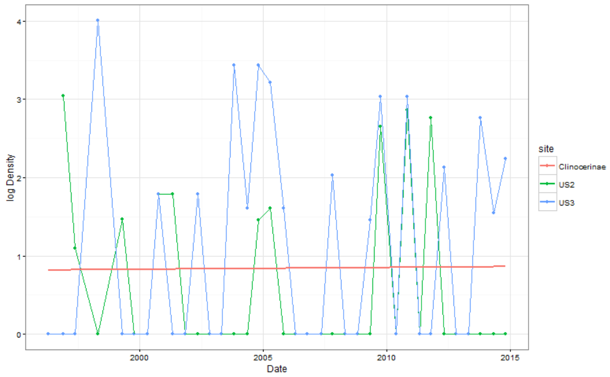


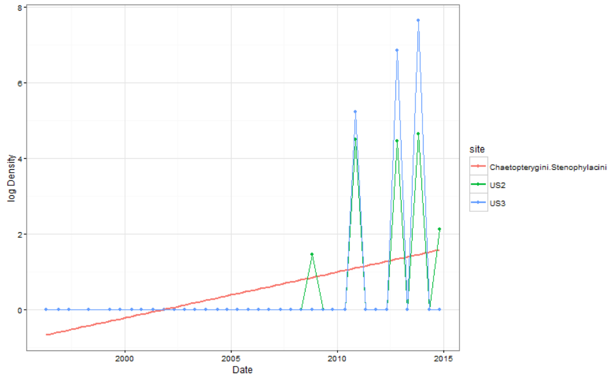












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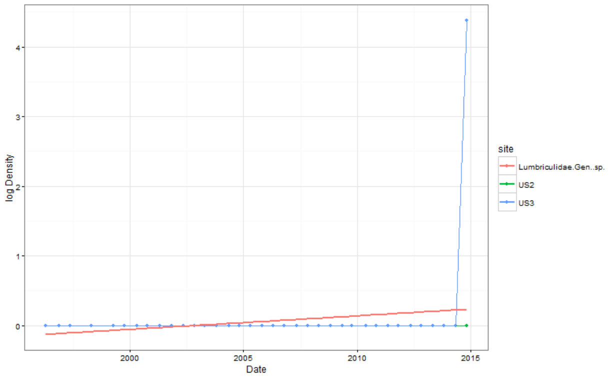

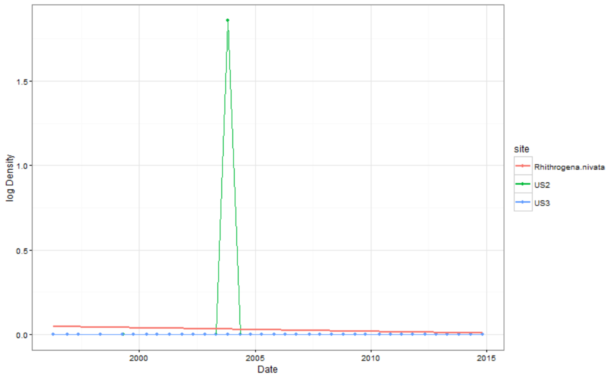

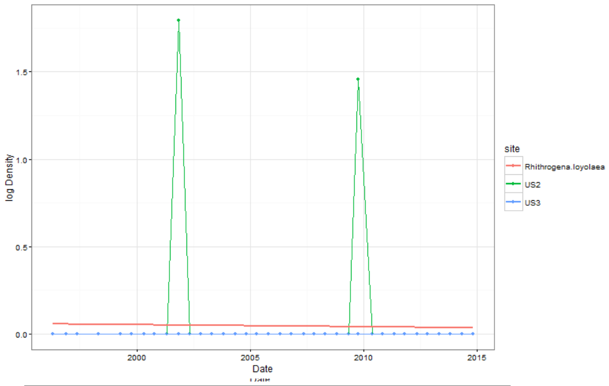

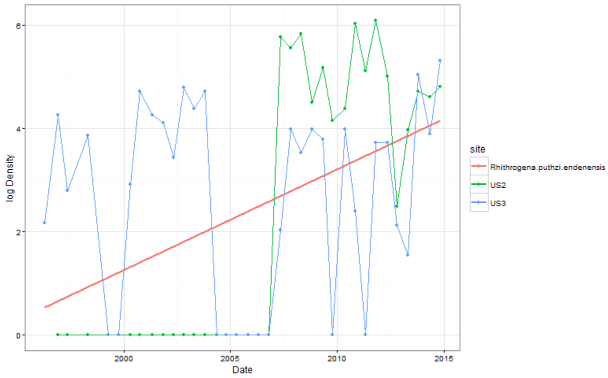

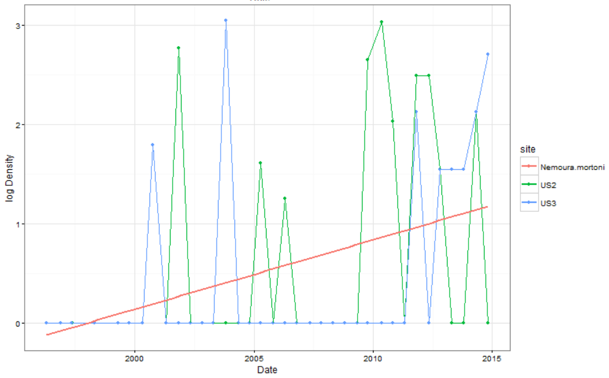

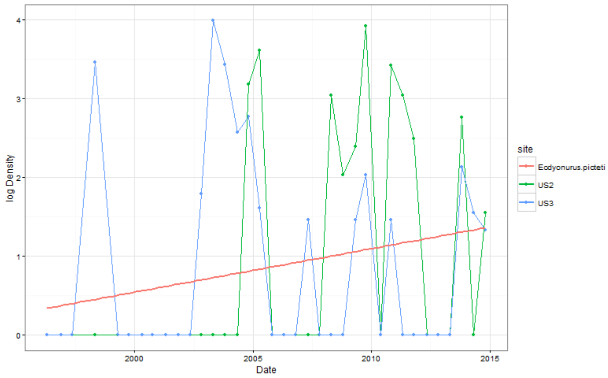

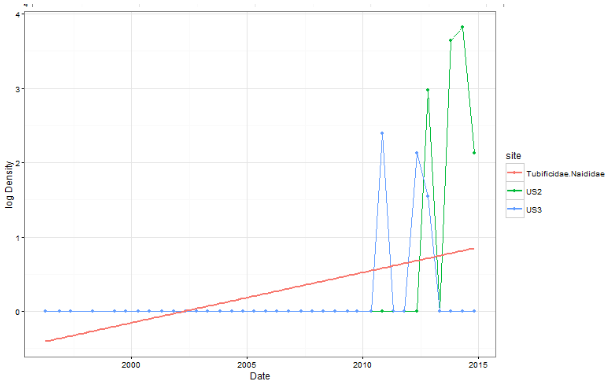

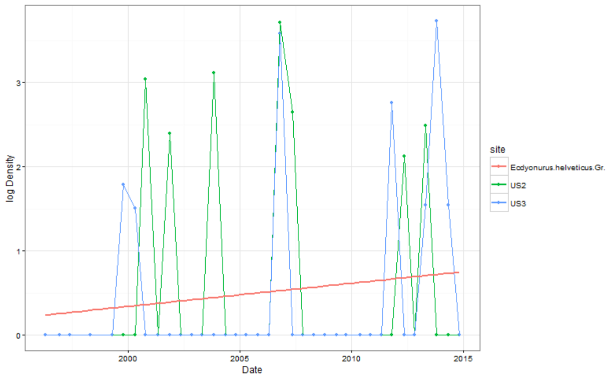

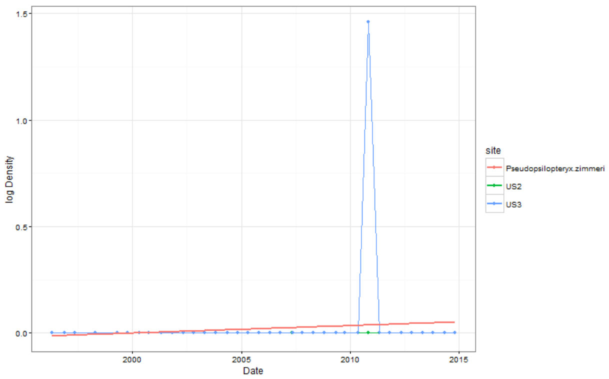

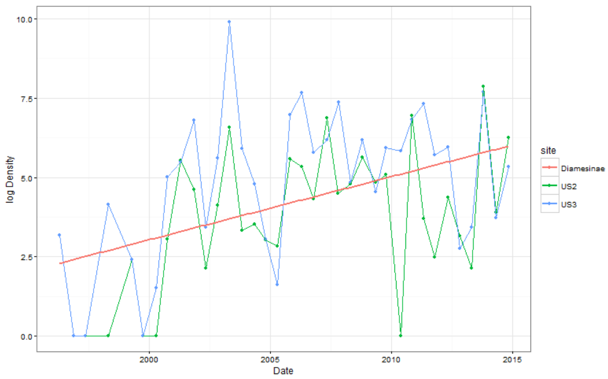

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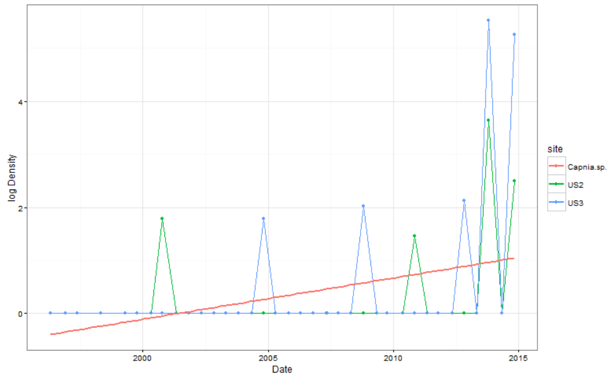

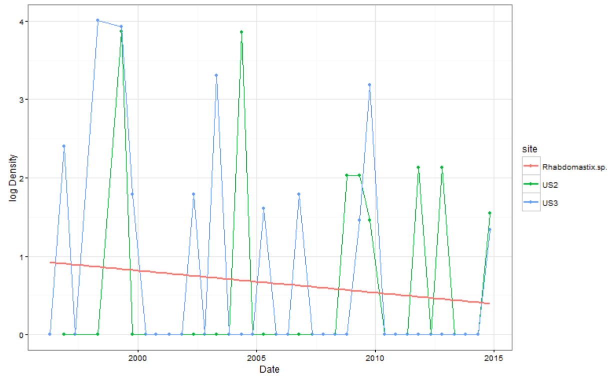

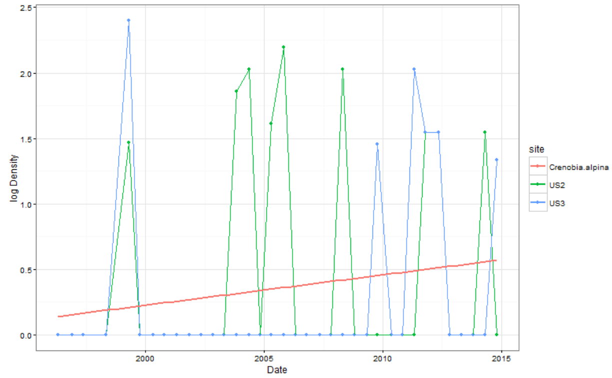

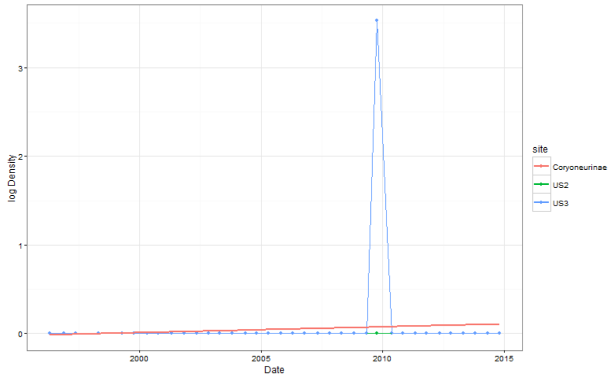

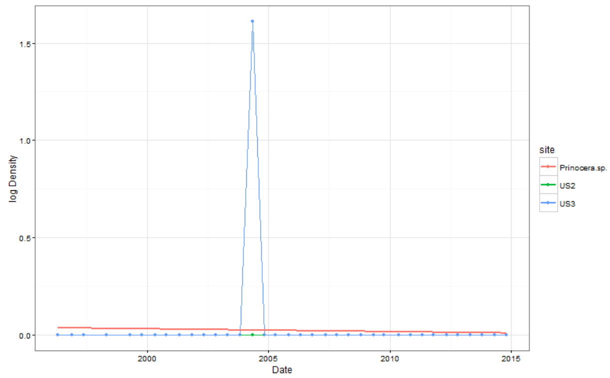

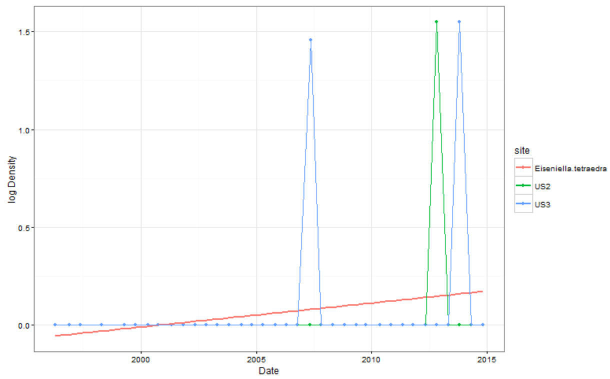

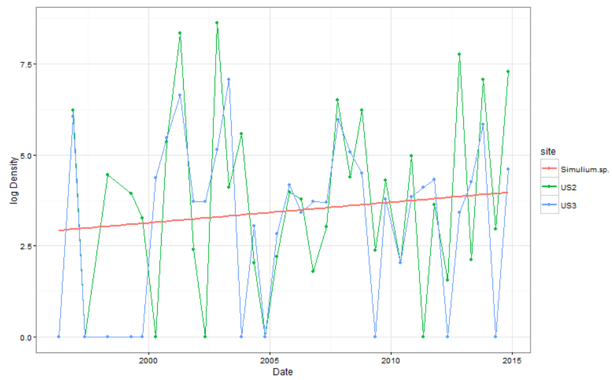

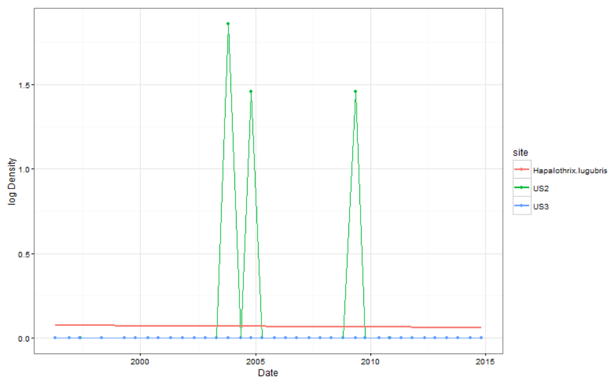

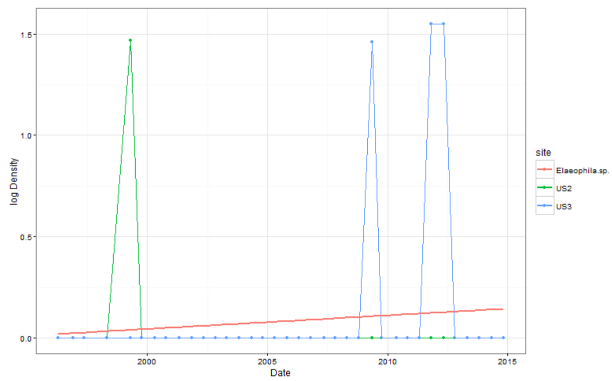

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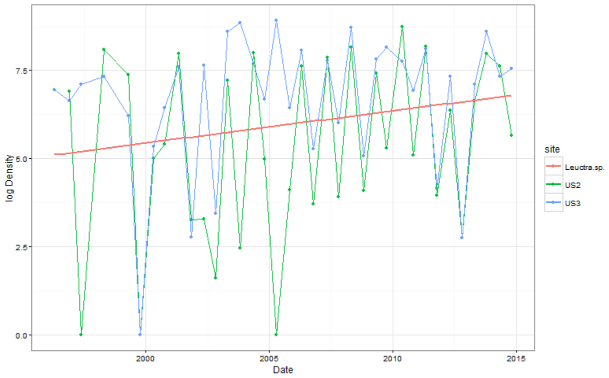

