University of Natural Resources and Life Sciences, Vienna Department of Water, Atmosphere and Environment Institute of Hydrobiology and Aquatic Ecosystem Management



Master thesis

Hydropeaking induced effects on drift and colonization of benthic invertebrates

Christina Kaltenbacher

h0840604

In partial fulfilment of the requirements

for the degree of Dipl.-Ing.

Study: Water Management and Environmental Engineering (447)

Supervisor: Ass. Prof. Dr. Wolfram Graf

Co-Supervisor: MSc. Lisa Schülting

Vienna, December 2016

Acknowledgement

Foremost, I want to thank my supervisors Dr. Wolfram Graf and MSc. Lisa Schülting for their continuous guidance, motivation and critical lecture throughout my entire working process. Thanks also go to Thomas Huber for his assistance and instructions during the identifications of the benthic invertebrates and to my fellow lab mate Klaus Prillinger for our motivating and inspiring exchange discussions.

I am extremely grateful to my family, especially my parents, who believed in me and supported me consistently, both morally and financially, during my years of studying.

Special thanks go to Katharina Leitner, not only for proofreading my Master thesis and giving helpful comments but also for being an invaluable friend and to Camilla Sandurkov, for proofreading my thesis and her precious friendship ever since 15 years. I further thank my friends Felix Bauer, Teresa Steger and Agnes Sturma for providing distraction and their moral support.

Abstract

The prevalent Master thesis was written within the scope of the Master program "Water management and environmental engineering" at the Institute for Hydrobiology and Aquatic Ecosystem Management of the University of Applied Life Sciences in Vienna, Austria. It focuses on the hydropeaking induced effects on colonization and drift of benthic invertebrates.

Therefore in Lunz am See, Lower Austria, two different test procedures were developed and performed in experimental flumes which allow discharge and pulse-release regulations. The first test procedure was carried out in six flumes as a short term experiment to observe night and day differences in drift of benthic invertebrates. Three of the flumes were used as treatment with a peakflow of 60 l/s and a baseflow of 6 l/s; simultaneously, the other three served as control with a constant flow of 6 l/s.

The second experimental setup was designed as a long-term six week colonization experiment in two experimental flumes, each consisting of three sub-flumes with three pool- and three riffle-sections. One of these flumes was subject to a continuous discharge of 25 l/s, whereas the other was provided with hydropeaking with a minimum flow of 20 l/s and a peak flow of 180 l/s once a day.

The outcomes show that hydropeaking has a significant effect on the community structure of benthic invertebrates. Even though a periodical increase of the discharge leads to a slightly higher taxa diversity, abundance and biomass – possibly due to diversified habitat conditions – as seen in the long-term experiment, the short-term experiment depicted the power of hydropeaking as almost up to 40 % of the invertebrates' abundance drifted. Compared to the drift during day, an increase of the nocturnal drift could be observed. However, this was mainly witnessed under hydropeaking circumstances, indicating that an increase of shear stress has a higher impact on benthic invertebrates during the night than during the day.

Zusammenfassung

Die vorliegende Masterarbeit wurde im Rahmen des Masterstudiums "Water Management and Environmental Engineering" am Institut für Hydrobiologie und Gewässermanagement (IHG) an der Universität für Bodenkultur in Wien, Österreich, verfasst. Sie beschäftigt sich mit den durch Schwall induzierten Effekten auf die Kolonisierung durch und Drift von Makrozoobenthos.

Zu diesem Zweck wurden zwei unterschiedliche Experimente in Lunz am See (Niederösterreich) in Versuchsrinnen, die eine Regelung der Menge und Dauer des Abflusses erlauben, durchgeführt.

Das erste Experiment, ein kurzzeitiger Versuch, beschäftigt sich mit der Drift von Makroinvertebraten. Dazu wurden drei Versuchsrinnen mit einem Abfluss von 60 l/s beschwallt, während drei weitere einen Grundabfluss von 6 l/s aufwiesen und somit als Kontrolle dienten. Jeweils zwei Versuchsdurchgänge wurden bei Tag und zwei bei Nacht durchgeführt.

Im zweiten Teil der Masterarbeit wurde die Kolonisierung von zwei Versuchsrinnen durch Makrozoobenthos nach einem sechswöchigen Langzeitversuch untersucht und ausgewertet. Auch hier gab es wiederum eine Kontrollrinne mit einem kontinuierlichen Abfluss von 25 l/s, während die andere Versuchsrinne einen Minimalabfluss von 20 l/s aufwies und einmal täglich mit 180 l/s beschwallt wurde.

In den Ergebnissen beider Studien ließen sich die Effekte von Schwall auf das Makrozoobenthos erkennen. Obwohl sich im Langzeitversuch zeigte, dass ein regelmäßiger Anstieg der Fließgeschwindigkeiten zu einer höheren Diversität, sowie Anzahl und Biomasse der Invertebraten führte – ein Grund könnte hier die möglicherweise positiv wirkende Variabilität der Lebensraumbedingungen sein – , so konnte im Kurzzeitversuch gezeigt werden, dass unter Schwalleinfluss bis zu 40 % der Individuen verdriftet werden.

Des Weiteren wurde ein Anstieg der nächtlichen Drift verglichen mit der Drift unter Tags bestätigt, was sich jedoch hauptsächlich unter Schwall beobachten ließ. Dies deutet auf eine erhöhte Auswirkung des Schwalls auf das Makrozoobenthos in der Nacht hin.

Ш

Index

1.	. Intro	oduction	1
	1.1	Hydropower in Austria	1
2.	. Drift	of benthic invertebrates	4
	2.1	Definition	4
	2.1.3	Behavioral drift	4
	2.1.2	2 Constant drift	4
	2.1.3	3 Catastrophic drift	4
	2.2	Effects of hydropeaking on community structure	5
	2.3	Effects on quantity	5
	2.4	Drift influencing factors	6
	2.4.2	Taxa specific drift behavior	6
	2.4.2	2 Diurnal drift patterns	7
	2.4.3	3 Other drift-influencing factors	8
3.	Colo	nization1	0
	3.1	Influencing factors for colonization1	0
	3.1.3	Habitat requirements1	1
	3.1.2	2 Dispersal ability1	2
4.	Rati	onale and hypotheses1	3
	4.1	Hypotheses of the short-term experiment1	4
	4.2	Hypotheses of the long-term experiment1	4
5.	. Met	hods1	5
	5.1	Short-term experiment	6
	5.1.3	Experimental design 1	6
	5.2	Long-term experiment 1	7
	5.2.2	Experimental design 1	7
	5.3	Lab work	9
	5.4	Statistical Analyses 2	0

6.	Re	sults o	f the short term experiment	21
e	5.1	Effe	cts of hydropeaking on drift	21
	6.1	L.1	Total drift of benthic invertebrates	21
	6.1.2		Drift of selected taxa	23
	6.1	L.3	Analyses of size categories	32
e	5.2	Diur	nal drift pattern	34
	6.2	2.1	Diurnal drift pattern of the totality of benthic invertebrates	34
	6.2	2.2	Diurnal drift pattern of selected taxa	36
7.	Re	sults o	f the long term experiment	43
7	7.1	Abio	otic results	43
7	7.2	Effe	cts of hydropeaking on colonization (treatment vs. control)	44
	7.2	2.1	Taxa diversity and composition	44
	7.2	2.2	Abundance and biomass	50
7	7.3	Hab	itat preferences (pool vs. riffle)	51
	7.3	3.1	Taxa diversity and composition	51
	7.3	3.2	Abundance and biomass	52
8.	Dis	scussio	n	54
٤	3.1	Sho	rt term experiment	54
	8.1	L.1	Effects of hydropeaking on drift	54
	8.1	L.2	Diurnal drift pattern	63
٤	3.2	Lon	g-term experiment	64
	8.2	2.1	Effect of hydropeaking on colonization	64
	8.2	2.2	Habitat preferences (pools vs. riffles)	67
9.	Su	mmary	y and Conclusion	68
10.		Bibliog	graphy	70
11.		Figure	S	75
12.		Tables		77
13.		Appen	dix	78

13.1	Mai	nn-Whitney tests for short-term experiment	. 78
13.1	1	Treatment-Control differences (abundance)	. 78
13.1	2	Treatment-Control differences (biomass)	. 79
13.1	3	Day-Night differences (abundance)	. 80
13.1	4	Day-Night differences (biomass)	. 82
13.2	Eco	logical parameters	. 84
13.2	2.1	Current Preference	. 84
13.2	2.2	Feeding type	. 85
13.2	2.3	Locomotion type and respiration	. 86
13.3	Mai	nn-Whitney tests for long-term experiment	. 87
13.3	8.1	Treatment-Control differences (abundance)	. 87
13.3	8.2	Treatment-Control differences (biomass)	. 88
13.3	8.3	Pool-Riffle differences (abundance)	. 89
13.3	8.4	Pool-Riffle differences (biomass)	. 90
13.4	Lon	g-term experiment species lists	. 91
13.4	1.1	Abundance	. 91
13.4	.2	Biomass	. 93

1. Introduction

1.1 Hydropower in Austria

With the increasing demand for renewable energy sources, the importance of hydropower – world's most significant renewable electricity source (Bratrich et al., 2004) – rose within the last decades and still does. Nowadays hydropower represents the main part of Austria's energy supply and accounts for 67,2 % of the country's total electricity production (Energie Control Austria, 2014), whereas in the EU-27 it provides about 10 % (Arcadis & Ingenieurbüro Floecksmühle, 2011). In Austria 5227 hydropower stations exist altogether (status 29.4.2011) of which 2619 contribute to the public grid (Habersack et al., 2012). While hydropower generation is of high economic relevance regarding electricity production especially in alpine regions and during the winter (due to higher energy demand and low discharge in this season), it also has its disadvantages such as considerably detrimental effects on aquatic ecosystems. Regarding all three phases of hydropower production, which include withdrawal, storage and release of water to the stream, the last phase (hydropeaking) poses the highest stress on aquatic ecosystems by evoking significant changes of the hydrological characteristics (Limnex, 2004; Maiolini et al., 2007).

In Austria, the extended use of hydropower leads to 811 km of hydropeaking-affected flowing course, which equals 2.6 % of the total stream network > 10 km² or 78 river segments (BMLFUW, 2010). Due to their higher application of hydropower plants, alpine regions tend to be more affected by the strain of the flow regime alteration. Hence, the most disturbed sections are set in the alpine regions and include the rivers Inn and Salzach as well as parts of the Mur, Enns and Drau. An overview of hydropeaking impacted stretches in large Austrian rivers is given in Figure 1 (BMLFUW, 2010; Schmutz et al., 2013).



Figure 1: Anthropogenic hydrological impacts and hydropeaking affected flowing courses (blue lines) in Austria (Schmutz et al., 2013)

The usage of intermittent hydropower with hydropeaking operation, where water is first stored and then released in times of power generation, results in alternating low flows and high discharge peaks. These water level fluctuations downstream of the hydropower plant in often very short time periods can lead to significant changes of **hydrological** as well as **morphological** characteristics of a water body, such as sediment transport, current, turbidity, temperature or streambed stability. Moreover, they can also cause alterations of **ecological** characteristics – such as the aquatic habitat and biocoenosis – by changing structure, trophic relation and the dynamics of the benthic population as well as by leading to a continuous removal of organic matter. Important influencing factors hereby – pertaining to the gravity of the hydropeaking's aftermath – are, besides of the hydropeaking intensity, the velocity of the rise and fall of the water level (up- and down-ramping speed) as well as the frequency of the peak events (Cushman, 1985; Allan & Flecker, 1993; Moog, 1994; Vinson, 2001; Maiolini, 2007; BMLFUW, 2010).

As described in Golemac (2011), the negative impacts of hydropeaking can be roughly divided into long-term and short-term effects. While short-term deficits describe mostly physical recurring processes due to gauge fluctuations, long-term problems are mainly the biological aftermaths of the recurring short-term impairments of the stream.

Examples of short-term (physical) disturbances (Golemac, 2011):

- Increase of shear stress and hydraulic pressure on the stream bed
- Change of water temperature
- Change of water turbidity

Examples of long-term disturbances/biological effects (Golemac, 2011):

- Drift of fish and benthic invertebrates
- Reduction of biomass, abundance and taxa diversity
- Reduction of natural reproduction and food supply
- Increase of colmation and the resulting clogging of the interstices, which leads to a habitat loss for fish and benthic invertebrates

Particularly for benthic invertebrates each hydropeaking event causes following phenomena (Moog, 1994):

- 1. The drift of benthic invertebrates increases during the hydropeaking, especially at the beginning and during the reduction of the flow.
- 2. Benthic invertebrates are trapped in cut-off pools after the hydropeaking event (stranding), where they die due to oxygen shortage. Invertebrates without gills (e.g. many Plecoptera)

are affected mostly, after that those with fixed gills (e.g. *Baetis* sp.) and finally those benthic invertebrates with moveable gills.

Thus, further development of hydropower may have significant effects on the ecological integrity as well as on other lotic characteristics and might therefore stand in contrast to the targets of the EU-WFD (Water Framework Directive) with its prohibition of deterioration (Habersack et al., 2012). According to the NGP (Nationaler Gewässerbewirtschaftungsplan), 37 % of Austria's running waters hold a "very good and good status" respectively "good potential" (in case of modified waterbodies), whereas the complementing 63 % are classified with an inferior status (BMLFUW, 2010). The status classification depends on hydromorphological, (physico-)chemical and biological characteristics. Hence the quality of the biological communities (benthic invertebrates, fish, macrophytes, phytoplankton or phytobenthos) plays an important role in the grouping of water bodies (Arcadis & Ingenieurbüro Floecksmühle, 2011). In 94 % of the cases, the inferior status is a result of the quality of fish and benthic invertebrates (BMLFUW, 2010). It is therefore important to minimize disadvantageous effects of hydropeaking on aquatic ecosystems to maintain or to improve the current status of the stream.

Naturally, changes in the discharge also occur in natural streams, but in comparison to anthropogenic variations they are extenuated in frequency as well as in their magnitude. Therefore natural disturbances do not pose such a risk to the stream's ecology as those of non-natural origin. They also influence a shorter part of a river than anthropogenic interferences (Bretschko & Moog, 1990; Seebacher & Zeiringer, 2011). Additionally, "besides size and frequency of man-induced floods, the unnatural independency of surface- and groundwater hydrology might be a reason for the adverse effects of intermittent power generation" (Bretschko & Moog, 1990). Furthermore, increasing drift caused by natural phenomena (with the exception of rare and catastrophic events) does not affect the benthic invertebrate community in a significant way (Bretschko & Moog, 1990).

3

2. Drift of benthic invertebrates

2.1 Definition

Drift can be defined as the intentional or unintentional movement of aquatic individuals due to several exterior or behavioral factors. In general, drift is caused by a combination of the following aspects:

- (i) The change of certain hydraulic or hydrological factors (e.g. discharge)
- (ii) Interactions with other benthic invertebrates
- (iii) Dislocation from the substrate by accident (Kohler, 1983, 1985)
- (iv) The urge of aquatic organisms to colonize new areas (Müller, 1982; Cellot, 1989)

Different types of benthic invertebrate drift have been defined (Brittain & Eikeland, 1988) and can be divided into three categories by Waters (1972):

- 1. Behavioral drift
- 2. Constant drift
- 3. Catastrophic drift

2.1.1 Behavioral drift

Behavioral drift is known as active drift and is influenced by endogenous factors. The organisms drift voluntarily in order to forage for food or to escape predators or rivals. A special form of behavioral drift is the "dispersion-drift", which allows egg- and larval stages to move downstream without spending energy (Waters, 1972).

2.1.2 Constant drift

The constant drift derives from accidental detachment of benthic organisms from the sediments. It occurs involuntarily, takes place permanently and is independent of extraordinary events (Waters, 1972).

2.1.3 Catastrophic drift

Catastrophic drift – also called passive drift – is induced by sudden changes of certain parameters, resulting for example in hydropeaking, pollution or substrate movement. Having an effect over a long stream distance (Moog, 1994), the resulting hydropeaking and water level fluctuations have an influence on benthic organisms, fish and other biota of the aquatic environment (Morgan et al.,

1991; Robinson et al., 2004; Seebacher & Zeiringer, 2011). They lead to an increase of velocity, water depth and shear forces and therefore can cause catastrophic drift of benthic invertebrates as well as a reduction of biomass. If additionally bed erosion takes place, often a volatile increase of drift occurs (Baumann & Schälchli, 2002; BMLFUW, 2010; Jones et al., 2012). This involuntary contact loss to the substrate is considered one of the major stresses on benthic invertebrates (Bruno et al., 2013).

2.2 Effects of hydropeaking on community structure

The question of whether the qualitative composition of benthic invertebrates – such as the amount or dominance of certain taxa – undergoes major changes during an anthropogenic hydropeaking is still not answered clearly as various experiments and enquiries show different outcomes. Moog (1994) observed a change of the benthic invertebrate composition in hydropeaking-affected rivers. An increase of tolerant taxa with a broad ecological variance (most of them Chironomidae), of robust forms such as Heptageniidae or Ephemerellidae and of "species which usually migrate actively into the substrate interstices to find protection against rapid increases in flow velocity" (such as Leptophlebiidae or Leuctridae) could be found, while other species decreased (Moog, 1994).

Generally, two different reactions of benthic invertebrates towards hydropeaking could be identified:

- On one hand research showed, that hydropeaking does have an effect on the abundance and biomass but not on the taxonomical composition (Bretschko & Moog, 1990; Moog, 1994; Tockner & Waringer, 1997; Céréghino et al., 2002).
- 2. On the other hand it is claimed that the taxonomical composition of benthic invertebrates undergoes major changes evoked by hydropeaking. This was for example shown in Moog's investigation of the Drava, where the species number declined by 46% (Bretschko & Moog, 1990; Moog, 1994). Only the benthic invertebrate taxa living in the interstices had the ability to remain under hydropeaking conditions. In some other case studies the impacts of hydropeaking also affected the benthic density as well as its diversity (Céréghino & Lavandier, 1998; Cortes et al., 2002; Maiolini et al., 2007).

2.3 Effects on quantity

The quantitative characteristics of benthic invertebrates, such as biomass and abundance are highly altered by hydropeaking (e.g. Jungwirth et al., 1990; Tockner & Waringer, 1997; Céréghino et al., 2002; Maiolini et al., 2007) and may suffer from a decline up to 95 % depending on the relation of minimal versus maximal discharge. This decrease in benthic quantity then may lead to a reduction in

fish production as well as to a minimization of the self-purification processes of the stream (Bretschko & Moog, 1990; Moog, 1994). Furthermore, the amount of drifting invertebrates is highest during the first daily hydropeaking. It is also higher during the discharge increase than during constant high flow, where the drift rate decreases after one or two hours (Bruder et al., 2012). Nevertheless, contrary to drift-tending invertebrates, non-drift-affine benthic invertebrate groups do not change their behavior significantly during the fluctuations in the flow regime (Bretschko & Moog, 1990; Moog, 1994). Research suggests that the primary influencing factors on the structure of benthic invertebrate communities are hydraulic features, followed by thermal regime (Céréghino et al., 2002).

Summarizing, it can be said that in all conducted studies so far, a decrease in benthic invertebrate biomass and density was observed, whereas the taxa diversity did not always undergo significant changes. Generally, anthropogenic hydropeaking leads to a reduction of abundance and biomass of more sensitive species and to a shift towards more resistant ones (Bruder et al., 2012).

2.4 Drift influencing factors

2.4.1 Taxa specific drift behavior

Depending on their morphological characteristics, life stages or functional traits, different taxa show different drift behavior and adaption strategies. Some taxa display multiple adaptations to resist high current, while others are lacking these and can be found mainly in low flowing habitats. These adaptations of benthic invertebrates to live in fast flowing waters can be of morphological, physiological and ethological kind. Morphological adaptations include for example (Moog, 2011):

- Claws and hooks (e.g. free living Trichoptera, Coleoptera, Simuliidae)
- (gill) suckers (e.g. Rhithrogena)
- Streamlined bodies: Some benthic invertebrates developed an elongated, drop-like body with a rounded cross section to be more resistant towards a higher current (e.g. Baetidae, Leptophlebiidae)
- Flattened body form (e.g. *Ecdyonurus*)
- Ballast: Some invertebrates use heavy ballast such as lateral stones, branches or shells to adapt (e.g. some Trichoptera, Gastropoda)

During disturbances in the flow regime, benthic invertebrates usually either tend to find shelter in the interstices (typically those with cylindrical body shapes) or swim and drift away (together with their food (POM – Particulate Organic Matter)). Then they seek refuge in the hyporheic habitat after a short distance, or they use the sediments as a shelter to escape the catastrophic drift. Different

faunal groups hereby make use of different strategies (Bretschko & Moog, 1990; Moog, 1994; Maiolini, 2007; Maiolini et al., 2007; Bruno et al., 2010).

As mentioned before, orders and families show different behavior to hydropeaking because of their behavioral or morphological adaptations.

