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Colonization of a 3rd order stream by dragonflies (Insecta: Odonata) – a best practice example of river restoration evaluated by the Dragonfly Association Index (lower Weidenbach, eastern Austria)

Andreas Chovanec & Johann Waringer

Restoration measures implemented on the lower section of a third order stream (Weidenbach, eastern lowlands of Austria) were assessed by carrying out a dragonfly survey. As required under the European Water Framework Directive the assessment was based on a comparison between a river type-specific, near-pristine reference situation and the actual status quo. As a result of large-scale river regulation, there were no natural sections of the river left. Therefore, the ecological requirements of dragonfly associations were correlated with river type-specific features for deriving type-specific communities. Twenty-six breeding species belonging to all six type-specific dragonfly associations were recorded. Applying the Dragonfly Association Index, the restored river section was allocated to class I ("high ecological status"), which corresponds to the reference situation and underlines the success of the implemented restoration measures. These measures were focused on increasing the sinuosity of the river and the in-stream habitat heterogeneity (e.g. by river widening and by creating meanders) and on improving the lateral connectivity in the river system (e.g. by creating backwaters). The results of the study emphasize the necessity of implementing type-specific restoration as a basis for the colonization by a dragonfly fauna characteristic for the river.

Chovanec A. & Waringer J., 2015: Besiedlung des unteren Weidenbaches in Niederösterreich durch Libellen (Insecta: Odonata) – ein Beispiel einer gelungenen Restrukturierung und ihre Bewertung durch Anwendung des Dragonfly Association Index.
Im Unterlauf und Mündungsbereich des Weidenbaches (Niederösterreich) durchgeführte Restrukturierungsmaßnahmen wurden im Rahmen einer libellenkundlichen Studie evaluiert. Gemäß der EU Wasserrahmenrichtlinie beruht der Bewertungsvorgang auf einem Vergleich des Ist-Zustandes mit einem gewässertyp-spezifischen Referenzzustand. Da keine natürlichen Abschnitte des betreffenden Gewässertyps mehr vorhanden sind, wurden die ökologischen Ansprüche von Libellenassoziationen mit hydro-morphologischen Parametern korreliert, um die flusstyp-spezifische Libellenfauna zu definieren. Im Untersuchungsgebiet wurden 26 bodenständige Arten nachgewiesen, Spezies aus allen sechs typ-spezifischen Assoziationen sind vertreten. Die Berechnung des Dragonfly Association Index ergibt den „sehr guten ökologischen Zustand" für diesen Abschnitt des Weidenbaches; dies entspricht dem Referenzzustand und unterstreicht die Bedeutung der Implementierung von gewässertyp-spezifischen Restrukturierungsmaßnahmen.

Keywords: Assessment, Dragonfly Association Index, ecological status, Odonata, restoration, river typology, Water Framework Directive.

Introduction

River engineering and fragmentation have led to severe disturbances of the ecological integrity of running water ecosystems as they have interrupted river and habitat continuity, disconnected the river channel from adjacent wetlands and floodplains, and caused hydrological alterations. River restoration has thus become one of the major challenges in international water management (Nilsson et al. 2005, Tockner et al. 2009, Vörösmarty et al. 2010). According to the Austrian River Basin Management Plan (FMAFEWM 2010) 65 % of the rivers with a catchment area > 10 km^2 fail to reach the quality objective "good ecological status" laid down in the European Water Framework Directive (WFD; Directive 2000/60/EC; European Community 2000). The main reasons for missing the target "good ecological status" are river regulation, large-scale drainage, and hydropower generation (FMAFEWM 2010).

Dragonflies have proved to be sound and reliable bio-indicators due to their complex habitat requirements during their whole life cycle and to their quick response to habitat changes. Their indicative value covers (semi)-aquatic habitat heterogeneity, connectivity aspects, the ecological quality of the land-water interface, and of the success of water management activities (Chwala & Waringer 1996, Chovanec & Raab 1997, Chovanec et al. 2004, D'Amico et al. 2004, Chovanec & Waringer 2005, Oertli 2008, Samways 2008, Simaika & Samways 2009, Mabry & Dettman 2010, Silva et al. 2010, Gallardo et al. 2012, Chovanec 2014a, Monteiro Júnior et al. 2015). This paper deals with an evaluation of restoration measures, which were carried out at the lower Weidenbach, a stream located in the eastern lowlands of Austria, using dragonfly surveys. As required under the WFD, an assessment of ecological status should be based on a comparison between a river type-specific reference situation and the actual status quo. At the Weidenbach, the assessment was performed by applying a method, which has been developed for all lowland river types in Austria, and which fulfils the requirements of the WFD (Chovanec et al. 2014b, 2015).

When considering river type-specific assessment procedures, a few questions arise, which are addressed in this study: How should type-specific abiotic characteristics and aquatic communities be derived when (near-)pristine river sections are missing? How should a 5-tiered assessment scheme be created to monitor the success of restoration measures in compliance with the requirements of the WFD? And, finally, how should a scientific concept be integrated in a framework of water management requirements (e. g. Moog & Chovanec 2000)?

