IV.3

HYDROPEAKING IMPACT ON A RIPARIAN GROUND BEETLE COMMUNITY

Kris Van Looy, Hans Jochems, Stijn Vanacker & Els Lommelen

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Abstract

The Common Meuse reach is strongly influenced by the operation of a hydropower plant at the upstream weir of Lixhe, especially during periods of low flow. Ecologically-based in-stream flow requirements and fluctuation thresholds have already been determined for this reach by reconstruction of the natural discharge course from historic and actual reference conditions. Nevertheless, more evidence from the present biota at risk has been demanded. This study therefore attempts to define boundary conditions for the low flow regime from the analysis of riparian ground beetles in this river reach. To achieve this, reference conditions for the hydroregime aspects of flow variation were determined. Then, using the habitat templet approach, the hydropeaking pressure was related to biological quality elements. Finally, after detecting the impact on the specific gravel bar ground beetles, thresholds and boundary conditions were determined for the hydropeaking pressure in peak velocity.

Introduction

River restoration projects generally aim to mitigate the effects of regulation works by rehabilitating geomorphological diversity, and promoting the recovery of degraded biota and the floodplain benefits from the river (Tockner & Schiemer, 1997). Problems can arise, however, when solutions are proposed without taking into account flow regime-related constraints (Kershner, 1997; Boulton et al., 2000; Gore et al., 2001). Economically as well as ecologically, low flows are a crucial element in the management of larger rivers of the temperate regions. Ecological criteria for low flow regime conditions are mostly addressed for in-stream flow requirements, in relation to deterioration of water quality and available habitat for lotic species (Gore et al., 2001). Impacts of hydropeaking were described mainly for aquatic species and communities (Scruton et al., 1997; Saltveit et al., 2001), yet no quantified rules have resulted from these studies. Constraints were also restricted to rapid flow decreases, as the emphasis was on stranding of fish and macroinvertebrates. Terrestrial riparian communities can be at risk as well, threatened by the rapid rise of water level. The responses of the riparian ground beetle community to hydropeaking pressures were therefore tested for the Common Meuse, where a reach-scale restoration programme is in development. This river restoration

project implies measures of bed widening, bank lowering and flood channel restoration over a river stretch of 50 km (Pedroli et al., 2002).

Ecologically-based in-stream flow requirements and fluctuation thresholds have already been determined for this reach by reconstruction of the natural discharge course from historic and actual reference conditions (Salverda et al., 1998). Nevertheless, more evidence from the present biota at risk has been demanded. As riparian ground beetles have proven good indicators for riverbank habitat integrity and especially for flow regime conditions (Van Looy et al., 2005), we tried to define boundary conditions for the low flow regime.

The approach used follows general recommendations in defining boundary conditions for hydromorphological aspects in river restoration, as formulated in the guidance documents for the European Water Framework Directive (Wallin et al., 2003). Firstly, derivation of reference conditions for the hydroregime aspects of flow variation corresponding to no, or only minor anthropogenic alterations was made. Next, using the habitat templet approach (see Townsend et al., 1997; Van Looy et al., 2005), the hydropeaking pressure was related to biological quality elements. And finally, after detecting the impact, the responses of the specific ground beetle gravel bar templet were screened for thresholds that might reveal boundary conditions for this hydropeaking pressure.

Studied river stretch

The river Meuse has been highly regulated over the last 150 years, heavily influencing the flow regime, bed form and riverbank habitat conditions (Micha & Borlée, 1989). Hydroregime aspects of importance to the biotic system can be determined in baseflow conditions (Growns & Growns, 2001) and variability (Richter et al., 1996; Poff et al., 1997), as was documented for the Meuse by Van Looy et al. (2005). At the gauging stations of Stenay, Lorraine Meuse (France, see Figure 4.13) and Borgharen-Smeermaas, Common Meuse (Belgium), the Coefficient of flow Variation (CV) values over the last 10–100 years have been analysed by Jochems & Van Looy (2001). CV value ranges over 10 year summer periods for historical (1911–1920) and present day (1989–1998) data were calculated. The resulting values and their corresponding standard deviations are presented for Borgharen and

Stenay in Figure 4.14. The 1911–1919 CV values, representing Meuse discharges before large-scale flow regulation took place, are close to the Stenay values. The present day Borgharen CV values show a significant alteration in flow regime.