Ephemeroptera for example are often used as an indicator due to their sensitive reaction towards changes in environmental circumstances. The families Siphlonuridae and Baetidae are swimming types with streamlined bodies. Heptageniidae on the contrary count among the clinging types and are therefore current-loving invertebrates with a flat body, claws and special gill-constructions, which help them to adapt to the current (Jungwirth et al., 2003). A study by Bruno et al. (2010) showed that small larval stages of Ephemeroptera and Plecoptera could seek refuge in the interstitial, while larger ones were drifting.

The larval stages of the **Plecoptera** live in and on the bottom of the water body; typical habitats are for example low-turbulence zones. Taxa taking shelter in the interstices include the Leuctridae, due to their slender body shape (Jungwirth et al., 2003). Nevertheless, Maiolini et al. (2007) showed that in their experiments many of the Plecoptera are drifting species as their density decreased nearly 90 % (from 1642 to 168 ind./m²). Furthermore, alterations in the community of Plecoptera were led back to the "sudden changes of discharge and temperature" – a fact which shows Plecoptera to be good indicator species for these two influencing factors (Maiolini et al., 2007).

Some members of the **Diptera** are also current-loving benthic invertebrates, including Simuliidae which cling to the bottom with the help of a hooked collar (Jungwirth et al., 2003). According to Waters (1972) Chironomidae do not drift very strongly. Other Diptera show no tendency to drift (Brusven, 1970).

Various **Coleoptera** are adapted to the current by their hook-shaped claws and streamlined bodies.

2.4.2 Diurnal drift patterns

Drift activity clearly shows a diurnal periodicity, with the density being significantly higher during the night (Fjellheim, 1980; Allan, 1987; Ramirez & Pringle, 1998). Concerning the exact time of the nightly drift peak, opinions differ from describing the peak at sunset and sometimes at 03:00 h (Ramirez & Pringle, 1998), to seeing it three hours after sunset (Elliott, 1967). However, it can be said that drift increases at dawn, maintaining a 24 hour rhythm. Permanent daylight causes this rhythm to trail off (Müller, 1966).

Reasons for this diurnal pattern can be seen in an existing relation between drift and light intensity (Elliott, 1967; Hynes, 1970). Benthic invertebrates tend to seek refuge during daylight and leave their

7

shelter at night. It has been observed that this diurnal drift patterns persists even during floods with higher total drifting rates (Hynes, 1970; Haney et al., 1983).

Another explanation for the day-night periodicity may lie in the interactions between benthic invertebrates and macroconsumers. The presence of diurnal predators can promote a strong nocturnal diel periodicity (Flecker, 1992) by increasing the activity of the invertebrates during night, stated in the "risk of predation" hypothesis (Allan, 1995). Additionally to diurnal predators, the presence of nocturnal ones can also effectuate the increased drift due to the urge of the benthic invertebrates to "release themselves into the water current to escape predation" (Hildrew & Townsend, 1980; Peckarsky, 1980; Walton Jr., 1980; Oberrisser & Waringer, 2011). Some invertebrates such as *Culex pipiens* have found ways to decrease the risk of predation by reducing their growth or delaying their developmental times in response to fish kairomones. A reaction of benthic invertebrates to those kairomones was also reported by Blaustein (1997) who observed a reduction of microcrustacea and a delay in hatching. Kairomones are chemical substances emitted by fish, giving another species (e.g. benthic invertebrates) the possibility to detect predators and to gain an adaptive benefit (Jourdan et al., 2016). They were furthermore reported to influence diel drift periodicity and induce a shift towards nocturnal drift due to the avoidance of predators (Huhta et al., 2000; Oberrisser & Waringer, 2011).

Different taxa show different day-night drift behavior, yet Boyero et al. (2005) observed daily drift variations only in very few species and even then only in some seasons. However, most taxa seem to be drifting in higher frequencies during the night. Baetidae, for example, show an active nocturnal drift behavior, whereas they seek shelter in the substrate at daytime (Campbell, 1985; Allan et al., 1988). Ephemeroptera and Plecoptera, as well as Simuliidae become nocturnal drifters in the course of their life cycle (Brusven, 1970; Adler et al., 1983). Additionally, most Trichoptera, aside from Limnephilidae, have a tendency to show a higher drift during the night (Golemac, 2011). Fjellheim (1980) perceived *Rhyacophila nubila* to become highly night active from the second instar on and lead the diurnal differences back to a "shift towards a more carnivorous way of life". Chironomidae show little day-night-fluctuations in their drift behavior. Coleoptera display no differences in their drift during the day and during the night (Golemac, 2011).

2.4.3 Other drift-influencing factors

Other factors that might influence a drift periodicity are physical ones such as temperature variations (Brewin & Ormerod, 1994), chemical ones including oxygen saturation or ecological ones such as the density dependence of drift of benthic invertebrates (Dimand, 1967).

Depending on family and morphological characteristics, a temperature variation can lead to a rise or fall of the drift of benthic invertebrates. *Baetis* sp. larvae for example become day-drifting when the temperature falls significantly (Müller, 1966). Furthermore, the lack of food sources and the resulting search for it can also be drift inducing (Kohler, 1983, 1985; Williams & Levens, 1988).

The different development of the seasons in different latitudes causes various annual periodical drift fluctuations. In Austria for instance, Baetidae show a maximal drift in June to July; Plecoptera drift is highest during the winter when they have their main growth period and a second time when they are about to hatch; Simuliidae also show two drift maxima: winter and midsummer (Müller, 1970).

Also the distance to the release point is of importance when analyzing the effects of drift. Among others, Moog (1994) and Céréghino et al. (2002) investigated the impact of hydropeaking on biomass loss of benthic invertebrates in correlation with the distance from the release point. Compared to undisturbed sections, a reduction of biomass of 75-95 % could be seen within the first kilometers of the stream and a decrease of 40-60 % was observed within the following 20-40 km (Moog, 1994). Maiolini et al. (2007) showed that the effect of hydropeaking lasted at least 10 km downstream, however also depending on the morphological structures of the river. "The various invertebrate orders were similarly affected, but their taxonomic composition varied with a downstream gradient" (Céréghino et al., 2002). The most serious benthic invertebrate losses occur in the first kilometers within the hydropeaking (Bretschko & Moog, 1990; Moog, 1994).

As mentioned above, the morphology of the river sections is an important factor for drift. Increasing shear stress leads to movement of heavier sediments and can result in clogging of the interstitial or significant changes of the habitat, depriving the organism of their living space. Thus, one reason for the disappearance or reduction of some species can be explained by the physiological stress on the organisms (Bruder et al., 2012).

3. Colonization

According to Fenoglio (2002) "macroinvertebrates continuously redistribute themselves in the riverbed." Consequently, it is very important to know about the colonization mechanisms to understand the restoration processes of aquatic ecosystems after disturbances. The recolonization process starts as soon as the originally prevalent conditions are restored. "Many studies have shown that macroinvertebrates can quickly colonize new or disturbed substrates" (Fenoglio et al., 2002). According to literature (Williams & Hynes, 1976; Olsen et al., 2007) there are different forms of colonization:

- Aerial colonization: This colonization can be equalized with oviposition. Insects distribute actively by flying or springing, or passively by wind or other animals and lay their eggs in the new surroundings (Tronstad et al., 2007).
- Vertical movement from the sediment: Benthic invertebrates tend to move deeper into the interstitial and seek shelter during floods; afterwards they recolonize (Williams & Hynes, 1976).
- **Downstream drifting:** The three forms of drift include catastrophic, behavioral and constant drift (see chapter 2.1).
- Upstream movement on or in the sediment

Following traits of quickly colonizing pioneers were characterized in literature (Townsend & Hildrew, 1994):

- High mobility
- Small body size
- Unspecific habitat requirements
- Resistance to changing environmental conditions
- More than one generation per year (polyvoltinism)

3.1 Influencing factors for colonization

The reasons for colonization lie in the gained ecological benefits, such as the prevention of inbreeding, better habitat conditions or fewer prevalent competitors in a newly colonized habitat (Bilton et al., 2001). Various important factors are hereby influencing, such as the dispersal ability of benthic invertebrates, the habitat requirements (texture of substrate as well as food supply), competition, life cycles or the season (Fenoglio et al., 2002). Brederveld et al. (2011) for example, suggest that habitat specialization and dispersal ability may be limiting factors for colonization.

3.1.1 Habitat requirements

Lakes and rivers show various compositions of the benthic fauna due to their differing conditions of current, temperature, oxygen supply or substrate. While lakes show a continuous water temperature of 4°C in greater depth, flowing waters exhibit strong annual and diurnal fluctuations. Oxygen can often be a limiting factor in lakes; rivers however are mostly well supported due to higher turbulences. Substrates tend to be of a higher grain fraction in the flowing waters compared to lakes. The water bodies itself also display a classification into various habitats. Meandering rivers show for example the typical development of two different habitats between and in the curves, mainly characterized by their water depths, flow velocities and substrates (Figure 2) (Jungwirth et al., 2003):

- 1. **Riffles** are shallow river passages with higher flow velocity, high shear stress and coarse substrate. They develop especially in areas with higher gradients and are often extended over the whole cross section of the river channel. Riffles are living space for many rheophilic¹ benthic invertebrates due to the higher prevalent currents. They can provide quantitative important spawning areas for fish spawning on gravel (e.g. grayling).
- 2. **Pools** are sections with higher water depth, which mainly form on the outer shore of river bends respectively in the area of influence of stream obstacles. They display a lower flow velocity, lower shear stress and less coarse substrate than riffles. Pools provide important coverage for predatory fish and are refuge for adult fish during low water periods.



Figure 2: Typical riffle and pool sequences

¹ = occurring in streams and preferring zones with moderate to high current

Different taxa require different habitat features like sediment particle size, temperature, detritus amount, flow velocity or nutrient concentration – depending for example on their functional feeding groups. While shredders need allochthonous food (leaf litter, wood debris), grazers feed on epilithic algae and passive filter-feeders depend on a current to feed (Jungwirth et al., 2003). Those taxa with a broad range of features show a higher tendency to be pioneers and colonize new areas (Townsend & Hildrew, 1994). These pioneers (e.g. Chironomidae, *Cleon simile*) are often the first colonizers, which show no specific ecological specialization, are not competitive and therefore quite sensitive species. They only colonize unrivaled ecosystems and are later replaced by ubiquist taxa. The pioneers mostly display a great ability to fly in order to quickly leave their habitats. Furthermore they show no visible ecological valence and no binding to habitats (Hebauer, 1988). After the first colonization by pioneers those taxa are generally substituted by ubiquists (high ecological scope, mediocre binding to habitats) and specialists (low ecological scope, high binding to habitats) due to their inability to fight competitors (Hebauer, 1988; Müller-Peddinghaus, 2011).

Olsen's experiment on disturbed streams showed that the total density of benthic invertebrates was not related to the flow velocity, nevertheless patches with higher flow velocity displayed a higher number of taxa (Olsen et al., 2007). As mentioned above (Chapter 2.2) it was observed, that hydropeaking decreases the abundance and the biomass but can also have an impact on the species composition. Depending on the different prevalent species, the taxa diversity may even experience a rise in disturbed river sections. This increase of taxa can be explained by Joseph Connell's "Intermediate Disturbance Hypothesis (IDH)" which describes the relationship between species diversity and disturbance. It is suggested that the diversity of species reaches a peak when the ecological disturbances are at an intermediate level. At this state both species – those thriving at early as well as those prospering at late succession stages – are able to coexist (Connell, 1978).

3.1.2 Dispersal ability

The dispersal ability of benthic invertebrates is crucial for colonizing new habitats; those with a higher ability to spread over long distances have higher chances to colonize new areas. For example the wings' length of active dispersers is an important criterion, as species which are not very widespread often display shorter wings than widespread ones (Malmqvist, 2000; Bilton et al., 2001). Moreover, a reproduction of benthic invertebrates in large numbers (r-strategy) is also a possible adjustment to dispersal. Whereas the larvae or eggs are dispersed passively by drift, the adults spread actively or are transported by wind (Bilton et al., 2001). However this is also dependent on the density of the stream network, as for example alpine upper reaches display less fragmentation of brooks than large rivers.

4. Rationale and hypotheses

The impacts of hydroelectric facilities on the aquatic environment have been in the focus since many years, yet the majority of studies to investigate drift have been conducted under base flow or normal conditions. The catastrophic drift induced by floods has been less investigated (Bruno et al., 2010). Hence the currently known background is not sufficient enough for the development of mitigation measures and to give management advice to reduce the effects on riverine biota. As some questions cannot or only partly be answered in the field, the HyTEC ("Hydromorphological and Temperature Experimental Channel") flumes in Lunz am See, Lower Austria, were constructed. They serve to analyze the cause-impact relationship of hydropeaking on flowing waters by carrying out pulse-release experiments. The HyTEC flumes offer the possibility to use identical treatment and control sections simultaneously, which may lead to a better comparison between base-flow and hydropeaking characteristics. Furthermore, several external disturbances on the investigations, which might have occurred in field experiments, can be eliminated by performing the tests in flumes. Hence, several studies concerning hydropeaking on benthic invertebrates have been conducted, two of which are part of this Master thesis.

According to Golemac's (2011) differentiation of long-term and short-term effects of the negative impacts of hydropeaking on benthic invertebrates (see chapter 1.1) the Master thesis covers both aspects with two separately conducted experiments in the HyTEC flumes.

1. Short-term/drift experiment

The first part of the Master thesis deals with the drift experiments, addressing short-term effects of hydropeaking on benthic invertebrates by quantifying drift responses. Quantitative and qualitative characteristics of the drift were investigated and statistically analyzed. Another emphasis of this experiment was placed on potential occurring diurnal variations of drift by comparing day- and night-drift.

2. Long-term/colonization experiment

The second part of this thesis presents results of a long-term experiment, dealing with the effect of hydropeaking on benthic invertebrate colonization. Here qualitative as well as quantitative aspects were considered. Furthermore it was aimed to observe the assemblages of the (re)colonizing species in pool and riffle habitats as well as to analyze and compare ecological traits and morphological attributes.

13

Following hypotheses were developed in regard of the literature research:

4.1 Hypotheses of the short-term experiment

- 1. Treatment and control scenarios differ significantly, with the drift of benthic invertebrates being higher during hydropeaking than under baseflow conditions. (H1)
- 2. The drift is highest during the up-ramping phase and then reaches a steady level. (H2)
- 3. Drift-resistant taxa (non-drifting taxa) show specific traits. (H3)
- The percentage of drift of large invertebrates is higher than the drift of small invertebrates².
 (H4)
- 5. There are differences in drift during night and day; the drift is higher during night. (H5)

4.2 Hypotheses of the long-term experiment

- 1. Hydropeaking affects benthic invertebrate colonization. (H1)
 - a. The treatment shows higher taxa diversity. (H1a)
 - b. The control shows higher biomass/abundance. (H1b)
 - c. In the treatment more rheophilic invertebrates can be found than in the control. (H1c)
- 2. Pools and riffles will be colonized by different species. (H2)
 - a. Riffles show higher taxa diversity, abundance and biomass than pool habitats. (H2a)
 - b. Rheophilic taxa can be found in the riffles, while those preferring slow flow velocities are found in the pools. (H2b)
 - c. The differences of colonization between pools and riffles are higher in the treatment than in the control. (H2c)
 - d. The differences of colonization considering abundance are higher between the riffles of control and treatment than between the pools of control and treatment. (H2d)
- 3. Colonizing pioneers show specific traits. (H3)

² For the definition of size classes see chapter 5.3.

5. Methods

The HyTEC facility (Figure 3), were the experiments took place, is located 600 m downstream of Lake Lunz (1113 m a.s.l.). The artificial flumes are supplied via two pipelines with water from Lake Lunz which is discharged downstream the flumes into the bypassing stream "Unterer Lunzer Seebach".

The discharge can be regulated and peak flows of up to 600 I/s can be produced to mimic hydropeaking. Furthermore the temperature can also be altered by using either the pipeline which collects water from the surface and/or the pipeline collecting water from the bottom of Lake Lunz. If water from both pipelines is used for an experiment, it is combined in the mixing tank at the beginning of the flumes. However, due to the temperature resemblance of the Lake Lunz to the "Unterer Lunzer Seebach" where the samplings were taken from, only water from the surface was used for both experiments conducted for this Master thesis.



Figure 3: Overview of the HyTEC facility in Lunz am See before the construction of the artificial flumes

The "Unterer Lunzer Seebach" flows downstream of Lake Lunz and is a small stream with the Strahler order three, located in the Northern Limestone Alps. It drains a catchment of 24.8 km² (Wimmer & Moog, 1994). The hydromorphological status of the "Unterer Lunzer Seebach" is classified as "very high" (BMLFUW, 2007, 2014) and the water temperature corresponds to the temperature of the epilimnion of Lake Lunz.

5.1 Short-term experiment

5.1.1 Experimental design

For the drift experiment, the six experimental flumes were filled with microlithal sediment (~ 15 cm). They are each 2 m long, with a start-up length of 1.5 m and a 0.5 m buffer zone at the end. Each of the six flumes has an exchangeable drift net (meshing size 100 μ m) at the end to collect the drifting invertebrates (Figure 4).



Figure 4: Scheme of the flumes for the drift experiment in Lunz am See

Sampling

The sampling took place on June 12^{th} and 13^{th} , 2014 in the "Unterer Lunzer Seebach". At the beginning of the experiment four samplings of altogether 0.25 m² were taken for each flume – two lentic and two in-stream – and collected in a bucket.

Each sampling was taken from an area of 25 x 25 cm (0.0625 m²) with a drift net (meshing size 100 μ m) which was positioned downstream the sampling site. The substrate was then dug over thoroughly to catch the specimens of all zones, including the interstitial.

Afterwards the lentic and in-stream samplings were mixed and introduced into the flumes. Testing began after an adaptation time of 30 minutes for the benthic invertebrates. The adaptation time (AT) was applied to ensure that the specimens were able to get used to the new environment.

The experiment

For the experiment three flumes were used for the treatment and three for the control. The treatment flumes were provided with a baseflow of 6 l/s (2 l/s per box) and a peakflow of 60 l/s (20 l/s per box), whereas the control flumes were provided with a continuous flow of 6 l/s.

Two runs were conducted during the day and two right after sunset in order to analyze the diurnal drift behavior. Each scenario was carried out twice to gain six treatment and six control results. The experiment itself can be divided into several phases (Figure 5) of ten minutes each:

- Up-ramping UR: The flow was increased to the maximum of 60 l/s; the water level was rising up.
- Peakflow P1 and P2: These were periods of constant high flow.
- Down-ramping DR: The water level was diminishing; the discharge was decreased to the baseflow.

After each phase the drift net was changed and the collected specimens were filled into small buckets. In the end, the remaining animals were washed out manually using another peakflow and the last drift net was removed. The samples of the non-drifting invertebrates were defined as "Rest".



Figure 5: Change of discharge during the phases over the project time

Altogether 36 samples were collected for each experiment (six samples per flume: AT, UR, P1, P2, DR, Rest). As two day- and two night-experiments were conducted, the total number of samples was 144.

5.2 Long-term experiment

5.2.1 Experimental design

The long-term colonization experiment was conducted in two experimental flumes located downstream of the drift experiment. They are approximately 20 m long, 3 m wide and consist of three sub-flumes, each with three pool- and three riffle-sections which are newly filled with gravel (microlithal) (Figure 6, Figure 7 & Figure 8).



Figure 6: Upstream view of flume 1

Figure 7: Upstream view of flume 2

The colonization experiment was conducted as a six-week project during August and September 2014. Before starting, the flumes were cleared of all benthic invertebrates manually by washing them out under high-flow conditions. During the six-week period, the right flume was used for treatment with a baseflow of 20 l/s and a daily peakflow of 180 l/s (in the evening for 30 minutes), whereas the left flume provided the control with a continuous flow of 25 l/s. Both showed the same morphological settings.



Figure 8: Scheme of the artificial flumes for the long-term experiment

Sampling

The sampling of the specimens was performed on September, 18th 2014, via a hand net

(A = 25x25 cm, mesh width 100 μ m). In each flume the following single samples were taken: nine riffle-samples (three per sub-flume), nine pool-samples (three per sub-flume), as well as two algae-samples in the plane of inclination following a riffle (N = 40 samples).

Measured abiotic factors included the flow velocity at v100, v40 and v0 (surface-, 40 %-depth- and bottom-velocity).

5.3 Lab work

The samples were preserved in 96% formaldehyde. In the laboratory they were sieved, using mesh sizes down to 500 μ m to separate the benthic invertebrates from the formaldehyde and coarse inorganic material.

Terrestrial invertebrates were not taken into consideration. Moreover *Hydrachnidia* were sorted out since it could not be ensured that these specimens were not coming through the pipes or from the mixing basins.