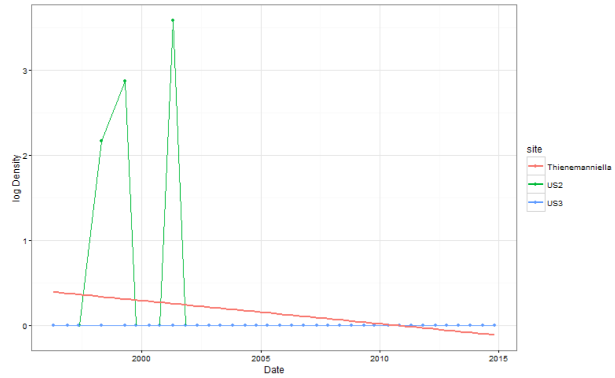

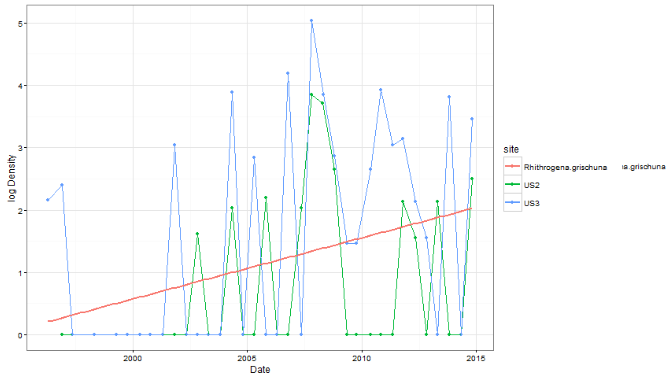

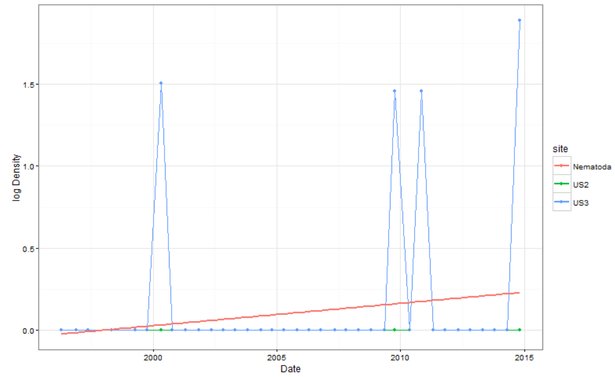

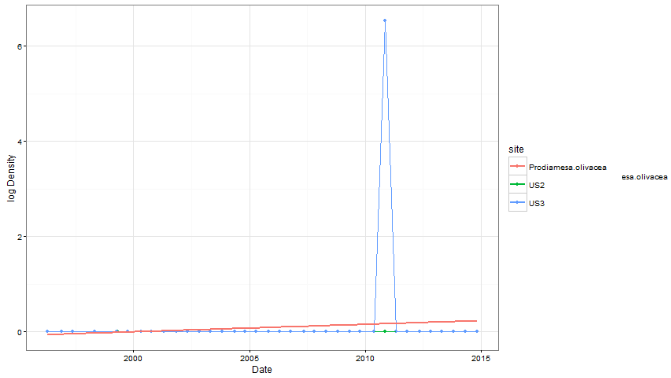

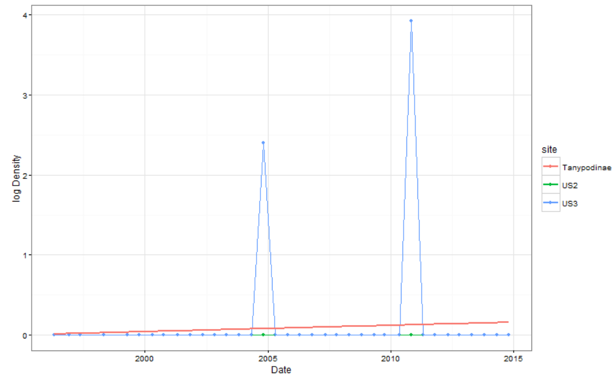

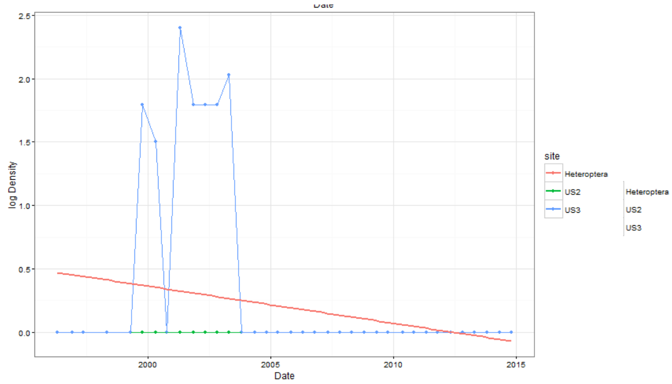

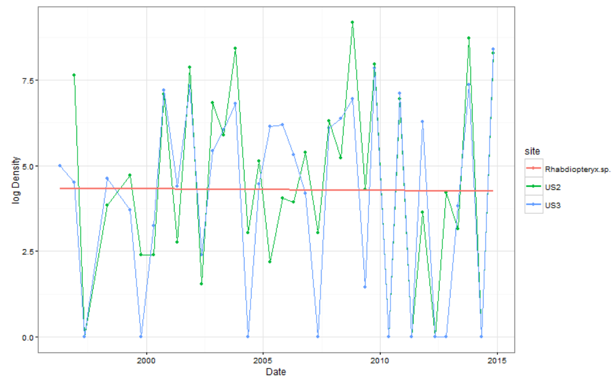

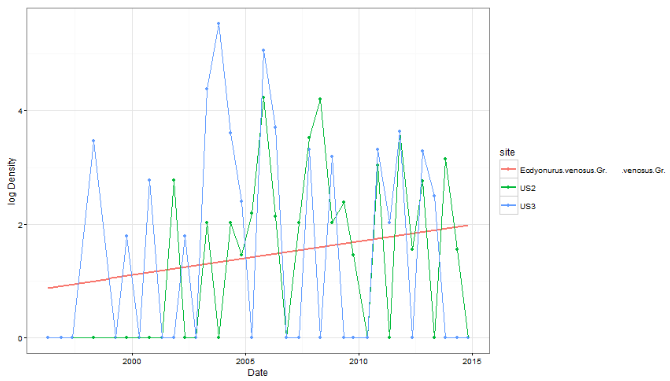

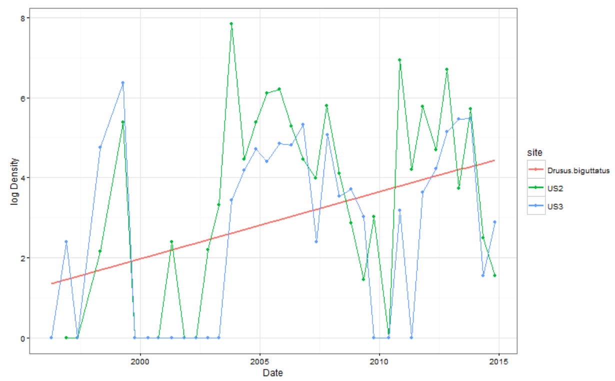

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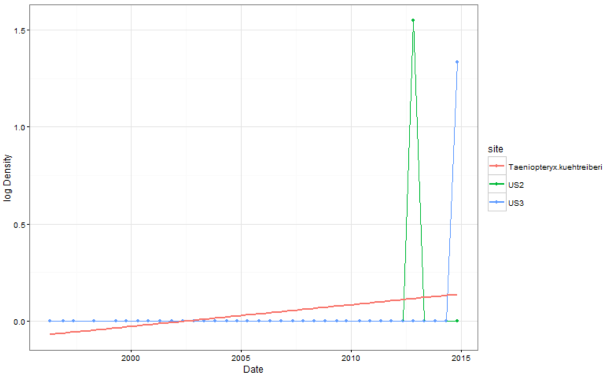

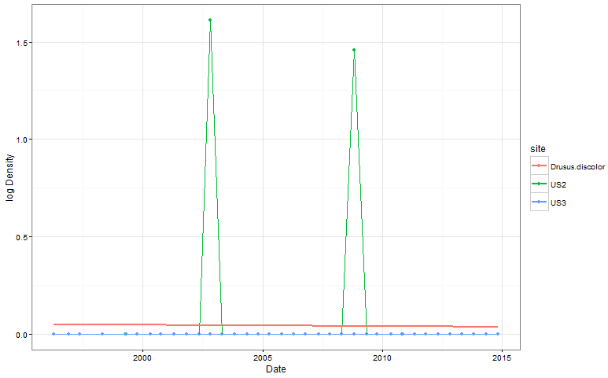

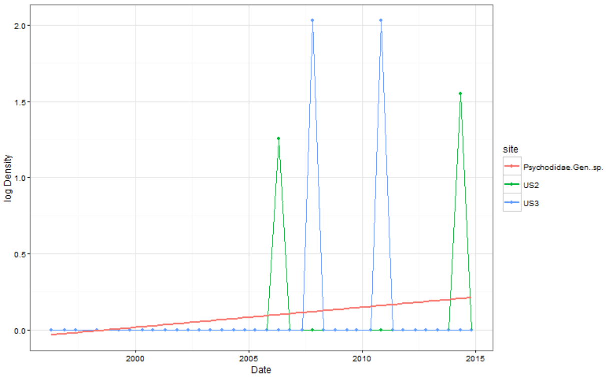

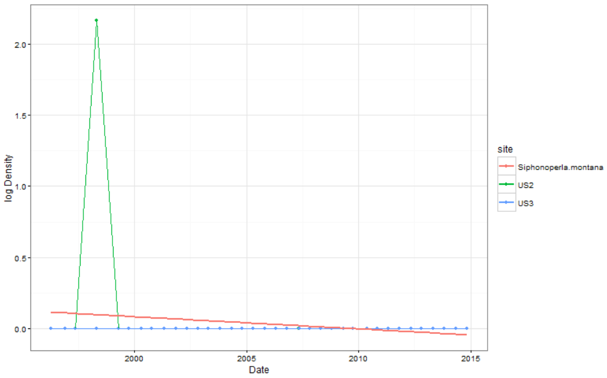

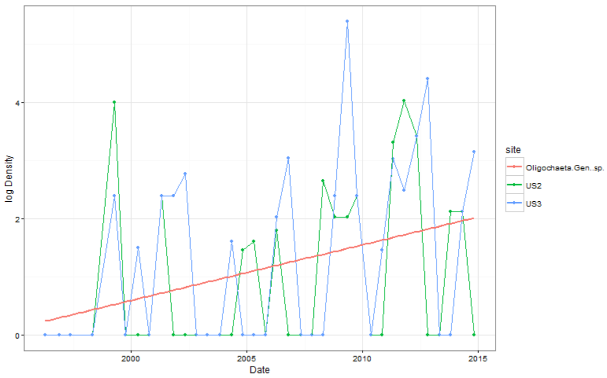

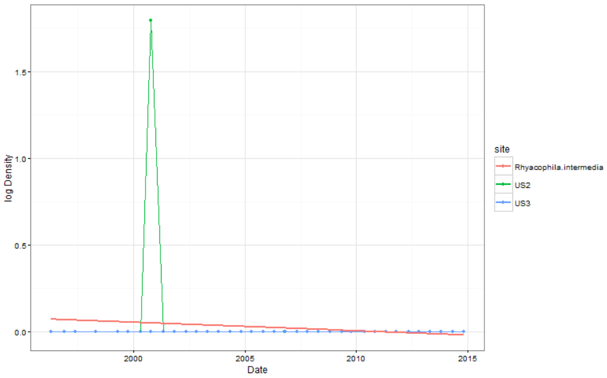

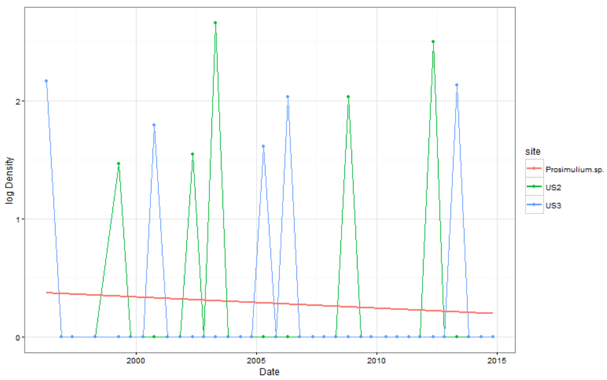

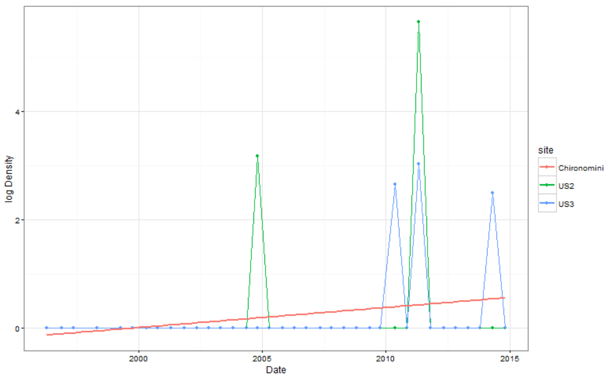

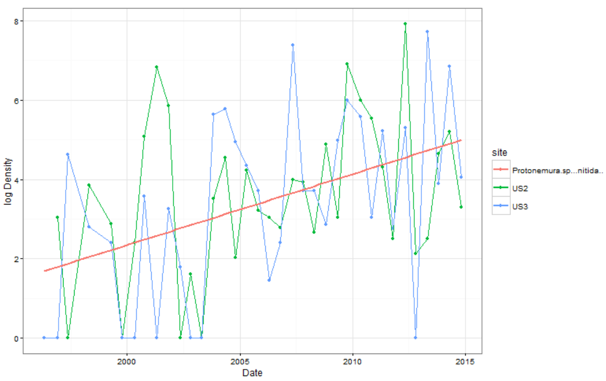

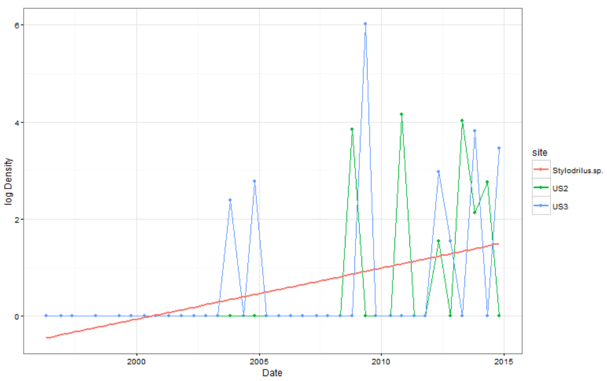

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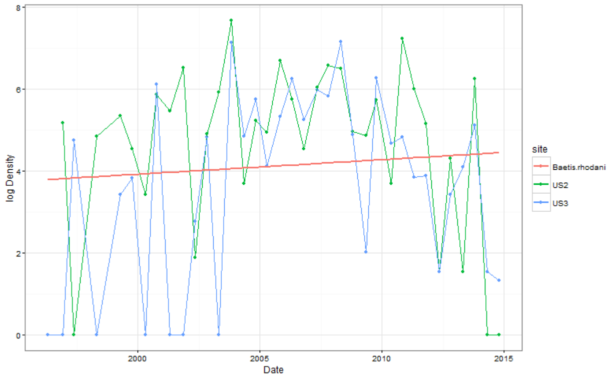

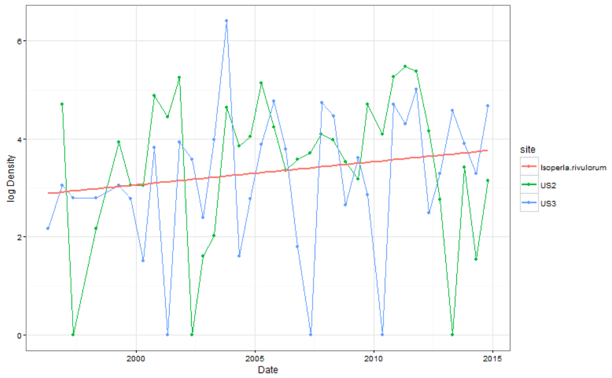

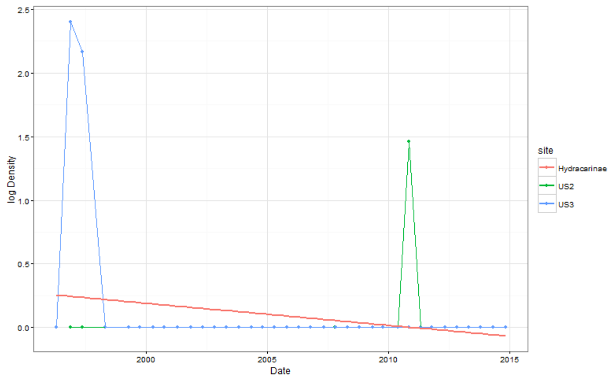

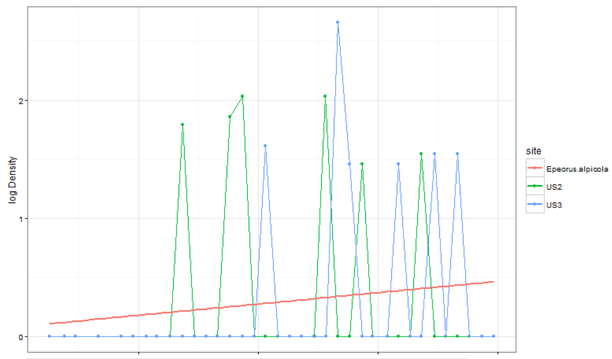

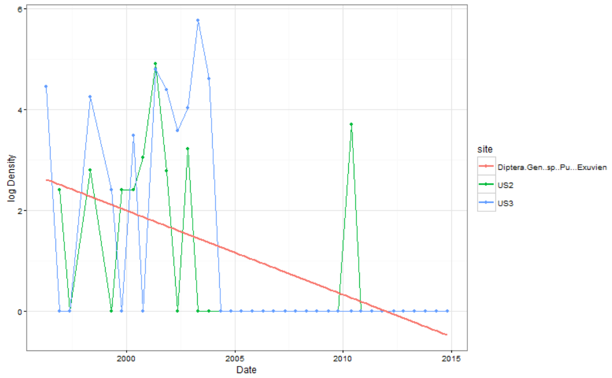

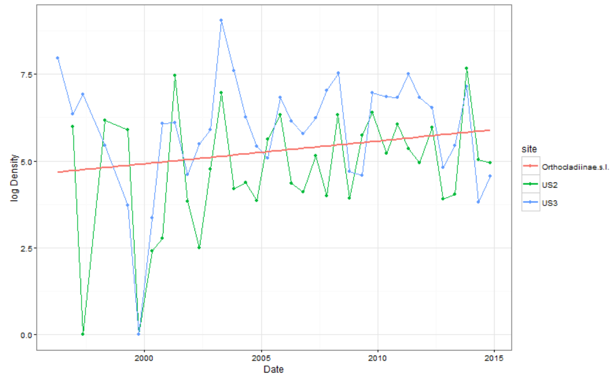

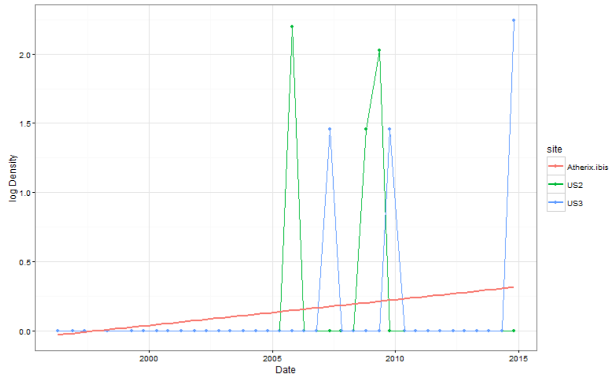

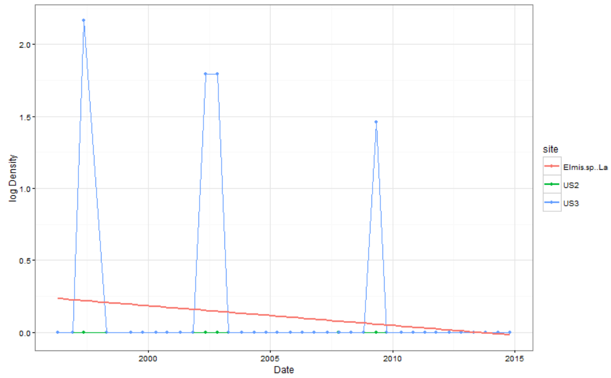

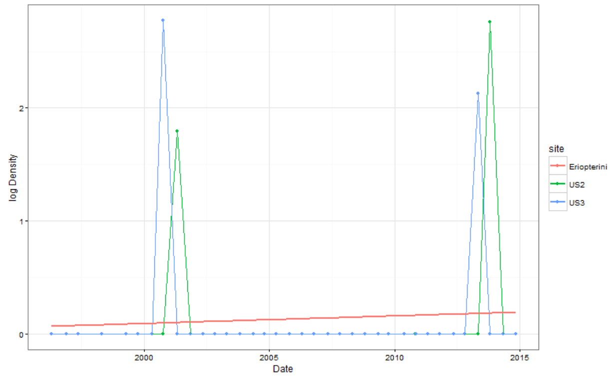

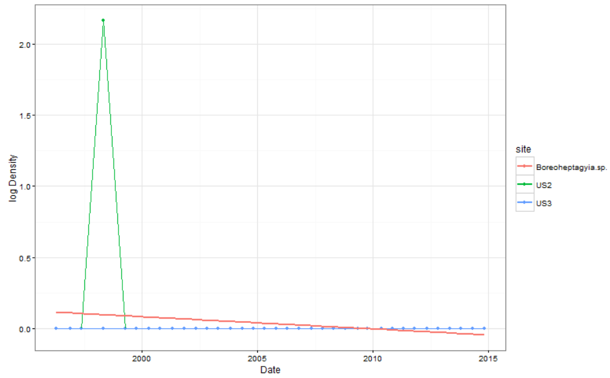

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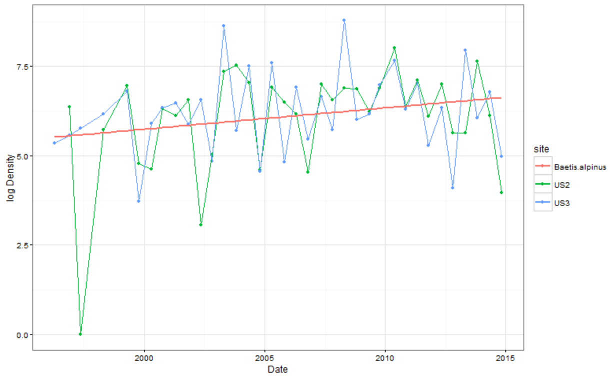