Figure 4.13 Map of the Meuse basin with inset for the reach level sampling stations and the position of the weirs of Lixhe and Borgharen.
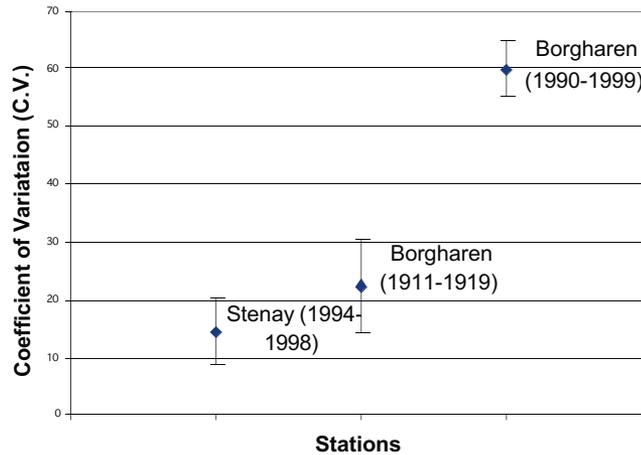
Figure 4.14 Comparison between summer mean Coefficient of flow Variation (CV) values (with SD) for upstream gauging station (Stenay), and Common Meuse present and historic situation (Borgharen present: 1990-1999 and historic:1911-1919).
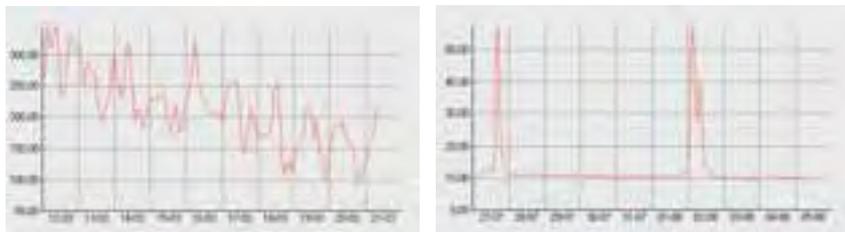

Figure 4.15 Hydropeaks (discharges in m³/s) of the Common Meuse in spring (a) and summer (low flow)(b) at the gauging station of Smeermaas a few kilometres downstream the weir.

Summer discharge fluctuations are influenced significantly by weir management and water abstraction to canals and by the operation of a hydroelectric power plant at Lixhe, which, when functioning, is particularly influential on the hydroregime during low flow conditions (Figure 4.15). Due to water abstractions and weir management, the low flow conditions are extreme in terms of baseflow and duration, and under these conditions the plant releases of 80m?/s enter the Common Meuse as peak flows, with the water level rising more than one metre per hour.

The peak velocity – the increase in discharge within an hour, expressed as a percentage of the discharge at that moment – is very high at close proximity to the

power station (41 at Smeermaas, the upstream gauging station for the Common Meuse reach), and reduces gradually over the 50 km reach to a value of 16 at Maaseik (the most downstream sampling station along the Common Meuse). The 80m³/s peaks flatten over the reach to increases of 20m^3/s.

Materials and methods

Sampling

In the summer of 1999 sampling was carried out on two gravel bank sites of the Common Meuse reach, 30 km apart (Maasmechelen and Elerweerd, see Figure 4.13). Thirty pitfalls were installed on each bar (six transects perpendicular to the river, with one pitfall in the steep bank zone and three on the gravel bar, making a grid over the site), and samples were taken daily for three weeks (30/6–8/7, 15–23/7 and 20–28/8). This fine-filtering sampling approach was executed in addition to the Meuse riverbanks sampling at catchment and reach level (See Van Looy et al., 2005).
The sampling at catchment scale was executed in 2000 using 14 stations spread along the middle to lower course of the river Meuse. The reach scale sampling of the Common Meuse was carried out for two consecutive years 1998 and 1999 on 17 gravel bank stations. Each station consisted of two plots; one higher on the riverbank and one close to the waterline, giving 34 plots in total. Ground beetles were sampled using pitfall traps (filled with 5% formaldehyde preservative), three traps in a row at 1m intervals forming a plot. Samples from the three traps were pooled and species identified in the laboratory. The traps were sampled every two weeks for the period May to October in both years.

