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Comparing and evaluating the dragonfly fauna (Odonata) of regulated and rehabilitated stretches of the fourth order metarhithron Gurtenbach (Upper Austria)

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Mitigation measures carried out at the regulated metarhithron Gurtenbach in Upper Austria were evaluated by a survey of the dragonfly fauna. The assessment method developed in this study was based on the longitudinal distribution of dragonflies along riverine biocoenotic regions (the "Rhithron-Potamon-Concept" explains changes in species composition along a river's length). Numerically expressed habitat preferences led to the definition of a set of six reference species. According to the requirements of the EU Water Framework Directive the current situation of the odonate species was compared with this inventory of river type-specific reference species and assessed in a five-tiered classification system of the "ecologic status". At the regulated stretch the record of five species (including one reference species) was classified as class IV ("poor ecological status"). At the three rehabilitated stretches a total of 23 species were found. Two stretches were classified as showing "good ecological status" (class II), due to the occurrence of two autochthonous reference species (*Calopteryx virgo*, *Onychogomphus forcipatus*). The sensitive method applied not only allowed the evaluation of the differences between regulated and rehabilitated stretches but also the assessment of potamalisation effects within the rehabilitated section due to river bed widening and backwater influences.

Keywords: rehabilitation; reference species; rhithron; assessment; river type; Water Framework Directive; ecological status

Introduction

As confirmed by numerous studies in the last decades, dragonflies are suitable organisms for the typological description and assessment of aquatic systems. Thus, dragonfly-based methods have been used more and more in different fields of applied limnology, water management and nature conservation: as far as running waters are concerned, see for example: Bried & Samways (2015), Buczyński, Szlauer-Łukaszewska, Tończyk, & Buczyńska (2017), Chovanec, Waringer, Raab, & Laister (2004), Golfieri, Hardersen, Maiolini, & Surian (2016), Miguel, Calvão, Vital, & Juen (2017), Monteiro Júnior, Juen, & Hamada (2015), Oertli (2008), Rehfeldt (1986), Silva, De Marco, & Resende (2010), Simaika & Samways (2012) and Waringer (1989).

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In Europe, the rehabilitation of regulated and/or impounded river sections represents one of the major challenges for present and future water management (e.g. International Commission for the Protection of the Danube River, 2015; Tockner et al., 2009). In Austria, for example, about 60% of the running waters with a catchment area > 10 km^2 have failed to reach the target “good ecological status”, which is stipulated in the EU Water Framework Directive (WFD; European Community, 2000). The reasons are manifold, including deficits in river morphology, longitudinal and lateral connectivity as well as hydrology due to flood control, energy production and agricultural hydraulic engineering (Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, 2017). Therefore, dragonfly surveys are used to an increasing degree for assessing the ecological integrity of Austrian running waters and for evaluating the effect of rehabilitation measures. Until now, the major focus of these projects was directed towards lowland rivers; thus, the methodology applied, which is in line with the requirements of the WFD, is based on a comparison of the status quo of the dragonfly fauna with a river-type-specific association pattern (Chovanec, Schindler, Waringer, & Wimmer, 2015; Chovanec & Waringer, 2015). The degree of deviation is expressed by means of an index-based five tier assessment scheme of the ecological status. One of the major reasons given for using an association-based approach is the high number of dragonfly species occurring at these potamon river types and the advantages of analysing ecological guilds (Corbet, 1993; Donath, 1987; Luke et al., 2017; Schmidt, 1971).

In contrast, the project presented in this paper deals with rehabilitation measures carried out at the lower course and mouth of a metarhithron stream: the Gurtenbach in western Upper Austria, a small river belonging to the bioregion Bavarian-Austrian Foothills of the Alps. Both the location of the hydraulic engineering works and the investigation design made it possible to compare the species inventory of the regulated stretch with the inventories of rehabilitated stretches. Because of their different hydrological and morphological features a detailed comparison of the rehabilitated stretches was also performed. Due to the significantly smaller dragonfly species spectrum occurring in rhithron river sections (Castella, 1987; Kuhn & Burbach, 1998; Sternberg et al., 1999), the assessment of the ecological status is based on reference species rather than on associations. According to the assessment philosophy of the WFD, the comparison of the current situation with the river type-specific reference species provided the basis for the evaluation approach.