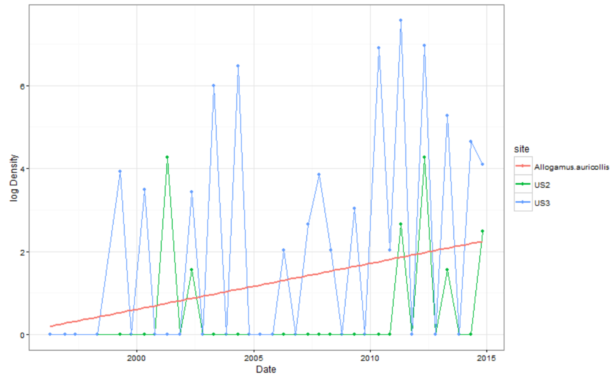

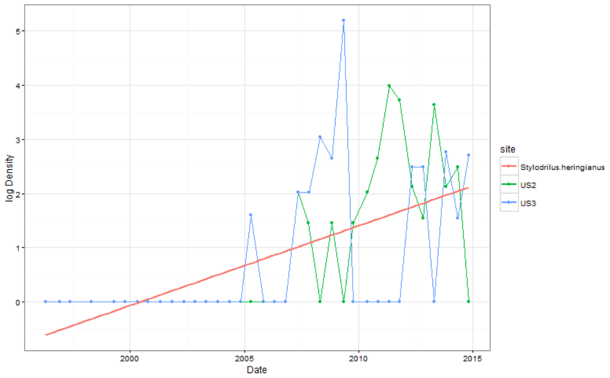

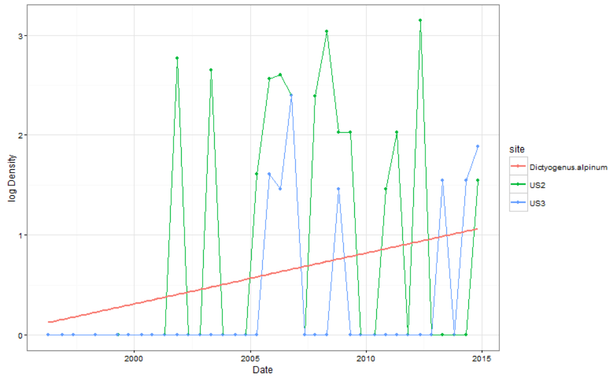

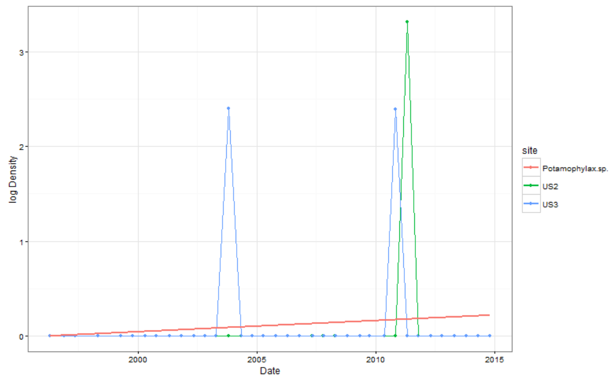

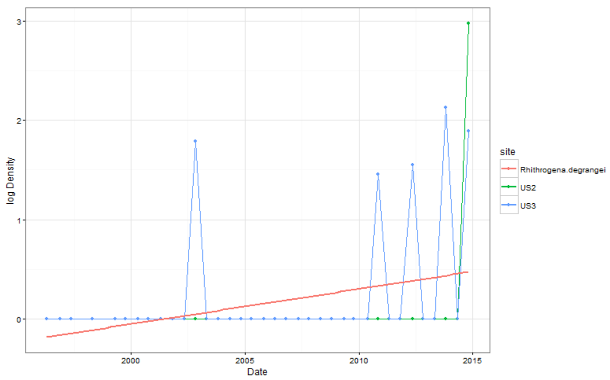

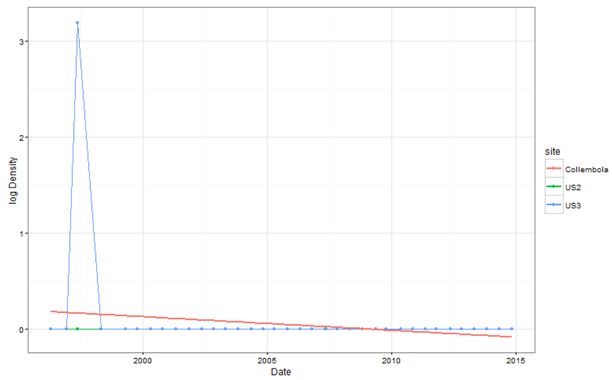

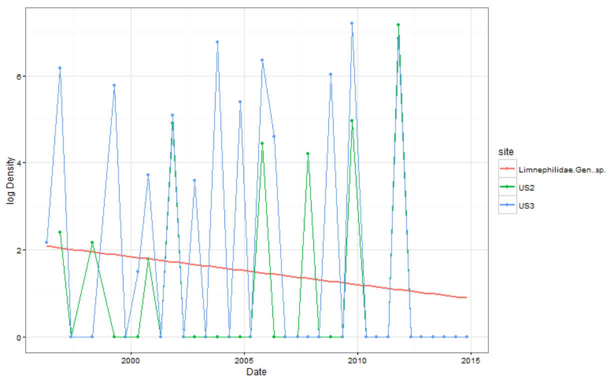

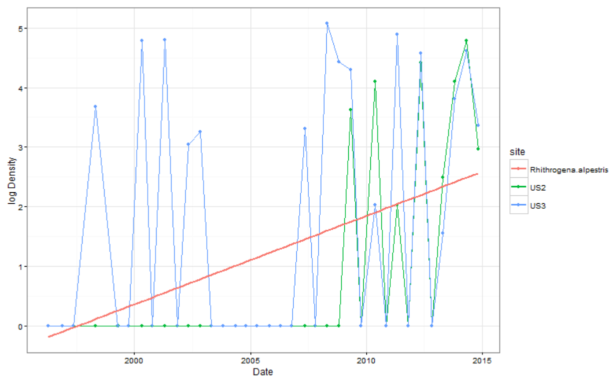

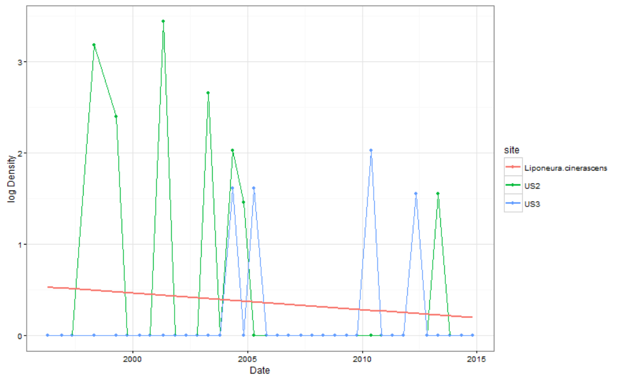
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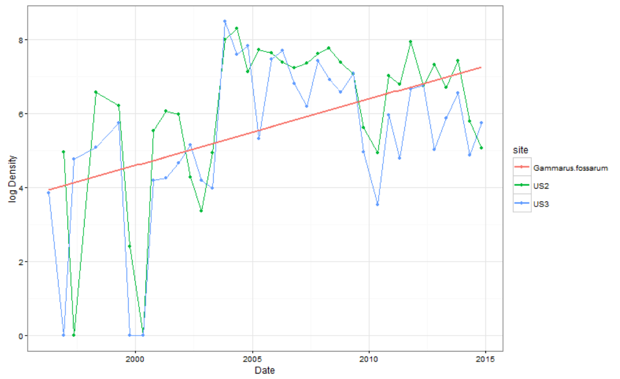
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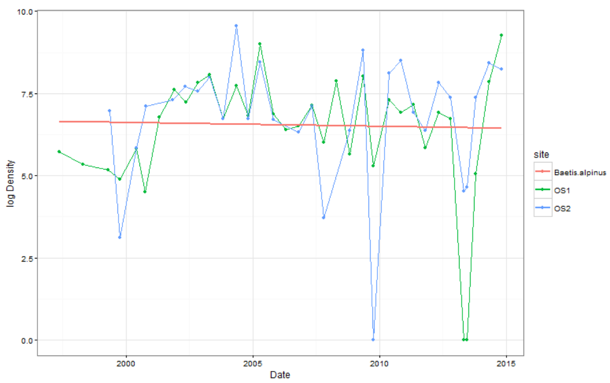

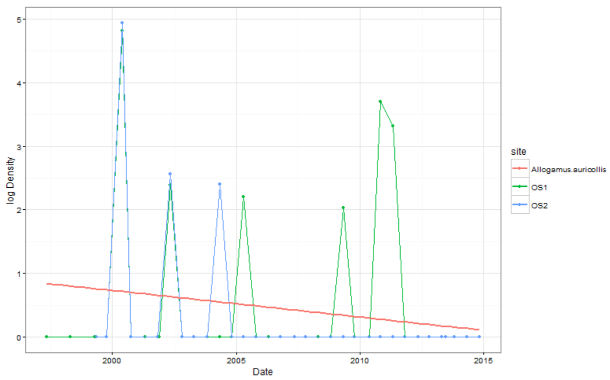

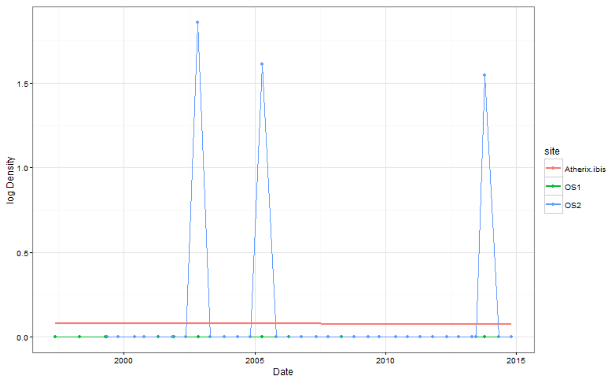

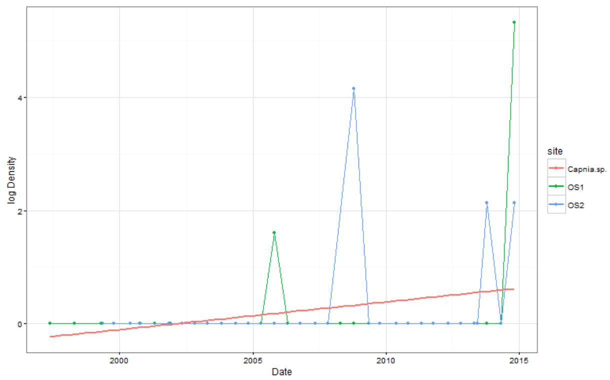

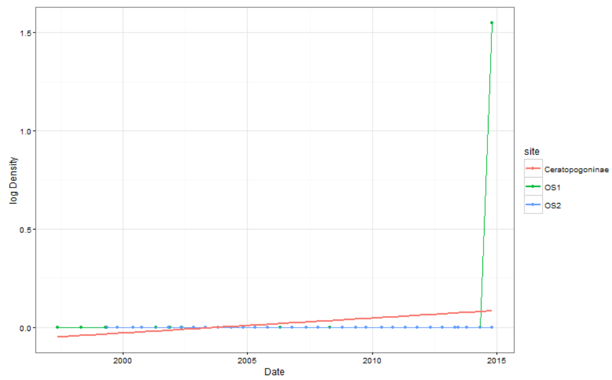

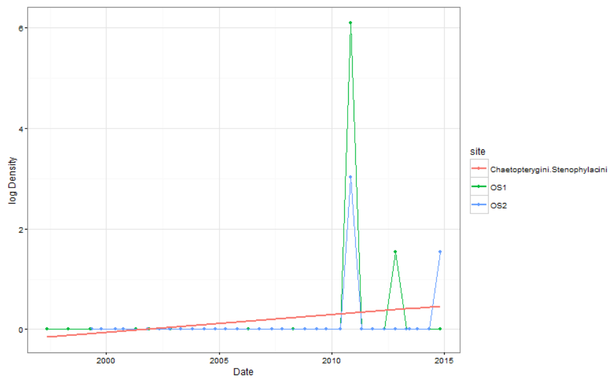

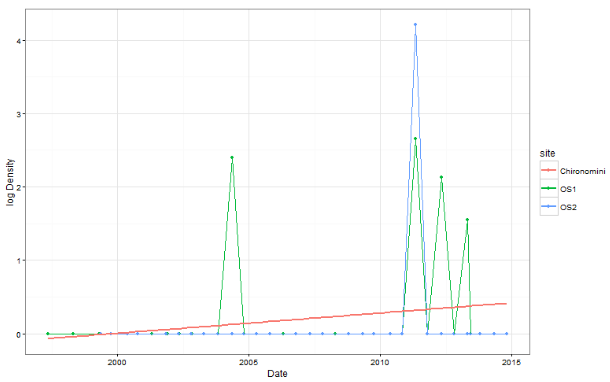

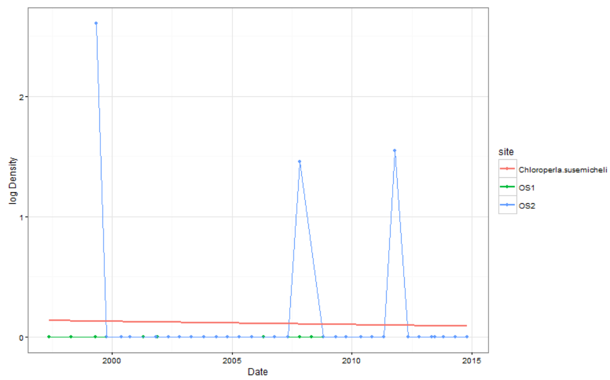

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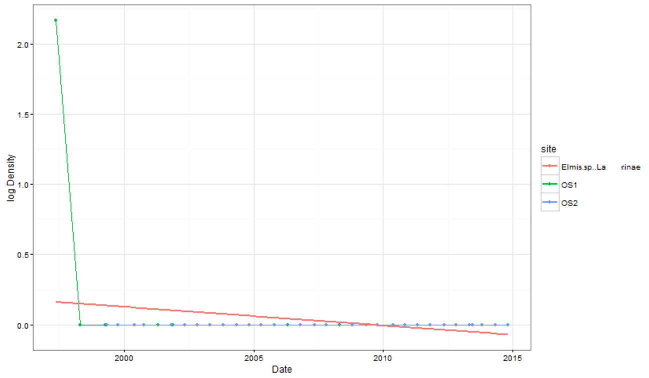

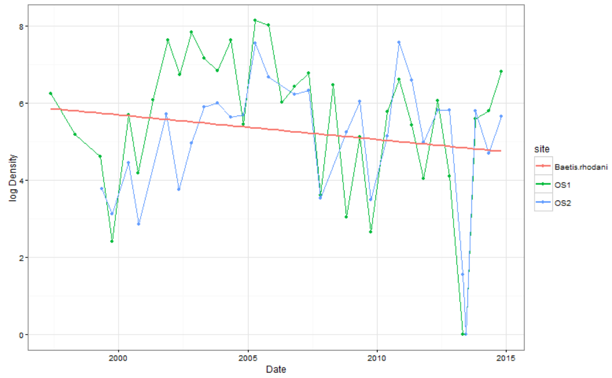

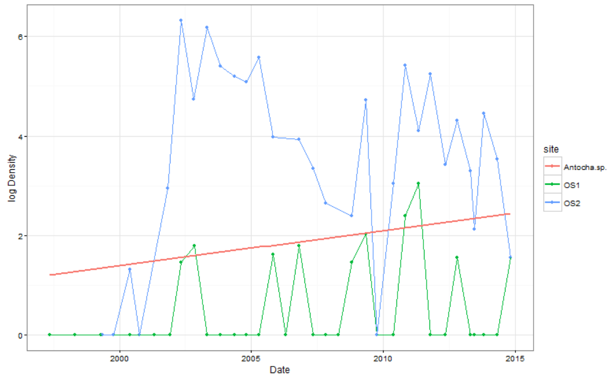

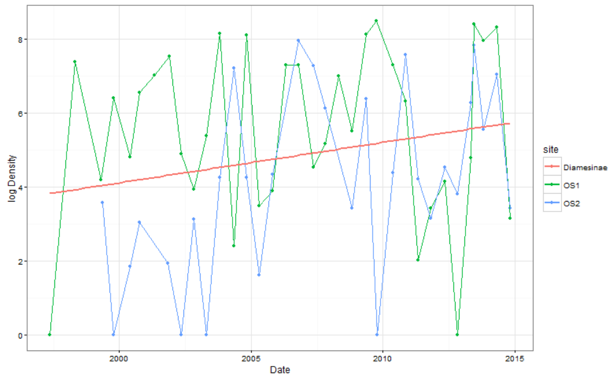

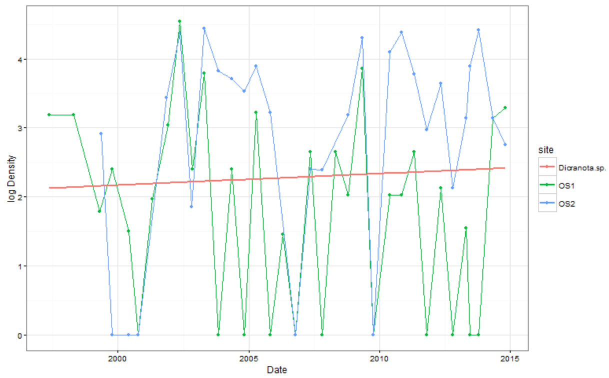

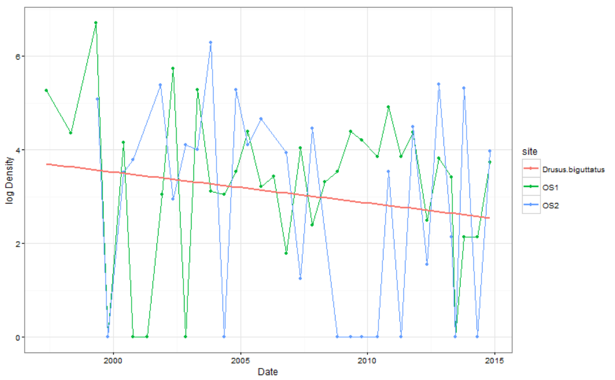

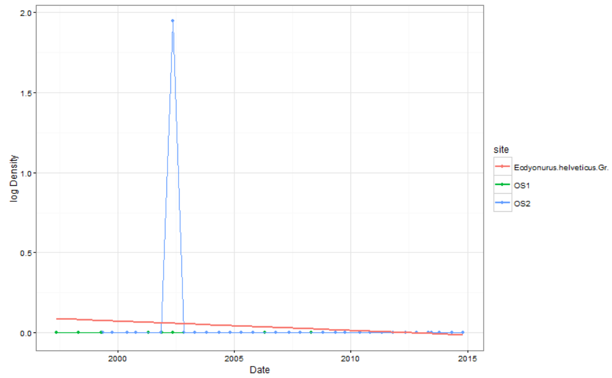

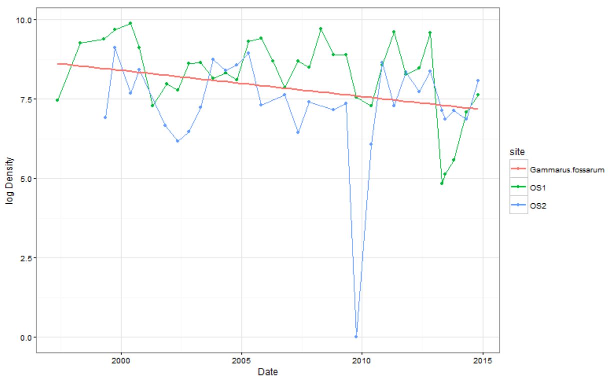

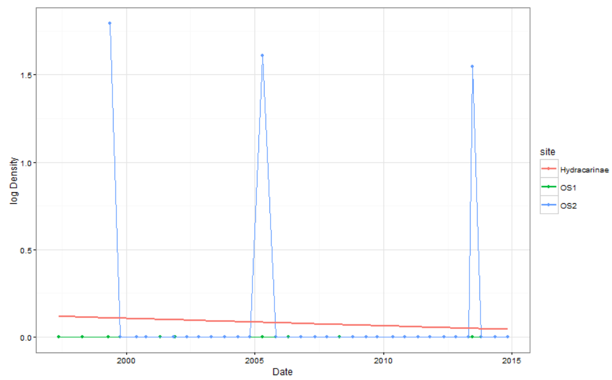

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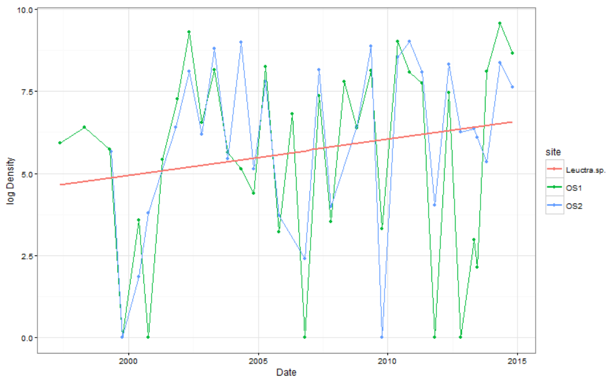