Habitat templet approach at reach scale

Habitat templets of the River Meuse riparian ground beetles were derived from the catchment scale sampling, with a clustering and ordination of species, species traits and site conditions (Van Looy et al., 2005). Eight groups of ground beetle species were attributed to specific riparian habitats.
For this hydropeaking analysis we selected the habitat templet of the pioneer

gravel bars, the group of ground beetles living closest to the waterline. Significantly associated species traits in this templet are: wing development, dorsal flattening, small size and late season activity (Jochems & Van Looy, 2001). These predominant resilience/resistance traits have been documented in the literature for riparian habitat-dwelling Carabid species (Den Boer et al., 1979; Desender, 1989; Stork, 1990; Desender et al., 1994). The body size and phenology traits conform to those indicated for in-stream macroinvertebrates by Townsend & Hilldrew (1994). From the reach scale sampling and with input from the detailed site sampling, the habitat templet of the pioneer gravel bar has been refined in terms of species composition and species traits for use at reach scale. The resulting habitat templet description will be useful in the interpretation of the correspondence analysis, indicator choice and species response functions.

Once the expected species present within a habitat have been determined, the conditions that are favourable to the presence of these species can then be examined. So, detecting the direct impact of hydropeaking on this habitat templet species group is achieved by a diversity analysis over the reach (from highly impacted to non-impacted at the downstream end).

Analysis

Once an impact has been identified, the relationship between the pressure and the biotic indicator must then be analysed. For this purpose, we performed a correspondence analysis for the catchment data, followed by logistic regression for identified key predictor variables to screen for boundary conditions in the reach scale data.

A filtering of hydrological indices (see Van Looy et al., 2005) was performed for the hydropeaking effects on the habitat templet at risk, the pioneer gravel bar. Water rising speed and peak velocity were retained as hydrological indices for the correspondence analysis, and further environmental variables included were habitat heterogeneity and width-depth ratio of the sampling sites.

The catchment scale data taken from the pioneer gravel bar habitat templet (12 species) for 16 sample plots (with abundance > 80) were entered in a correspondence analysis. Based on the lower gradient length in the DCA, a redundancy analysis (RDA), carried out using CANOCO 4.0 (Ter Braak, 1988), was performed

to highlight interrelations between the environmental factors and species and to show the relevant environmental variables for this group.

The reach scale data taken from the pioneer gravel bar habitat templet for 62 sample plots (with abundance > 50) were entered in a correspondence analysis (Canonical Correspondence Analysis), followed by a multiple regression for the detected relevant variables. For the selected variables an ANOVA and multiple regression using STATISTICA (Statsoft Inc., 2001) showed the response of species diversity to these variables.

Results

The sampling of the two gravel bars yielded 6507 ground beetles from 71 species. In the day to day sampling, the ecological rationale beneath the habitat templets was revealed (Figure 4.16). With the waterline feeding strategy for the species group of the pioneer gravel bars being to forage on collembola and stranded organisms, the flow-related habitat condition of this community was highlighted, as already indicated by several authors (Hering & Plachter, 1997; Hering, 1998; Sadler et al., 2004). As these organisms are feeding immediately at the waterline, they are obviously sensitive to rapid rises of water level. The resilience traits pre-dominating the templet of these highly disturbed sites (Townsend & Hilldrew, 1994) are key to their response to such a disturbance regime. Their ability to fly and swim allows them to endure a certain degree and frequency of habitat disturbance. This group of species and their predominant traits was defined for the pioneer gravel bar habitat templet of the Common Meuse and is shown in Table 4.9.
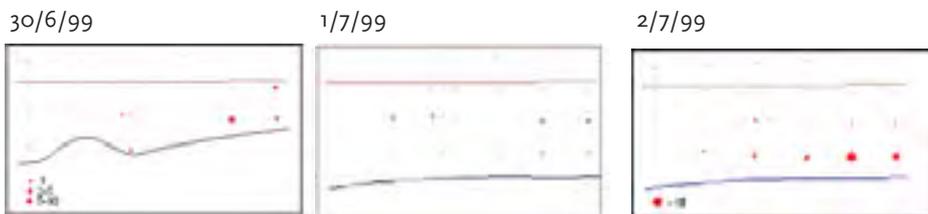
30/6/99　　　　　　　　1/7/99　　　　　　　　2/7/99

Figure 4.16 Indicator species of the pioneer gravel bar (Bembidion punctulatum) in the detailed riverbank survey. The blue lines represent the daily (mean) waterline, the size of the red dots indicates the individuals of the species sampled. The ground beetles were documented to follow the waterline in the day to day sampling after a small flow increment on 30/6.

Table 4.9 Habitat and life traits of the pioneer gravel bar habitat templet species of the Common Meuse.