The methodology applied in the present study is based on stream zonation patterns of a river according to the longitudinal distribution of riverine organisms along biocoenotic regions. This is in essence a phenomenon of spatial succession, driven by both physiographic and biological inputs along the longitudinal gradient of a river. In Europe, this fact has led to a subdivision of rivers into typical fish regions (Thienemann, 1925). This concept was expanded into the rhithron–potamon concept by including benthic organisms and abiotic characteristics as well (Illies, 1961; Illies & Botosaneanu, 1963); Moog (1992) included the littoral and profundal areas into this system. The current (with the associated substrate size fractions) and water temperature may prove to be the most useful abiotic indicators for distinguishing the longitudinal river zones (Huet, 1949; Moog & Chovanec, 2000).

By strictly considering autecological data in terms of species traits, the classification of aquatic organisms according to the concept of biocoenotic regions represents one of the relevant data sources for investigations and assessment procedures according to the WFD. Macroinvertebrates including larval odonates represent one of the four quality elements listed in the WFD within the routine monitoring. This study carried out at the Gurtenbach is the first investigation, in which the concept of biocoenotic regions is applied for imaginal dragonflies alone, which allows the benefit of a reliable and sound ecological concept and the advantages of dragonflies as bioindicators (e.g. Chovanec & Waringer, 2001; Samways, 2008).

Methods

Study area

The Gurtenbach is located in the Innviertler- und Hausruckviertler Hügelland, which is part of the bioregion Bavarian-Austrian Foothills of the Alps (Fink, Moog, & Wimmer, 2000; Moog, Schmidt-Kloiber, Ofenböck, & Gerritsen, 2004). This bioregion belongs to the Illies ecoregion Central Highlands (1978) and – in an administrative context – to the province of Upper Austria. The stream originates at 480 m above sea level and flows for 23 km. The Gurtenbach's mouth into the River Inn is at 315 m above sea level (48.33375°N, 13.34600°E). Here the stream flows into the section of the River Inn impounded by the hydroelectric power station Schärding. At its lower section and mouth the Gurtenbach is a fourth order stream draining a catchment area of 101.3 km^2 (Berg & Gumpinger, 2009; Kapfer, Schay, & Heinisch, 2012; Wimmer & Moog, 1994). In a pristine situation this wandering, partly meandering river type is morphologically characterised by a sequence of steep and flat embankments, the substrate is dominated by micro- (> 2 cm up to 6 cm) and meso-lithal (> 6 cm up to 20 cm), in areas of reduced flow velocity sand and/or mud are deposited (Wimmer & Wintersberger, 2009; Wimmer, Wintersberger, & Parthl, 2007).

Up to 2009 the lowermost 1.2 km of the river were regulated by a straightened concrete bed. In 2009, the lowermost section (400 m) of the Gurtenbach, including its mouth into the River Inn, was rehabilitated. Four 100 m stretches were selected for dragonfly surveys: G1 – regulated, straightened and concreted stretch, with a width of about 5 m, flow velocity up to 30 cm s^{-1}; some grasses in gaps in the concrete formwork; river bed covered with algae; only occasional sediment deposits (Figure 1). G2 – directly following G1; widened stretch (width: 12–15 m) with river type-specific substrate; flow velocity: few cm s^{-1} up to 50 cm s^{-1}; substrate dominated by micro-lithal and stones; bank protection by rip rap at the undercut bank; helophytes and a gravel bank in the slip-off-slope, riparian trees and helophytes at the undercut bank (Figure 2). G3 – directly following G2, stretch with high morphodynamics; wandering, river type-specific course, steep embankments with riparian trees and gravel banks with pioneer vegetation; heterogeneous flow velocities (few cm s^{-1} up to 50 cm s^{-1}) and substrate conditions (sand, gravel, cobbles); river width: 5–10 m (Figure 3). G4 – directly following G3; hydrologically influenced by the backflow from the impounded River Inn; significantly reduced flow velocity (standing water conditions up to few cm s^{-1}); width: about 20 m; substrate dominated by finer grain-sizes such as sand and mud; vegetation dominated by riparian trees (Figure 4).

Field methods

Adult and freshly hatched individuals were counted at the four 100 m river stretches. In order to cover all phenological groups, five field trips were performed in 2017: 28 May, 11 June, 6 July, 8 August and 26 August. For the purpose of a practice-oriented approach, larvae and exuviae were not sampled. Individuals were identified by sight and by photographs. When necessary, specimens were caught with a handnet and released after identification. The numbers of individuals recorded during the field investigations were transferred into a five-class abundance system. To allocate numbers of individuals to abundance classes, dragonfly family-specific habitat requirements (e.g. due to territorial behaviour patterns) were taken into account (Table 1). The abundance class was determined by the largest number of individuals per species recorded during the field trips.

The assessment approach is based on records of river type-specific species with certainly, probably or possibly autochthonous populations. The estimation of autochthony is based on

Figure 1. Stretch G1 in the regulated section of the Gurtenbach (28 May 2017; Photo A. Chovanec).