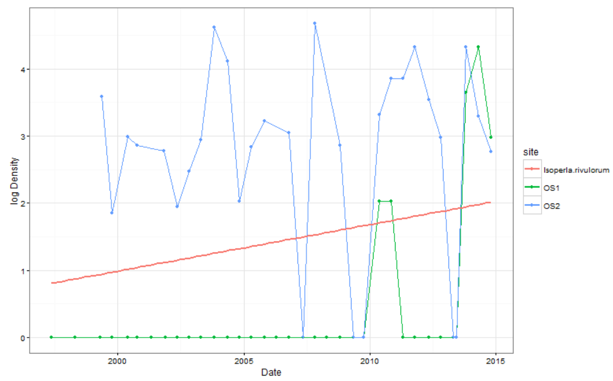

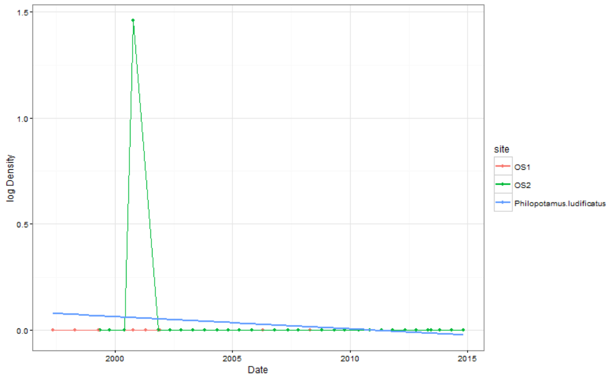

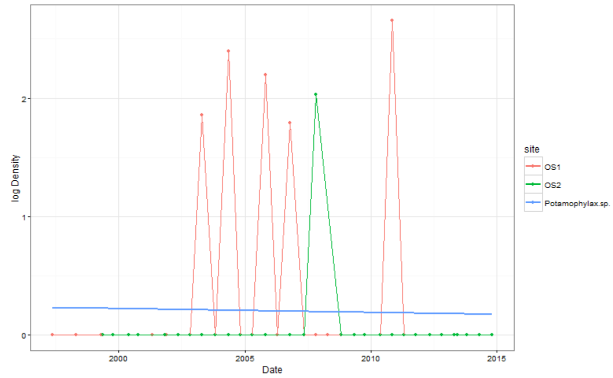

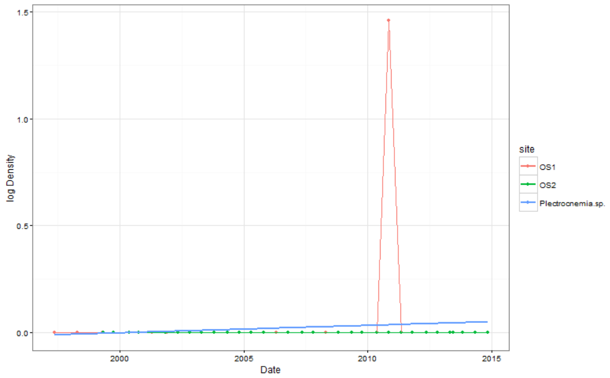

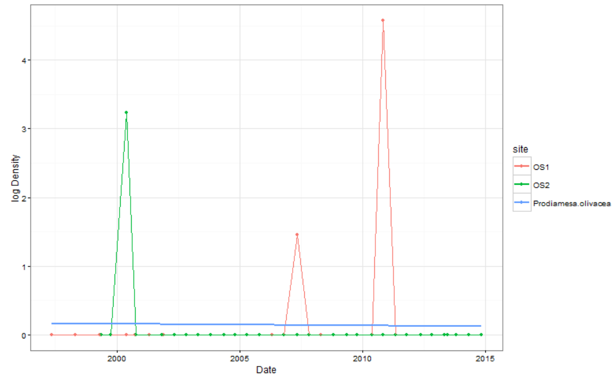

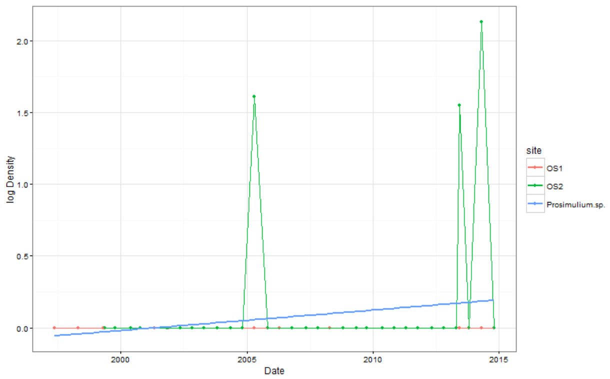

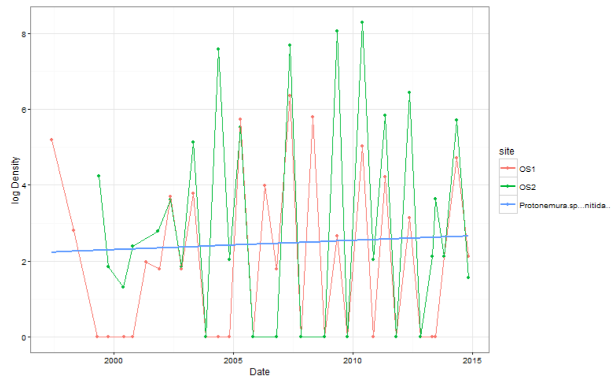

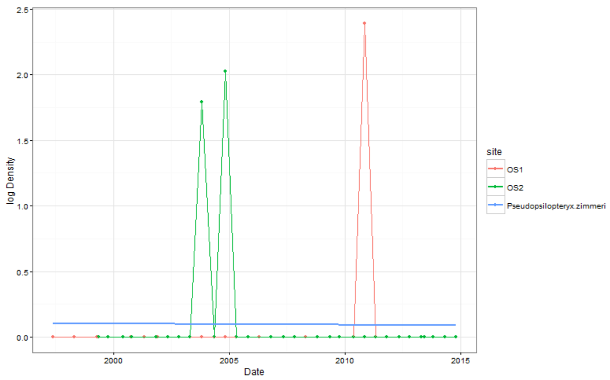

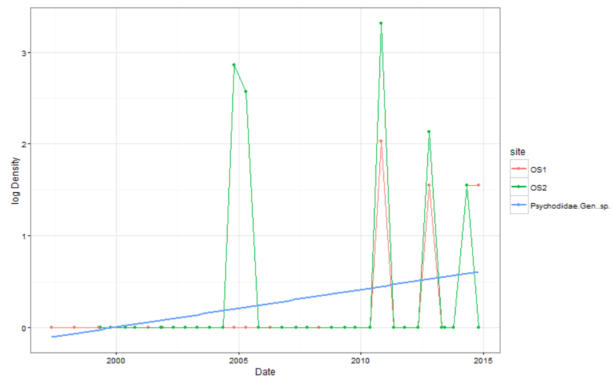

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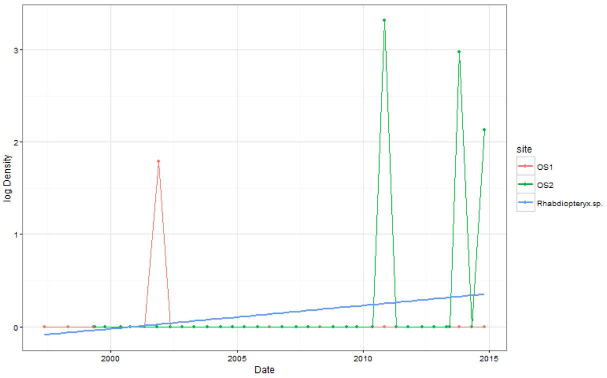

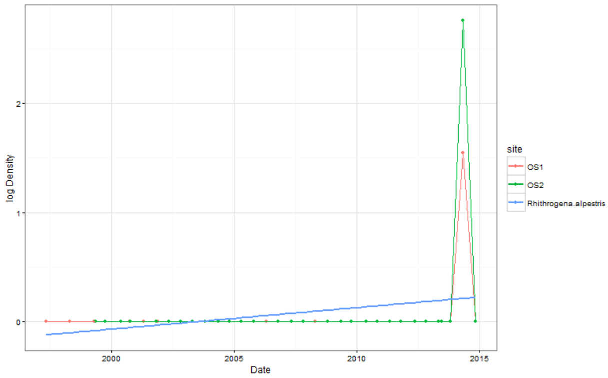

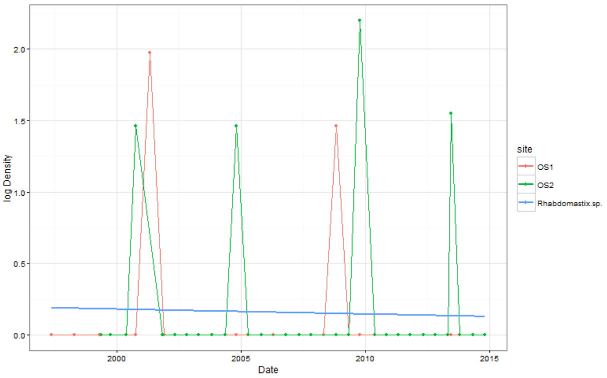

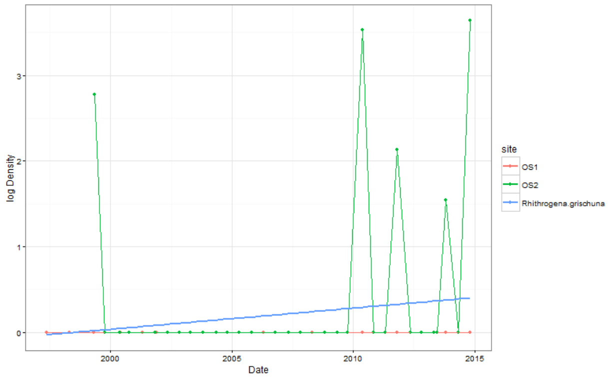

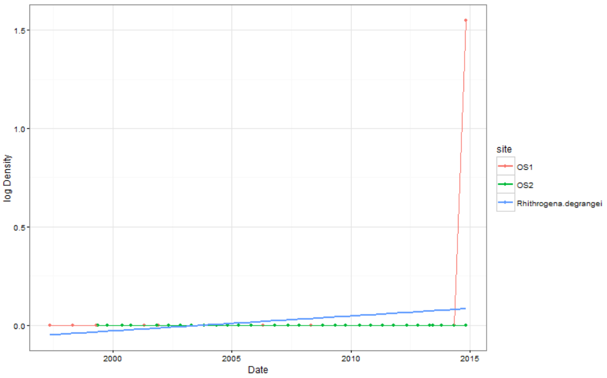

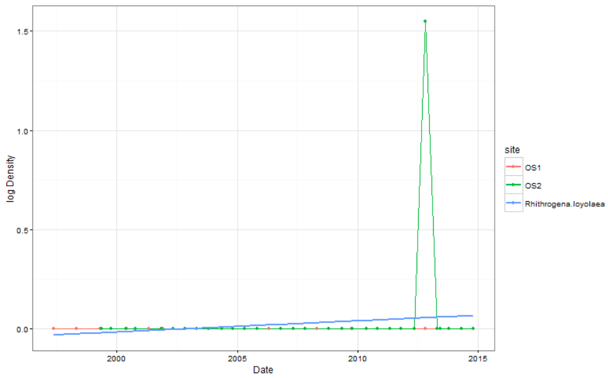

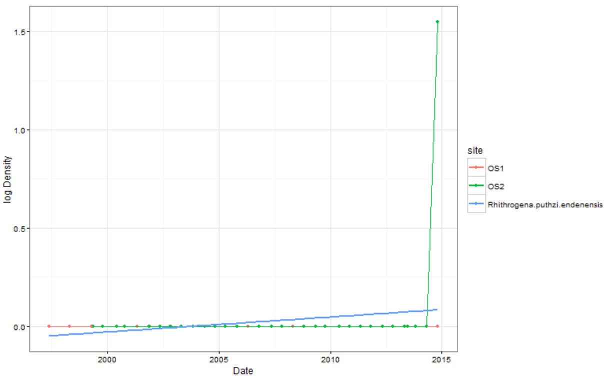

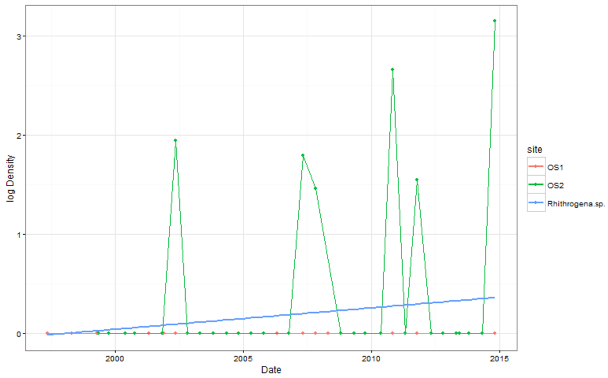

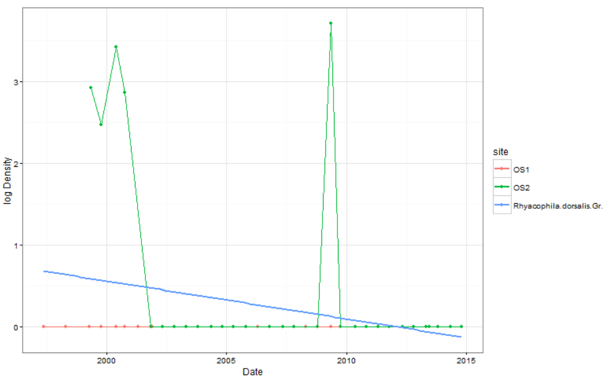

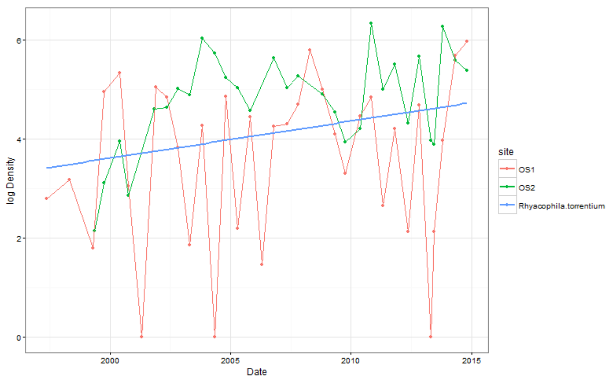

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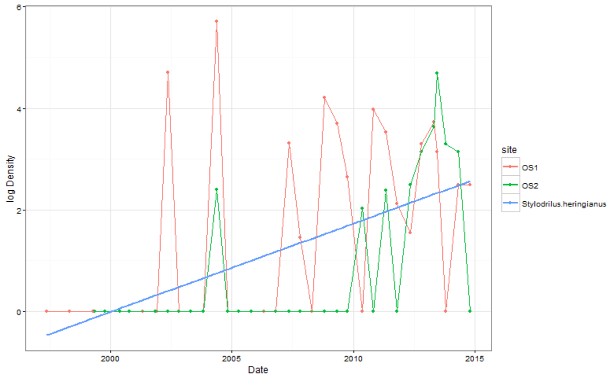

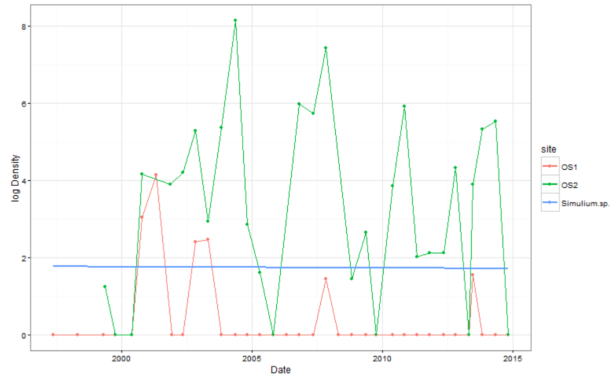

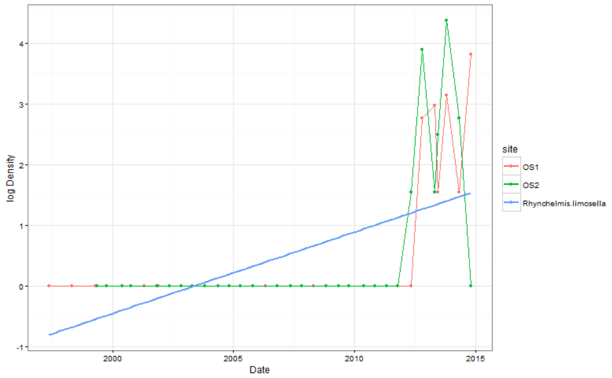

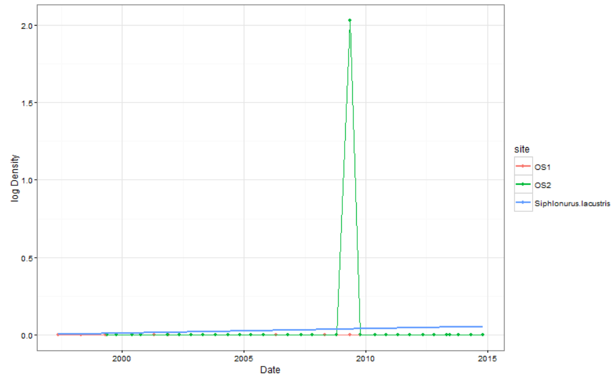

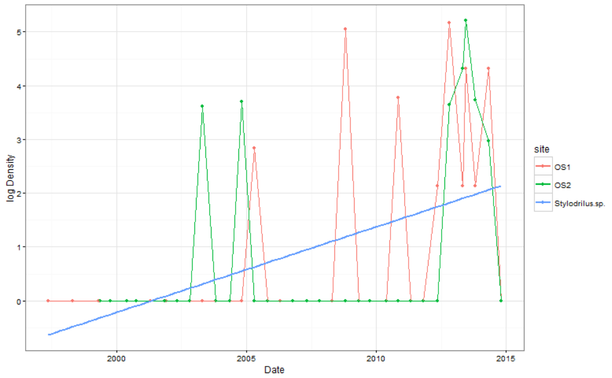

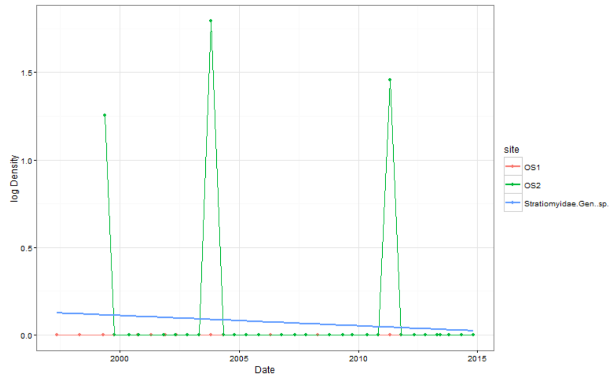

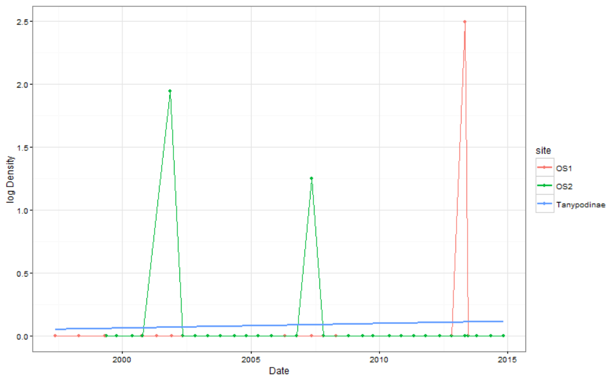

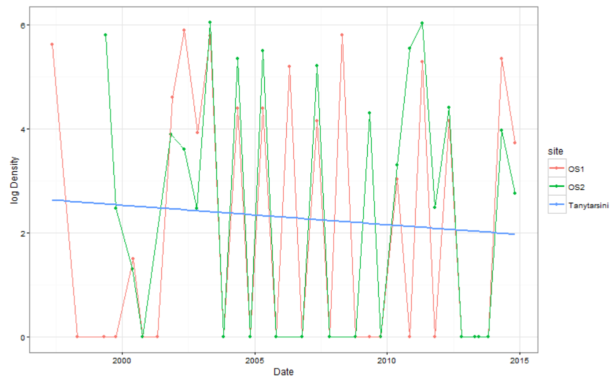

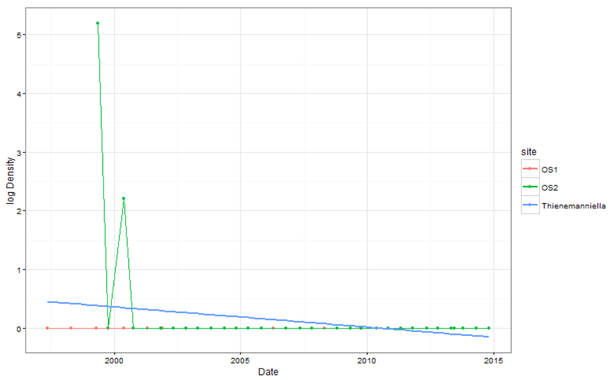

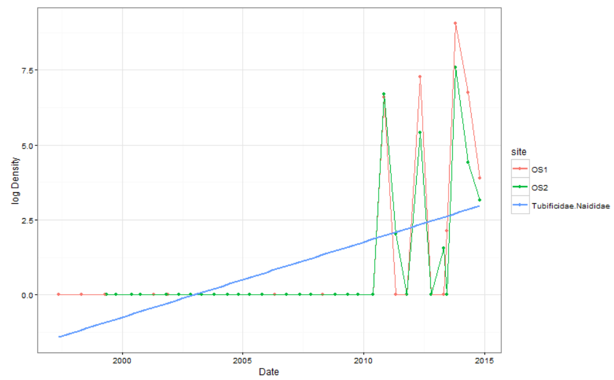

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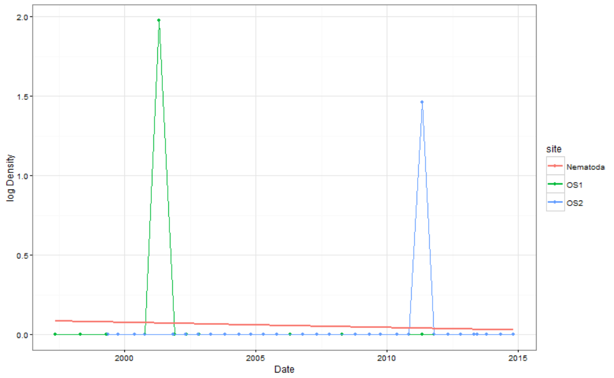