In the laboratory the sampled specimens were counted and identified to the lowest taxonomic level as possible. Besides, their dry weight was measured with a precision balance on an accuracy of 0.0001 g. Additionally, they were metered in length (size classes) for the short-term experiment. For the orders Ephemeroptera, Plecoptera and Trichoptera the size classes were defined as follows:

- Class A (> 5 mm)
- Class B (2 5 mm)
- Class C (< 2 mm)

Chironomidae were divided into two classes:

- Class A (> 5 mm)
- Class B (< 5 mm)

Keys to genera were available for:

- General (Tachet et al., 2000)
- Coleoptera (Jäch, 2006)
- Ephemeroptera (Bauernfeind & Humpesch, 2001)
- Fresh water mollusks (Glöer & Meier-Brook, 2001)
- Plecoptera (Graf, 2015)
- Trichoptera (Pitsch, 1993; Waringer & Graf, 1997)

The classification of species traits (Chapter 8.1.1, appendix) were based on expert judgement as well as on the following sources:

- Merritt (1996)
- AQEM expert consortium (2002): Ecological classifications by AQEM expert consortium, www.aqem.de
- Bauernfeind et al. (1995), Bauernfeind et al. (2002), Graf et al. (1995a), Graf et al. (1995b),
 Graf et al. (2002a), Graf et al. (2002b), Jäch et al. (1995), Schmedtje et al. (1996)

5.4 Statistical Analyses

The received data were first transferred into MS-Excel 2007 and for the short-term experiment the following adaptations were made:

Abundance & Abundance/m²

... Absolute number of specimens of a certain taxa level in a sample (per m^2) in (Ind/ m^2)

$$Abd_m^2 = Abd \cdot 4$$

Total Drift

... Sum of the drifting invertebrates

$$Drift_{tot} = \sum_{DR}^{UR} Abd$$

Drift rate

... The drift rate shows the proportion of drifting individuals to the total amount of individuals in the regarded phase of the experiment. This drift rate was used for analysis to eliminate falsifications of the results due to a possible dependence of drift on density. The index varies between zero and one.

$$Drift_rate_phase = \frac{Drift_phase}{\sum_{Rest}^{phase} Abd_phase}$$

For the long-term experiment no further adaptation of the data was necessary.

The data were then evaluated statistically and graphically using IBM SPSS Statistics 21 and 22. The Mann-Whitney test was conducted predominantly. A significance level of α = 0.05 (5 % significance level alpha) was applied. With a significance of less than 0.05 the null hypothesis could therefore be rejected. The null hypotheses to be discarded were deposited with grey.

For the long-term experiment the program PCORD 5 was used to analyze the data with the means of an NMDS-plot.

6. Results of the short term experiment

6.1 Effects of hydropeaking on drift

In this chapter the effect of hydropeaking on the abundance and biomass of benthic invertebrates as well as on their behavior was examined, considering differences between treatment and control. The total drift rates (abundance and biomass) and the drift rates of the different phases (UR to DR) were analyzed for the totality of benthic invertebrates as well as for certain taxonomical orders and species.

6.1.1 Total drift of benthic invertebrates

The total drift share of the specimens was about 40 % in the treatment and 15 % in the control. These drifts (abundance) in percentage as well as in absolute numbers are illustrated in Figure 9. Regarding the biomass, the total drift rate also showed a difference between treatment and control; higher biomass drifted under hydropeaking conditions (Figure 10). In contrast to the abundance however, the disparity for drift of biomass between treatment and control was less pronounced. It accounted for about 5 % in the control and for approximately 14 % in the treatment.



Figure 9: Total drift (abundance) of specimens in % Figure 10: Total drift (biomass) of specimens in % and absolute numbers

and gram

The substantially increase of the total drift rate by hydropeaking can also be seen in the boxplots in Figure 11 and Figure 12; there was an explicit distinction between treatment and control.



Figure 11: Total drift rate (abundance), showing the difference in treatment and control (N = 4; n = 8258 respectively 9608)

Figure 12: Total drift rate (biomass), showing the difference in treatment and control (N = 4; n = 8258 respectively 9608)

Analyzing the drift rates of abundance during the various phases, again a clearly visible difference between control and treatment could be observed, as seen in Figure 13. The treatment drift rates always displayed higher values than those in the control. In both cases, the up-ramping phase showed the highest drift. This observation could also be made for the biomass, where the drift rate during UR was higher in the treatment compared to the control and displayed the highest value of all phases. However, the drift rates of the other phases P1, P2 and DR showed no clear discrepancy between treatment and control (Figure 14).



Figure 13: Treatment and control drift rates (abundance) during the phases UR-DR (N = 4; n = 8258, 9608)



Figure 14: Treatment and control drift rates (biomass) during the phases UR-DR (N = 4; n = 8258, 9608)

With the Mann-Whitney test significant differences for the abundance were observed in the drift rates between control and treatment during all experimental phases as well as in the total drift rate (Table 1). Yet, apart from the total drift rate during the day and the drift phase UR (Table 2), no significant differences in the drifted biomass were shown between treatments and controls, therefore matching the analysis of the graphics above.

Table 1: Mann-Whitney test comparing benthic invertebrate drift (abundance) for treatment-controldifferences ($\alpha = 0.05$, N = 4; n = 8258, 9608)

	Drift_rate_tot	Drift_rate_UR	Drift_rate_P1	Drift_rate_P2	Drift_rate_DR
MW-test	0,000	0,001	0,000	0,004	0,000

Table 2: Mann-Whitney test comparing benthic invertebrate drift (biomass) for treatment-control-differences ($\alpha = 0.05$, N = 4; n = 8258, 9608)

	Drift_rate_tot	Drift_rate_UR	Drift_rate_P1	Drift_rate_P2	Drift_rate_DR
MW-test	0,006	0,002	0,093	0,423	0,815

6.1.2 Drift of selected taxa

For each of the taxonomic orders a generally prevailing increase of drift could be seen in the treatments compared to the controls. The difference appeared to be greatest for Diptera and Coleoptera; Ephemeroptera and Trichoptera displayed great disparities, whereas Plecoptera seemed to be less affected (Figure 15).



Figure 15: Difference of treatment and control drift for the various taxonomical orders (N = 4; n = 84-4704)

MW-test order level	Drift_rate_tot	Drift_rate_UR	Drift_rate_P1	Drift_rate_P2	Drift_rate_DR
Coleoptera	0,000	0,002	0,000	0,118	0,016
Diptera	0,000	0,009	0,000	0,000	0,000
Ephemeroptera	0,000	0,001	0,013	0,449	0,011
Gastropoda	0,050	0,776	0,036	0,328	0,328
Oligochaeta	0,083	0,274	0,360	0,360	0,460
Plecoptera	0,190	0,169	0,651	0,608	0,976
Trichoptera	0,001	0,001	0,091	0,288	0,651

Table 3: MW-test on order level for significances in treatment-control ($\alpha = 0.05$, N = 4; n = 84-4704)

Further investigation of the Mann-Whitney test on taxonomical order, family and species level (Table 3, appendix) revealed significant differences between control and treatment. The highest drift rate appeared in the up-ramping phase throughout the entire experiment. The other phases (P1, P2 and DR) displayed no uniform pattern.

Coleoptera

Coleoptera showed a higher drift in the treatment than in the control (approx. 37 % vs. 13 %). Significant differences in the drift of abundance were found for the total drift rate and all phases (with exception of phase P2), and in the total drift rate, as well as the phases UR and P1 for the drift of biomass.

The drift rate of Coleoptera in the treatment was approximately 18 % in the UR phase and decreased continuously afterwards. The drift rates in the control exhibited a small peak in phase P2 (Figure 16).



Figure 16: Drift rate of Coleoptera regarding treatment and control (N = 4)

The sampling of the Coleoptera consisted mostly of the families Elmidae (larvae and adult; approx. 75 %) and Scirtidae (larvae; approx. 20 %); other dominating families were Gyrinidae (larvae) and Dytiscidae (larvae and adult) (Figure 17).



Figure 17: Percentage of drifting vs. non-drifting specimens of selected Coleoptera families

Elmidae drifted about three times higher in the treatment than in the control. Significant differences of the abundance were observed in all drift rates except for phase P2. *Elmis* Iv. (total drift rate, UR), *Riolus* Iv. (total drift rate, UR, P1, DR) and *Riolus* ad. (P1) displayed significant differences, whereas *Elmis* ad. showed none. For the biomass significant differences were observed for *Elmis* sp. in the total drift rate as well as in UR; for *Riolus* sp. in the total drift rate, UR and P1. Scirtidae showed only a slight increase of drift in the treatment and therefore no significant differences neither for the abundance nor the biomass could be detected. For the families Dytiscidae as well as Gyrinidae no drift was observed in the control, while the majority (over 60 % of Gyrinidae and over 90 % of Dytiscidae) drifted under hydropeaking circumstances.

Ephemeroptera

A clear increase of drift was observed for Ephemeroptera in the treatment compared to the control (35 % vs. 16 %). As for Coleoptera, significant differences in the abundance could be found in the total drift rate and in all phases except P2. Significant differences of biomass for Ephemeroptera were identified in the total drift rate and the phase UR.

The highest drift rate for Ephemeroptera could be observed in the up-ramping-phase. Afterwards the curves dropped steeply in the treatment. An increase of the drift rate in the DR phase could be shown in the treatment scenarios, whereas the control showed a steady decline of the drift rate (Figure 18).



Figure 18: Drift rate of Ephemeroptera regarding treatment and control (N = 4)

The species composition of Ephemeroptera was dominated by Ephemerellidae (*Ephemerella ignita*; approx. 70 %) and Baetidae (approx. 25 %), other families included Caenidae, Heptageniidae and Leptophlebiidae (Figure 19).



Figure 19: Percentage of drifting vs. non-drifting specimens of selected Ephemeroptera families

Baetidae as well as Leptophlebiidae showed a mediocre increase of drift in the treatment, rising from 24 % to 30 % and from 2 % to 13 %. This was mirrored in the results of the Mann-Whitney test for the abundance and biomass, where the family of Baetidae was only significant in the UR-phase and species of *Baetis* sp. showed no significant differences at all. Significant differences of Leptophlebiidae and one of their species *Habrophlebia lauta* were observed in the total drift rate. The drift of Caenidae and Ephemerellidae rose significantly under hydropeaking circumstances (20 % to 76 %, respectively 11 % to 37 %). Hence, the family of Ephemerellidae and their species *Ephemerella ignita* displayed significant differences in the total drift rate of the abundance and biomass as well as in the phases UR, P1 and DR. Heptageniidae, on the contrary, depicted a decrease of drift in the treatment, yet their abundance was too low for the conduction of a Mann-Whitney test.

Plecoptera

In comparison to the average drift rate of all individuals, Plecoptera showed a relatively low drift. This taxonomical order also displayed an increase of drift in the treatment compared to the control, however the difference was minor (20 % vs 16 %). No significant differences were found for the drift of abundance, the biomass on the contrary displayed a significant difference in the phase UR.

Of all taxonomical orders, Plecoptera showed the lowest drift rate in the UR phase. The drift was continuously decreasing during the phases UR, P1 and P2 (Figure 20), but showed a small peak in the phase P2 in the treatment as well as the control.



Figure 20: Drift rate of Plecoptera regarding treatment and control (N = 4)

The species composition of Plecoptera was dominated by the family of Leuctridae (represented by *Leuctra* sp.), followed by Nemouridae (predominantly *Protonemura* sp.) (Figure 21).

Nemouridae drifted in the treatment only in UR and P1 and showed a drift increase in the treatment from 34 % to 44 %; there were no significant differences in any phase. The drift of Leuctridae was 5 % in the control and 15 % under hydropeaking circumstances. A significant difference of the abundance and the biomass could be observed in the total drift rate. Periodidae and Periidae were not present in high quantity. However, it could be seen that they did not show very high drift.



Figure 21: Percentage of drifting vs. non-drifting specimens of selected Plecoptera families

Trichoptera

Trichoptera was amongst those taxonomical orders which drifted the least in the treatment as well as in the control. There was still a clearly visible gap between those two scenarios (22 % vs. 8 %). Significant differences for the abundance were observed in the total drift rate and the UR-phase. The biomass displayed no significant differences.

Drift of Trichoptera was by far highest in the UR-phase of the treatment, afterwards a continuous decrease to a drift rate of 0 % in the DR-phase followed (Figure 22).



Figure 22: Drift rate of Trichoptera regarding treatment and control (N = 4)
The sampling of Trichoptera was dominated by Hydropsychidae (*Hydropsyche* sp.) and Polycentropodidae (*Polycentropus flavomaculatus*). Other important families were Lepidostomatidae (*Lepidostoma hirtum*), Leptoceridae (mainly *Athripsodes* sp.), Limnephilidae and Rhyacophilidae (*Rhyacophila* s. str.) (Figure 23).



Figure 23: Percentage of drifting vs. non-drifting specimens of selected Trichoptera families

The drift of Polycentropodidae increased with the hydropeaking from about 3 % to 20 %. Significant differences for the abundance occurred in the total drift rate and the UR phase and for the biomass in the total drift rate. For Lepidostomatidae a considerable impact by hydropeaking could be seen (7 % vs. 37 %), but the abundance was too low for a Mann-Whitney test. Hydropsychidae and Leptoceridae drifted less in the control than in the treatment, yet neither of them displayed any significant differences in the abundance or the biomass. Limnephilidae and Rhyacophilidae showed no difference in their drift behavior between treatment and control. Limnephilidae drifted hardly, whereas Rhyacophilidae showed a high drift tendency (about 40 %). As *Rhyacophila* s. str. normally

do not tend to drift in such high abundance, it could be assumed that the adaptation time was too short or the experimental setup was too stressful for this species. Therefore, the results of *Rhyacophila* s. str. cannot be considered as valid for any conclusions of their drift behavior.

Diptera

The drift of Diptera was above average and in the treatment higher than in the control (56 % vs. 16 %). Significant differences of abundance were identified for the total drift rate and for all phases UR-DR due to Chironomidae, which showed an increase of drift in the treatment (from 16 % to 56 %) and significant differences in all tested drift rates. No significant differences of biomass were observed on order level, yet they occurred for Chironomidae in the total drift rate and all phases except P2.

Even though Ceratopogonidae displayed an enormous increase of drift in the treatment (0 % to 82 %), they showed – possibly due to the low abundance in the control scenario – no significant differences. Empididae and Limoniidae also revealed an increase of drift under hydropeaking (Figure 24).



Figure 24: Percentage of drifting vs. non-drifting specimens of selected Diptera families

As seen in Figure 25, a high drift rate of Diptera was observed in the UR-phase; the drift rates in the control declined continuously. The drift was higher in the treatment than in the control.



Figure 25: Drift rate of Diptera regarding treatment and control (N = 4)

Gastropoda

In the order Gastropoda significant differences of the abundance occurred in the total drift rate and the phase P1, though differences were not significant for the biomass. Most of the occurring families of Gastropoda – Lymnaeidae, cf. Hydrobiidae and Valvatidae – showed an increase of drift in the treatment. In contrast, Planorbidae experienced a minor decrease of drift under hydropeaking.

Oligochaeta

The drift of Oligochaeta doubled from 31 % to 63 % in the treatment, yet no significant differences between control and treatment were observed. They displayed such a wide range of results that it could be assumed that these experiments were not suitable for this taxon.

6.1.3 Analyses of size categories

In this chapter the different size categories of the specimens considering differences between treatment and control scenarios (Figure 26 and Figure 27) are analyzed according to the classification described in Chapter 5.3.

The observation of the size classes of Diptera (only Chironomidae) showed that specimens of the category A drifted predominantly in the treatment, but rarely in the control. In contrast, the category B drifted in the control as well as in the treatment. They also drifted in higher numbers during hydropeaking. The treatment displayed almost no differences in drift between category A and B, if at all, category B showed slightly higher shares.

Taking into account the size of the Ephemeroptera, all three categories A-C showed a higher drift in the treatment than in the control. Class C generally drifted the most, followed by A and B. In the UR-phase in particular, an increased drift could be seen in the treatment.



Figure 26: Size distribution of Diptera and Ephemeroptera, considering differences between treatment and control

The class A of the Plecoptera had to be removed from analyses due to too few representatives. However, it could be observed that, whereas in category C the drift dominated in the UR and DR phases, only category B showed any drifting reaction during the other phases P1 and P2. Additionally, for all size categories the drift was mostly higher in the treatment than in the control tests.

Observing the Trichoptera by their size, it was visible that category C had by far the highest percentage of drift in the phases UR, P1 and P2 of the treatment as well as of the control. Moreover the drift in the treatment was higher than in the control. The categories A and B drifted only minimally in the control.

33



Figure 27: Size distribution of Plecoptera and Trichoptera, considering differences between treatment and control

6.2 Diurnal drift pattern

In this chapter differences between drift during the day and during the night are analyzed. The aim of this is to find a diurnal drift pattern, considering the total drift of all specimens as well as of selected taxonomical orders and species.

6.2.1 Diurnal drift pattern of the totality of benthic invertebrates

As can be seen in the figures below (Figure 28 & Figure 29), the drift of abundance as well as of biomass was higher during the night than during the day in the treatment and in the control. However, the difference was less pronounced in the control; abundance drift increased from 14 % to 16 % in the control, but from 33 % to 45 % in the treatment. Regarding the biomass, the drift in the control accounted for 4 % during the day and 7 % during the night in the control, but increased from 11 % to 18 % in the treatment.



Figure 28: Percentage and absolute numbers respectively of drifting vs. nondrifting specimens, day and night drift (abundance)



Figure 29: Percentage and gram respectively of drifting vs. non-drifting specimens, day and night drift (biomass)

This difference between the drift of abundance during the day and the night can also be seen in Figure 30, the drift rate in treatment scenarios was clearly higher during the night than during the day, yet here no considerable difference was visible in the boxplots of the control. Figure 31 shows an increased drifted biomass in the nocturnal treatment, whereas the control displayed barely a difference between night and day.



Figure 30: The total drift rate (abundance) during day and night (N = 4; n = 3159 - 6449)

Figure 31: Total drift rate (biomass) during day and night (N = 4; n = 3159 - 6449)

There were no significant differences between day and night in the Mann-Whitney tests for abundance as well as biomass (Table 4 & Table 5). Nevertheless, significance fell short to meet its level of 0.05 in the treatment of the abundance.

Table 4: Mann-Whitney test on day-night-differences of abundan	ice ($\alpha = 0.05$, N = 4; n = 3159-6449)
--	---

MW-test	Drift_rate_tot
Treatment	0,065
Control	0,931

Table 5: Mann-Whitney test on day-night-differences of biomass ($\alpha = 0.05$, N = 4; n = 3159-6449)

MW-test	Drift_rate_tot
Treatment	0,548
Control	0,786

6.2.2 Diurnal drift pattern of selected taxa

Regarding the boxplots describing the drift rates of different taxonomic orders (Figure 32), each order showed an increase of the drift rate in the treatment during night, except for Trichoptera.

Nocturnal drift was usually higher in the control flumes, but Diptera (Chironomidae), Ephemeroptera (*Ephemerella ignita*) and Oligochaeta had a higher day drift.

For the biomass a nearly continuous ascent of the drift rate in the treatment was recorded during the night on order level with the exception of Plecoptera. In the control flumes, the day drift was mostly higher, yet again only Plecoptera showed a higher drift at night.



Figure 32: Difference of night and day drift in treatment and control for selected groups (N = 4; n = 30-3215)

M	W-test order level	Treatment	Control
Treatment	Coleoptera	0,180	0,052
	Diptera	0,041	0,247
Ephemeroptera		0,132	0,537
	Gastropoda	0,016	1
	Oligochaeta	0,548	0,071
	Plecoptera	0,485	0,004
	Trichoptera	0,699	0,177

Table 6: MW-test on taxonomical order level concerning day-night-differences (α = 0.05, N = 4; n = 30-3215)

The results of the Mann-Whitney test on order level (Table 6) displayed that only Diptera and Gastropoda showed significant differences between day and night drift in the treatment. In the control however, the only significant difference occurred for the order of Plecoptera.

This did not apply to family and species level (see appendix). Here the only significant differences in the control were identified for Scirtidae Iv. No significant differences between day and night were

found in the treatments on family level, but they occurred on species level for *Baetis* sp., *Baetis rhodani* and *Riolus* ad.

Additionally, for the biomass no significance differences on order and genus-family level in the total drift rate could be observed.

Coleoptera

The drift of Coleoptera (Figure 33) was higher during the night than during the day in the treatment (41 % vs. 32 %) as well as in the control (16 % vs. 9 %). No significant differences were found either for abundance or biomass.

		Tre	eatment					C	Control	
	0	% 20%	40% 60%	6 80%	100%		(0% 20%	40% 60%	80% 100%
CIDAE	Day		12		2	CIDAE	Day		2	
DYTIS	Night		22		1	DYTIS	Night		5	
IDAE	Day	151		281		IDAE	Day	48	441	
ELM	Night	262		314		ELM	Night	91	649	
VIDAE	Day					VIDAE	Day		7	
GYRIN	Night	-	3	2		GYRIN	Night		5	
LIDAE	Day	26	119			TIDAE	Day	6	130	
SCIRT	Night	47	168	3		SCIRI	Night	91	322	
	■ drifting ■ non-drifting					■ drifting	non-driftir	ng		

Figure 33: Diurnal drift patterns of selected Coleoptera families in treatment and control

Elmidae displayed a clearly visible increase of the drift rate during the nocturnal experiments, increasing from 10 % to 12 % in the control and from 35 % to 46 % in the treatment; yet no significant differences were observed apart from the drift rate of *Riolus* ad. in the treatment. Scritidae also demonstrated a significantly higher drift rate during the night, which was especially visible in the control scenarios (5 % vs. 22 %). The treatment did not show such high differences between day and night drift (18 % vs. 22 %). No particular disparity could be observed for Gyrinidae, whereas Dytiscidae showed a minimally increased drift in the nocturnal treatment (86 % vs. 95 %). No significant differences of abundance and biomass were found for both families.