Figure 2. Stretch G2 in the rehabilitated section of the Gurtenbach (11 June 2017; Photo A. Chovanec).

Figure 3. Stretch G3 in the rehabilitated section of the Gurtenbach (6 July 2017; Photo A. Chovanec).

Figure 4. Stretch G4 in the rehabilitated section of the Gurtenbach (28 May 2017; Photo A. Chovanec).

Table 1. Allocation of numbers of specimens/100 m to abundance classes (Chovanec et al., 2015).

	Single	Rare	Frequent	Abundant	Extremely abundant
Zygoptera without Calopterygidae	1	2–10	11–25	26–50	> 50
Calopterygidae and Libellulidae	1	2–5	6–10	11–25	> 25
Anisoptera without Libellulidae	1	2	3–5	6–10	> 11

the scheme of Chovanec &Waringer (2001). The differentiation into certain, probable or possible autochthony provides the basis for a more sensitive interpretation of the results (see also Bried, Dillon, Hager, Patten, & Luttbeg, 2015; Chovanec & Waringer, 2015; Patten, Bried, & Smith-Patten, 2015). The following criteria were considered to determine whether a species was certainly, probably or possibly autochthonous at a river stretch. Records of:

- newly hatched specimens (certain autochthony) and/or
- reproductive behaviour, such as copula, tandem or egg deposition (probable autochthony) and/or
- imagines in abundance class 3, 4 or 5 (probable autochthony) and/or
- imagines (irrespective of the abundance class) over a longer period of time (at least at two surveys; possible autochthony).

The following criteria were to be considered in order to determine whether a species is certainly, probably or possibly autochthonous at the whole river section with several stretches investigated:

- (certain, probable or possible) autochthony in at least one stretch according to the criteria above (the highest degree of autochthony at one stretch is responsible for the section's degree) and/or
- records of imagines (irrespective of the abundance class) at two or more stretches of the section (possible autochthony).

Assessment

In the WFD, an overall assessment of rivers is laid down, with particular reference to the term "ecological status". Apart from pollution aspects, the assessment has to include an evaluation of deficits in river connectivity, morphology and hydrology. Five classes of ecological status are defined: high, good, moderate, poor and bad. The "good ecological status", the target situation, is defined as a slight deviation from the river type-specific reference status (i.e. "high ecological status"). The WFD environmental objective prohibits deterioration from "high" to "good". The assessment methodology therefore requires a typological classification of rivers according to relevant abiotic characteristics, as well as a description of river type-specific reference conditions for biological quality elements, which, as mentioned above, also include benthic invertebrates (Chovanec et al., 2015).

In Austria, the definition of 15 bioregions based on the ecoregions according to Illies (1978) as well as abiotic and biotic characterisations (Moog et al., 2004; Wimmer, Chovanec, Moog, Fink, & Gruber, 2000) is the key spatial element of river typology and, thus, for the implementation of the WFD. Within the bioregions, a more detailed classification of rivers based on biocoenotic regions, the size of the catchment area and on the altitude is used. For each river type, hydromorphological reference conditions (Wimmer et al., 2007) are defined.

In the dragonfly based approach of the present paper, assessment is based on the presence or absence of river type-specific reference species. These are defined as species naturally occurring

Table 2. Odonate species of Austria (in alphabetical order) with at least one valency point for the metarhithron zone (grey); the six reference species for metarhithron rivers of the Bavarian-Austrian Foothills of the Alps are underlined, those species which probably do not occur at this river type are in parentheses.

	EUC	HYC	ER	MR	HR	EP	MP	HP	Lit
Calopteryx virgo				2	6	2			
(*Coenagrion mercuriale*)	1	1	2	2	2	2			
(*Coenagrion ornatum*)		1		2	3	4			
(*Cordulegaster bidentata*)	2	3	3	2					
Cordulegaster boltonii	1	2	3	2	2				
(*Cordulegaster heros*)		1	3	3	3				
Onychogomphus forcipatus				2	3	3		1	1
Ophiogomphus cecilia				1	2	5	2		
Orthetrum brunneum	1	1		1	1	1	1	1	3
(*Orthetrum coerulescens*)	2	1	1	1	1	1		1	2
Pyrrhosoma nymphula		1		1	1	1	1	1	4
(*Somatochlora meridionalis*)		1		1	2	3	2		1

Abbreviations: EUC, eucrenon; HYC, hypocrenon; ER, epirhithron; MR, metarhithron; HR, hyporhithron; EP, epipotamon; MP, metapotamon; HP, hypopotamon; LIT, littoral; PRO, profundal.