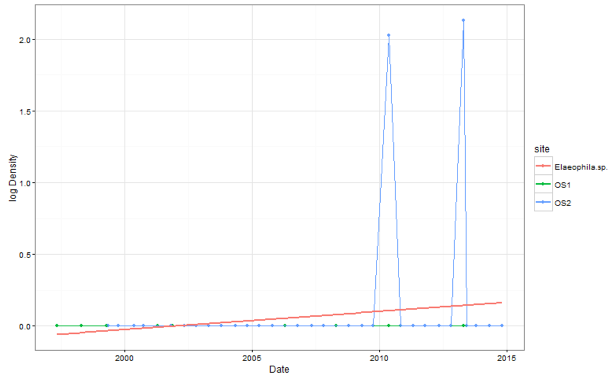

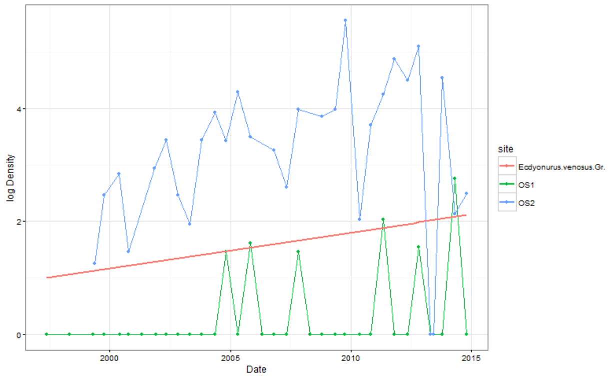

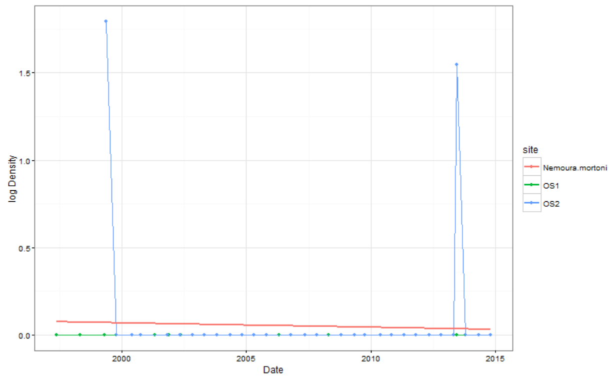

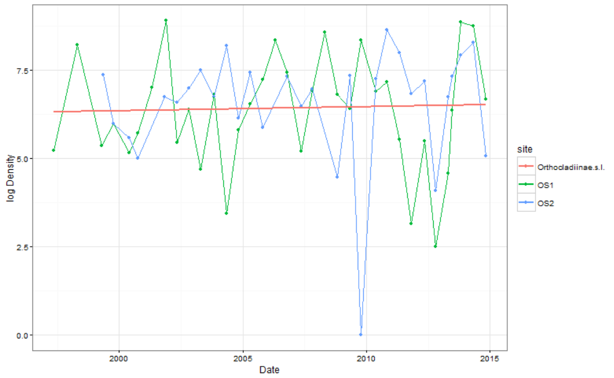

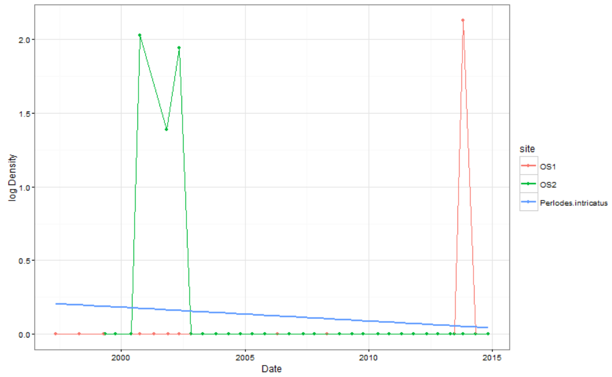

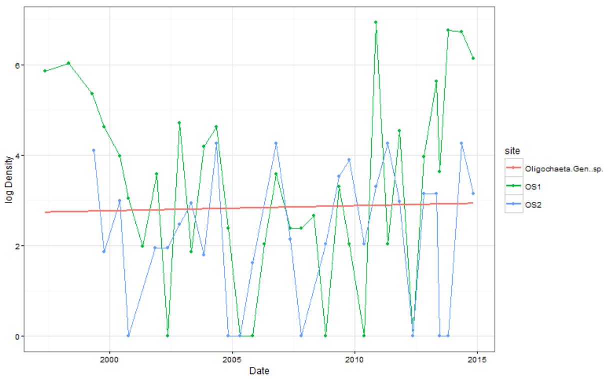

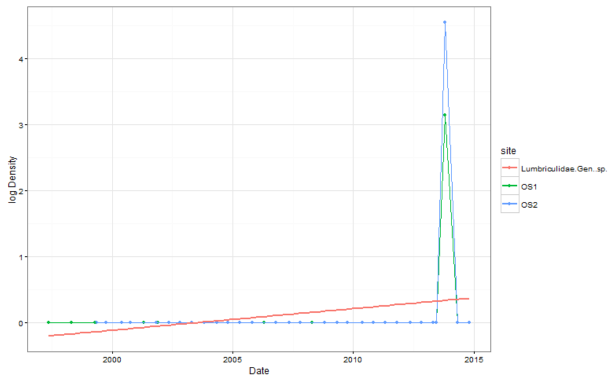

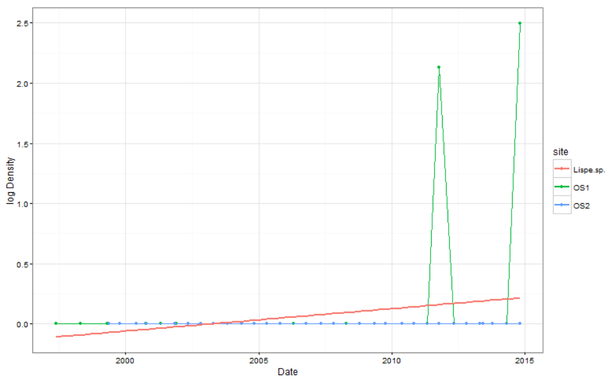

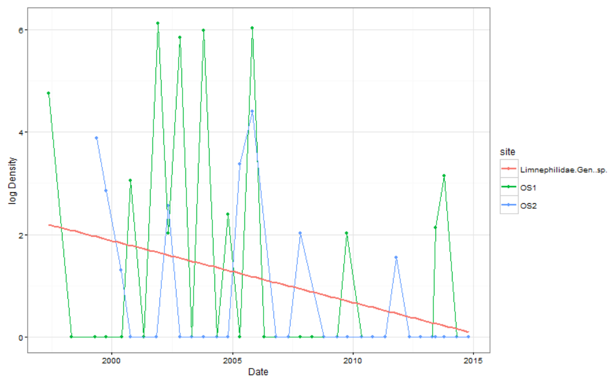

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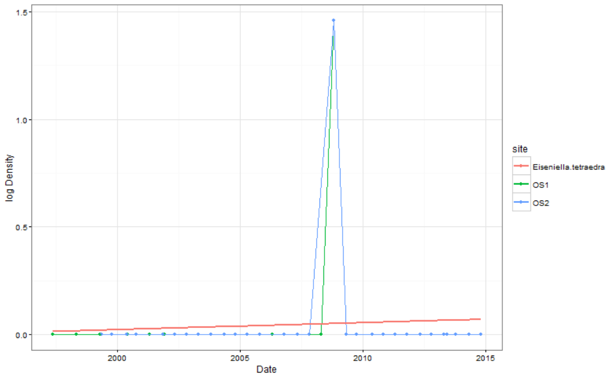

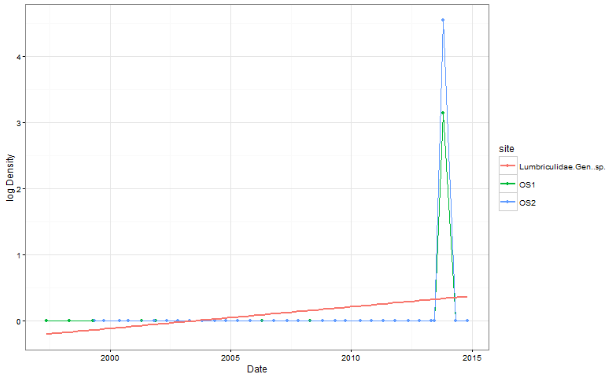

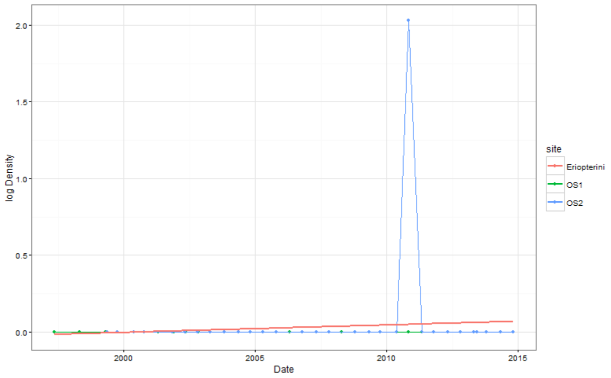

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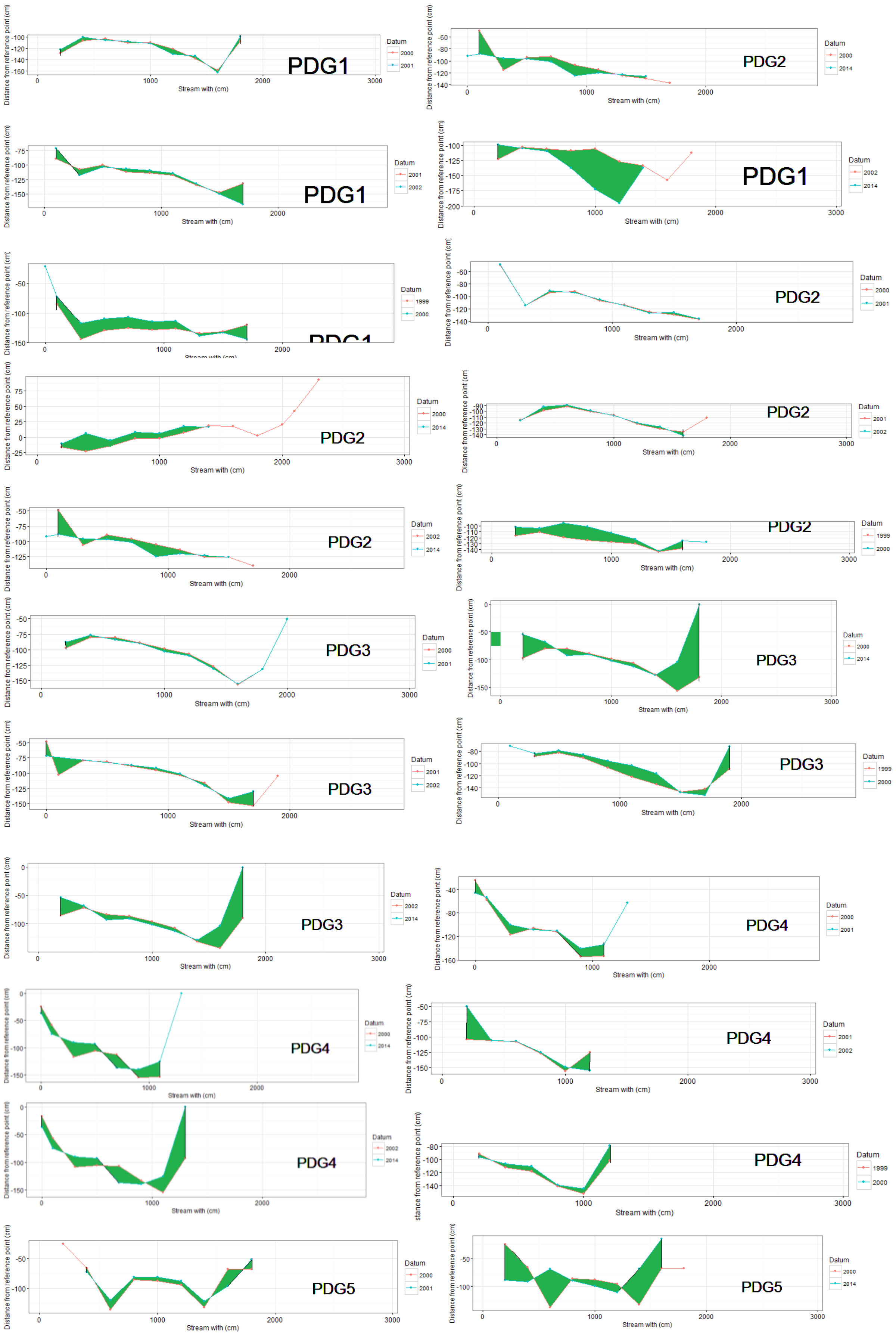
Transect area measurements



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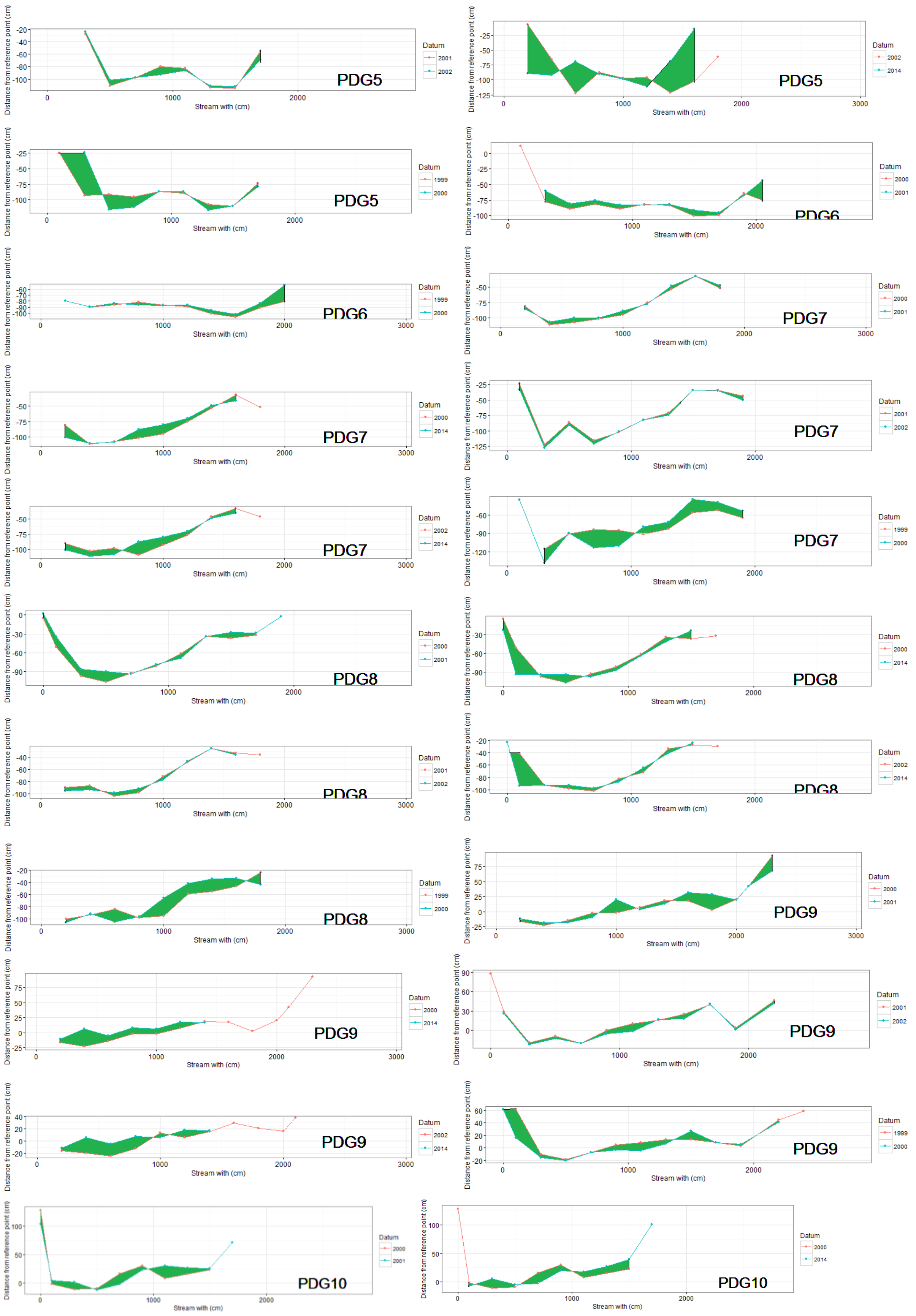