Ephemeroptera

During the treatment as well as during the control scenarios, the drift of Ephemeroptera (Figure 34) was approximately twice as high during the night than during the day, accounting for 14 % drift rate vs. 27 % drift rate in the control and 17 % vs. 40 % under hydropeaking. No significant differences on the order level were displayed regarding the abundance or the biomass.

		Tre	eatment						Control		
	0	% 20%	40% 60%	80%	100%		(0% 20%	40% 60	0% 80%	100%
IDAE	Day	94	336			IDAE	Day	79	2	97	
BAET	Night	256	4	35		BAET	Night	355	1	.025	
IDAE	Day		11	3		IDAE	Day		4		
CAEN	Night		15	5		CAEN	Night	2		4	
MER.	Day	338	80	7		MER.	Day	129	94	5	
EPHE	Night	645		853		EPHE	Night	198	160	0	
AGEN.	Day	1	9			AGEN.	Day		8		
HEPT/	Night		4			HEPT/	Night	4		9	
OHLEB.	Day	8	59			HLEB.	Day		26		
LEPTOI	Night	6	35			LEPTOI	Night	1	16		
		drifting	non-drift	ng				drifting	g 🔳 non-dr	rifting	

Figure 34: Diurnal drift patterns of selected Ephemeroptera families in treatment and control

Baetidae showed an increase of the nocturnal drift compared to the drift during day; the difference was higher in the treatment than in the control. They were mostly represented by *Baetis rhodani* and small specimens of *Baetis* sp., which both displayed significant differences between day and night drift in the treatment of abundance. No day-night-regularity for Caenidae (*Caenis* sp.), Heptageniidae (*Ecdyonurus* sp.) and Leptophlebiidae could be detected. Furthermore the nocturnal drift of Ephemerellidae was only increased in the treatment (30 % vs. 43 %). There were no significant differences in abundance and biomass for all four families.

Plecoptera

A clearly higher nocturnal drift was observed for Plecoptera in the control (2 % vs. 23 %) as well as in the treatment (16 % vs. 25 %). Generally, Plecoptera tended to drift more during night (Figure 35), yet only the control displayed a significant difference in the Mann-Whitney test.



Figure 35: Diurnal drift patterns of selected Plecoptera families in treatment and control

A tendency for Leuctridae to increased nocturnal drift could be seen in both scenarios. For Nemouridae a clear day-night-drift-pattern was only visible in the control. No significant differences were observed for the taxonomical levels family and species.

Trichoptera

The diurnal difference in the drift of Trichoptera (Figure 36) was clearly observable in the control (3 % vs. 11 %), yet the drift in the treatment was nearly identical (22 % vs. 23 %). Thus a day-nightdistinction could not be made. The Mann-Whitney tests showed no significant differences on any taxonomical level (order, family and species).

Hydropsyche sp., *Polycentropus flavomaculatus*, Limnephilidae, Rhyacophilidae s. str.-group as well as Leptoceridae drifted during day as well as during night with no visible differences. Only *Lepidostoma hirtum* tended to drift in slightly higher rates during the night.

Treatment						Control				
	0	% 20%	40% 60%	80% 100%	,		0% 20	9% 40% 60	0% 80%	100%
ROPS.	Day	8	37		ROPS.	Day	2	48		
НУDF	Night	6	36		НУД	Night	8	92		
OST.	Day	2	8		DOST.	Day		10		
LEPIC	Night	7		7	LEPIC	Night	2	17		
DCER.	Day	5	13		DCER.	Day	1		4	
ГЕРТС	Night	4	9		LEPTO	Night	1	16		
EPHIL.	Day		22		EPHIL.	Day		9		
LIMNE	Night		7		LIMNE	Night	1	5	.	
ENTR.	Day	13	48		ENTR.	Day	1	35		
ΡΟΓΥΟ	Night	9	36		ΡΟΓΥΟ	Night	1	32		
сорн.	Day	7	9		COPH.	Day		5		
КНҮА (Night	2	6		RHYA(Night		8	8	
		drifting	non-drifting	5			■ drift	ing non-dr	ifting	-

Figure 36: Diurnal drift patterns of selected Trichoptera families in treatment and control

Diptera

Diptera showed an increase of drift during the night in the treatment (50 % vs. 60 %) and therefore a significant difference in the drift rate. This was not observed in the control (Figure 37), where a decrease was monitored (20 % vs. 14 %). The families Chironomidae and Ceratopogonidae displayed a nocturnal increase in drift in the treatment, but not in the control where Chironomidae showed a drift decline during the night and Ceratopogonidae did not drift at all. A slight decrease of drift during the night could also be observed for Empididae in both and Limoniidae in treatment scenarios. They were only present in few numbers and therefore no general pattern could be detected.

Gastropoda

The nocturnal drift of Gastropoda was higher during the night than during the day in the treatment (12 % vs. 24 %) as well as in the control (0 % vs. 6 %). They displayed a significant difference of the drift rate in the treatment. While Hydrobiidae and Planorbidae showed a decline of drift during the night, Lymnaeidae and Valvatidiae experienced a nocturnal increase in the treatment (Figure 37).



Figure 37: Diurnal drift patterns of selected Diptera, Gastropoda and Oligochaeta families in treatment and control

Oligochaeta

As seen in Figure 37, Oligochaeta displayed only a nocturnal increase of drift in the treatment (56 % vs. 62 %); in the control a decline was visible (44 % vs. 8 %). Therefore no general diurnal drift pattern could be observed and no significant differences were identified. These and the results described in Chapter 6.1.2 lead to the assumption that the data on Oligochaeta in this experiment are not sufficient for further scientific interpretations.

7. Results of the long term experiment

7.1 Abiotic results

During the experiment the flow velocities at v100 and v40 (surface-, 40 %-depth- and bottomvelocity) were measured with a micro propeller and the mean flow velocity was calculated using the following equation (Kreps, 1975):

Additionally the flow velocity near the bottom (v0) was measured. The outcomes of the measurements and the calculations are listed below (Table 7 and Table 8).

		Channel 1		Chan	nel 2	Channel 3	
		Baseflow	Peakflow	Baseflow	Peakflow	Baseflow	Peakflow
Pool (1)	V _{mean}	0,04	0,31	0,13	0,43	0,06	0,25
	v0	0,01	0,03	0,01	0,07	0,02	0,10
Riffle (2)	V _{mean}	0,14	0,57	0,07	0,60	0,10	0,64
	v0	-	0,62	-	0,53	-	0,31
Pool (3)	V_{mean}	0,02	0,19	0,01	0,31	0,03	0,17
	v0	0,01	0,04	0,00	0,04	0,00	0,03
Riffle (4)	V _{mean}	0,25	0,55	0,28	0,67	0,28	0,69
	v0	-	0,57	-	0,47	-	0,56
Pool (5)	V _{mean}	0,02	0,16	0,01	0,31	0,00	0,22
	v0	0,01	0,08	0,00	0,06	0,00	0,05
Riffle (6)	\mathbf{v}_{mean}	0,19	0,57	0,14	0,60	0,23	0,68
	v0	-	0,38	-	0,46	-	0,53

Table 7: Measured flow velocity in the treatment channels (m/s)

Table 8: Measured flow velocity in the control channels (m/s)

		Channel 4	Channel 5	Channel 6
		Baseflow	Baseflow	Baseflow
Pool (1)	V _{mean}	0,02	0,08	0,02
	v0	0,00	0,00	0,00
Riffle (2)	V _{mean}	0,27	0,18	0,24
	v0	-	-	-
Pool (3)	V _{mean}	0,05	0,00	0,02
	v0	0,01	0,00	0,00
Riffle (4)	V _{mean}	0,29	0,19	0,26
	v0	-	-	-

Pool (5)	V _{mean}	0,00	0,03	0,00
	v0	0,00	0,00	0,00
Riffle (6)	V _{mean}	0,21	0,10	0,19
	v0	-	-	-

The analysis of the flow velocity (Figure 38) shows that the treatment scenarios generally displayed a higher variability than the control scenarios. Furthermore the median, the minima and maxima are higher in the treatment compared to the control as well as in the riffles compared to the pools.



Figure 38: Velocities in treatment (left) and control (right), showing the minimum, maximum and median as well as the variety of the current

7.2 Effects of hydropeaking on colonization (treatment vs. control)

7.2.1 Taxa diversity and composition

The collected samples from the colonization experiment displayed 42 different taxa in total: Six Coleoptera taxa, one Crustacea taxon, five Diptera taxa, eleven Ephemeroptera taxa, three Gastropoda taxa, one Odonata taxon, two Oligochaeta taxa, six Plecoptera taxa and seven Trichoptera taxa. A detailed species/taxon list can be found in the appendix (Chapter 13.4).

Altogether 35.849 specimens and a biomass of 9.48 g were sampled and identified (Table 9 & Table 10).

	Р	ool	Ri	iffle
Order	Control	Treatment	Control	Treatment
Coleoptera	9	3	2	6
Crustacea			1	
Diptera	332	300	2.180	1.659
Diptera Pupae	123	89	508	478
Ephemeroptera	189	207	484	591
Gastropoda	12	5	18	25
Odonata				1
Oligochaeta	604	1.423	6.628	19.131
Plecoptera	8	2	82	40
Trichoptera	21	47	183	458
Total [ind]	1.298	2.076	10.086	22.389

Table 9: Total abundance of different orders in pool and riffle habitats

Table 10: Total biomass of different orders in pool and riffle habitats

	Ρ	ool	Ri	ffle
Order	Control	Treatment	Control	Treatment
Coleoptera	0,02	0,0005	0,0021	0,0016
Crustacea			0,0003	
Diptera	0,1071	0,0325	0,7626	1,0854
Diptera Pupae	0,0336	0,0118	0,2086	0,3029
Ephemeroptera	0,34435	0,29765	0,5255	0,35475
Gastropoda	0,09175	0,0194	0,0284	0,39395
Odonata				0,019
Oligochaeta	0,2257	0,1633	0,8794	1,6444
Plecoptera	0,00035	0,00005	0,00195	0,0029
Trichoptera	0,0363	0,0191	0,3443	1,52255
Total [g]	0,85915	0,5443	2,75315	5,32745

The predominant taxa and their abundance in the different scenarios and habitats are listed below (Figure 39), The following taxa with an abundance of five or lower were not considered in the graph: *Amphinemura* sp. (2), *Ancylus fluviatilis* (1), *Asellus aquaticus* (1), *Baetis alpinus/lutheri* (2), Calopterygidae (1), Ceratopogonidae (2), *Ecdyonurus* sp. (2), *Eiseniella tetraedra* (3), *Empididae* pup. (1), *Ephemerella ignita* (3), Gyrinidae lv. (2), *Habroleptoides* sp. (4), *Haliplus* lv. (1), Chloroperlidae (1), Hydroporinae lv. (1), *Hydropsyche angustipennis* (2), *Orectochilus* lv. (4), Perlodidae (2), *Phyrganea* sp. (5), *Plectrocnemia* sp. (1), *Rhyacophila* s. str. (3) and Tipulidae (4).

		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
á	Treatment vs. Control					229					57	
letis s	Treatment	2					227					
Ba	Control	0					57					
camb	Treatment vs. Control			33					59			
Baetis tus/s us	Treatment	1					32					
fusca	Control	2					57					
ticus	Treatment vs. Control				1	15					43	
is mu	Treatment	0					115					
Baet	Control	0					43					
odani	Treatment vs. Control				31					19		
iis rho	Treatment	0					31					
Baet	Control	0					19					
S	Treatment vs. Control					22					7	
Caeni	Treatment				12					10		
	Control			3					4			
iidae	Treatment vs. Control			1852	2				2503	3		
onom	Treatment		300					1552				
Chir	Control	3	332				2	171				
iidae	Treatment vs. Control			513	3				61	C		
onom pup.	Treatment		89					424				
Chir	Control		122					488				
лае	Treatment vs. Control			315					467			
beonir	Treatment				192					123		
CIC	Control			179					288			
iidae	Treatment vs. Control					47					16	
agen	Treatment	0					47					
Hept	Control		2					14				
/che	Treatment vs. Control				1	.06					40	
ropsy sp.	Treatment	0					106					
Нуd	Control	0					40					

■ Control ■ Treatment ■ Pool ■ Riffle

	C	% 10	0% 2	0% 30	0% 4	0%	50%	60%	70%	80%	6 9 0%	6 100
che ell.	Treatment vs. Control					92					1	9
ropsy og./pe	Treatment	0					92					
Hyd inc	Control	2					1	7				
ila	Treatment vs. Control				194					g	9	
dropt	Treatment	28					1	.66				
Η̈́	Control	10					89	Э				
m	Treatment vs. Control	4					64					
euctra	Treatment	0					4					
Ľ	Control	1					63					
Nem	Treatment vs. Control			14					1	5		
oura/ urella	Treatment	2						12				
Nemo	Control	-	5					1	0			
eta	Treatment vs. Control				205	52					7231	
cocha	Treatment	1423 <mark></mark>					1912	9				
Olig	Control	603					662	8				
dae	Treatment vs. Control	-		8					11			
orbic	Treatment		2					6				
Plai	Control			5					6			
us s lv.	Treatment vs. Control		2					4	1			
tamb ulatu	Treatment						2					0
Pla mac	Control	_		2						2		
sndo	Treatment vs. Control				107	7					41	
centro avom	Treatment	19	9					88				
Polyc fl	Control	8	8					33				
sn	Treatment vs. Control	0					6					
rhydr	Treatment	0										
Po	Control						6					0
ura	Treatment vs. Control				21						9	
onem	Treatment	0					21					
Proto	Control	1					5	3				

■ Control ■ Treatment ■ Pool ■ Riffle



Figure 39: Abundance of selected taxa in the different scenarios and habitats

The analysis of the current preferences shows a distribution as seen in Figure 40. Those with the characteristics "limnobiont", "limnophilic" and "limno to rheophilic" were merged into the category "limnophilic", while those invertebrates considered "rheo to limnophilic", "rheophilic" or "rheobiont" were summed up in the category "rheophilic".



Figure 40: Distribution of the limnophilic and rheophilic specimens in the pools and riffles of treatment and control

It was monitored that much more rheophilic individuals than limnophilic ones colonized the new area; the overall abundance was about six times higher. Moreover the abundance of rheophilic

individuals was about three times higher in the treatment than in the control; the amount of limnophilic invertebrates doubled (Figure 40).

A higher number of taxa was observed in the treatment compared to the control scenario. Altogether, a totality of 37 taxa was found in the treatment, while in the control the taxa accounted for 30. A detailed list of the various taxa of each group in treatment and control can be found in Table 11 and Table 12.

		Taxa in the treatment
Coleoptera	4	Gyrinidae Iv., Haliplus Iv. Orectochilus Iv., Platambus Iv.
Crustacea	/	
Diptera	4	Ceratopogonidae, Chironomidae, Simulium, Tipulidae
Ephemeroptera	11	Baetis sp., Baetis lutheri, Baetis fuscatus/scambus, Baetis muticus, Baetis rhodani, Caenis sp., Cloeoninae, Ecdyonurus sp., Ephemerella ignita, Habroleptoides sp., Heptageniidae
Gastropoda	3	Ancylus fluviatilis, Planorbis sp., Radix sp.
Odonata	1	Calopterygidae
Oligochaeta	2	Oligochaeta Gen. sp., Eiseniella tetraedra
Plecoptera	5	Amphinemura sp., Leuctra sp., Nemoura/Nemurella sp., Perlodidae, Protonemura sp.
Trichoptera	7	Hydropsyche angustipennis, Hydropsyche incognita/pellucidula, Hydroptila sp., Phryganea sp., Plectrocnemia sp., Polycentropus flavomaculatus, Rhyacophila s. str.

Table 12: Number of taxa in the control

		Taxa in the control
Coleoptera	3	Hydroporinae lv., Platambus maculatus lv., Prohydrus lv.
Crustacea	1	Asellus aquaticus
Diptera	3	Chironomidae, Simulium, Empididae
Ephemeroptera	9	Baetis fuscatus, Baetis muticus, Baetis rhodani, Baetis scambus, Caenis sp., Cloeoninae, Ephemerella ignita, Habroleptoides confusa, Heptageniidae
Gastropoda	2	Planorbis sp., Radix sp.
Odonata		
Oligochaeta	2	Oligochaeta Gen. sp., Eiseniella tetraedra
Plecoptera	5	Chloroperlidae, <i>Leuctra</i> sp., <i>Nemoura/Nemurella</i> sp., Perlodidae, <i>Protonemura</i> sp.
Trichoptera	5	Hydropsyche incognita/pellucidula, Hydroptila sp., Phryganea sp., Polycentropus flavomaculatus, Rhyacophila s. str.

7.2.2 Abundance and biomass

As presented in Table 9 the treatment showed more than twice as many specimens than the control. Disregarding Oligochaeta (due to their high abundance), the control displayed higher abundances than the treatment, although differences were small (4152 vs. 3911). In contrast, the biomass did not show such an enormous difference between treatment and control (Table 10), yet the biomass was also higher under hydropeaking circumstances. The same pattern was observed when excluding Oligochaeta from the results; the treatment still displayed higher biomass (2,5072 g vs. 4,06405 g).

Diptera and Plecoptera showed a higher abundance in the control, whereas no clearly visible difference for Coleoptera, Crustacea, Gastropoda and Odonata could be detected. On the contrary, a higher abundance of Ephemeroptera, Oligochaeta and Trichoptera was found in the treatment.

Furthermore Coleoptera and Ephemeroptera displayed higher biomass in the control, no clearly visible difference for Crustacea and Odonata could be observed. A higher biomass of Diptera, Gastropoda, Oligochaeta, Plecoptera and Trichoptera was found in the treatment.

The conducted Mann-Whitney test for the total abundance (Table 13) showed no significant differences between the treatment and the control in the riffle as well as in the pool habitats. However, the significance level of $\alpha = 0.05$ fell short to be reached in the pool ($\alpha = 0.100$). Additionally, the test was taken on taxonomical order and on species level, where no significant differences between treatment and control scenarios could be identified (see appendix).

Table 13: Mann-Whitney test for treatment/control difference of abundance ($\alpha = 0.05$, N = 6; n = 1298-22389)

MW-test	
Pool	0,100
Riffle	0,200

The Mann-Whitney test was also carried out for the biomass, where also no significant differences between treatment and control could be observed on any level (Table 14, appendix).

Table 14: Mann-Whitney test for treatment/control differences of biomass (α = 0.05, N =6; n = 1298-22389)

MW-test	
Pool	0,400
Riffle	0,100

Some taxa showed a clear tendency to occur either in the treatment or in the control with higher abundance (see appendix). In the order of Ephemeroptera, *Baetis* sp., Heptageniidae and *Caenis* sp. were found in higher frequencies in the treatment; all of them showed abundance up to three times higher than in the control. Cloeoninae behaved contrary. In the orders Trichoptera and Plecoptera, *Hydropsyche* sp., *Hydroptila* sp., *Polycentropus* sp. and *Protonemura* sp. occurred more often in the treatment, whereas *Leuctra* sp. clearly preferred the control scenarios.

While in the order of Diptera, *Simulium* sp. had a tendency to colonize the treatment scenarios, Chironomidae were found more often in the control.

7.3 Habitat preferences (pool vs. riffle)

7.3.1 Taxa diversity and composition

Riffles displayed a higher number of taxa than the pool habitats; accounting for 39 taxa vs. 24 taxa. A detailed list of the various taxa of each group in treatment and control can be found in Table 15 and Table 16.

		Taxa in the riffles
Coleoptera	3	Gyrinidae Iv., Orectochilus Iv., Platambus maculatus Iv.
Crustacea	1	Asellus aquaticus
Diptera	5	Ceratopogonidae, Chironomidae, <i>Simulium</i> , Tipulidae, Empididae pup.
Ephemeroptera	12	Baetis sp., Baetis lutheri, Baetis fuscatus, Baetis muticus, Baetis rhodani, Baetis scambus, Caenis sp., Cloeoninae, Ecdyonurus sp., Ephemerella ignita, Habroleptoides confusa, Heptageniidae
Gastropoda	3	Ancylus fluviatilis, Planorbis sp., Radix sp.
Odonata	1	Calopterygidae
Oligochaeta	2	Eiseniella tetraedra, Oligochaeta Gen. Sp.
Plecoptera	5	Amphinemura sp., Leuctra sp., Nemoura/Nemurella sp., Perlodidae, Protonemura sp.
Trichoptera	7	Hydropsyche angustipennis, Hydropsyche incognita/pellucidula, Hydroptila sp., Phryganea sp., Plectrocnemia sp., Polycentropus flavomaculatus, Rhyacophila s. str.