at pristine metarhithron rivers of the Bavarian-Austrian Foothills of the Alps. A 10-point system was used for the whole Austrian benthic macroinvertebrate fauna to numerically describe the stream zonation pattern (Moog & Hartmann, 2017). Also in the case of the Odonata, the allotment procedure follows Zelinka & Marvan (1961) and scores individual species according to their occurrence within the stream zones (Chovanec, Waringer, Holzinger, Moog, & Janecek, 2017). The sum of valency values for each species across the longitudinal zonation spectrum is 10. A species which, for example, exclusively lives in one zone would have 10 valency points in this zone; another species occurring throughout the whole longitudinal river profile would have one point in each zone. The distribution of points and the number of points/zone indicate how broad or narrow the ecological tolerance and plasticity of the species is (Moog & Chovanec, 2000).

The Austrian inventory of Odonate species comprises 78 species (Holzinger, Chovanec, & Waringer, 2015), at least one valency point for the metarhithral was assigned to 12 of them (Chovanec et al., 2017; Table 2). However, the occurrence of some of these 12 species in this river type is, due to their distribution patterns – *Coenagrion mercuriale* (Charpentier), *Coenagrion ornatum* (Sélys), *Cordulegaster heros* Theischinger, *Somatochlora meridionalis* Nielsen – and/or ecological preferences for spring brooks or smaller streams with a catchment area < 100 km^2 – *Cordulegaster bidentata* Sélys, *Orthetrum coerulescens* (Fabricius) – not probable (Holzinger et al., 2015; Lang, Müller, & Waringer, 2001; Raab, Chovanec, & Pennerstorfer, 2006; Sternberg & Buchwald, 2000; Wildermuth & Martens, 2014). Hence, those species indicated by parentheses in Table 2 have not been included in the set of reference species (underlined).

Thus, in this study, reference species are defined as those species occurring in the bioregion Bavarian-Austrian Foothills of the Alps with at least one valency point in the metarhithral zone: *Calopteryx virgo* (Linnaeus), *Cordulegaster boltonii* (Donovan), *Onychogomphus forcipatus* (Linnaeus), *Ophiogomphus cecilia* (Geoffroy in Fourcroy), *Orthetrum brunneum* (Fonscolombe), and *Pyrrhosoma nymphula* (Sulzer). The sum of valency points for the metarhithral for these species is nine. The mean number of valency points (1.5) per species results from the total sum of valency points being divided by the number of species (six): Species with a number of points > 1.5 are defined as first-degree indicator species (*C. virgo*, *C. boltonii*, *O. forcipatus*), species with a number of points < 1.5 (*O. cecilia*, *O. brunneum*, *P. nymphula*) are second-degree indicator species. Due to their higher valency points for the metarhithron and, thus, due to their higher indicator potential, the scheme for assessing the ecological status is based on the presence of autochthonous populations of the three first-degree indicators. The integration of the

Table 3. Classification of the ecological status of metarhithron rivers of the bioregion Bavarian-Austrian Foothills of the Alps.

	Ecological status																	
First-degree indicators	I			II								III				IV		V
Calopteryx virgo	x	x	x	x	x	x	x	x				x				x		
Cordulegaster boltonii	x		x		x	x			x	x			x					
Onychogomphus forcipatus	x	x					x	x	x		x			x				
Second-degree indicators (no. of spp.)	≥ 0	> 1	> 1	> 1	0	1	0	1	≥ 0	≥ 1	≥ 1	1	0	0	> 1	0	1	

Abbreviations: x, occurrence of (certainly, probably or possibly) autochthonous populations. Classes of ecological status: I, high; II, good; III, moderate; IV, poor; V, bad.

second-degree indicators makes it possible to develop a more refined and detailed approach (Table 3).

European and Austrian Red List classifications (Kalkman et al. 2010; Raab, 2006) are not taken into account for assessing the ecological status; information on the species' threats are given as additional information on the species' vulnerability and the ecological value of the habitats.

Results

Table 4 provides stretch-by-stretch-specific detailed data on the recorded numbers of specimens, abundance classes and observations of reproduction behaviour. This information is the basis of the overview of the results comparing species inventories, abundance classes and classifications of autochthony given in Table 5. At the regulated stretch G1 five species were found including one first-degree indicator species (*C. virgo*) in a possibly autochthonous population. One species – *Platycnemis pennipes* (Pallas) – probably autochthonously occurred. Individual numbers were extremely low, the highest number of specimens per species sighted at one field trip was three. The total number of individuals recorded at all five dates was 17 (Table 4). Due to the species inventory, this stretch is classified as "poor ecological status".