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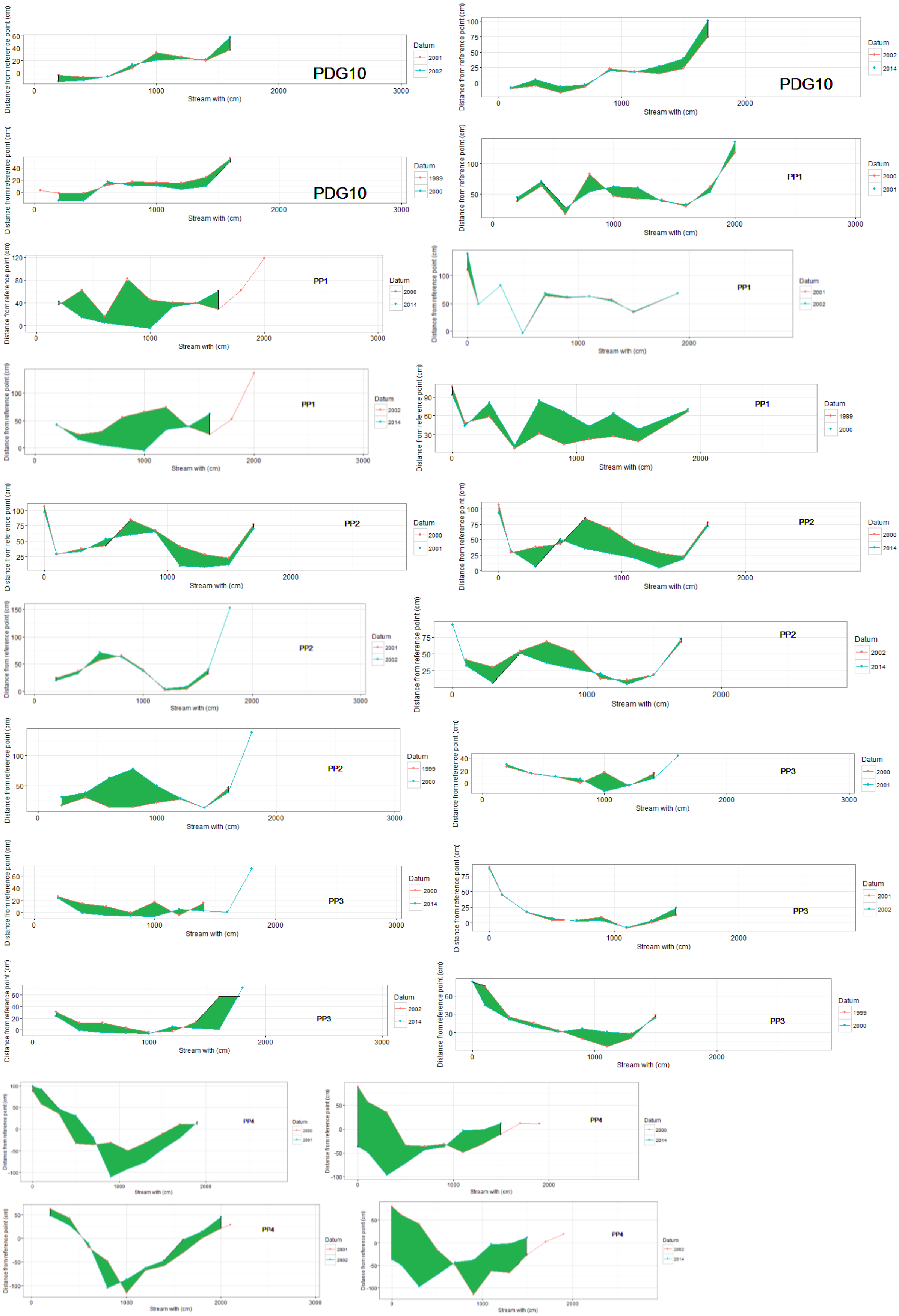

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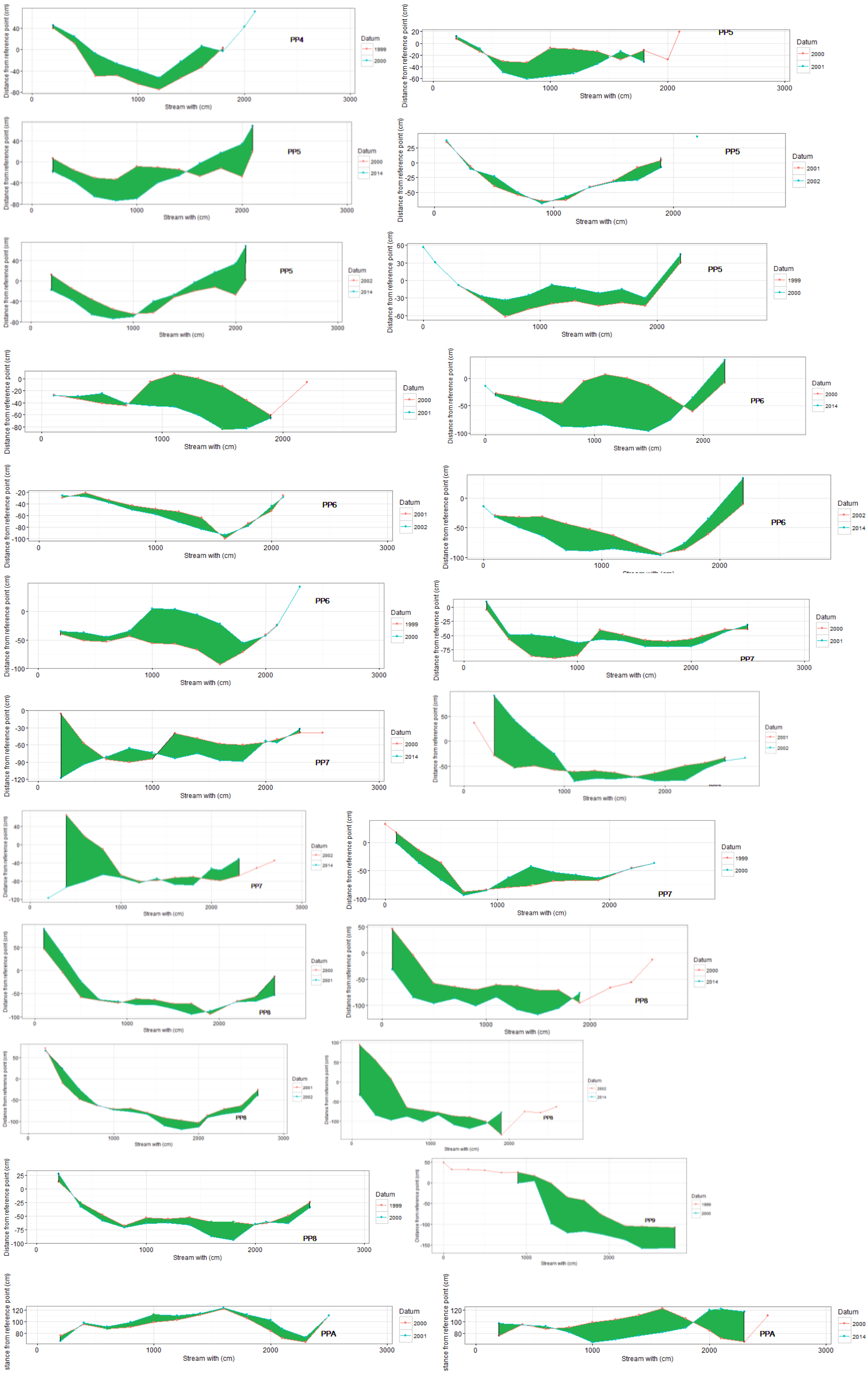

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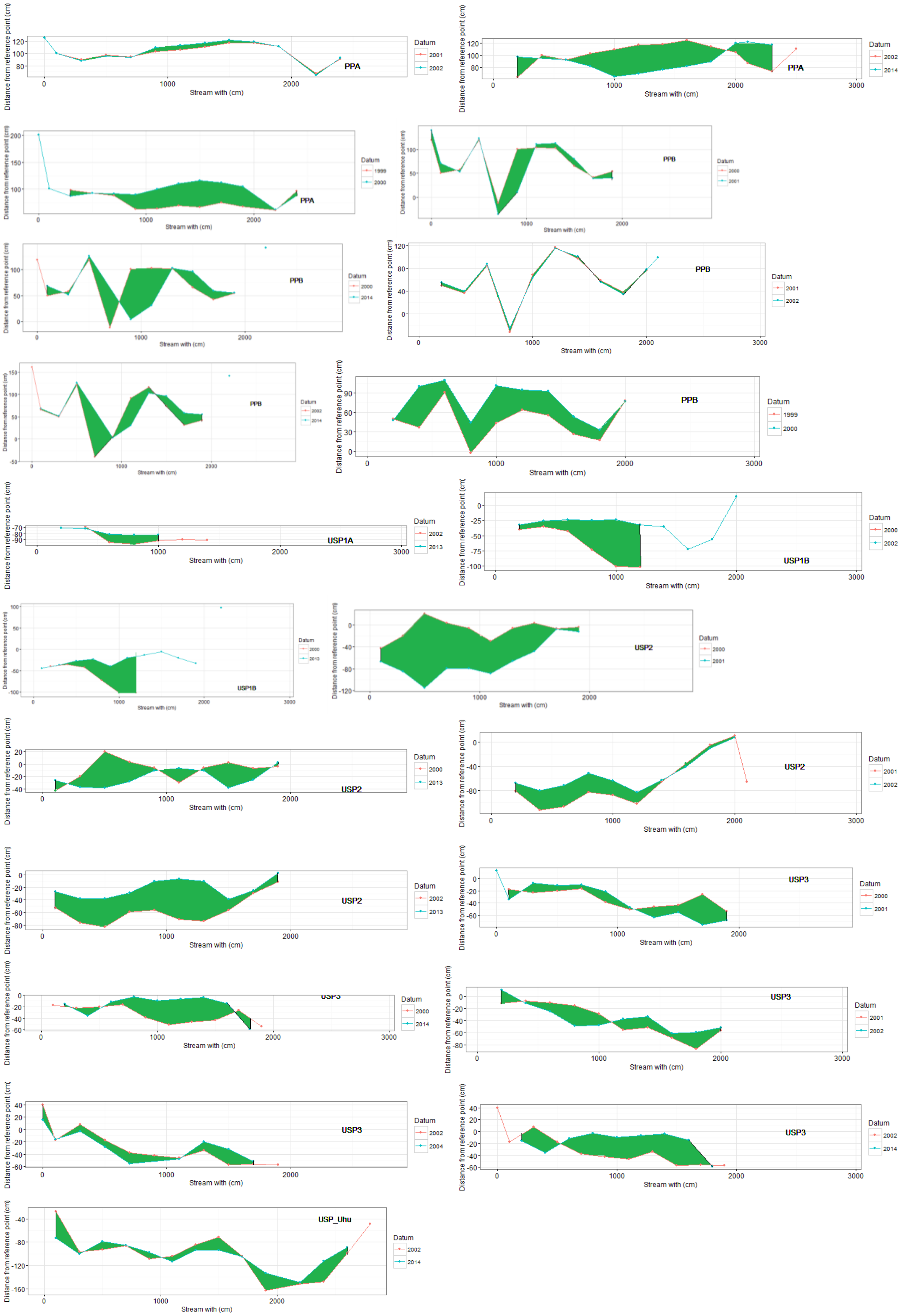
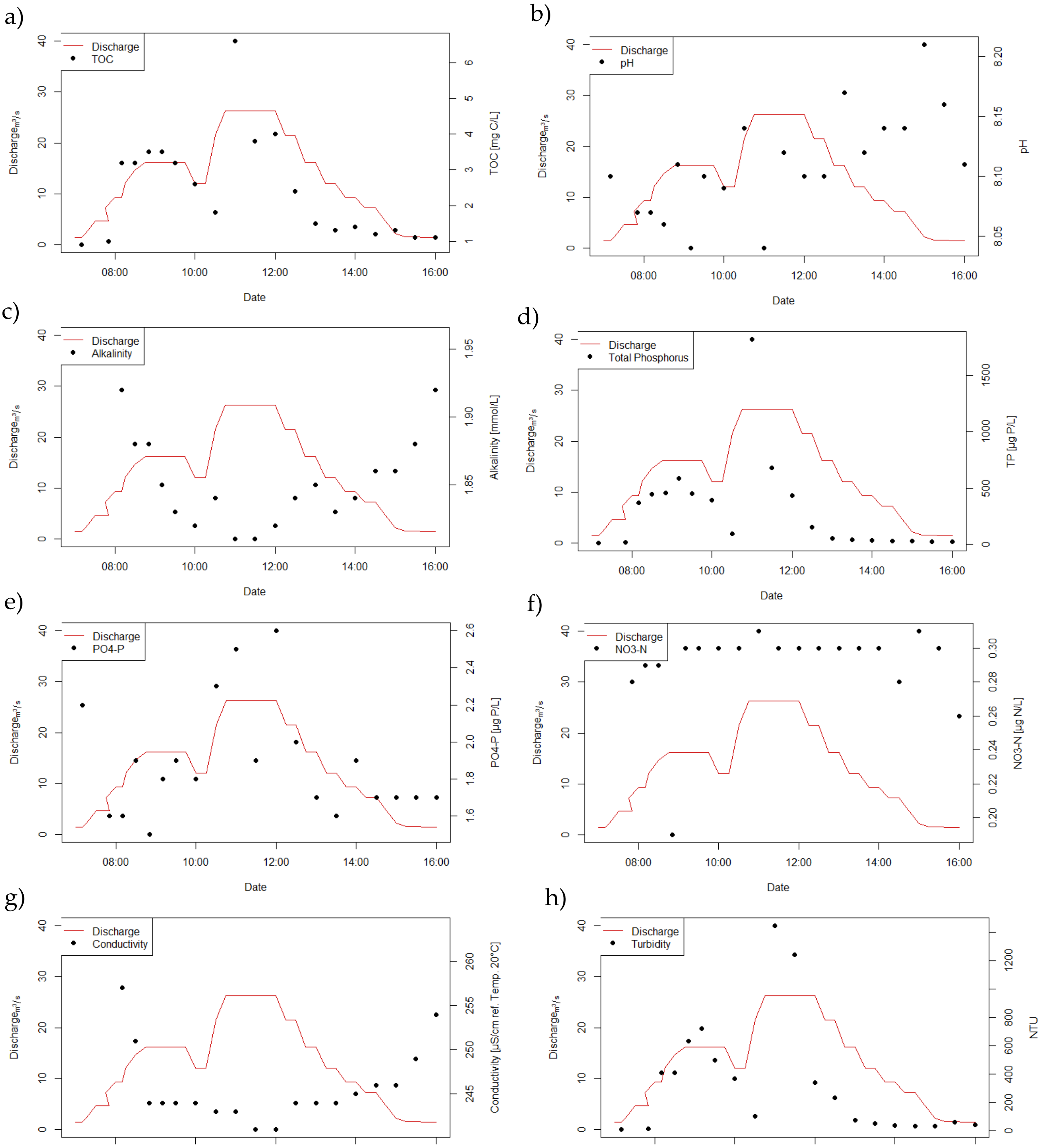
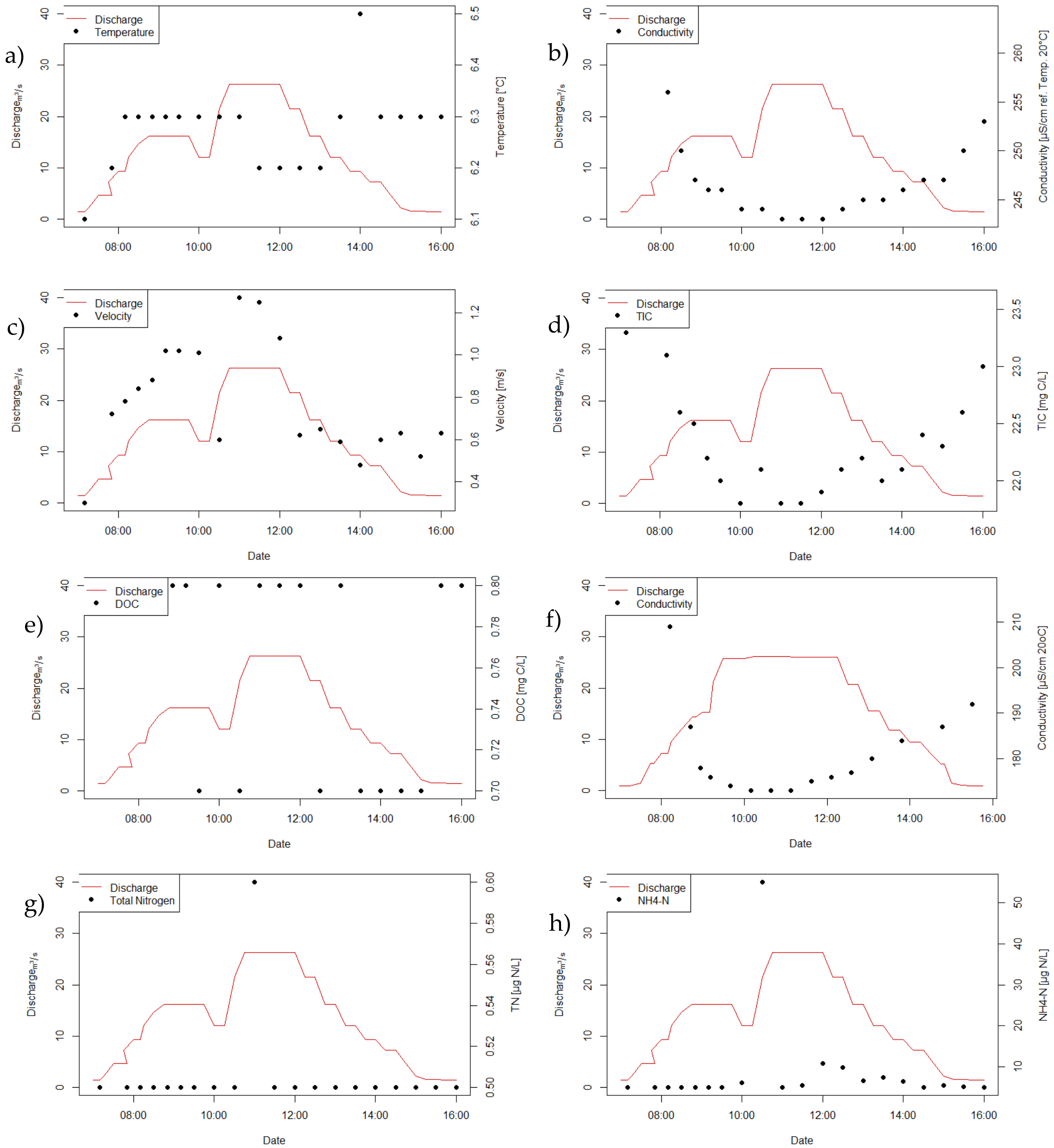


Appendix Results Chapter 2

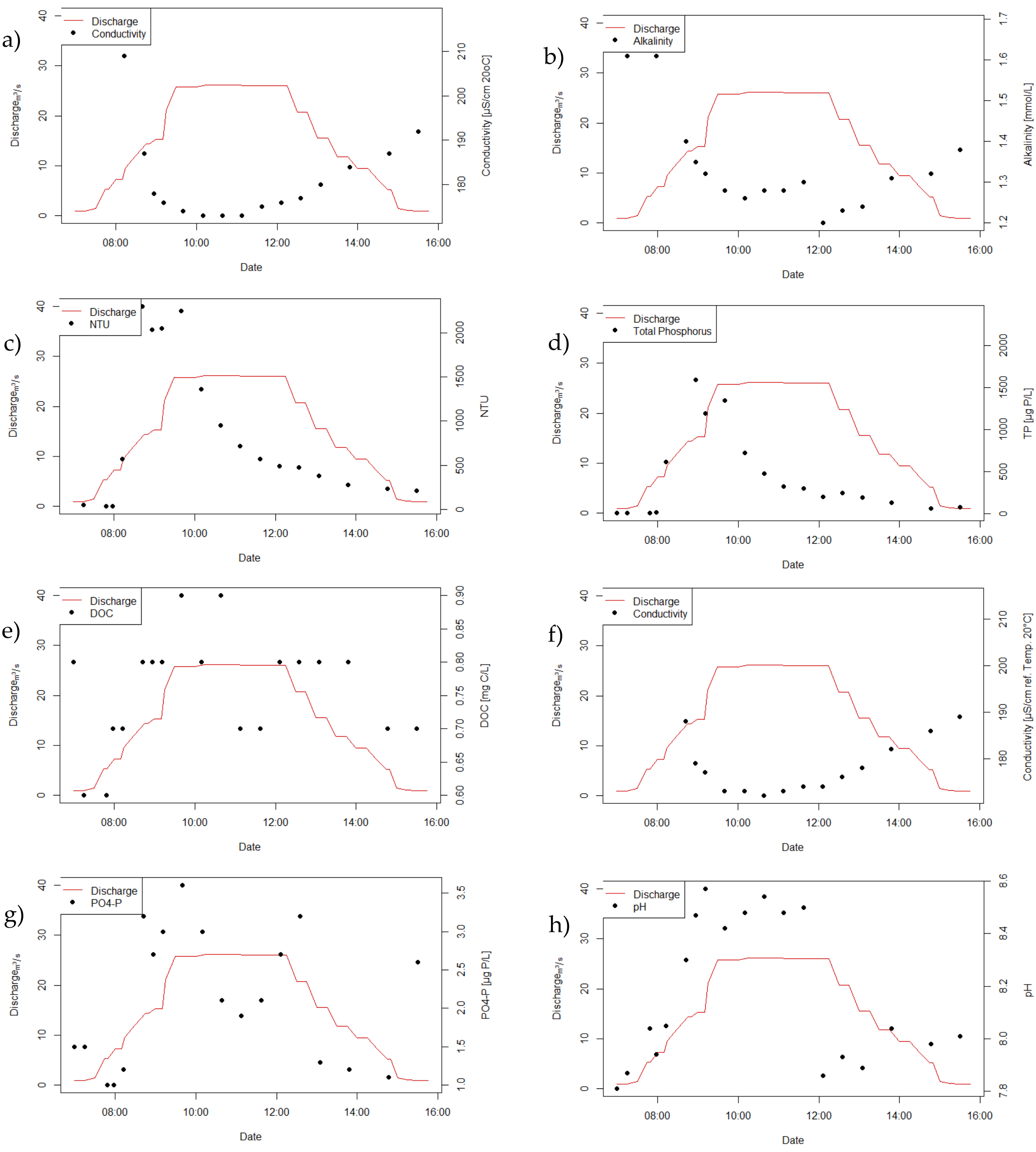
Chemical and physical parameters against Time