Table 15: Number of taxa in the riffles

Table 16: Number of taxa in the pools

		Taxa in the pools
Coleoptera	4	Haliplus Iv., Hydroporinae Iv., Platambus maculatus Iv., Porhydrus Iv.
Crustacea	/	
Diptera	2	Chironomidae, Simulium

Ephemeroptera	6	Baetis sp., Baetis fuscatus/scambus, Caenis sp., Cloeoninae, Habroleptoides confusa, Heptageniidae
Gastropoda	2	Planorbis sp., Radix sp.
Odonata	/	
Oligochaeta	2	Eiseniella tetraedra, Oligochaeta Gen. Sp.
Plecoptera	4	Chloroperlidae, Leuctra sp., Nemoura/Nemurella sp., Protonemura sp.
Trichoptera	4	Hydropsyche incognita/pellucidula, Hydroptila sp., Phryganea sp., Polycentropus flavomaculatus

When considering the two different habitat conditions (pools and riffles) in Figure 40, it was observed that the riffles displayed more limnophilic as well as more rheophilic individuals than the pools. The difference in abundance between pools and riffles was yet far higher for the rheophilic invertebrates – their abundance accounted for about 25 times higher in the riffles than in the pools, while the limnophilic invertebrates occurred three times as many in the riffles.

7.3.2 Abundance and biomass

It was shown that the abundance of specimens (disregarding Oligochaeta) was about five times higher in riffles than in pools. If the order of Oligochaeta was also taken into account, the discrepancy between those two habitats as well as between treatment and control would have been even larger. The dominance of individuals in the riffles compared to the pools is clearly observable, even though especially the treatment riffles showed a wide range of abundance (approx. 20000 to 40000 individuals). The pools did not show such high variability and their difference in abundance between control and treatment was very low.

The riffles also displayed an about up to five times higher biomass than the pools. Here, the order of Oligochaeta was again not taken into account. However, with the consideration of Oligochaeta the biomass distribution would show no grave changes.

All taxonomical orders displayed a higher number of individuals in the riffles than in the pools. However, Coleoptera, Crustacea and Odonata occurred in very low numbers and were therefore not representative (Table 9).

On a lower taxonomic level only a few taxa colonized the pools more frequently or equally than the riffles (*Porhydrus lv., Habroleptoides* sp., *Caenis* sp. and Cloeoninae; see appendix).

The Mann-Whitney test for the abundance in Table 17 did not display significant differences between pools and riffles, yet the significances fell short to be reached in the treatment as well as in the control ($\alpha = 0.100$). Also no significant differences between the pools and riffles could be detected on taxonomical order and species level (appendix).

Table 17: Mann-Whitney test for pool/riffle differences of abundance ($\alpha = 0.05$, N = 6; n = 1298-22389)

MW-test	
Control	0,100
Treatment	0,100

A discrepancy between pools and riffles in the biomass is displayed in Table 10; all orders with exception of Coleoptera showed a higher biomass in the riffles. The Mann-Whitney test for the differences of the biomass showed neither for the total nor for any other taxonomical level any significant difference (Table 18, appendix).

Table 18: Mann-Whitney test for pool/riffle biomass differences ($\alpha = 0.05$, N = 6; n = 1298-22389)

MW-test	
Control	0,100
Treatment	0,100

8. Discussion

8.1 Short term experiment

8.1.1 Effects of hydropeaking on drift

As mentioned above, hydropeaking has a high destructive impact on benthic invertebrate communities by causing a significant loss of biomass and abundance due to catastrophic drift (e.g. Jungwirth et al., 1990; Tockner & Waringer, 1997; Céréghino et al., 2002; Maiolini et al., 2007). Whereas qualitative characteristics may not suffer from extreme alterations, the quantitative characteristics are changed explicitly, suffering a decrease in abundance of sometimes up to 95 % (Bretschko & Moog, 1990; Moog, 1994). The catastrophic drift resulting from hydropeaking is therefore considered one of the major stresses on benthic invertebrates (Bruno et al., 2013).

Chapter 6.1 thus examined the differences of the treatment and control scenarios as well as the total drift graphically and statistically. When regarding the drift, it was observed that both – abundance and biomass – show the drift in the treatment scenarios to be higher than in the control scenarios. Consequently, a clearly visible distinction between hydropeaking and unaffected controls could be made. This statement is valid not only for the totality of specimens but also for each taxonomical order (Figure 15, Table 3). This could be confirmed by the Mann-Whitney-test, which explicitly showed significant differences in the drift of abundance during all phases as well as in the total drift rate. Furthermore significances for the drift of biomass could be observed in the total drift rate and the UR-phase.

However, the percentage of the drift of abundance was far higher than that of drifting biomass. This quantitative difference in the two drift rates could be explained by the composition of benthic invertebrates in the drift. While many small and therefore light individuals drifted during the experiments, many of the specimens remaining in the rest – such as Gastropoda, *Hydropsyche incognita/pellucidula* or other Trichoptera – were heavier.

With these results the **hypothesis H1** (treatment and control differ significantly) could be verified completely for abundance as well as for biomass. Due to this outcome the destructive and negative effect of hydropeaking on the composition of benthic invertebrates was confirmed.

According to Bruder et al. (2012), the drift rises during the discharge increase rather than during constant high flow. Hence, a hypothesis was developed stating that the amount of drifting benthic invertebrates is highest during the UR phase and will then decrease during the other phases P1-DR until it reaches a steady level (hypothesis H2).

It could be observed that in the treatment scenarios – during the day as well as during the night – a clearly visible decrease in the average drift rate of all individuals from phase UR to phase P1

54

occurred. This also appeared to be the case during the control scenarios yet to a much lesser extent and not significantly. Hence, part of this effect could be led back to a possible shortage of the adaptation time (AZ). However, the discrepancy was about three times higher in the treatment than in the control so it can be assumed that most of the specimens drifted due to the increased discharge and not because of the brief adaptation time. In the phases P1 to DR the drift rate remained almost constant in all scenarios, only with small fluctuations up to 2-3 %. The decline in drift rate from the up-ramping phase to phase P1 therefore demonstrated the highest decrease of drift.

Regarding these outcomes, the **hypothesis H2** (drift is highest during the up-ramping-phase and then reaches a steady level) could be assumed to be true, with the exception of the order Diptera. Yet also Diptera displayed their highest drift rate in the UR phase. On these grounds further research with a longer adaptation time is recommended.

A possible explanation by Moog (1994) that drift in general increases not due to the high discharge, but due to the change in the flow rate (during the up- and down-ramping phases), cannot be confirmed. Even though the drift rate sometimes increased in the down-ramping phase³ – mostly in the nocturnal treatment scenarios – no general pattern could be observed. It might only be said, that the specimens probably had a higher sensibility towards a change of flow velocity during the night than during the day. However, most of the time, the arrival of the surge had higher impact on the drift rate of benthic invertebrates than the higher anthropogenic flow velocity or the change of the current itself.

As the difference between base flow and hydropeaking conditions could generally be confirmed, also taxa-specific responses were observed. The orders most affected by hydropeaking were Diptera (Chironomidae Gen. sp.), followed by Coleoptera and Ephemeroptera. This is a result which was also observed for example by Brusven (1970), Turcotte & Harper (1982), Flecker (1992) or Pringle & Ramírez (1998).

In the following discussion, drift occurring in the control scenarios is assumed to be "basic drift" (consisting of behavioral and constant drift) since no alteration in flow velocity took place. The drift in the treatment scenarios on the other hand is composed of "basic drift" as well as "passive/catastrophic drift" induced by hydropeaking. The selected results were rearranged and summoned up in Table 19, making an attempt to define the sensitivity of taxa to increased discharge as well as to identify drift affine taxa. Due to different taxonomical resolution the analyses contain species, genus, tribes and families:

³ In the DR phase of the scenarios (1) Treatment_night of the overall drift rate, (2) Treatment_night of Coleoptera, (3) Treatment_night of Ephemeroptera, (4) Control_day of Ephemeroptera, (5) Treatment_night of Plecoptera, (6) Control_night of Plecoptera, (7) Control_night of Trichoptera

Table 19: Overview of drift results

Group	Family	Taxon	Scenario	drift	hydro- peaking affected ¹
	DYTISCIDAE	Oreodytes sp. Ad. (n = 4)	Control	0%	+
	DYTISCIDAE	<i>Oreodytes</i> sp. Ad. (n = 4)	Treatment	100%	
	DYTISCIDAE	<i>Oreodytes</i> sp. lv. (n = 2)	Control	0%	+
	DYTISCIDAE	Oreodytes sp. lv. (n = 31)	Treatment	90%	
	ELMIDAE	<i>Elmis</i> sp. ad. (n = 60)	Control	12%	+
	ELMIDAE	<i>Elmis</i> sp. ad. (n = 38)	Treatment	32%	
ERA	ELMIDAE	<i>Elmis</i> sp. lv. (n = 156)	Control	10%	+
PTE	ELMIDAE	<i>Elmis</i> sp. lv. (n = 159)	Treatment	38%	
LEO	ELMIDAE	<i>Riolus</i> sp. ad. (n = 167)	Control	30%	~
8	ELMIDAE	<i>Riolus</i> sp. ad. (n = 174)	Treatment	44%	
	ELMIDAE	<i>Riolus</i> sp. lv. (n = 837)	Control	8%	+
	ELMIDAE	<i>Riolus</i> sp. lv. (n = 616)	Treatment	42%	
	GYRINIDAE	Orectochilus sp. lv. (n = 12)	Control	0%	+
	GYRINIDAE	Orectochilus sp. lv. (n = 5)	Treatment	60%	
	SCIRTIDAE	Scirtidae Gen. sp. lv. (n = 549)	Control	18%	-
	SCIRTIDAE	Scirtidae Gen. sp. lv. (n = 360)	Treatment	20%	
4	CERATOPOGONIDAE	Ceratopogonidae Gen. sp. (n = 10)	Control	0%	+
ER/	CERATOPOGONIDAE	Ceratopogonidae Gen. sp. (n = 61)	Treatment	82%	
Tqio	CHIRONOMIDAE	Chironomidae Gen. sp. (n = 2142)	Control	17%	+
	CHIRONOMIDAE	Chironomidae Gen. sp. (n = 1870)	Treatment	55%	
	BAETIDAE	<i>Baetis</i> sp. (n = 902)	Control	31%	-
	BAETIDAE	<i>Baetis</i> sp. (n = 538)	Treatment	34%	
	BAETIDAE	Baetis lutheri (n = 42)	Control	43%	-
	BAETIDAE	Baetis lutheri (n = 35)	Treatment	40%	
	BAETIDAE	Baetis muticus (n = 45)	Control	7%	+
	BAETIDAE	Baetis muticus (n = 27)	Treatment	33%	
EPHEMEROPTERA	BAETIDAE	Baetis rhodani (n = 628)	Control	20%	~
	BAETIDAE	Baetis rhodani (n = 411)	Treatment	26%	
	BAETIDAE	Baetis scambus (n = 129)	Control	16%	-
	BAETIDAE	Baetis scambus (n = 127)	Treatment	17%	
	BAETIDAE	Cloeoninae Gen. sp. (n = 2)	Control	0%	+
	BAETIDAE	Cloeoninae Gen. sp. (n = 24)	Treatment	50%	
	CAENIDAE	Caenis horaria (n = 9)	Control	22%	+
	CAENIDAE	Caenis horaria (n = 34)	Treatment	76%	
	EPHEMERELLIDAE	Ephemerella ignita (n = 2870)	Control	12%	+
	EPHEMERELLIDAE	Ephemerella ignita (n = 2641)	Treatment	37%	
	HEPTAGENIIDAE	<i>Ecdyonurus</i> sp. (n = 21)	Control	19%	_
	HEPTAGENIIDAE	Ecdyonurus sp. (n = 14)	Treatment	7%	
	LEPTOPHLEBIIDAE	Habrophlebia lauta (n = 43)	Control	2%	~
	LEPTOPHLEBIIDAE	Habrophlebia lauta (n = 107)	Treatment	13%	

PLECOP- TERA	LEUCTRIDAE	<i>Leuctra</i> sp. (n = 232)	Control	6%	2
	LEUCTRIDAE	<i>Leuctra</i> sp. (n =270)	Treatment	15%	
	NEMOURIDAE	Protonemura sp. (n = 127)	Control	35%	~
	NEMOURIDAE	<i>Protonemura</i> sp. (n = 44)	Treatment	43%	
TRICHOPTERA	HYDROPSYCHIDAE	Hydropsyche sp. (n = 30)	Control	13%	+
	HYDROPSYCHIDAE	Hydropsyche sp. (n = 10)	Treatment	30%	
	HYDROPSYCHIDAE	Hydropsyche incog./pell. (n = 86)	Control	6%	2
	HYDROPSYCHIDAE	Hydropsyche incog./pell. (n = 63)	Treatment	13%	
	HYDROPSYCHIDAE	Hydropsyche siltalai (n = 34)	Control	3%	+
	HYDROPSYCHIDAE	Hydropsyche siltalai (n = 14)	Treatment	21%	
	LEPIDOSTOMATIDAE	<i>Lepidostoma hirtum</i> (n = 29)	Control	7%	+
	LEPIDOSTOMATIDAE	<i>Lepidostoma hirtum</i> (n = 24)	Treatment	38%	
	LEPTOCERIDAE	Athripsodes sp. (n = 19)	Control	5%	+
	LEPTOCERIDAE	<i>Athripsodes</i> sp. (n = 22)	Treatment	36%	
	LEPTOCERIDAE	<i>Oecetis testacea</i> (n = 2)	Control	0%	2
	LEPTOCERIDAE	<i>Oecetis testacea</i> (n = 8)	Treatment	13%	
	LIMNEPHILIDAE	Limnephilidae Gen. sp. (n = 15)	Control	7%	-
	LIMNEPHILIDAE	Limnephilidae Gen. sp. (n = 29)	Treatment	0%	
	POLYCENTROPODIDAE	Polycentropus flavom. (n = 69)	Control	3%	+
	POLYCENTROPODIDAE	Polycentropus flavom. (n = 105)	Treatment	20%	
	RHYACOPHILIDAE	Rhyacophila s. str. (n = 21)	Control	38%	-
	RHYACOPHILIDAE	Rhyacophila s. str. (n = 24)	Treatment	38%	

¹ For classification following boundaries were determined: increase of drift from control to treatment 0-5 % ... - (not affected),

6-15 % ... ~ (slightly affected)

16-100 % ... + (highly affected)

Some taxa are generally more drift affine than others. Ephemeroptera, particularly *Baetis* sp. were reported to dominate drift, Diptera (e.g. Simuliidae) likewise tend to be drift affine. Some Trichoptera (e.g. *Rhyacophila*, Hydropsychidae) on the other side mostly display low drift densities. Plecoptera also constitute a substantial component of the drift (Mendel & Müller, 1978; Allan, 1987; Allan et al., 1988; Humphries, 2002; Hieber et al., 2003; Gibbins et al., 2010).

This coincides with the results in Table 19 where most basic drifters were found in the order of Ephemeroptera, whereas Trichoptera and Coleoptera only showed few basic drifting taxa. Those taxa which were identified as basic drifters during the experiments (e.g. *Scirtidae* Iv., *Baetis lutheri*) showed to be less affected by hydropeaking than those which displayed just little or no drift during control at all (e.g. Dytiscidae, Ceratopogonidae, *Athripsodes, Lepidostoma hirtum*).

According to these outcomes it might be possible that the specimens who tend to be drift affine (basic drifters) are used to withstand higher shear stress due to their higher activity in the flowing waters. However it could be that some of those specimens displaying an overall high drift in the control scenarios are possibly not very well suited for this kind of experiment (e.g. *Rhyacophila* s. str).

Species traits

To assess the stress of hydropeaking on the different taxa various ecological and morphological parameters of the predominant taxa in this experiment were evaluated based on classifications mentioned in Chapter 5.3. Regarding the current preferences, feeding types or locomotion types following assumptions could be made:

1. Feeding type:

For the different feeding types (passive filter feeders (PFF), gatherers, shredders, predators and grazers) no significant pattern in their drift behavior – neither a diurnal one, nor a pattern related to hydropeaking – could be identified (Figure 41). This coincides with observations made by Boyero et al. (2005), showing that daily drift variations occur in very few functional feeding groups.



Figure 41: Percentage and absolute numbers respectively of drifting vs. non-drifting different feeding types control (left) vs. treatment (right)

All of the different feeding types showed an increase of drift in the treatment compared to the control. However, most of the predator species displayed affection by hydropeaking above average (e.g. *Oreodytes*) (Figure 42). This was also observed by Maiolini et al. (2007), who recorded a decrease of predator species downstream a hydropeaking release point.



Figure 42: Percentage and absolute numbers respectively of drifting vs. non-drifting different specimens of feeding types control (left) vs. treatment (right)

2. Locomotion type:

Some taxa (e.g. *Leuctra* sp.) which display the locomotion type "burrowing" (they burrow themselves in substrates) showed a moderate drift behavior in treatments and their drift increased below average compared to other locomotion types. Furthermore, it could be seen that most of those taxa representing swimming or sprawling locomotion characteristics (e.g. *Oreodytes* sp., *Ceratopogonidae* sp., *Ephemerella* sp., *Caenis* sp.) generally displayed a higher sensibility towards hydropeaking than those living in the interstice due to their inability to hide in the substrate. Some clingers (e.g. *Riolus* sp., *Elmis* sp.) were observed to drift substantially higher in the treatment compared to the control (Figure 43 & Figure 44).



Figure 43: Percentage and absolute numbers respectively of drifting vs. non-drifting different locomotion types control (left) vs. treatment (right)



Figure 44: Percentage and absolute numbers respectively of drifting vs. non-drifting different specimens of locomotion types control (left) vs. treatment (right)

3. Current preference:

The taxa of the orders Ephemeroptera, Plecoptera and Trichoptera which were classified as rheophilic (e.g. *Baetis* sp., *Hydropsyche* sp.) did not show a very high tendency to drift following hydropeaking treatment. They were quite resistant to higher velocities. This did not apply to Coleoptera, which were also described as rheophilic (e.g. *Elmis* sp., *Oreodytes* sp.), but were observed to drift strongly during hydropeaking. In general it could be observed that indifferent species as well as those with a limnophilic (L) character tended to drift the most, whereas those with a rheophilic (R) character displayed less affection (Figure 45 & Figure 46).





L to R ... Limnophil to rheophil, R to L ... Rheophil to limnophil



Figure 46: Percentage and absolute numbers respectively of drifting vs. non-drifting different current preference types control (left) vs. treatment (right)

The analyses of different species traits matched those of Schülting et al. (2016), who discovered rheophilic and interstitial taxa (e.g. *Hydropsyche* sp., *Leuctra* sp.) not to be highly influenced by hydropeaking, whereas limnophilic taxa (e.g. *Lepidostoma hirtum*) displayed higher drift rates.

Nevertheless, most of the parameters were not suitable for a clear distinction of drifting and nondrifting specimens. Due to these results it can be assumed, that **hypothesis H3** – drift-resistant taxa (non-drifting taxa) show specific traits – is only partly true as only some specific traits also showed a certain drift behavior.

Effects of hydropeaking on different size classes

Bruno et al. (2010) claimed that small larval stages of Ephemeroptera and Plecoptera could seek refuge in the interstitial, while larger ones were drifting more. To investigate this theory, **hypothesis H4** ("The percentage of drift of large invertebrates is higher than the drift of small invertebrates") was tested and the results were given in chapter 6.1.3. In summary, it could be observed, that nearly all orders showed their smallest class C (Ephemeroptera, Plecoptera, Trichoptera) or B (Chironomidae) to dominate drift in percentage during treatment as well as during the control scenarios. The larger classes A and B (EPT) or solely A (Chironomidae) tended to drift less. Therefore the **hypothesis H4** was proven wrong. An explanation could be that the smallest individuals were not strong enough to withstand the hydropeaking wave and cling to the substrate or take cover in the interstitial.

This correlates with the observations of Waringer (1989) who showed that young instars of *Allogamus auricollis* possess less resistance to drift under higher currents than later ones. While first instars displayed about 5.3×10^{-6} N total resistance of drift, last instars were able to resist drift up to

547.5x10⁻⁶ N. Fjellheim (1980) recorded a higher drift of young *Rhyacophila nubila* compared to later instars as well. Again, further research to show possible patterns is recommended.

Moreover all size classes were identified to drift highest in the UR phase. These results could imply that most of the specimens were influenced by the change of the flow velocity in the UR and not by the high velocity itself, also observed by Moog (1994). As they sought shelter in the interstitial or clung to the substrate, they stopped drifting after acclimatization.

8.1.2 Diurnal drift pattern

So far, studies have shown a diurnal periodicity in the drift of benthic invertebrates, with the nocturnal drift being higher (e.g. Elliott, 1967; Hynes, 1970; Ramirez & Pringle, 1998). Even though this behavior is taxa-specific, most individuals seem to show higher drift during the night (Campbell, 1985). To verify this statement the **hypothesis H5** ("There are differences in drift during night and day; the drift is higher during night") was formed and researched in chapter 6.2.