In contrast, the total number of species recorded at the three rehabilitated stretches was 23 (Table 5), with three of them certainly autochthonous – *Calopteryx splendens* (Harris), *C. virgo* and *Chalcolestes viridis* (Vander Linden); five species probably autochthonous – *Coenagrion puella* (Linnaeus), *Ischnura elegans* (Vander Linden), *P. pennipes*, *Somatochlora flavomaculata* (Vander Linden) and *Sympetrum striolatum* (Charpentier); and four species possibly autochthonous – *Aeshna mixta* Latreille, *Anax imperator* Leach, *O. forcipatus* and *Orthetrum cancellatum* (Linnaeus). With *C. virgo* and *O. forcipatus* two of the three first-degree indicators were recorded, one of the second-degree indicators (*P. nymphula*) was also sighted, but only as single record at G2.

Two first-degree indictors occurred at the stretches G2 and G3, with *C. virgo* certainly autochthonous (Figure 5), and *O. forcipatus* possibly autochthonous (Figure 6). At G4 only *C. virgo* was detected. *Cordulegaster boltonii* was not sighted at all. Species numbers of the three rehabilitated stretches differed significantly (Table 5): G4 was the stretch with the highest total number of species (17), at G2 the highest number auf autochthonous species (nine) were detected. Stretch G3 (with the highest number of *O. forcipatus* specimens) was colonised by five autochthonous species. The stretches G2 and G3 – with a total number of 16 species, 10 of them autochthonous – are classified as "good ecological status" due to the appearance of two first-degree indicators. *Calopteryx virgo* was the Zygoptera species with the highest abundances:

Table 4. Numbers of specimens and abundance classes (Ab.-Class) recorded at the four stretches of the Gurtenbach (G1–G4).

	28/05	11/06	06/07	08/08	26/08	Ab.-Class./ Autochth.
G1						
Calopteryx splendens			1		1	1*
Calopteryx virgo		3	1		3	2*
Ischnura elegans			2			2
Platycnemis pennipes		2,Ta	2			2**
Sympetrum striolatum					2	2
G2						
Calopteryx splendens	1Te	2	1	1	1	2***
Calopteryx virgo	40,Te	100,C	60	15	2, E	5***
Coenagrion puella	4	2				2*
Erythromma lindenii		1				1
Erythromma najas		1				1
Ischnura elegans	4	3				2*
Pyrrhosoma nymphula	1					1
Platycnemis pennipes		15,Ta C	3	1		3**
Aeshna mixta				1	1	1*
Anax imperator	1	2				2*
Brachytron pratense		1				1
Onychogomphus forcipatus		1	1	1		1*
Orthetrum cancellatum				1		1
Sympetrum striolatum			1		1	1*
G3						
Calopteryx splendens		1				1
Calopteryx virgo	12	20	15	2	1	4**
Coenagrion puella	5					2
Coenagrion pulchellum		1				1
Platycnemis pennipes				1		1
Aeshna mixta				2	1	2*
Anax imperator	1		1			1*
Onychogomphus forcipatus		1	2			2*
Somatochlora flavomaculata			1			1
Orthetrum cancellatum				1		1
Sympetrum striolatum					3, Ta	2**
G4						
Calopteryx splendens		2				2
Calopteryx virgo	15	15,C	7			4**
Chalcolestes viridis			1,Te			1***
Coenagrion puella		5	12			3**
Enallagma cyathigerum			3			2
Ischnura elegans	1	5,C	4			2**
Platycnemis pennipes		15,Ta E	10			3**
Aeshna isoceles		1				1
Aeshna mixta				1	1	1*
Anax imperator	1	1	1			1*
Anax parthenope		1				1
Somatochlora flavomaculata		1	4			3**
Somatochlora metallica			1			1
Crocothemis erythraea			1			1
Libellula depressa			1			1
Orthetrum cancellatum			1			1
Sympetrum striolatum					1	1

Notes: Te, tenerals; observation of reproduction behaviour: C, copula; Ta, tandem; E, egg deposition; Autochthony (Autochth.): * possibly autochthonous; ** probably autochthonous; *** certainly autochthonous.

during the field trip in June about 100 individuals were recorded at G2. The classification of this species as certainly autochthonous was due to the detection of freshly hatched individuals at this stretch in May. G4 was the stretch with the highest number of certainly and probably

Table 5. Dragonfly species recorded at the four stretches of the Gurtenbach (G1–G4).