Species	Vegetation	Substrate	Phenology	Dispersion	Ecological group
Amara aenea	Scarce vegetation	No preference	Late Spring	High, macropteric	Stenotope, xerofilic
Anisodactylus binotatus	High vegetation of grasses, sedges	Open, wet clay and sand	Spring macropteric	High, stenotope, hygrofilic	Modestly
Bembidion decorum	Unvegetated riverbanks	Gravel, sand	Late Spring	High, macropteric	Stenotope, hygrofilic
Bembidion punctulatum	Unvegetated riverbanks	Gravel	Late Spring	High, macropteric	Stenotope, hygrofilic
Bembidion atrocoeruleum	Unvegetated riverbanks	Gravel	Late Spring	High, macropteric	Stenotope, hygrofilic
Bembidion testaceum	Unvegetated riverbanks	Dry gravel, sand	Spring	Low, brachypteric	Modestly stenotope, xerofilic
Bembidion lampros	Open terrain	No preference	Spring	High, wing-dimorphism	Very eurytope
Harpalus affinis	Open vegetation	Gravel, sand, loam	Spring and autumn	High, macropteric	Modestly stenotope, xerofilic
Panagaeus bipustulatus	Open medium-wet grassland	Dry gravel, sand	Spring	High, macropteric	Modestly stenotope, xerofilic
Perileptus areolatus	Unvegetated riverbanks	Gravel or coarse sand	Late Spring	High, macropteric	Stenotope, hygrofilic
Thalassophilus longicornis	No preference	Very wet gravel and coarse sand	Spring macropteric	High, hygrofilic	Stenotope,
Trechus quadristriatum	Mosaic vegetation	No preference	Autumn	High, macropteric	Stenotope, hygrofilic

Over 16 000 carabid beetles were examined and identified from the reach level sampling carried out in 1998 and 1999. The catchment sampling yielded 4892 ground beetles extracted from the pitfalls and were determined to species level. Redundancy analysis for the environmental variables and the pioneer gravel bar community (12 species) at catchment scale showed peak velocity to be the environmental variable with the highest biplot score (Figure 4.17), as did the CCA at reach level (see Van Looy et al., 2005). Figure 4.17 shows a group responding to the water rising speed and peak velocity: Harpalus affinis, Bembidion testaceum, B. decorum, B. punctulatum and Panagaeus bipustulatus. Their predominating traits are small body size and no or minimum developed wings, making them vulnerable to the rapid flow increases. Still, they are quick colonizers of the open riparian

habitat, so their presence on the gravel bars is unaffected by the habitat aspects of surface and higher refuge. A second group of species – responding to the first axis, with Bembidion lampros and Amara aenea – is related to habitat heterogeneity and width–depth ratio, and shows a less strict habitat preference and are not strict xerophilic species. This group selects the well-established larger gravel bars, offering enough refuge for peak flows.

The impact of hydropeaking on the species group of pioneer gravel bars is indicated by the increasing average richness along the reach (Figure 4.18). Peak velocity is the environmental variable best representing the hydropeaking effect, showing a similar linear trend over the reach – albeit opposite to the species richness.
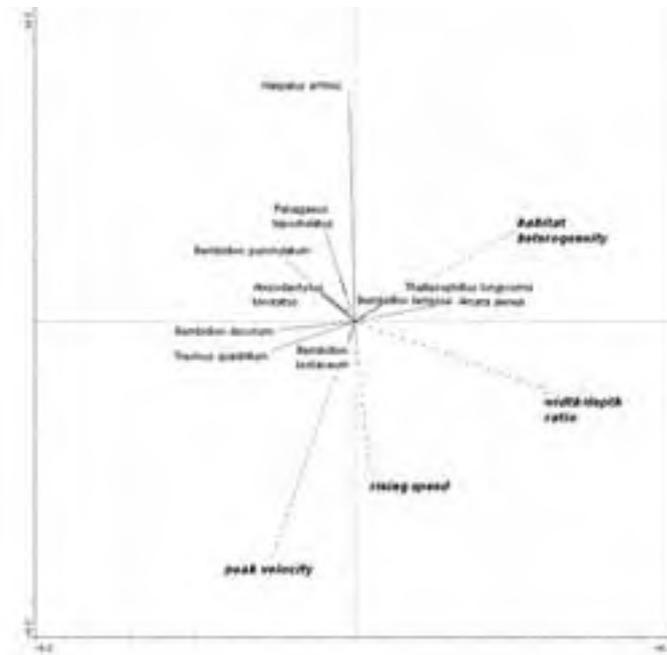