The evaluations of boxplots of the overall drift rate (abundance and biomass) showed a difference between day and night in the treatment, yet no considerable difference in the control. The drift rate (abundance) was over 10 % higher in the treatment during the night than during the day (33 % vs.

45 %). These results were confirmed by the Mann-Whitney tests, where the day-night-difference in the treatment fell short to meet its significance of 0.05 (obtained value: $\alpha = 0,065$) and the control did not display significant difference (obtained value: $\alpha = 0,931$). On the contrary, the values in Mann-Whitney test for the drift of biomass did not show a possible significant difference (obtained value treatment: $\alpha = 0,548$, control: $\alpha = 0,786$).

The observation that drift changed predominantly in the treatment but not in the control, could lead to the assumption that the increase of the nocturnal drift was mainly caused unintentionally by catastrophic (passive) drift. This assumption debilitated the "risk of predation" theory, which states, that the increased nocturnal drift activity can be led back to the presence or absence of predatory macroconsumers (Allan, 1995) and therefore is volitional drift.

A possible explanation for the rising drift during night might be that – according to Hynes (1970) and Elliott (1967) – benthic invertebrates show a higher nocturnal activity because of the drift-light intensity relation. Therefore, they are more affected by the increase of discharge and the increasing prevalent shear stress. It also supports the statement of Hynes (1970 and Haney et al. (1983), who discovered the diurnal drift pattern to persist even during floods.

Considering different taxa and their diurnal drift behavior, following assumptions could be made: Coleoptera, which are expected to show no day/night fluctuations (Golemac, 2011), displayed a minimal higher nocturnal drift (e.g. *Elmis* lv., *Riolus* ad., *Scirtidae* lv.). Ephemeroptera and Plecoptera,

63

which are said to become night drifter during their life cycle (Brusven, 1970; Adler et al., 1983), did not show increased nocturnal drift in class C compared to class B. Furthermore, Baetidae, a family supposed to be active during night (Campbell, 1985), showed an increase in drift during the night (e.g. *Baetis rhodani, Baetis muticus*). Moreover, no general diurnal pattern for Trichoptera (e.g. *Hydropsyche* sp.) could be observed. Chironomidae did display only little or no day/night fluctuations, which was also observed by Golemac (2011).

Some of these results coincide with the outcomes of Schülting et al. (2016) whose experiments were similar to those conduced for this master thesis. Scirtidae and *Baetis* sp. were observed to drift higher during the night in the treatment as well as in the control, whereas *Hydropsyche* sp. and *Polycentropus flavomaculatus* showed a contrary drift behavior with higher drift rates during the day. In addition, Chironomidae, *Ecdyonurus* sp. and *Leuctra* sp. showed a higher nocturnal drift in the treatment.

Summing up, the experiments showed disparities between day and night but no significant differences could be observed. As a consequence no general proof for a higher nocturnal drift could be identified in these experiments. Additionally, none of the assumptions for the diurnal behavior of different families could be totally verified or falsified. However, due to these observations a higher impact of nocturnal hydropeaking on benthic invertebrates can be expected. This was also verified by Schülting et al. (2016), whose experiments displayed a significant difference between the drift during day and night.

The observations of this experiment lead to the conclusion that it might be advantageous for the specimens to conduct pulse-releases during the day rather than during night to reduce the detrimental effect of hydropeaking.

8.2 Long-term experiment

8.2.1 Effect of hydropeaking on colonization

Since hydropeaking can have a detrimental effect on benthic invertebrates, it could be assumed that the colonization process would be affected in several ways and therefore a visible difference between treatment and control could be observed.

The NMDS-analysis (non-metric multidimensional scaling) in Figure 47 shows these relations between the two different scenarios treatment and control as well as between the two habitats pools and riffles.



Axis 1

Figure 47: NMDS-analysis of the habitat and scenario patterns

It could be observed that the results for the riffles and for the pools cluster together and within these groups differences between control and treatment communities become visible. While the pool communities in the control channel showed low scattering, the riffle communities in the controls displayed a wider spread. The treatments showed higher variation. The taxa composition between pool and riffle in controls show higher difference than pools and riffles of treatments.

As the analyses showed in chapter 7, the taxa diversity was explicitly higher in the treatment than in the control with 37 to 30 taxa, confirming thus the results of Olsen et al. (2007), who also monitored a higher number of taxa in patches with higher flow velocity, and therefore also confirming the **hypothesis H1a** ("The treatment shows higher taxa diversity than the control").

While 25 taxa occurred in the treatment as well as in the control flumes, species which only could be found in the control (*Asellus aquaticus*, Chloroperlidae, Empididae pup., Hydroporinae Iv. and *Porhydrus* Iv.) showed either indifferent or limnophilic current preferences. Those taxa living solely in the treatment (*Amphinemura, Ancylus fluviatilis, Baetis lutheri,* Calopterygidae, Ceratopogonidae, *Ecdyonurus, Gyrinidae* Iv., *Haliplus* Iv., *Hydropsyche angustipennis, Orectochilus* Iv., *Plectrocnemia,* Tipulidae) displayed mostly rheophilic characters. Exceptions such as *Haliplus* Iv., *Plectrocnemia* sp. or Tipulidae, which are classified as limnophilic taxa, occurred only in such small quantities that they did not qualify for further discussion.

The increase of taxa diversity in the treatment compared to the control could be explained by the "Intermediate Disturbance Hypothesis (IDH)", suggesting that due to the coexistence of species that prosper at early as well as those thriving at late succession stages the diversity of species reaches its peak when the disturbances are at a mediocre level (Connell, 1978).

However, not only the taxa diversity was higher in the treatment sections, but also the abundance and the biomass. Even though no significant differences between the two scenarios could be identified, **hypothesis H1b** ("The control shows higher biomass/abundance") is therefore proven
wrong and has to be changed into "*The treatment shows higher biomass and abundance than the control*". A possible explanation for the dominance of abundance and biomass as well as the higher taxa diversity in the hydropeaking affected flumes compared with the baseflow flumes might be that the majority of the colonizing species possessed "rheophilic", "rheobiontic" or "rheo- to limnophilic" characteristics. These observations also confirm **hypothesis H1c** ("In the treatment more rheophilic invertebrates can be found than in the control"). As seen in Figure 38, the median of the flow velocity is higher in the treatment. Taxa preferring higher currents therefore colonize the treatment more frequently than the control. Furthermore, the habitat variability is also higher in the treatment than in the control, these varying hydrological conditions might be advantageous for many benthic invertebrates in terms of oxygen or nourishment supply.

As Olsen et al. (2007) supposed that the total density of benthic invertebrates was not related to the flow velocity, another explanation for the dominance of the treatment scenario in terms of abundance, biomass and diversity might not lie in the hydrological criteria but in the aquatic fauna of the surrounding environment. Considering the possible influence of the nearby lake, the experiment could possibly have had different outcomes when performed in other environments; further experiments in various environmental settings are recommended.

The analysis of the community structure (Chapters 7.2 and 7.3) showed that the colonizing taxa in the riffles and pools as well as in the treatment and control scenarios displayed several specific traits (**hypothesis H3**) according to their favored natural habitat and flow velocity preference. Generally, most of the colonizing species were rheophilic.

Those invertebrates characterized with a robust form (e.g. Heptageniidae or Ephemerellidae) were mainly found in the riffles and showed an increase of abundance in the treatment scenarios, verifying Moog's (1994) observation. Most of the species with a resistance towards higher current and described as rheophilic (e.g *Baetis* sp., *Hydropsyche* sp.) were also observed to colonize the riffles and increase in abundance during the treatment. On the other hand, those with flow-sensitive characteristics (e.g. Cloeoninae) were present in the pool habitats and even showed a decrease under hydropeaking conditions.

Moog (1994) also depicted a shift of the benthic invertebrate composition under hydropeaking towards euryoecous species, which were mostly Chironomidae. This observation could not be verified for this experiment as the sampled Chironomidae – even though they preferred higher currents and colonized mainly riffles – displayed a decline in abundance in the treatment scenarios. Since Chironomidae in general show a broad variety of different specific traits, a further determination of the exact taxa would have been necessary to make accurate statements. However most of the other euryoecous species experienced an abundance increase.

66

His other observation of the increase of "species which usually migrate actively into the substrate interstices to find protection against rapid increases in flow velocity" (such as Leptophlebiidae or Leuctridae) could also not be confirmed. *Leuctra* sp. generally favored riffle habitats, but they did not colonize under hydropeaking circumstances.

8.2.2 Habitat preferences (pools vs. riffles)

Due to their different characteristics for example in flow velocity and shear stress, it was assumed that riffles and pools also might show differences in their colonization (H2). This could be verified in chapter 7.3, where it was observed, that riffles displayed by far a higher abundance of specimens as well as biomass compared to pool habitats. Furthermore the diversity, as suspected by Olsen et al. (2007), displayed a higher number of taxa in the patches with higher flow velocity. Hence these results the **hypothesis H2a** ("Riffles show higher taxa diversity, abundance and biomass than pool habitats") could be confirmed. The reason for these observations might be that most of the colonizing taxa had a rheophilic character and therefore preferred the riffle habitats with their faster flow velocity (Chapter 7.1). In course of this evaluation **hypothesis H2b** ("Rheophilic taxa can be found in the riffles, while those preferring slow flow velocities are found in the pools") was also verified, as most of the rheophilic individuals dominated the colonization of the riffles of treatment and control (Figure 38).

The NMDS-analysis in Figure 47 displayed the differences and relations between the various habitats and showed that the disparities between pools and riffles are higher in the control than in the treatment, therefore falsifying hypothesis H2c ("The differences of colonization between pools and riffles are higher in the treatment than in the control"). This is visible as the data points for the pools are not very close to the data points of the riffles in the control, whereas in the treatment scenarios the data points for pools are adjacent to those of the riffles and display a pattern not as dense. The explanation for the higher difference between pool and riffles in the control might lie in the variance of the flow velocities, supporting the Intermediate Disturbance Hypothesis (Connell, 1978). Even though the measured current was higher in the treatment, the difference of the range between the velocities of pools and riffles was higher in the control than in the treatment, as seen in Figure 38. Moreover, the NMDS-analysis in Figure 47 shows that hypothesis H2d ("The differences of colonization considering abundance are higher between the riffles of control and treatment than between the pools of control and treatment") is correct. This can be observed as the data points of the pools cluster together, but those for the riffles are more widespread. This could also be explained with the flow velocities' variety (Figure 38), which displayed a higher difference between the riffles of control and treatment than between the pools of control and treatment.

67

9. Summary and Conclusion

The conducted experiments display that hydropeaking definitely has an impact on the aquatic ecology by increasing the shear stress and therefore the drift of benthic invertebrates, especially forcing early instars to drift in higher frequencies rather than later ones.

Even though the long term experiment shows that a certain (mediocre) variability of the flow velocity might even be advantageous for taxa diversity, abundance and biomass in the treatment and riffles – possibly due to the diversified habitat conditions – the destructive power of hydropeaking is observed in the short term experiment, where almost 40 % of the invertebrates drifted.

As the drift is highest during an increase of discharge rather than during constant high flow, it could be concluded that in terms of hydropeaking the flow velocity should be increased slowly to allow the specimens to adapt to the changing circumstances and to reduce the drift.

Furthermore, the outcomes of the day-night-drift comparison display a clearly higher nocturnal drift in the treatment compared to the drift during the day. Since these observations are mainly made under hydropeaking circumstances, it could be recommended to hydropower stations to conduct pulse-releases – if possible – during the day to avoid a higher detrimental effect on benthic invertebrates. However, since no significant differences between day and night drift can be found, probably multiple peaks over a longer period instead of only one peak in discharge should be tested to verify these outcomes and to make a general and significant statement on day-night-difference in drift.

As more rheophilic than limnophilic specimens colonized the treatment in the long term experiment and most of them (apart from Coleoptera) also showed a generally higher resistance towards hydropeaking in the short term experiment, it can be concluded, that rheophilic benthic invertebrates are less affected by an increase of discharge. The colonizing taxa under higher discharge circumstances (treatment, riffles) also displayed other specific traits such as robust forms or a euryoecous character.

Nonetheless, most of the observed specific traits were not suitable for a clear distinction of drifting and non-drifting benthic invertebrates. Only the feeding type 'predator' and the locomotion types 'swimming', 'diving' and 'sprawling' showed a higher sensitivity towards hydropeaking. Consequently, further research on specific traits and their reaction to hydropeaking is recommended.

Nevertheless, the results of these experiments have to be considered from a critical point of view as the experimental set-ups did not exactly mirror a natural environment and thereby cannot be applied to exactly depict the reaction of the benthic invertebrates under random circumstances. It has to be taken into consideration that the peak flow currents of this experiment are still lower than those compared to field situation. Moreover the nearby lake Lunz and the oviposition of the specimens could have led to an influence of the colonization in the long term experiment.

Additionally, Chironomidae appeared to be not appropriate for the conducted short term experiment. They displayed a high drift in all phases of the short term experiment and their drift did not reach a steady level; same applied for *Rhyacophila* s. str. A high drift in the control as well as the treatment scenarios was observed for Oligochaeta, but no significant differences could be found. Therefore it has to be assumed, that experimental setup are not suitable for all specimens as some might need a higher adaptation time.

10. Bibliography

Adler, P. H., R. W. Light & K. C. Kim, 1983. The aquatic drift patterns of black flies (Diptera: Simuliidae). Hydrobiologia 107: 183–191.

Allan, J. D., 1987. Macroinvertebrate drift in a Rocky Mountain stream. Hydrobiologia 144: 261–268.

Allan, J. D., 1995. Stream Ecology. Chapman & Hall, London.

Allan, J. D. & A. S. Flecker, 1993. Biodiversity Conservation in Running Waters. BioScience 43: 32–43.

Allan, J. D., G. N. Herbst, R. Ortal & Y. Regev, 1988. Invertebrate drift in the Dan River, Israel. Hydrobiologia 160: 155–163.

Arcadis, & Ingenieurbüro Floecksmühle, 2011. Broschüre: Hydropower Generation in the context of the EU WFD. Aachen .

Bauernfeind, E., O. Moog & P. Weichselbaumer, 1995. Ephemeroptera. In: Moog, O. (ed.): Fauna Aquatica Austriaca, Lieferung 1995. Wasserwirtschaftskataster, Bundesministerium für Land- und Forstwirtschaft, Wien.

Bauernfeind, E., O. Moog & P. Weichselbaumer, 2002. Ephemeroptera. In: Moog, O. (ed.): Fauna Aquatica Austriaca, Lieferung 2002, Wasserwirtschaftskataster, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien.

Bauernfeind, E. & U. H. Humpesch, 2001. Die Eintagsfliegen Zentraleuropas (Insecta: Ephemeroptera). Bestimmung und Ökologie. Naturhistorisches Museum, Wien.

Baumann, P. & U. Schälchli, 2002. Trübung und Schwall im Alpenrhein. Wasser Energie Luft 94: 307–315.

Bilton, D. T., J. R. Freeland & B. Okamura, 2001. Dispersal in Freshwater Invertebrates. Annual Review of Ecology and Systematics 32: 159–181.

Blaustein, L., 1997. Non-consumptive effects of larval Salamandra on crustacean prey: Can eggs detect predators?. Oecologia 110: 212–217.

BMLFUW, 2007. Hydrologischer Atlas Österreichs. Wien .

BMLFUW, 2010. Nationaler Gewässerbewirtschaftungsplan 2009 – NGP 2009. Wien .

BMLFUW, 2014. Wasser Informationssystem Austria (WISA). Wien. , http://wisa.bmlfuw.gv.at.

Boyero, L., M. Valladolid & M. Arauzo, 2005. Dynamics of invertebrate benthic communities and drift in a regulated river of central Spain. International Review of Hydrobiology 90: 392–411.

Bratrich, C., B. Truffer, K. Jorde, J. Markard, W. Meier, A. Peter, M. Schneider & B. Wehrli, 2004. Green hydropower: A new assessment procedure for river management. River Research and Applications 20: 865–882.

Brederveld, R. J., S. C. Jähnig, A. W. Lorenz, S. Brunzel & M. B. Soons, 2011. Dispersal as a limiting factor in the colonization of restored mountain streams by plants and macroinvertebrates. Journal of Applied Ecology 48: 1241–1250.

Bretschko, G. & O. Moog, 1990. Downstream effects of intermittent power generation. Water Science and Technology 22: 127–135.

Brewin, P. A. & S. J. Ormerod, 1994. Macroinvertebrate drift in streams of the Nepalese Himalaya. Freshwater Biology 32: 573–583.

Brittain, J. E. & T. J. Eikeland, 1988. Invertebrate drift - A review. Hydrobiologia 166: 77–93.

Bruder, A., S. Schweizer, S. Vollenweider, D. Tonolla & T. Meile, 2012. Schwall und Sunk :

Auswirkungen auf die Gewässerökologie und mögliche Sanierungsmassnahmen. Wasser Energie Luft 4: 257–264.

Bruno, M. C., B. Maiolini, M. Carolli & L. Silveri, 2010. Short time-scale impacts of hydropeaking on benthic invertebrates in an Alpine stream (Trentino, Italy). Limnologica Elsevier 40: 281–290.

Bruno, M. C., A. Siviglia, M. Carolli & B. Maiolini, 2013. Multiple drift responses of benthic invertebrates to interacting hydropeaking and thermopeaking waves. Ecohydrology 6: 511–522.

Brusven, M. A., 1970. Drift periodicity and usptream dispersion of stream insects. Journal of Entomological Society of British Columbia 67: 48–59.

Campbell, R. N. B., 1985. Comparison of the drift of live and dead Baetis nymphs in a weakening water current. Hydrobiologia 126: 229–236.

Cellot, B., 1989. Macroinvertebrate movements in a large European river*. Freshwater Biology 22: 45–55.

Céréghino, R., P. Cugny & P. Lavandier, 2002. Influence of intermittent hydropeaking on the longitudinal zonation patterns of benthic invertebrates in a mountain stream. International Review of Hydrobiology 87: 47–60.

Céréghino, R. & P. Lavandier, 1998. Influence of hypolimnetic hydropeaking on the distribution and population dynamics of Ephemeroptera in a mountain stream. Freshwater Biology 40: 385–399.

Connell, J., 1978. Connell, J. 1978. Diversity in tropical rain forest and coral reefs (Disturbio intermedio).pdf. Science 199: 1302–1310, http://www.sciencemag.org/cgi/content/abstract/199/4335/1302.

Cortes, R. M. V., M. T. Ferreira, S. V. Oliveira & D. Oliveira, 2002. Macroinvertebrate community structure in a regulated river segment with different flow conditions. River Research and Applications 18: 367–382.

Cushman, R. M., 1985. Review of Ecological Effects of Rapidly Varying Flows Downstream from Hydroelectric Facilities. North American Journal of Fisheries Management 5: 330–339.

Dimand, J. B., 1967. Evidence that Drift of Stream Benthos is Density Related. Ecology 48: 855–857.

Elliott, J. M., 1967. Invertebrate drift in a Dartmoor stream. Arch. Hydrobiol. 63: 202–237.

Energie Control Austria, 2014. E-Control: Statistikbroschüre 2014. Wien .

Fenoglio, S., P. Agosta, T. Bo & M. Cucco, 2002. Field experiments on colonization and movements of stream invertebrates in an Apennine river (Visone, NW Italy). Hydrobiologia 474: 125–130.

Fjellheim, A., 1980. Differences in drifting of larval stages of Rhyacophila nubila (Trichoptera). Holarctic Ecology 3: 99–103, http://doi.wiley.com/10.1111/j.1600-0587.1980.tb00714.x.

Flecker, A. S., 1992. Fish predation and the evolution of invertebrate drift periodicity: evidence from Neotropical streams. Ecology 73: 438–448.

Gibbins, C., R. J. Batalla & D. Vericat, 2010. Invertebrate drift and benthic exhaustion during disturbance: Response of mayflies (Ephemeroptera) to increasing shear stress and river-bed instability. River Research and Applications 26: 499–511.

Glöer, P. & C. Meier-Brook, 2001. Süßwassermollusken. Ein Bestimmungsschlüssel für die Bundesrepublik Deutschland. 13. Aufl., Hamburg.

Golemac, 2011. Masterarbeit: Makrozoobenthos-Drift in der Möll bei Möllbrücke. Wien .

Graf, W., U. Grasser & A. Weinzierl, 1995a. Plecoptera. In: Moog, O. (ed.): Fauna Aquatica Austriaca, Lieferung 1995. Wasserwirtschaftskataster, Bundesministerium für Land- und Forstwirtschaft, Wien.

Graf, W., U. Grasser & J. Waringer, 1995b. Trichoptera. In: Moog, O. (ed.): Fauna Aquatica Austriaca, Lieferung 1995. Wasserwirtschaftskataster, Bundesministerium für Land- und Forstwirtschaft, Wien.

Graf, W., U. Grasser & A. Weinzierl, 2002a. Plecoptera. In: Moog, O. (ed.): Fauna Aquatica Austriaca, Lieferung 2002. Wasserwirtschaftskataster, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien.