	RL	G1	G2	G3	G2,3	G4	G2-4
Calopteryx splendens	NT	1*	2***	1	2***	2	2***
Calopteryx virgo	NT	2*	5***	4**	5***	4**	5***
Chalcolestes viridis						1***	1***
Coenagrion puella			2*	2	2*	3**	3**
Coenagrion pulchellum	VU			1	1		1
Enallagma cyathigerum						2	2
Erythromma lindenii	EN		1		1		1
Erythromma najas	NT		1		1		1
Ischnura elegans		2	2*		2*	2**	2**
Pyrrhosoma nymphula			1		1		1
Platycnemis pennipes		2**	3**	1	3**	3**	3**
Aeshna isoceles	VU					1	1
Aeshna mixta			1*	2*	2*	1*	2*
Anax imperator			2*	1*	2*	1*	2*
Anax parthenope						1	1
Brachytron pratense	VU		1		1		1
Onychogomphus forcipatus	VU		1*	2*	2*		2*
Somatochlora flavomaculata	EN			1	1	3**	3**
Somatochlora metallica						1	1
Crocothemis erythraea						1	1
Libellula depressa						1	1
Orthetrum cancellatum			1	1	1*	1	1*
Sympetrum striolatum		2	1*	2**	2**	1	2**
total number of spp.		5	14	11	16	17	23
total number of autochthonous spp.		3	9	5	10	8	12
certainly autochthonous spp. ***		0	2	0	2	1	3
probably autochthonous spp. **		1	1	2	2	5	5
possibly autochthonous spp. *		2	6	3	6	2	4

Notes: G2,3; G2–4: aggregated results for the rehabilitated stretches G2 and G3 and for the whole rehabilitated section G2,3, and 4 respectively; 1–5: abundance classes (see Table 1); * possibly autochthonous; ** probably autochthonous; *** certainly autochthonous.

autochthonous species (six). *Calopteryx virgo* was the only indicator species found. Because of the influence of the impounded River Inn on the hydrological condition of G4 this stretch – such as the River Inn – has to be classified as "heavily modified water body" (Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, 2017), which – according to the WFD – cannot be assessed in terms of "ecological status".

At G1 two species listed in the Austrian Red List were found: both *Calopteryx*-species are classified as "near threatened". At the rehabilitated stretches a total of nine threatened species were recorded, two "endangered", four "vulnerable" and three "near threatened" (Table 5). *Somatochlora flavomaculata* ("endangered") found at G4 was the Anisoptera species in the highest abundance class (class 3). The individuals were found at the periphery of the water body, foraging at the edges of copses and in meadows (Figure 7). No species listed in the European Red List was recorded.

Discussion

The total length of the Austrian rivers with a catchment area > 10 km^2 comprises about 32,500 km, 15% of them belong to the biocoenotic region metarhithron; within the bioregion Bavarian-Austrian Foothills of the Alps this portion is even higher (737 of 3626 km; i.e. 20%). These figures underline the importance of this river type for the whole river network of this country. The number of dragonfly species autochthonously occurring at this river type is small. The method

Figure 5. *Calopteryx virgo* at Stretch G2 in the rehabilitated section of the Gurtenbach (11 June 2017; Photo A. Chovanec).

of distributing 10 valency points according to each species' ecological requirements as far as the longitudinal distribution is concerned allows a sound and detailed numerical description of the individual ecological niches as well as a good overview of the overall preferences of this insect order: 24 of the 780 points (3.1%) are allocated to the crenon zones, 67 (8.6%) to the rhithron zone, 191 (24.5%) to the potamon zone, and 498 (63.8%) to the littoral zone (Chovanec et al., 2017). Twenty of the 67 points allotted to the rhithron zone are allocated to 12 species in the metarhithron. The highest number of points per species in this zone is 3 (*C. heros*), indicating that no species occurring in Austria stenoeciously colonises this longitudinal zone.

The choice of the set of indicator species was not only governed by the allocation of valency points but also by the species' overall species traits and spatial distributions. Due to these factors the selection of *C. virgo* and *O. forcipatu*s is distinct. As far as *C. boltonii* is concerned, Schorr (1990) emphasises that this species colonises small brooks up to a width of 2 m (see also Koch, Schuster, Kordges, Bußmann, & Kronshage, 2014); in that case the river type of the Gurtenbach would have been too large to consider *C. boltonii* as reference species. Several authors (Faltin, 1998; Sternberg, Buchwald, & Stephan, 2000; Wildermuth & Martens, 2014) point out that *C. boltonii* also occurs at broader streams and smaller rivers. Laister (2001, 2012) and Schwarz, Schwarz-Waubke, & Laister (2007) found *C. boltonii* at rivers up to a width of 15 m in Upper Austria, in some cases syntopic with *C. virgo* and *O. forcipatus*. *Cordulegaster boltonii* was not detected in the present study; but the author could find it at another metarhithron river section situated in this bioregion, the Waldzeller Ache, with a width of about 7 m. The catchment area of this stream at the investigated stretch, which is situated about 15 km away from the Gurtenbach's mouth, is about 75 km^2. At the Waldzeller Ache *C. boltonii* occurred together, *inter alia*, with *C. virgo*, *O. forcipatus* and *O. brunneum* (Chovanec, 2017a).