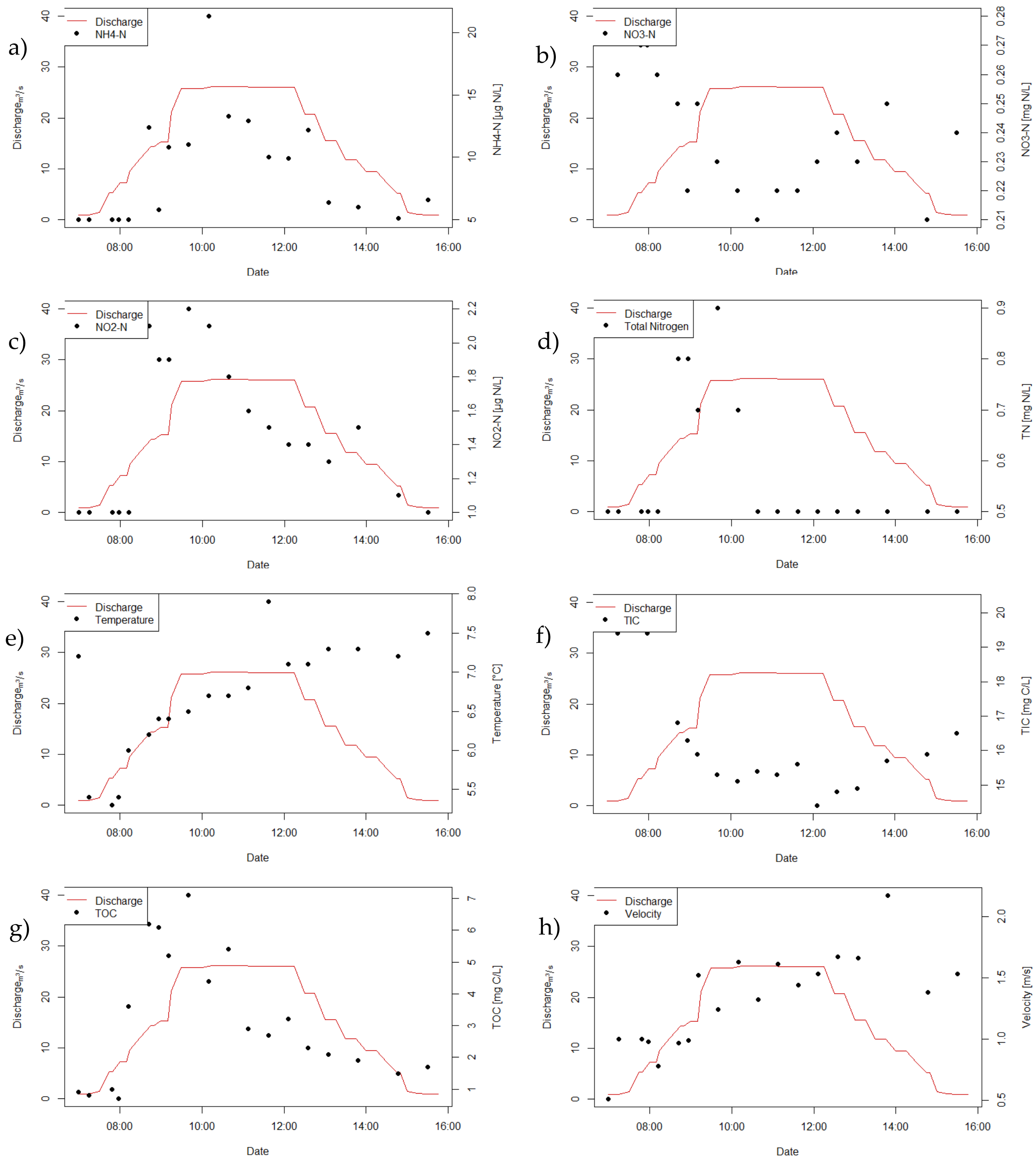
App. Figure 4 a)-h): Upper Spol discharge and physical and chemical parameters against time.



App. Figure 5 a)-h): Upper Spol discharge and physical and chemical parameters against time.



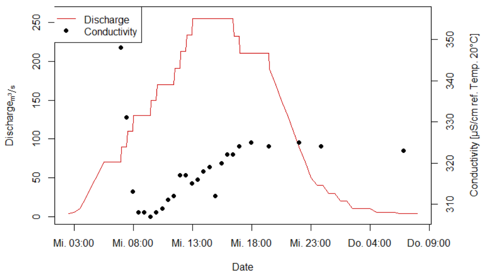
App. Figure 6 a)-h): Lower Spol discharge and physical and chemical parameters against time



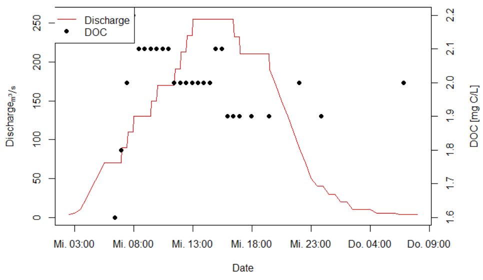
App. Figure 7 a)-h): Lower Spol discharge and physical and chemical parameters against time

Appendix Results Chapter 2

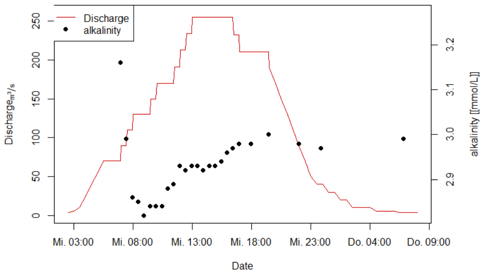
a)


Discharge
Conductivity
Discharge$_{m^3/s}$
Conductivity [µS/cm ref. Temp. 20°C]
Mi. 03:00
Mi. 08:00
Mi. 13:00
Mi. 18:00
Mi. 23:00
Do. 04:00
Do. 09:00
Date

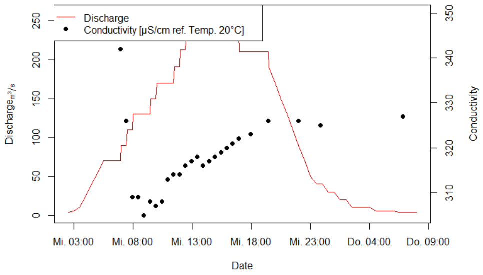
b)


Discharge
DOC
Discharge$_{m^3/s}$
DOC [mg C/L]
Mi. 03:00
Mi. 08:00
Mi. 13:00
Mi. 18:00
Mi. 23:00
Do. 04:00
Do. 09:00
Date

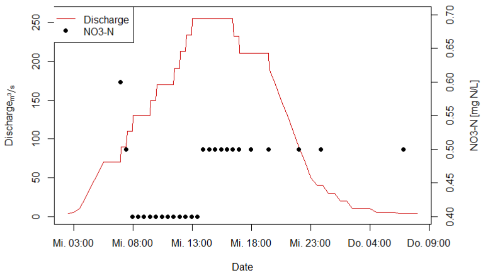
c)


Discharge
alkalinity
Discharge$_{m^3/s}$
alkalinity [[mmol/L]]
Mi. 03:00
Mi. 08:00
Mi. 13:00
Mi. 18:00
Mi. 23:00
Do. 04:00
Do. 09:00
Date

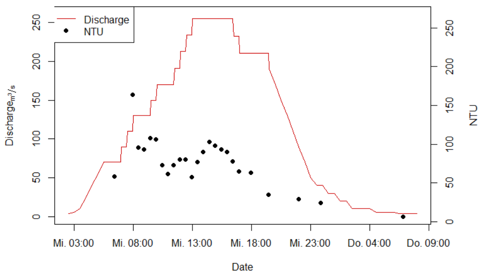
d)


Discharge
Conductivity [µS/cm ref. Temp. 20°C]
Discharge$_{m^3/s}$
Conductivity
Mi. 03:00
Mi. 08:00
Mi. 13:00
Mi. 18:00
Mi. 23:00
Do. 04:00
Do. 09:00
Date

e)

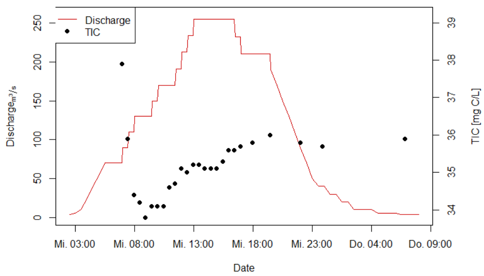

Discharge
NO3-N
Discharge$_{m^3/s}$
NO3-N [mg N/L]
Mi. 03:00
Mi. 08:00
Mi. 13:00
Mi. 18:00
Mi. 23:00
Do. 04:00
Do. 09:00
Date

f)


Discharge
NTU
Discharge$_{m^3/s}$
NTU
Mi. 03:00
Mi. 08:00
Mi. 13:00
Mi. 18:00
Mi. 23:00
Do. 04:00
Do. 09:00
Date

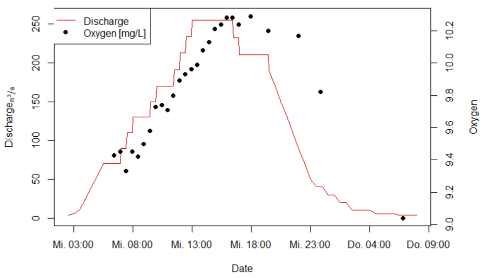
g)

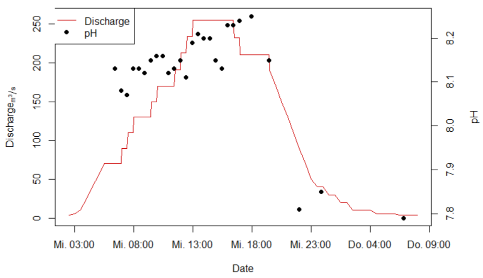
h)

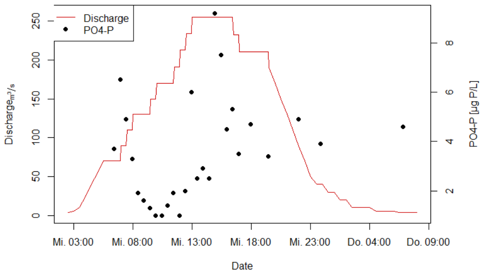

Discharge
TIC
Discharge$_{m^3/s}$
TIC [mg C/L]
Mi. 03:00
Mi. 08:00
Mi. 13:00
Mi. 18:00
Mi. 23:00
Do. 04:00
Do. 09:00
Date

i)

j)



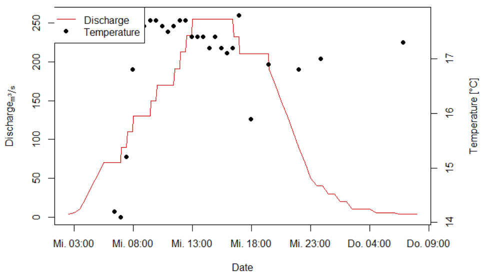




App. Figure 8 a)-j): Sarine discharge and physical and chemical parameters against time.

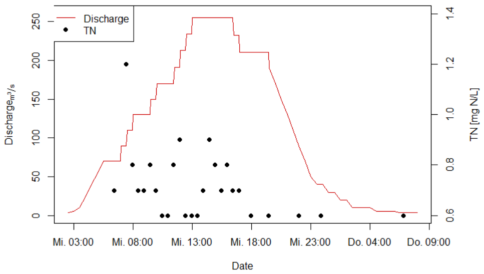
a)

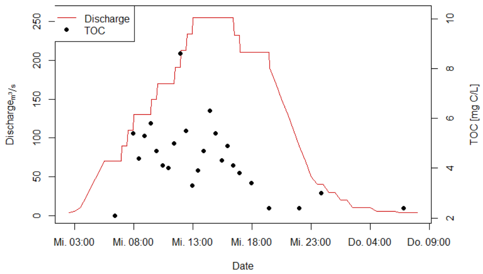
b)



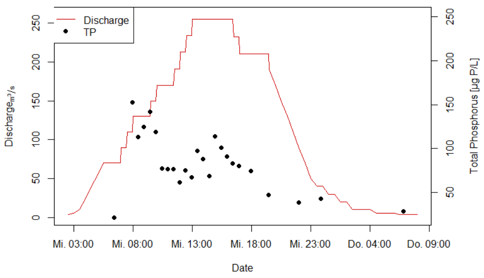
c)

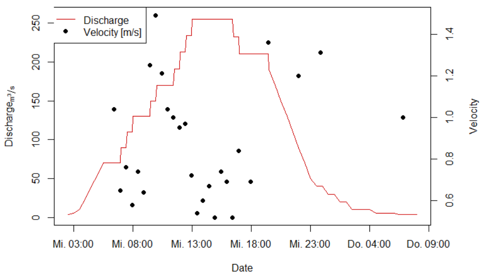
d)





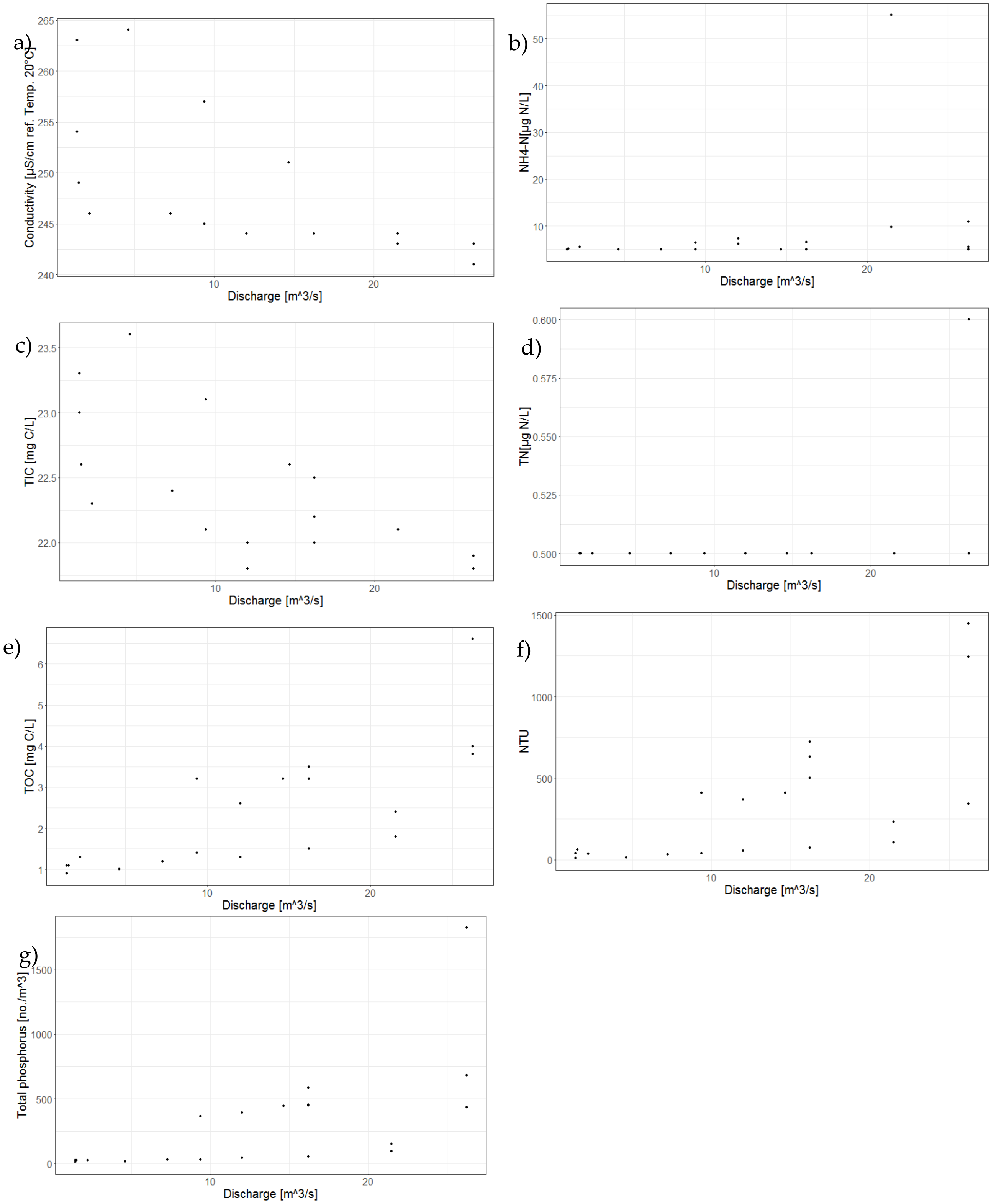
e)



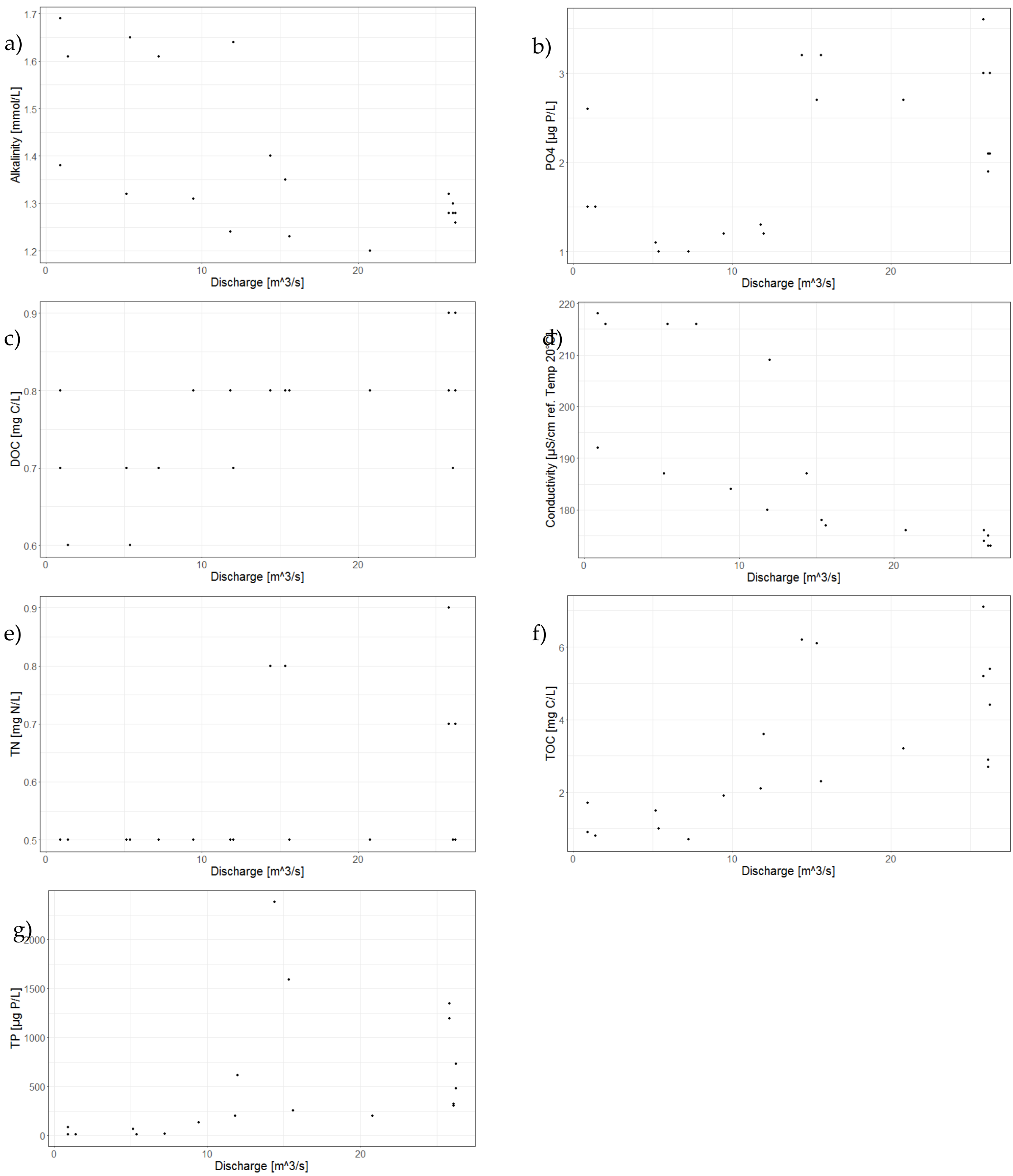


App. Figure 9 a) -e): Sarine discharge and physical and chemical parameters against time.