Graf, W., U. Grasser & J. Waringer, 2002b. Trichoptera. In: Moog, O. (ed.): Fauna Aquatica Austriaca, Lieferung 2002. Wasserwirtschaftskataster, Bundesministerium für Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien.

Graf, W., 2015. Skriptum zur Vorlesung "Ecology and taxonomy of selected invertebrate groups" - Plecoptera. Universität für Bodenkultur, Wien.

Habersack, H., B. Wagner, C. Hauer & E. Jäger, 2012. Wasserkraft in Österreich - aktueller Bestand und Decision Support System (DSS WASSERKRAFT). Österreichische Wasser- und Abfallwirtschaft 64: 336–343.

Haney, J. F., T. R. Beaulieu, R. P. Berry, D. P. Mason, C. R. Miner, E. S. McLean, K. L. Price, M. A. Trout, R. A. Vinton & S. J. Weiss, 1983. Light intensity and relative light change as factors regulating stream drift. Arch. Hydrobiol. 97: 73–88.

Hebauer, F., 1988. Gesichtspunkte der ökologischen Zuordnung aquatischer Insekten zu den Sukzessionsstufen der Gewässer. Ber. ANL 12: 229–239.

Hieber, M., C. T. Robinson & U. Uehlinger, 2003. Seasonal and diel patterns of invertebrate drift in different alpine stream types. Freshwater Biology 48: 1078–1092.

Hildrew, A. G. & C. R. Townsend, 1980. Aggregation, interference and foraging by the larvae of Plectrocnemia conspersa (Trichoptera: Polycentropodinae). Animal Behaviour 28: 553–560.

Huhta, A., T. Muotka & P. Tikkanen, 2000. Nocturnal drift of mayfly nymphs as a antipredator mechanism. Freshwater Biology 45: 33–42.

Humphries, S., 2002. Dispersal in drift-prone macroinvertebrates: A case for density-independence. Freshwater Biology 47: 921–929.

Hynes, H. B. N., 1970. The ecology of stream insects. Annual Review of Entomology 15: 25-42.

Jäch, M., J. Kodada, O. Moog, W. Paill & S. Schödl, 1995. Coleoptera (authors depending on family). In: Moog, O. (Ed.): Fauna Aquatica Austriaca, Lieferungen 1995, 2002. Wasserwirtschaftskataster, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien.

Jäch, M., 2006. Wasserkäfer. Skriptum zum Spezialpraktikum (Sommersemester 2006). Universität Wien.

Jones, J. I., J. F. Murphy, A. L. Collins, D. A. Sear, P. S. Naden & P. D. Armitage, 2012. The Impact Of Fine Sediment On Macro-Invertebrates. River Research and Applications 28: 1055–1071.

Jourdan, J., J. Baier, R. Riesch, S. Klimpel, B. Streit, R. Müller & M. Plath, 2016. Adaptive growth reduction in response to fish kairomones allows mosquito larvae (Culex pipiens) to reduce predation risk. Aquatic Sciences 78: 303–314.

Jungwirth, M., G. Haidvogl, O. Moog, S. Muhar & S. Schmutz, 2003. Angewandte Fischökologie an Fließgewässern. Facultas Verlags- und Buchhandels AG, Wien.

Jungwirth, M., O. Moog & S. Schmutz, 1990. Auswirkungen der Veränderungen des Abflußregimes auf die Fisch- und Benthosfauna anhand von Fallbeispielen. Landschaftswasserbau 10: 194–234.

Kohler, S. L., 1983. Positioning on substrates, positioning changes, and diel drift periodicities in mayflies. Can. J. Zool. 61: 1362–1368.

Kohler, S. L., 1985. Identification of Stream Drift Mechanisms - an Experimental and Observational Approach. Ecology 66: 1749–1761.

Kreps, H., 1975. Praktische Arbeit in der Hydrographie: 25 Jahre im Dienste der Hydrographischen Landesabteilung Steiermark.

Limnex, 2004. Auswirkungen des Schwallbetriebs auf das Ökosystem der Fließgewässer: Grundlagen zur Beurteilung. Grundlagenstudie im Auftrag des WWF Schweiz, Zürich.

Maiolini, B., 2007. Effects of hydropeaking on the hyporheos of an Alpine stream: preliminary results. Geophysical Research Abstracts 9:.

Maiolini, B., L. Silveri & V. Lencioni, 2007. Hydroelectric power generation and disruption of the natural stream flow: effects on the zoobenthic community. Studi Trent. Sci. Nat. Acta Biol. 83: 21–26.

Malmqvist, B., 2000. How does wing length relate to distribution patterns of stoneflies (Plecoptera) and mayflies (Ephemeroptera)?. Biological Conservation 93: 271–276.

Mendel, H. & K. Müller, 1978. The colonization cycle of Amphinemura sulcicollis Ris (Ins. Plecoptera) in the Abisko area. Hydrobiologia 60: 109–111.

Merritt, R. W., 1996. An introduction to the aquatic insects of North America. Kendall-Hunt, Dubuque, IA.

Moog, O., 1994. Quantification of daily peak hydropower effects on aquatic fauna and management to minimize environmental impacts. Biological Conservation 67: 188–189.

Moog, O., 2011. The life in moving fluids - Physiologic and anatomic aspects of aquatic invertebrate life (oxygen, habitats, current). Script for Ecology of benthic invertebrates (812.343) 2nd unit.

Morgan, R. P., R. E. Jacobsen, S. B. Weisberg, L. A. McDowell & H. T. Wilson, 1991. Effects of Flow Alteration on Benthic Macroinvertebrate Communities below the Brighton Hydroelectric Dam. Journal of Freshwater Ecology 6: 419–429.

Müller, K., 1966. Die tagesperiodik von fliesswasserorganismen. Zeitschrift für Morphologie und Ökologie der Tiere 56: 93–142.

Müller, K., 1970. Tages- und Jahresperiodik der Drift in Fließgewässern in verschiedenen geographischen Breiten. OIKOS Supplementum 13: 21–44.

Müller, K., 1982. The colonization cycle of freshwater insects. Oecologia 52: 202–207.

Müller-Peddinghaus, E. H., 2011. Flight-morphology of Central European caddisflies (Insecta: Trichoptera) in relation to their ecological preferences. Dissertation, University of Duisburg-Essen.

Oberrisser, P. & J. Waringer, 2011. Larval salamanders and diel drift patterns of aquatic invertebrates in an Austrian stream. Freshwater Biology 56: 1147–1159.

Olsen, D. a, C. D. Matthaei & C. R. Townsend, 2007. Patch history, invertebrate patch dynamics and heterogeneous community composition: perspectives from a manipulative stream experiment. Marine and Freshwater Research 58: 307–314.

Peckarsky, B. L., 1980. Predator-prey interactions between Stoneflies and Mayflies : behavioral observations. Ecology 61: 932–943.

Pitsch, T., 1993. Zur Larvaltaxonomie, Faunistik und Ökologie mitteleuropäischer Fließwasser-Köcherfliegen (Insecta: Trichoptera). Landschaftsentwicklung und Umweltforschung, Sonderheft 8:1-316.

Pringle, C. M. & A. Ramírez, 1998. Use of both benthic and drift sampling techniques to assess tropical stream invertebrate communities along an altitudinal gradient, Costa Rica. Freshwater

Biology 39: 359–373.

Ramirez, A. & C. M. Pringle, 1998. Invertebrate drift and benthic community dynamics in a lowland neotropical stream, Costa Rica. Hydrobiologia 386: 19–26.

Robinson, C. T., U. Uehlinger & M. T. Monaghan, 2004. Stream ecosystem response to multiple experimental floods from a reservoir. River Research and Applications 20: 359–377.

Schmedtje, U. & M. Colling, 1996. Ökologische Typisierung der aquatischen Makrofauna. Informationsberichte des Bayerischen Landesamtes für Wasserwirtschaft 4/96, 543 pp.

Schmutz, S., A. Melcher, B. Zeiringer, T. Friedrich, M. Fuhrmann, W. Graf, F. Greimel, N. Höller, M. Jungwirth, P. Leitner, O. Moog, K. Müllner, G. Ochsenhofer, G. Salcher, C. Steidl & G. Unfer, 2013. Schwallproblematik an Österreichs Fließgewässern – Ökologische Folgen und Sanierungsmöglichkeiten.

Schülting, L., C. K. Feld & W. Graf, 2016. Effects of hydro- and thermopeaking on benthic macroinvertebrate drift. Science of The Total Environment .

Seebacher, M. & B. Zeiringer, 2011. Schwallproblematik in Österreich. , http://hydropeaking.boku.ac.at/.

Tachet, H., P. Richoux, M. Bournaud & Usseglio-Polatera, 2000. Invertébrés d'eau douce, systématique, biologie, écologie. CNRS Éditions, Paris.

Tockner, K. & J. A. Waringer, 1997. Measuring drift during a receding flood: Results from an Austrian mountain Brook (Ritrodat-Lunz). Internationale Revue Der Gesamten Hydrobiologie 82: 1–13.

Townsend, C. R. & A. G. Hildrew, 1994. Species traits in relation to a habitat templet for river systems. Freshwater Biology 31: 265–275.

Tronstad, L. M., B. P. Tronstad & A. C. Benke, 2007. Aerial colonization and growth: rapid invertebrate responses to temporary aquatic habitats in a river floodplain. Journal of the North American Benthological Society. , 460–471.

Turcotte, P. & P. P. Harper, 1982. Drift patterns in a high Andean stream. Hydrobiologia 89: 141–151.

Vinson, M. R., 2001. Long-term dynamics of an invertebrate assemblage downstream from a large dam. Ecological Applications 11: 711–730.

Walton Jr., O. E., 1980. Invertebrate drift from predator - prey associations. Ecology (Washington D C) 61: 1486–1497.

Waringer, J. A., 1989. Resistance of cased caddis larva to accidental entry into the drift: the contribution of active and passive elements. Freshwater Biology 21: 411–420.

Waringer, J. & W. Graf, 1997. Atlas der österreichischen Köcherfliegenlarven. Facultas Universitätsverlag, 286pp, Wien. Ergänzungen 2004.

Waters, T. F., 1972. The Drift of Stream Insects. Annual Review of Entomology. , 253–272.

Williams, D. D. & H. B. N. Hynes, 1976. The recolonization mechanisms of stream benthos. Oikos 27: 265–272.

Williams, D. D. & G. P. Levens, 1988. Evidence that hunger and limb loss can contribute to stream invertebrate drift. Journal of the North American Benthological Society 7: 180–187.

Wimmer, R. & O. Moog, 1994. Flußordnungszahlen österreichischer Fließgewässer. Umweltbundesamt, ed. .

11. Figures

Figure 1: Anthropogenic hydrological impacts and hydropeaking affected flowing courses (blue lines)
in Austria (Schmutz et al., 2013)1
Figure 2: Typical riffle and pool sequences
(http://www.oxbowriver.com/Web_Pages/Services_Pages/Services_NCD/NCD_Riffles.html)
Figure 3: Overview of the HyTEC facility in Lunz am See before the construction of the artificial flumes
Figure 4: Scheme of the flumes for the drift experiment in Lunz am See
Figure 5: Change of discharge during the phases over the project time
Figure 6: Upstream view of flume 1
Figure 7: Upstream view of flume 2
Figure 8: Scheme of the artificial flumes for the long-term experiment
Figure 9: Total drift (abundance) of specimens in % and absolute numbers
Figure 10: Total drift (biomass) of specimens in % and gram21
Figure 11: Total drift rate (abundance), showing the difference in treatment and control (N = 4; n =
8258 respectively 9608)
Figure 12: Total drift rate (biomass), showing the difference in treatment and control (N = 4;
Figure 13: Treatment and control drift rates (abundance) during the phases UR-DR (N = 4; n = 8258,
9608)
Figure 14: Treatment and control drift rates (biomass) during the phases UR-DR (N = 4; n = 8258,
9608)
Figure 15: Difference of treatment and control drift for the various taxonomical orders (N = 4; n = 84-
4704)
Figure 16: Drift rate of Coleoptera regarding treatment and control (N = 4)
Figure 17: Percentage of drifting vs. non-drifting specimens of selected Coleoptera families
Figure 18: Drift rate of Ephemeroptera regarding treatment and control (N = 4)
Figure 19: Percentage of drifting vs. non-drifting specimens of selected Ephemeroptera families 27
Figure 20: Drift rate of Plecoptera regarding treatment and control (N = 4)
Figure 21: Percentage of drifting vs. non-drifting specimens of selected Plecoptera families
Figure 22: Drift rate of Trichoptera regarding treatment and control (N = 4)
Figure 23: Percentage of drifting vs. non-drifting specimens of selected Trichoptera families 30
Figure 24: Percentage of drifting vs. non-drifting specimens of selected Diptera families
Figure 25: Drift rate of Diptera regarding treatment and control (N = 4)
Figure 26: Size distribution of Diptera and Ephemeroptera, considering differences between
treatment and control

Figure 27: Size distribution of Plecoptera and Trichoptera, considering differences between
treatment and control
Figure 28: Percentage and absolute numbers respectively of drifting vs. non-drifting specimens, day
and night drift (abundance)
Figure 29: Percentage and gram respectively of drifting vs. non-drifting specimens, day and night drift
(biomass)
Figure 30: The total drift rate (abundance) during day and night (N = 4; n = 3159 - 6449)
Figure 31: Total drift rate (biomass) during day and night (N = 4; n = 3159 - 6449)
Figure 32: Difference of night and day drift in treatment and control for selected groups (N = 4; n =
30-3215)
Figure 33: Diurnal drift patterns of selected Coleoptera families in treatment and control
Figure 34: Diurnal drift patterns of selected Ephemeroptera families in treatment and control 39
Figure 35: Diurnal drift patterns of selected Plecoptera families in treatment and control
Figure 36: Diurnal drift patterns of selected Trichoptera families in treatment and control
Figure 37: Diurnal drift patterns of selected Diptera, Gastropoda and Oligochaeta families in
treatment and control
Figure 38: Velocities in treatment (left) and control (right), showing the minimum, maximum and
median as well as the variety of the current
Figure 39: Abundance of selected taxa in the different scenarios and habitats
Figure 40: Distribution of the limnophilic and rheophilic specimens in the pools and riffles of
treatment and control
Figure 41: Percentage and absolute numbers respectively of drifting vs. non-drifting different feeding
types control (left) vs. treatment (right)
Figure 42: Percentage and absolute numbers respectively of drifting vs. non-drifting different
specimens of feeding types control (left) vs. treatment (right)
Figure 43: Percentage and absolute numbers respectively of drifting vs. non-drifting different
locomotion types control (left) vs. treatment (right)60
Figure 44: Percentage and absolute numbers respectively of drifting vs. non-drifting different
specimens of locomotion types control (left) vs. treatment (right)
Figure 45: Percentage and absolute numbers respectively of drifting vs. non-drifting different
specimens of current preference types control (left) vs. treatment (right)
Figure 46: Percentage and absolute numbers respectively of drifting vs. non-drifting different current
preference types control (left) vs. treatment (right)62
Figure 47: NMDS-analysis of the habitat and scenario patterns

12. Tables

Table 1: Mann-Whitney test comparing benthic invertebrate drift (abundance) for treatment-control-
differences (α = 0.05, N = 4; n = 8258, 9608)
Table 2: Mann-Whitney test comparing benthic invertebrate drift (biomass) for treatment-control-
differences (α = 0.05, N = 4; n = 8258, 9608)23
Table 3: MW-test on order level for significances in treatment-control (α = 0.05, N = 4; n = 84-4704)
Table 4: Mann-Whitney test on day-night-differences of abundance (α = 0.05, N = 4; n = 3159-6449)
Table 5: Mann-Whitney test on day-night-differences of biomass (α = 0.05, N = 4; n = 3159-6449) 36
Table 6: MW-test on taxonomical order level concerning day-night-differences (α = 0.05, N = 4; n =
30-3215)
Table 7: Measured flow velocity in the treatment channels (m/s)
Table 8: Measured flow velocity in the control channels (m/s)
Table 9: Total abundance of different orders in pool and riffle habitats
Table 10: Total biomass of different orders in pool and riffle habitats 45
Table 11: Number and specification of taxa in the treatment
Table 12: Number and specification of taxa in the control
Table 13: Mann-Whitney test for treatment/control difference of abundance (α = 0.05, N = 6; n =
1298-22389)
Table 14: Mann-Whitney test for treatment/control differences of biomass (α = 0.05, N =6; n = 1298-
22389)
Table 15: Number and specification of taxa in the riffles 51
Table 16: Number and specification of taxa in the pools
Table 17: Mann-Whitney test for pool/riffle differences of abundance (α = 0.05, N = 6; n = 1298-
22389)
Table 18: Mann-Whitney test for pool/riffle biomass differences (α = 0.05, N = 6; n = 1298-22389) . 53
Table 19: Overview of drift results

13. Appendix

13.1 Mann-Whitney tests for short-term experiment

Mann-Whitney-test family level	Drift_rate_tot	Drift_rate_UR	Drift_rate_P1	Drift_rate_P2	Drift_rate_DR
Oligochaeta	0,068	0,237	0,360	0,360	0,460
Baetidae	0,169	0,016	0,740	0,566	0,525
Ceratopogonidae	0,400	1	0,400	0,400	0,400
Chironomidae	0,000	0,004	0,000	0,000	0,000
Elmidae	0,000	0,001	0,000	0,151	0,032
Ephemerellidae	0,000	0,000	0,000	0,316	0,002
Hydropsychidae	0,364	0,669	0,669	0,740	0,740
Leptoceridae	0,667	0,667	1	0,667	1
Leptophlebiidae	0,033	0,183	0,517	0,833	0,833
Leuctridae	0,044	0,347	0,169	0,487	0,118
Nemouridae	0,286	0,071	0,143	0,286	0,143
Planorbidae	1	0,400	0,800	1	1
Polycentropodidae	0,000	0,008	0,776	0,529	0,776
Scirtidae	0,651	0,260	0,833	0,104	0,740

13.1.1 Treatment-Control differences (abundance)

Mann-Whitney-test species level	Drift_rate_tot	Drift_rate_UR	Drift_rate_P1	Drift_rate_P2	Drift_rate_DR
Athripsodes	0,667	0,667	1	0,667	1
Baetis	0,562	0,217	0,365	0,065	0,401
Baetis lutheri	0,533	0,267	0,533	0,267	1
Baetis muticus	0,500	0,500	0,500	1	1
Baetis rhodani	0,566	0,059	0,051	0,487	0,651
Baetis scambus	1	0,534	0,945	0,181	0,945
Ceratopogonidae	0,400	1	0,400	0,400	0,400
Chironomidae	0,000	0,004	0,000	0,000	0,000
Elmis ad.	0,800	0,400	0,800	1	1
Elmis Iv.	0,000	0,010	0,512	0,314	0,251
Ephemerella ignita	0,000	0,000	0,000	0,316	0,002
Habrophlebia lauta	0,033	0,183	0,517	0,833	0,833
Hydropsyche Incog./pell.	0,310	0,690	0,690	1	1
Hydropsyche siltalai	0,667	0,667	1	1	1

Leuctra	0,044	0,347	0,169	0,487	0,118
Oligochaeta	0,068	0,237	0,360	0,360	0,460
Planorbidae	1	1	1	1	1
Polycentropus flavomac.	0,000	0,026	0,776	0,529	0,776
Protonemura	0,571	0,095	0,190	0,190	0,095
Riolus ad.	0,173	0,349	0,029	1	0,223
Riolus Iv.	0,000	0,005	0,000	0,217	0,002
Scirtidae Iv.	0,651	0,260	0,833	0,104	0,740

13.1.2 Treatment-Control differences (biomass)

Mann-Whitney-Test order level	Drift_rate_tot	Drift_rate_UR	Drift_rate_P1	Drift_rate_P2	Drift_rate_DR
Coleoptera	0,001	0,002	0,000	0,200	0,541
Diptera	0,093	0,321	0,059	0,200	0,114
Ephemeroptera	0,000	0,001	0,139	0,321	0,743
Gastropoda	0,048	0,368	0,109	0,368	0,368
Oligochaeta	0,383	0,710	0,318	0,209	0,710
Plecoptera	0,093	0,021	0,200	0,888	0,888
Trichoptera	0,046	0,006	0,074	0,200	1

Mann-Whitney-test family_genus level	Drift_rate_tot	Drift_rate_UR	Drift_rate_P1	Drift_rate_P2	Drift_rate_DR
Athripsodes	0,667	0,667	1	0,667	1
Baetis	0,074	0,000	0,236	0,423	0,541
Ceratopogonidae	0,500	1	0,500	0,500	0,500
Chironomidae	0,000	0,004	0,000	0,093	0,008
Elmis	0,004	0,027	0,481	0,321	0,423
Ephemerella	0,000	0,002	0,004	0,370	0,036
Habrophlebia	0,033	0,183	0,517	0,833	0,833
Hydropsyche	0,530	0,639	0,639	0,755	0,755
Leuctra	0,036	0,236	0,139	0,541	0,423
Oligochaeta	0,383	0,710	0,318	0,209	0,710
Polycentropus	0,017	0,267	0,833	0,517	0,833
Protonemura	1	0,667	1	1	1
Riolus	0,000	0,002	0,004	0,277	0,743
Scirtidae	0,114	0,815	0,321	0,321	0,743