Figure 6. *Onychogomphus forcipatus* at Stretch G3 in the rehabilitated section of the Gurtenbach (6 July 2017; Photo A. Chovanec).

Particularly according to their larval habitat requirements, the indication values of the three first-degree indicators cover a broad range of typological features of this metarhithron river type. Autochthonous occurrence of *C. virgo* indicates – among intact flow velocity, oxygen conditions and water temperature – particularly the presence of type-specific riparian vegetation with its relevant submerged structures, such as roots (Donath, 1984; Rüppell, Hilfert-Rüppell, Rehfeldt, & Schütte, 2005; Zahner, 1959). Therefore, *C. virgo* may also occur at regulated and straightened rivers with appropriate riparian vegetation (Chovanec, 2014). In contrast *C. boltonii* and *O. forcipatus* depend on type-specific current and sediment conditions. The larvae of *C. boltonii* preferably occur in areas with sandy and clayey sediments and reduced flow velocity, the larvae of *O. forcipatus* prefer sandy and gravel conditions with slow or also faster flow velocities (Suhling & Müller, 1996). Adult males of *C. boltonii* perch on riparian vegetation, whereas those of *O. forcipatus* preferably sit on gravel banks on stones near the water surface (Martens, 2001). The different habitat needs of the three first-degree indicator species are reflected in the assessment scheme (Table 3). As regulation measures mainly lead to monotonous current and substrate conditions, *C. boltonii* and *O. forcipatus* are considered to be more sensitive to river type-specific morphodynamic processes. If one of these two species is recorded as autochthonous population, the ecological status has to be classified at least as "moderate". "Good ecological status" can be reached also without detecting *C. virgo*.

One of the benefits of using dragonflies as bioindicators is their reaction to small scale differences in habitat quality and current conditions. This is clearly illustrated by the results of this study: the monotonous structure, the lean riparian vegetation and the lack of substrate and morphodynamics at G1 led to a dragonfly fauna poor in species and individuals; first-degree indicators are only represented by rare specimens of *C. virgo*. *Platycnemis pennipes* was the only species with observed reproduction behaviour; like *C. virgo* it can also be found at regulated

Figure 7. *Somatochlora flavomaculata* was found between the forest strip and pavement accompanying G4 (6 July 2017; Photo A. Chovanec).

rivers (Chovanec, 2014). The rehabilitated stretch G2, downstream directly connected to G1, is characterised by the colonisation of two first-degree indicators and the appearance of a large number of other species, particularly using the helophytes of the slip-off slope in an area with significantly reduced flow velocity. Dense and sunny stands of *Phalaris arundinacea* L., which were chosen as perching sites, and slightly reduced current velocities due to the river widening were responsible for the highest abundances of *C. virgo* found at this river section; the classification as certainly autochthonous was due to records of tenerals. Records of *O. forcipatus* were restricted to a small single gravel bank which was also located in the slip-off slope of G2; Chovanec (2016) and Petzold (2015) underline that this species colonises suitable structures, even if they are patchy and small.

Potamalisation effects in rhithron zones arise if current velocities and morphodynamic processes are reduced. Species with peaks in their valency point distribution in the hyporhithron, potamon, or even in the littoral occur (e.g. in the case of impoundment or residual water conditions; Moog, 1993; Moog & Chovanec, 2000). Due to river widening, a slight potamalisation effect is evident at G2; besides the two first-degree indicators, possibly and probably autochthonous species with main preferences for epi- and metapotamon rivers as well as littoral zones (*P. pennipes*) and for littoral areas (*C. puella*) occurred. The occurrence of a small certainly autochthonous population of *C. splendens*, verified by the record of one teneral male, is a good indicator for slight potamalisation effects in this metarhithron zone. This species is typical of the epi- (four points) and metapotamon (three points). *Ischnura elegans* was also found at G2, a species with a broad habitat spectrum reaching from the hyporhithron (one point) to the littoral (four points; Chovanec et al. 2017). At G3 these species are missing or do not occur autochthonously.