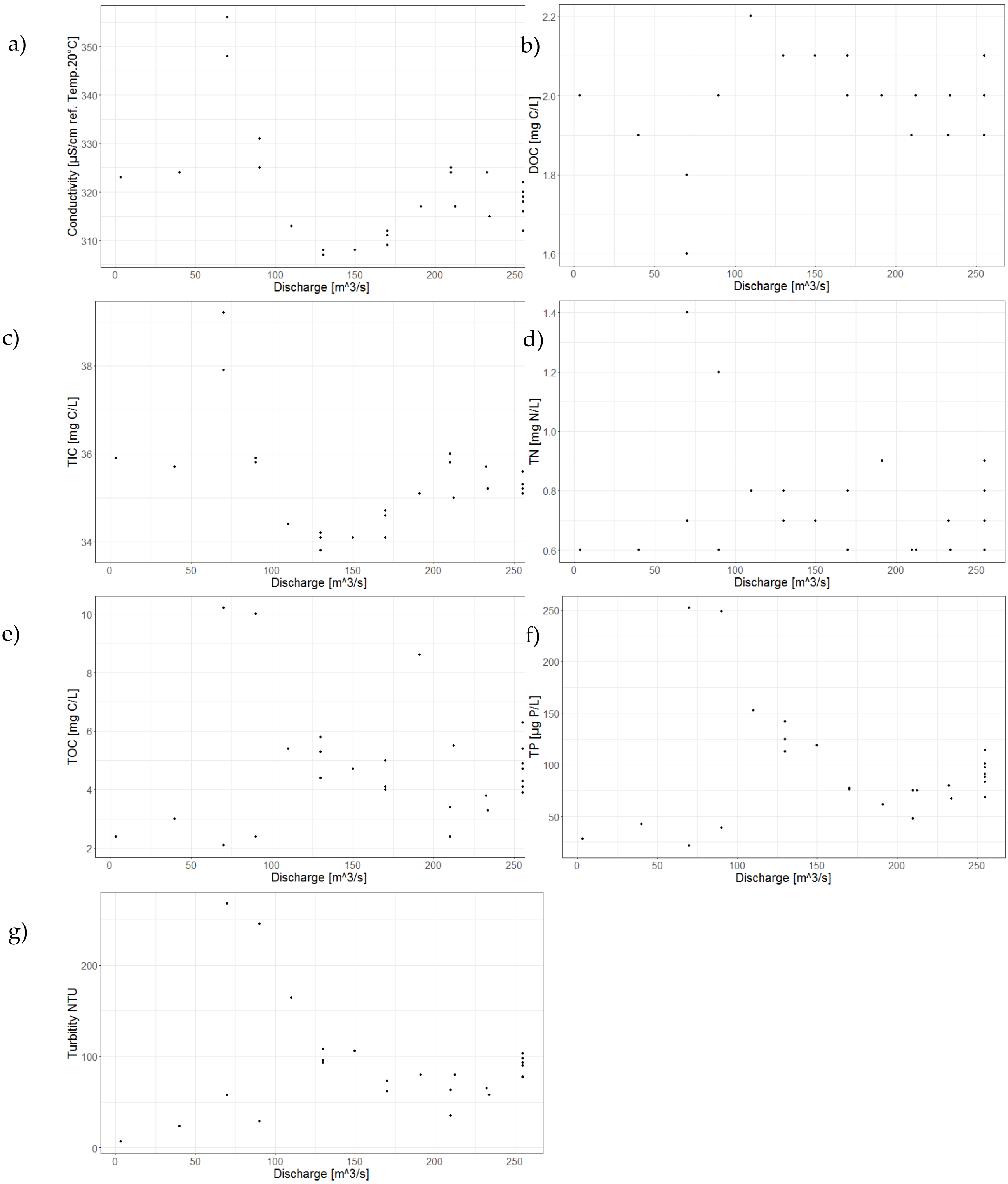
Chemical parameters against discharge



App. Figure 10 a)- g): chemical parameter against discharge from the upper Spol.

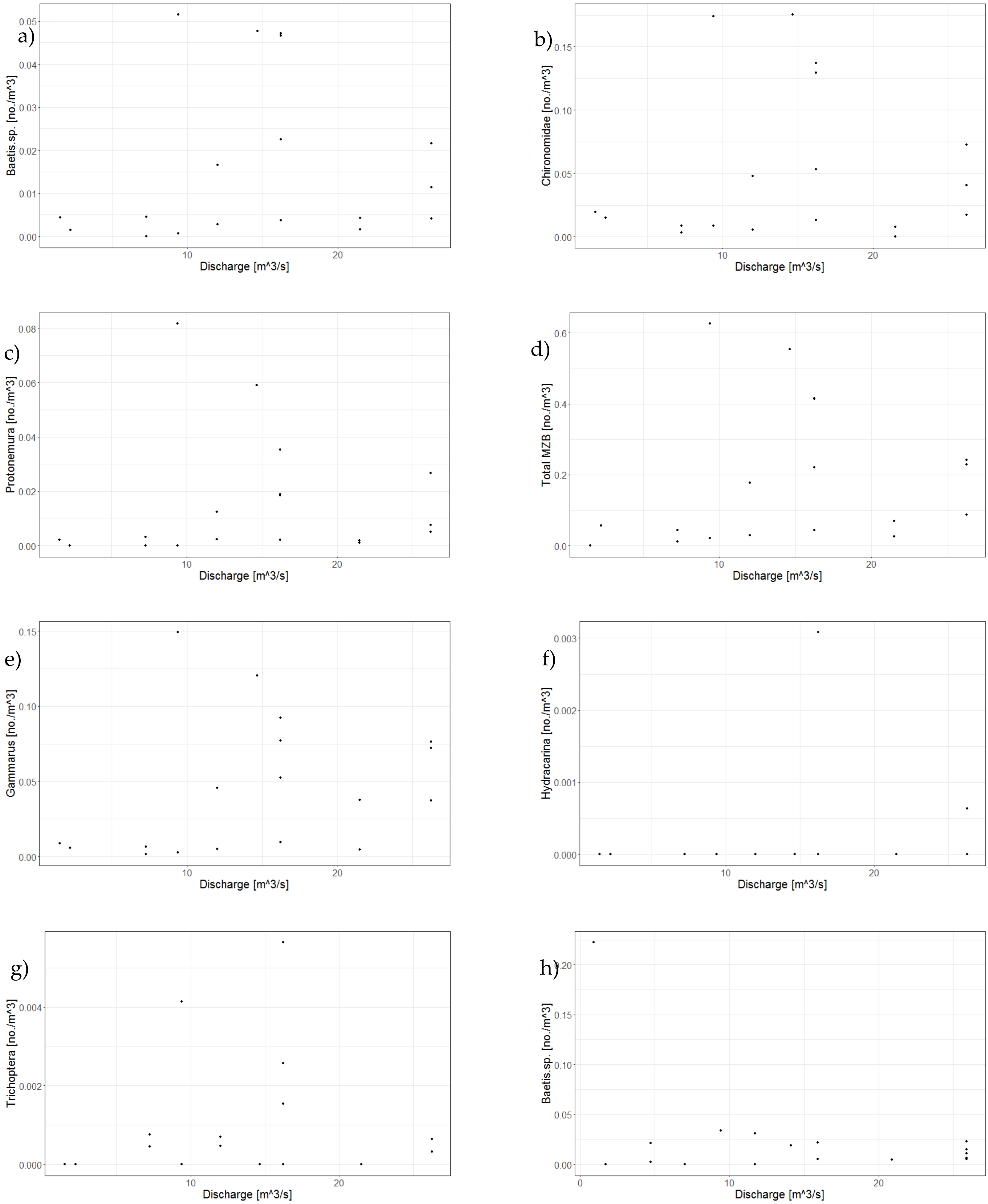


App. Figure 11 a) -g): Chemical parameters against discharge from the lower Spol.

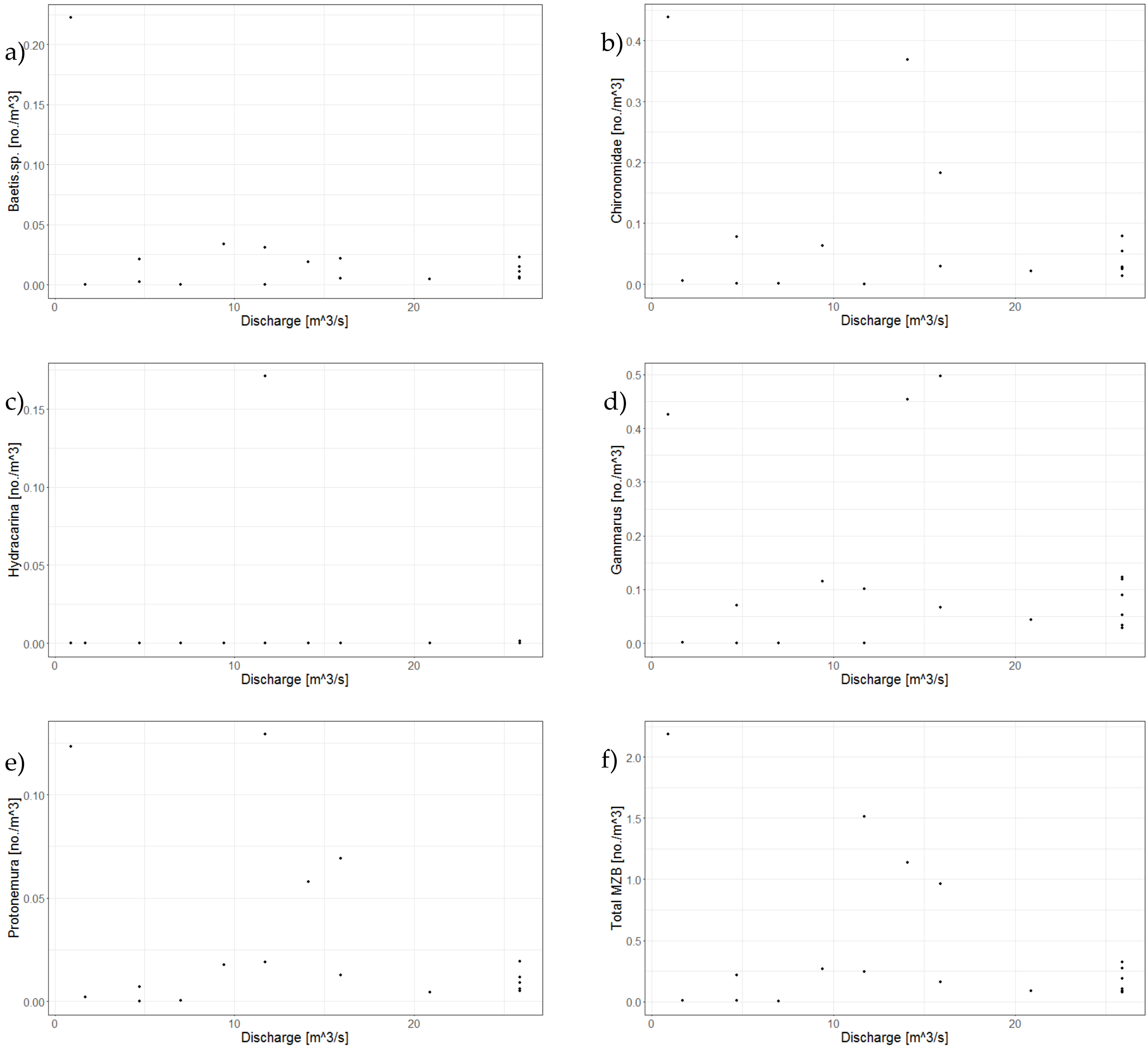


App. Figure 12 a) -g): chemical Parameters against discharge from the Sarine.

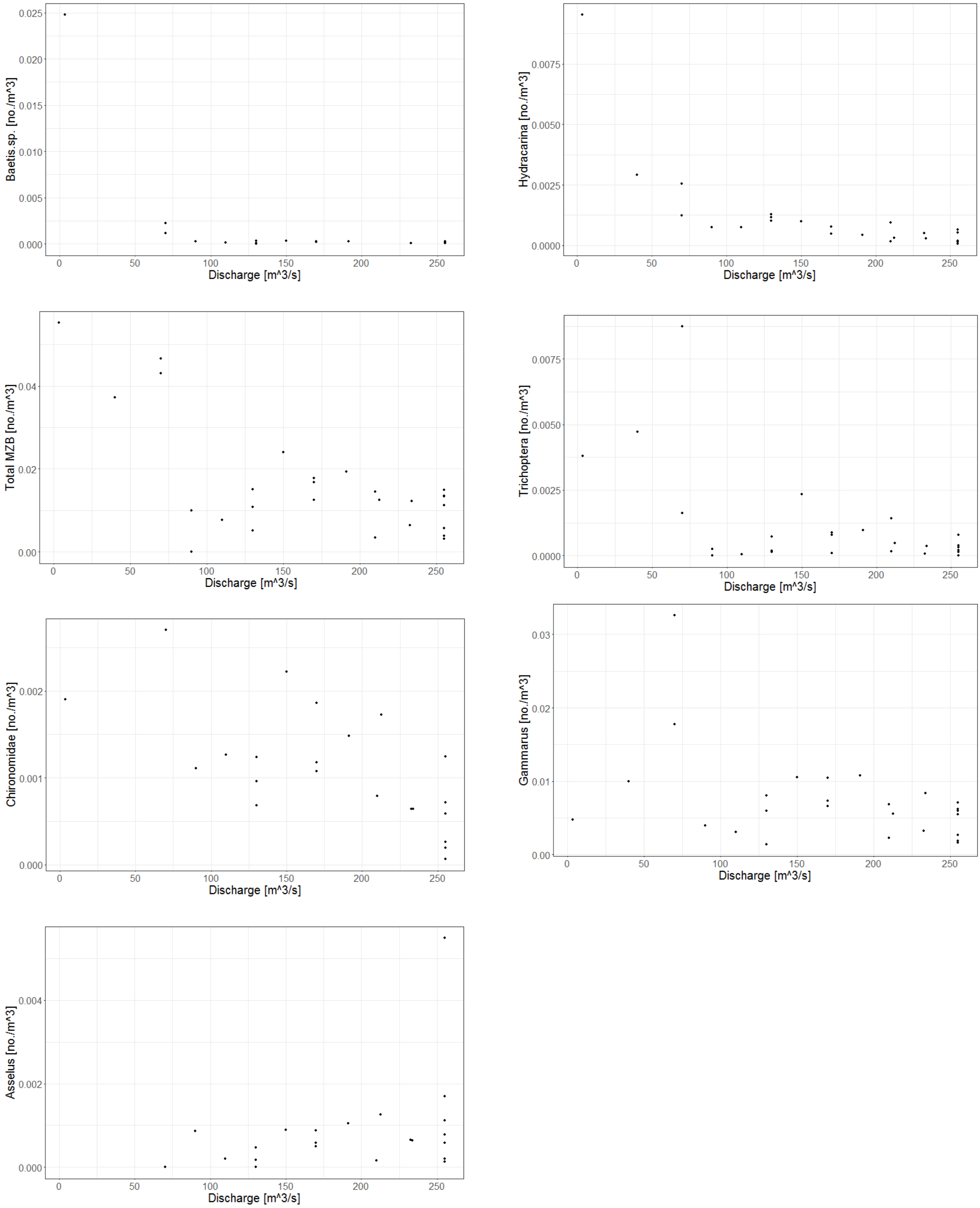
Macrozoobenthos against discharge



App. Figure 13 a)-h): Taxa or groups against discharge from the upper Spol.

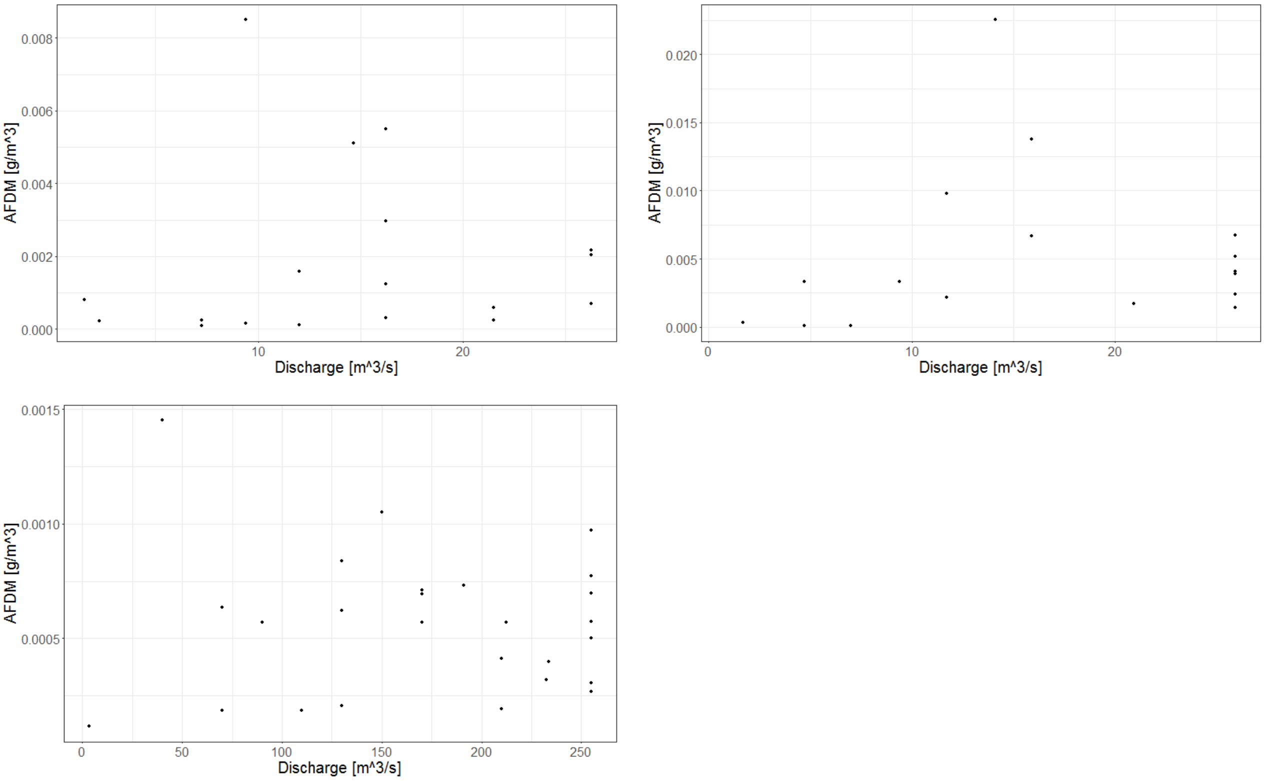


App. Figure 14 a)-f): Taxa or groups against discharge from the lower Spol.



App. Figure 15 a)-g): Taxa groups against discharge from the Sarine.

Seston against discharge



App. Figure 16: AFDM against discharge of the a) upper Spol, b) lower Spol and c)Sarine.