13.1.3 Day-Night differences (abundance)

Mann-Whitney-te	Drift_rate_tot	
Treatment	Oligochaeta	0,421
	Baetidae	0,093
	Chironomidae	0,180
	Dytiscidae	0,667
	Elmidae	0,310
	Ephemerellidae	0,589
	Hydropsychidae	1
	Leptophlebiidae	1
	Leuctridae	0,394
	Nemouridae	1
	Planorbidae	0,667
	Polycentropodidae	0,905
	Scirtidae	0,485
Control Oligochaeta		0,071
	Baetidae	0,329
	Chironomidae	0,247
	Elmidae	1
	Ephemerellidae	0,931
	Hydropsychidae	1
	Leptophlebiidae	1
	Leuctridae	0,082
	Lymnaeidae	1
	Nemouridae	0,333
	Polycentropodidae	0,700
	Scirtidae	0,004

Mann-Whitney-test species level		Drift_rate_tot		
Treatment	Baetis	0,009		
	Baetis lutheri	1		
Baetis rhodani		0,015		
	Baetis scambus	0,087		
	Chironomidae	0,180		
	Elmis Iv.	0,329		

	Ephemerella ignita	0,589
	Habrophlebia lauta	1
	Hydropsyche Incog./pell.	1
	Leuctra	0,394
	Oligochaeta	0,421
	Oreodytes lv.	1
	Polycentropus flavomac.	0,905
	Protonemura	1
	Riolus ad.	0,017
	Riolus Iv.	0,792
	Scirtidae Iv.	0,485
Control	Baetis	0,126
	Baetis lutheri	0,500
	Baetis rhodani	0,329
	Baetis scambus	0,533
	Chironomidae	0,247
	Elmis ad.	1
	Elmis Iv.	0,548
	Ephemerella ignita	0,931
	Habrophlebia lauta	1
	Hydropsyche Incog./pell.	1
	Leuctra	0,082
	Oligochaeta	0,071
	Polycentropus flavomac.	0,700
	Radix	1
	Riolus ad.	0,067
	Riolus Iv.	0,662
	Scirtidae Iv.	0,004

13.1.4 Day-Night differences (biomass)

Mann-Whitne	Drift_rate_tot	
Treatment	Coleoptera	0,262
	Diptera	1
	Ephemeroptera	0,381
	Gastropoda	0,250
	Oligochaeta	1
	Plecoptera	0,381
	Trichoptera	0,714
Control	Coleoptera	1
	Diptera	0,250
	Ephemeroptera	0,786
	Gastropoda	1
	Oligochaeta	0,571
	Plecoptera	0,143
	Trichoptera	0,571

Mann-Whitney	/-Test genus_family level	Drift_rate_tot		
Treatment	Baetis	0,262		
	CHIRONOMIDAE	1		
	Elmis	0,381		
	Ephemerella	1		
	Habrophlebia	1		
	Hydropsyche	0,800		
	Leuctra	0,548		
	Oligochaeta	1		
	Oreodytes	0,667		
	Planorbis	1		
	Polycentropus	0,629		
	Riolus	0,381		
	Scirtidae	1		
Control	Baetis	0,786		
	CHIRONOMIDAE	0,143		
	Elmis	0,786		
	Ephemerella	0,071		
	Habrophlebia	1		

Hydropsyche	0,629
Leuctra	0,250
Oligochaeta	0,571
Radix	1
Riolus	1
Scirtidae	0,250

13.2 Ecological parameters

13.2.1 Current Preference

Valid taxon	alid taxon current preference			се				
Genus	Species	lib	lip	Irp	rlp	rhp	rhb	ind
Elmis	sp. Ad.					1		
Elmis	sp. Lv.					1		
Riolus	sp. Ad.							
Riolus	sp. Lv.							
Oreodytes	sp. Ad.					1		
Oreodytes	sp. Lv.					1		
Orectochilus	sp. Lv.							
Scirtidae	Gen. sp. Lv.							
Chironomidae	Gen. sp.							1
Ceratopogonidae	Gen. sp.							1
Baetis	lutheri					1		
Baetis	muticus				1			
Baetis	rhodani					1		
Baetis	scambus					1		
Caenis	horaria		1					
Ephemerella	sp.				1			
Ecdyonurus	sp.					1		
Habrophlebia	lauta			1				
Leuctra	sp.					1		
Protonemura	sp.					1		
Hydropsyche	incogn./pell.					1		
Hydropsyche	siltalai					1		
Hydropsyche	sp.					1		
Rhyacophila	s. str. sp.						1	
Limnephilidae	Gen. sp.							1
Polycentropus	flavomac.			1				
Lepidostoma	hirtum			1				
Athripsodes	sp.							
Oecetis	testacea							1
Leptoceridae	Gen. sp.			1				

lib limnobiont lip limnophil lrp limno to rheophil rlp rheo to limnophil rhp rheophil rhb rheobiont ind indifferent

13.2.2	Feeding	type
--------	---------	------

Valid taxon						fe	edin	g typ	е			
Genus	Species	Classification	gra	min	xyl	shr	gat	aff	pff	pre	par	oth
Elmis	sp. Ad.	Grazer	10									
Elmis	sp. Lv.	Grazer	10									
Riolus	sp. Ad.	Grazer	10									
Riolus	sp. Lv.	Grazer	10									
Oreodytes	sp. Ad.	Predator								10		
Oreodytes	sp. Lv.	Predator								10		
Orectochilus	sp. Lv.	Predator								10		
Scirtidae	Gen. sp. Lv.	Shredder										
Chironomidae	Gen. sp.		2	1			3	2		1	1	
Ceratopogonidae	Gen. sp.	Predator								10		
Baetis	lutheri	Gatherer	5				5					
Baetis	muticus	Gatherer	5				5					
Baetis	rhodani	Gatherer	5				5					
Baetis	scambus	Gatherer	5				5					
Caenis	horaria	Gatherer					10					
Ephemerella	sp.	Grazer	5				5					
Ecdyonurus	sp.	Grazer	5				5					
Habrophlebia	lauta	Gatherer	2				8					
Leuctra	sp.	Shredder	3			3	4					
Protonemura	sp.	Shredder	3			5	2					
Hydropsyche	incogn./pell.	Passive filter feeders	2						5	3		
Hvdropsvche	siltalai	Passive filter feeders	2						5	3		
Hydropsyche	sp.	Passive filter feeders	2						5	3		
Rhvacophila	s. str. sp.	Predators								10		
Limnephilidae	Gen. sp.	Shredders	2			5	1			2		
Polycentropus	flavomac.	Predators					-		1	9		
Lepidostoma	hirtum	Shredders	5		3	2						
Athripsodes	sp.	Shredders				5	3			2		
Oecetis	testacea	Predators								10		
Leptoceridae	Gen. sp.											

grazers and scrapers gra miners min xylophagous taxa xyl shredders shr gatherers/collectors gat aff active filter feeders passive filter feeders pff predators pre

- par parasites
- oth other feeding types

13.2.3	Locomotion	type and	respiration
--------	------------	----------	-------------

Valid taxon				lo	comoti	on type	e	I
Genus	Species	Classification	sws	swd	bub	spw	ses	oth
Elmis	sp. Ad.	Clinger						
Elmis	sp. Lv.	Clinger						
Riolus	sp. Ad.	Clinger						
Riolus	sp. Lv.	Clinger						
Oreodytes	sp. Ad.	Swimming		4		4		2
Oreodytes	sp. Lv.	Swimming		4		4		2
Orectochilus	sp. Lv.	Swimming						
Scirtidae	Gen. sp. Lv.	Clinger						
Chironomidae	Gen. sp.			1		1	4	4
Ceratopogonidae	Gen. sp.	Swimming		7				3
Baetis	lutheri	Swimming						
Baetis	muticus	Swimming			5	5		
Baetis	rhodani	Swimming		6		4		
Baetis	scambus	Swimming		6		4		
Caenis	horaria	Sprawler						10
Ephemerella	sp.	Sprawler		1	1	8		
Ecdyonurus	sp.	Sprawler						
Habrophlebia	lauta	Swimming						
Leuctra	sp.	Burrowing			5	5		
Protonemura	sp.	Sprawler				5		5
Hydropsyche	incogn./pell.	Sessil						
Hydropsyche	siltalai	Sessil						
Hydropsyche	sp.	Sessil		1		4	5	
Rhyacophila	s. str. sp.	Sprawler						
Limnephilidae	Gen. sp.	Sprawler				10		
Polycentropus	flavomac.	Sessil						
Lepidostoma	hirtum	Sprawler						
Athripsodes	sp.	Sprawler						
Oecetis	testacea	Sprawler				5	5	
Leptoceridae	Gen. sp.	Sprawler		5		5		

sws	swimming/scating
swd	swimming/divind
bub	burrowing/boring
spw	sprawling/walking
ses	(semi)sessil
oth	other

13.3 Mann-Whitney tests for long-term experiment

MW-te		
Pool	Diptera	1
	Diptera Pupae	0,400
	Ephemeroptera	1
	Oligochaeta	0,100
	Trichoptera	0,200
Riffle	Diptera	0,700
	Diptera Pupae	0,700
	Ephemeroptera	0,100
	Gastropoda	1
	Oligochaeta	0,100
	Plecoptera	0,100
	Trichoptera	0,100

13.3.1 Treatment-Control differences (abundance)

Mann-Wł	nitney-test species level	
Pool	Chironomidae	1
	Chironomidae pup.	0,400
	Cloeoninae	0,700
	Oligochaeta	0,100
Riffle	Baetis	0,200
	Baetis fuscatus/scambus	0,400
	Baetis muticus	0,200
	Baetis rhodani	0,333
	Chironomidae	0,200
	Chironomidae pup.	0,400
	Cloeoninae	0,200
	Heptageniidae	0,500
	Hydropsyche	1
	Hydropsyche incogn./pell.	0,200
	Hydroptila	0,400
	Oligochaeta	0,100
	Polycentropus	0,200
	Polycentropus flavom.	0,500

Simulium	0,500
Simulium pup.	1

13.3.2 Treatment-Control differences (biomass)

Γ

MW-te		
Pool	Coleoptera	0,200
	Diptera	0,100
	Diptera Pupae	0,100
	Ephemeroptera	0,700
	Gastropoda	0,400
	Oligochaeta	0,700
	Plecoptera	0,500
	Trichoptera	1
Riffle	Coleoptera	1
	Diptera	0,200
	Diptera Pupae	0,700
	Ephemeroptera	0,400
	Gastropoda	0,100
	Oligochaeta	0,400
	Plecoptera	1
	Trichoptera	0,100

Mann-White		
Pool	Baetis	0,667
	Caenis	0,100
	Chironomidae	0,100
	Cloeoninae	0,700
	Hydroptila	0,700
	Nemoura/Nemurella	0,667
	Oligochaeta	0,700
	Planorbidae	1
	Platambus	0,667
	Polycentropus	0,800
	Radix	1
Riffle	Baetis	0,400

Caenis	0,800
Chironomidae	0,200
Cloeoninae	0,400
Ephemerella	0,667
Heptageniidae	0,200
Hydropsyche	0,100
Hydroptila	0,700
Leuctra	0,100
Nemoura/Nemurella	0,700
Oligochaeta	0,400
Perlodidae	1
Phryganea	1
Planorbidae	1
Polycentropus	0,100
Protonemura	0,400
Radix	0,100
Rhyacophila	1
Simulium	0,200

13.3.3 Pool-Riffle differences (abundance)

MW-test order level				
Control	Diptera	0,100		
	Diptera Pupae	0,100		
	Ephemeroptera	0,100		
	Gastropoda	1		
	Oligochaeta	0,100		
	Trichoptera	0,200		
Treatment	Diptera	0,100		
	Diptera Pupae	0,100		
	Ephemeroptera	0,100		
	Oligochaeta	0,100		
	Trichoptera	0,100		

Mann-Whitr		
Control	Chironomidae	0,100

	Chironomidae pup.	0,100
	Cloeoninae	0,400
	Oligochaeta	0,100
Treatment	Chironomidae	0,100
	Chironomidae pup.	0,100
	Cloeoninae	0,700
	Hydroptila	0,100
	Oligochaeta	0,100

13.3.4 Pool-Riffle differences (biomass)

MW-te		
Control	Coleoptera	0,400
	Diptera	0,100
	Diptera Pupae	0,100
	Ephemeroptera	0,400
	Gastropoda	0,700
	Oligochaeta	0,100
	Plecoptera	0,100
	Trichoptera	0,100
Treatment	Coleoptera	0,333
	Diptera	0,100
	Diptera Pupae	0,100
	Ephemeroptera	0,700
	Gastropoda	0,100
	Oligochaeta	0,100
	Plecoptera	0,500
	Trichoptera	0,100

Mann-Whitr		
Control	Baetis	0,500
	Caenis	0,200
	Chironomidae	0,100
	Cloeoninae	0,700
	Heptageniidae	0,200
	Hydropsyche	1

	Hydroptila	0,200
	Leuctra	0,500
	Nemoura/Nemurella	0,200
	Oligochaeta	0,100
	Phryganea	1
	Planorbidae	1
	Platambus	0,667
	Polycentropus	1
	Protonemura	0,500
	Radix	0,700
	Simulium	1
Treatment	Baetis	0,200
	Caenis	0,400
	Chironomidae	0,100
	Cloeoninae	0,400
	Hydroptila	0,400
	Nemoura/Nemurella	0,500
	Oligochaeta	0,100
	Planorbidae	0,800
	Polycentropus	0,100
	Radix	0,200

13.4 Long-term experiment species lists

13.4.1 Abundance

		Pool		Riffle	
Order	Taxon_name	Control	Treatment	Control	Treatment
Coleoptera	Gyrinidae lv.				2
Coleoptera	Haliplus lv.		1		
Coleoptera	Hydroporinae lv.	1			
Coleoptera	Orectochilus lv.				4
Coleoptera	Platambus lv.		2		
Coleoptera	Platambus maculatus lv.	2		2	
Coleoptera	Porhydrus lv.	6			
Total Coleoptera		9	3	2	6
Crustacea	Asellus aquaticus			1	
Total Crustacea				1	
Diptera	Ceratopogonidae				2

Diptera	Chironomidae	332	300	2171	1552
Diptera	Simulium			9	101
Diptera	Tipulidae				4
Total Diptera		332	300	2180	1659
Diptera Pupae	Chironomidae pup.	122	89	488	424
Diptera Pupae	Empididae pup.			1	
Diptera Pupae	Simulium pup.	1		19	54
Total Diptera Pupae		123	89	508	478
Ephemeroptera	Baetidae		1		
Ephemeroptera	Baetis		1	57	227
Ephemeroptera	Baetis alpinus/lutheri				1
Ephemeroptera	Baetis fuscatus			6	
Ephemeroptera	Baetis fuscatus/scambus	2	1	49	32
Ephemeroptera	Baetis lutheri				1
Ephemeroptera	Baetis muticus			43	115
Ephemeroptera	Baetis rhodani			19	31
Ephemeroptera	Baetis scambus			2	
Ephemeroptera	Caenis	3	3	3	8
Ephemeroptera	Caenis juv.		9	1	2
Ephemeroptera	Cloeoninae	179	192	288	123
Ephemeroptera	Ecdyonurus				2
Ephemeroptera	Ephemerella ignita			2	1
Ephemeroptera	Habroleptoides	2			1
Ephemeroptera	Habroleptoides confusa	1			
Ephemeroptera	Heptageniidae	2		14	47
Total Ephemeroptera		189	207	484	591
Gastropoda	Ancylus fluviatilis				1
Gastropoda	Planorbidae	3	2	6	5
Gastropoda	Planorbis	2			1
Gastropoda	Radix	7	3	12	18
Total Gastropoda		12	5	18	25
Odonata	Calopterygidae				1
Total Odonata					1
Oligochaeta	Eiseniella tetraedra	1			2
Oligochaeta	Oligochaeta	603	1423	6628	19129
Total Oligochaeta		604	1423	6628	19131
Plecoptera	Amphinemura				2
Plecoptera	Chloroperlidae	1			
Plecoptera	Leuctra	1		63	4
Plecoptera	Nemoura/Nemurella	5	2	10	12
Plecoptera	Perlodidae			1	1
Plecoptera	Protonemura	1		8	21
Total Plecoptera		8	2	82	40
Trichoptera	Hydropsyche			40	106
Trichoptera	Hydropsyche angustip. ssp.				2

Trichoptera	Hydropsyche incogn./pell.	2		17	92
Trichoptera	Hydroptila	10	28	89	166
Trichoptera	Phryganea	1		3	1
Trichoptera	Plectrocnemia				1
Trichoptera	Polycentropus	2	11	23	61
Trichoptera	Polycentropus flavomaculatus	6	8	10	27
Trichoptera	Rhyacophila s. str.			1	2
Total Trichoptera		21	47	183	458
Total		1298	2076	10086	22389

13.4.2 Biomass

		F	Pool	R	liffle
Order	Taxon_name	Control	Treatment	Control	Treatment
Coleoptera	Gyrinidae lv.				0,0005
Coleoptera	Haliplus lv.		0,0001		
Coleoptera	Hydroporinae lv.	0,002			
Coleoptera	Orectochilus lv.				0,0011
Coleoptera	Platambus lv.		0,0004		
Coleoptera	Platambus maculatus lv.	0,0026		0,0021	
Coleoptera	Porhydrus lv.	0,0154			
Total Coleoptera		0,02	0,0005	0,0021	0,0016
Crustacea	Asellus aquaticus			0,0003	
Total Crustacea				0,0003	
Diptera	Ceratopogonidae				0,0007
Diptera	Chironomidae	0,1071	0,0325	0,7483	0,4575
Diptera	Simulium			0,0143	0,2208
Diptera	Tipulidae				0,4064
Total Diptera		0,1071	0,0325	0,7626	1,0854
Diptera Pupae	Chironomidae pup.	0,0306	0,0118	0,1558	0,1578
Diptera Pupae	Empididae pup.			0,0022	
Diptera Pupae	Simulium pup.	0,003		0,0506	0,1451
Total Diptera Pupae		0,0336	0,0118	0,2086	0,3029
Ephemeroptera	Baetidae		0,00005		
Ephemeroptera	Baetis		0,0005	0,1495	0,182
Ephemeroptera	Baetis fuscatus/scambus	0,0047	0,0011	0,0022	0,0114
Ephemeroptera	Baetis muticus				0,0091
Ephemeroptera	Baetis rhodani				0,0106
Ephemeroptera	Caenis	0,00015	0,00015	0,00055	0,00045
Ephemeroptera	Caenis juv.		0,00135	0,00005	0,0001
Ephemeroptera	Cloeoninae	0,3389	0,2945	0,3624	0,12775
Ephemeroptera	Ecdyonurus				0,0035
Ephemeroptera	Ephemerella ignita			0,0087	0,00005
Ephemeroptera	Habroleptoides	0,0005			0,00005
Ephemeroptera	Heptageniidae	0,0001		0,0021	0,00975

Total Ephemeroptera		0,34435	0,29765	0,5255	0,35475
Gastropoda	Ancylus fluviatilis				0,0079
Gastropoda	Planorbidae	0,00005	0,0071	0,001	0,01165
Gastropoda	Planorbis	0,0224			0,0068
Gastropoda	Radix	0,0693	0,0123	0,0274	0,3676
Total Gastropoda		0,09175	0,0194	0,0284	0,39395
Odonata	Calopterygidae				0,019
Total Odonata					0,019
Oligochaeta	Eiseniella tetraedra	0,0492			0,0637
Oligochaeta	Oligochaeta	0,1765	0,1633	0,8794	1,5807
Total Oligochaeta		0,2257	0,1633	0,8794	1,6444
Plecoptera	Amphinemura				0,00005
Plecoptera	Chloroperlidae	0,00005			
Plecoptera	Leuctra	0,00005		0,00085	0,00015
Plecoptera	Nemoura/Nemurella	0,0002	0,00005	0,00065	0,0014
Plecoptera	Perlodidae			0,00005	0,00005
Plecoptera	Protonemura	0,00005		0,0004	0,00125
Total Plecoptera		0,00035	0,00005	0,00195	0,0029
Trichoptera	Hydropsyche			0,28915	0,4687
Trichoptera	Hydropsyche incogn./pell.	0,0131			0,9223
Trichoptera	Hydroptila	0,00255	0,00255	0,0099	0,01095
Trichoptera	Phryganea	0,00005		0,01995	0,0088
Trichoptera	Plectrocnemia				0,002
Trichoptera	Polycentropus	0,0055	0,00925	0,0226	0,1041
Trichoptera	Polycentropus flavom.	0,0151	0,0073		0,0017
Trichoptera	Rhyacophila s. str.			0,0027	0,004
Total Trichoptera		0,0363	0,0191	0,3443	1,52255
Total		0,85915	0,5443	2,75315	5,32745