The lack of bank protection by rip rap allows river type-specific erosion and sediment relocation processes at G3 resulting in larger gravel banks. Thus, at G3 more individuals of *O. forcipatus* were detected. At both stretches, G2 and G3, the syntopic occurrence of autochthonous *C. virgo* and *O. forcipatus* resulted in the classification "good ecological status", indicating the existence of heterogeneous river width and depth as well as current conditions based on morphodynamic processes and of a mosaic of type-specific bed structures.

The backflow conditions at G4 and at the mouth of the Gurtenbach lead to significantly reduced current velocities with fine grained substrate and, therefore, nearly standing water conditions. Because of this significant potamalisation effect, *O. forcipatus* was not found at this stretch. Here the highest number of certainly or probably autochthonous limnophilic species was found, i.e. species with most valency points allotted for the littoral (*C. viridis*: 6, *C. puella*: 8, *S. flavomaculata*: 8 points for littoral). The positive effect of the river type-specific assessment is not that high species numbers *per se* are decisive for good classifications, but the occurrence of species which are typical for the river type investigated. In the case of G4 the backwater of the impounded River Inn leads to significant changes in the hydrologic and substrate conditions of the Gurtenbach. Due to the WFD, surface water bodies are designated as heavily modified where their physical characteristics have been substantially altered and the changes to their hydrological and morphological characteristics necessary to achieve good surface water status would have a significant adverse impact on water uses, such as hydropower generation. In that case it is not possible to reach a "good ecological status" and hence, the classification scheme of "ecological potential" has to be applied. The ecological potential of a water body represents the degree to which the quality of the water body's aquatic ecosystem approaches the maximum it could achieve, given the heavily modified characteristics of the water body (Kampa & Hansen, 2004). Due to the probably autochthonous population of the first-degree indicator species *C. virgo* and a high total number of species, for G4 the categorisation into "high ecological status" is proposed.

Although the valency point maximum of *Aeshna mixta* and *A. imperator* is in the littoral zone, both species are often recorded at running waters (e.g. Chovanec, 2017b) and they occurred at all rehabilitated stretches investigated in this study. Potamalisation effects favour the occurrence of both species (Chovanec, 2017c). However, the investigation of the dragonfly assemblages at the regulated and the three rehabilitated stretches showed that the mitigation measures led to a significant improvement of the ecological integrity of the lowermost section of the Gurtenbach. The single records of several endangered species rarely occurring in Upper Austria (Laister, 1994, 2001, 2017) – *Coenagrion pulchellum* (Vander Linden), *Erythromma lindenii* (Sélys), *Aeshna isoceles* (Müller), *Brachtron pratense* (Müller) – show that intact river systems with near-natural or extensively used riparian areas not only serve as breeding habitat for type-specific species, but also as important part of the terrestrial habitat of other species (e.g. for maturing or foraging; e.g. Wildermuth, 2012) as well as stepping stone biotope. The definition of reference species for the larger metarhithron zones of the bioregion Bavarian-Austrian Foothills of the Alps is based on riverine longitudinal zonation patterns of Odonata. The methodological approach focusing on the autochthonous occurrence of dragonfly reference species provided a sensitive instrument, which – even on a small scale – allowed differentiation between the ecological status of a regulated stretch, a rehabilitated stretch with slight potamalisation effects, a near-pristine rehabilitated stretch, and a rehabilitated stretch with significant potamalisation effects due to backwater influences, respectively.

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Glossary

Biocoenotic regions: changes in species composition along a river's length establish longitudinal zonation patterns. These biocoenotic regions are called:

- Crenon (Eucrenon, Hypocrenon) – spring-fed headwaters of a river
- Rhithron (Epi-, Meta-, Hyporhithron) – cooler upland sections of a river
- Potamon (Epi-, Meta-, Hypopotamon) – warmer and less steep rivers of the lowlands.

Bioregion: A bioregion is an ecologically and geographically defined area, which is smaller than the ecoregion.

Littoral: The littoral region is an interface zone between the land of the drainage basin and the open water of standing waters (Wetzel, 1983).

Potamalisation: Due to, for example, impoundment or river bed widening, rhithron stretches may change their abiotic and biotic characteristics. Thus, water temperature, flow velocity, and substrate as well as the species composition do not correspond to the rivertype-specific conditions, but are more similar to potamon conditions.

Stream order: The smallest, permanently flowing stream is termed first order, and the union of two streams of order n creates a stream of order $n + 1$ (Allen, 1995; Strahler, 1964). Stream orders represent an ideal system for classifying major aspects of running waters, taking into account a number of abiotic factors changing from source to mouth. There are strong correlations between stream orders and size of catchment area as well as discharge (Wimmer & Moog, 1994).