Figure 4.17 Redundancy Analysis biplot of the sampled pioneer gravel bar habitat templet and the environmental variables.
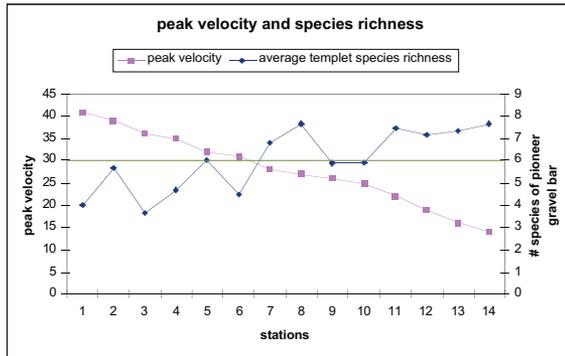
Figure 4.18 Average species richness for the pioneer gravel bar templet over the plots of the Common Meuse stations (green line indicates optimising peak velocity value).

ANOVA revealed a significant relationship between species diversity in the pioneer gravel bar habitat templet and peak velocity over the Common Meuse sampling plots (F:315.12, p< 0.0001) (Figure 4.19). With multiple regression, a significant regression function was derived for the species diversity (beta=-0.56, F:29.9, p< 0.0001).
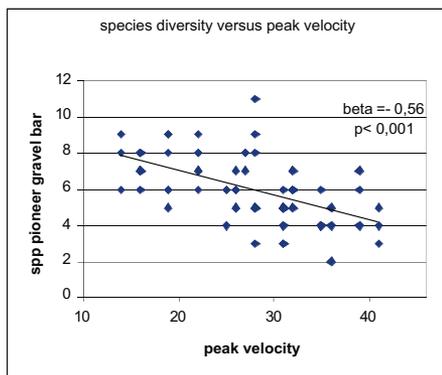

Figure 4.19 Species diversity of the pioneer gravel bar templet group(14spp) for the Common Meuse plots, related to peak velocity with the regression function.

The linear regression for species diversity shows the optimum conditions for carabid communities of the dynamic habitats in the zones where the human-induced discharge fluctuations are dampened; a point also illustrated by the average plot species richness in Figure 4.18. The responses of indicator species to peak velocity

using logistic regression (Harpalus affinis and Bembidion decorum, respectively chi^2= 25.9, p<0.001 and chi^2= 22.1, p<0.001) confirmed significantly the threshold value of peak velocity as 30 (Figure 4.20).

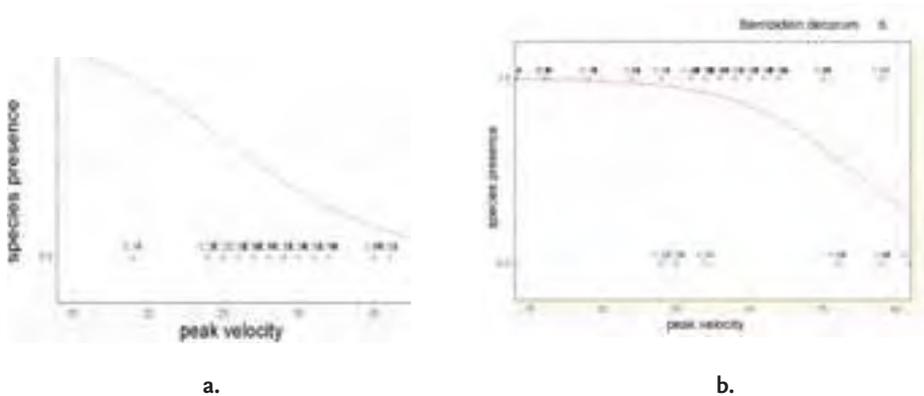a.   b.

Figure 4.20 Logistic regression results of the indicator species for the peak velocity, Harpalus affinis (fig a), and Bembidion decorum (fig b) showing the threshold peak velocity value of 30 (30% discharge increase per hour) as the bending point in the logit presence-absence regression function.

Discussion

Research into low flow regime conditions is an expanding field in light of integrated water management and sustainable water use being confronted with water shortages and strong regulation impacts.
In-stream flow evaluations are mostly based on single-species approaches, or combinations of target (mainly fish) species' habitat availability (IFIM, PHAB-SIM, Bovee, 1985; Stalnaker et al., 1995). Gore et al. (2001) reviewed macroinvertebrate in-stream flow habitat requirements, useful in stream management and restoration. They concluded that including benthic macroinvertebrate diversity in fish-based evaluations showed significant differences, especially for minimum flow requirements. Growns & Growns (2001) demonstrated the impact of flow regulation on aquatic macroinvertebrate and periphytic diatom communities. Their results showed significant effects of hydropeaking and indicated different responses for different habitats studied in the impacted rivers.

Ward & Stanford (1979) illustrated potential effects of different kinds of flow regime modifications on zoobenthos, with emphasis on the factors controlling available habitat and drift. They stressed hydromorphological effects of flow modifications on availability of food and substrate for this aquatic community. These effects on current velocity, depth fluctuations and turbidity correspond to those indicated for other groups; the bed and bank instability are specific to this group. This impact of flow regulation on bed and bank structure was also documented for in-stream habitat conditions (Walker et al., 1979), as well as for riparian vegetation (Kauffman et al., 1997; Sparks et al., 1998; Friedman & Auble, 1999). But this latter effect results more from general flow regime alterations such as duration and level of low flows, and less from hydropeaking.

Hydropeaking studies are mainly focussed on the falling limb of the peak hydrograph (rapid flow decreases caused by hydropeaking), with effects of changes in current speed or dessication, causing drift or stranding of organisms (Cushman, 1985; Valentin et al., 1994; Saltveit et al., 2001).
Our study is novel in this respect because it emphasizes the biotic responses and impact of hydropeaking on the peak's rising limb. We identified this response in a significant relationship between the habitat templet group species richness and peak velocity.

The habitat templet theory has been applied for hypothesis testing of species responses to disturbance (Townsend & Hilldrew, 1994; Townsend et al., 1997). Here, we explore the use of the habitat templet approach to derive boundaries for specific hydroregime conditions, and the research outline gave strong confidence to the detected responses. As we started from a multiscale, over-year observation of communities and species, the habitat templet approach in combining species traits to grouping and deriving relationships to the physical environment, proved useful for our purposes. The observed spatial and temporal patterns in species distribution over the riparian zone, detected in the local detailed study, were useful to interpret the overall observed species assemblages and trends. Indicative power for the correlation results lie in the sampled abundance of the indicator species (Bembidion decorum n= 1968 and Harpalus affinis n= 201) and the fact that this is their preferred habitat and they have well established populations over this river reach.

As we detected a significant impact and pressure response, we were able to identify boundary conditions, thanks to the gradual dampening of the pressure over the river reach and the multiscale approach of our investigation. The presence of unimpaired sites – in the upstream reach as well as in the most downstream sampling stations for the Common Meuse reach – and the screening for a range of environmental variables over the locations, allowed the identification of peak velocity as a critical factor, plus the detection of a threshold value because the whole pressure gradient was sampled over the Common Meuse reach. This threshold value can be proposed as a boundary condition for large gravel-bed rivers with hydropeaking problems. For smaller highland rivers, thresholds for the communities of that river type might be higher, whereas in lowland rivers, lower boundary conditions can be expected.

Our analysis adds strongly to the method of natural flow reconstruction (Poff et al., 1997; Salverda et al., 1998), as it gives a tangible measure for critical boundaries and the pressure–impact relationship. Our results gave a comparable measure for the critical peak velocity as obtained with the flow reconstruction method (Salverda et al., 1998).
Possible sustainable Common Meuse recolonisation of species of this habitat present in the upstream part of the catchment (e.g. Thalassophilus longicornis, Perileptus areolatus, Bembidion elongatum) will depend on the habitat quality (influenced by hydropeaking pressure) and the great distances. Argument for protection of riparian ground beetle fauna on a larger spatial scale, in view of the evidence of habitat fragmentation and dispersal limitations, has already been provided by Andersen & Hanssen (2005).

Conclusion

At the weir of Borgharen, measures were taken to dampen the strong fluctuations caused by the turbine releases of Lixhe, and so for the optimisation of the sluices and weir management criteria for an acceptable fluctuation, further research was needed. From our analysis, boundary setting was possible for this specific hydromorphological pressure. The results indicate that fluctuations of the Common Meuse low flow regime should be dampened by ? to reach an acceptable peak velocity value of 30. Amelioration of the situation can also be aided by the proposed restoration measures. Widening of the riverbed is a very successful measure in dampening discharge fluctuations. Hydropeaks of 80 m^3/s entering the Common Meuse can be topped by the enlargement of the river bed. The bed enlargement of the first restoration site of the reach can be designed in such dimensions that it dampens the hydropeaking impact to an acceptable peak velocity. In conclusion, we can state that this habitat templet analysis revealed tangible measures for the hydraulic management and the rehabilitation project.