Methods

River typology and assessment:

Assessing the ecological status of surface waters is one of the key elements of the WFD. An assessment has to include, *inter alia*, an evaluation of river hydrology, morphology, and connectivity. Five classes of ecological status are defined in the WFD: high – good – moderate – poor – bad. "Good ecological status", which corresponds to the WFD's quality objective, is defined as a slight deviation from the river type-specific reference status (*i.e.* "high ecological status"). The environmental objective specified in the WFD aims to prevent deterioration from "high" to "good ecological status". Therefore, the assessment process 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 – according to the WFD – also include benthic invertebrates.

In order to implement the principles and obligations established in the WFD, Austrian rivers are categorized on the basis of their allocation to one of Austria's 15 bioregions, the size of the catchment area and their altitude range (Wimmer et al. 2012). For the bioregion Eastern Ridges and Lowlands, this scheme was slightly adapted for the purpose of dragonfly-based assessment (Chovanec et al. 2014b, 2015). Where nearly undisturbed river stretches no longer exist, a situation either known or assumed to have existed prior to large-scale channel regulation and industrialization (*i.e.* a situation around the mid-19th century) has to be used as reference situation. Historical maps and faunistic data, as well as old paintings may provide useful information (Wiesbauer & Denner 2013).

Weidenbach – typological characterization:

The epipotamal Weidenbach stream is located in the lowlands of the Austrian province of Lower Austria in the northeastern part of the country and belongs to the bioregion Eastern Ridges and Lowlands (Wimmer et al. 2000, Moog et al. 2004), which is situated within the ecoregion Hungarian Lowlands (Illies 1978). The Weidenbach originates at 250 m above sea level and flows for 34 km. It is a third order stream that flows into the River Morava (141 m.a.s.l.). It drains a catchment of 227 km^2. The bioregion Eastern Ridges and Lowlands covers an area of about 12,500 km^2, which corresponds to about 15 % of the size of the Austrian territory. It belongs to the Pannonian climate zone, with warm dry summers, cold winters and little snow (annual precipitation 400–600 mm). The stream is characterized by a winter-pluvial flow regime with an average annual discharge of about 0.2 m^3/s at its mouth (Land und Wasser 2008; Chovanec et al. 2014a).

In Austria, the rivers of the bioregion Eastern Ridges and Lowlands have a total length of about 12,000 km. Most of the rivers flow at altitudes between 115 and 500 m.a.s.l. The length of rivers with a catchment area > 10 km^2 located in this bioregion in Austria is 4,750 km, which corresponds to 16% of the length of Austria's total network of rivers with a catchment area > 10 km^2. Of these, only 30 km (0.6%), particularly in the upper reaches, have been assessed as having "high ecological status", while 662 km (14%) have "good ecological status" (FMAFEWM 2010). Consequently no reference sites are available for a river type such as the lower reach of the Weidenbach.

The pristine river course can be described as wandering and meandering. As one can perceive from maps of the 18^{th} and 19^{th} century, there used to be extensive wetlands, floodplain meadows and, in some places, wide strips of floodplain forest along the Weidenbach and other rivers of this area. A painting by Kozlowsky from1932 (Provincial Museum of Lower Austria) shows large periodical wetland areas in the landscape before the river was regulated. Flow velocity used to be slow because of the river's shallow slope. From the mid-19^{th} century onwards, the character of the landscape has fundamentally changed as a result of large-scale drainage and river engineering for the purpose of land reclamation and flood control. River courses became straightened and degraded trapezoidal channels, with steep embankments and narrow riparian strips. These measures caused an increase in flow velocity, a decrease in the morpho-dynamics of the river and in habitat heterogeneity, while also interrupting the connection between the river and floodplain areas. According to the Austrian River Basin Management Plan, the current ecological status of the water body of the Weidenbach, in which the investigation area is situated, has been classed as "poor" (FMAFEWM 2010).

Within the last 10 years, the Weidenbach has been subjected to numerous restoration measures with the aim to improve both, existing flood protection systems for villages and towns and the ecological situation. In most cases these measures included in-stream habitat and riparian restoration and the creation of retention areas by river widening. The retention areas, which are largely free from other uses (especially agriculture), enable morpho-dynamic processes. The different morphological conditions *(i.e.* those of a straightened channel as compared to those under different types of restoration) along the Weidenbach are shown in Fig. 1 (Chovanec et al. 2014a):

Regulated stretch: Straightened channel with low sinuosity, no backwaters, regulated in a trapezoidal cross section with steep banks, reduced habitat heterogeneity, uniform and monotonous morphometric and flow conditions.

Restoration type 1 (RT1): Restoration measures along the main channel: increase in sinuosity, construction of in-stream structures (willow rootstocks, living fascines), riparian restoration, river widening.

Restoration type 2 (RT2): Measures of RT1 + creation of islands and /or "blind" side channels connected to the main channel at the downstream end; thereby considering lateral connectivity to some extent.

Restoration type 3 (RT3): Measures of RT2 + measures to increase lateral connectivity by creating side arms and isolated backwaters, expanding riparian zones; implemented in retention areas.

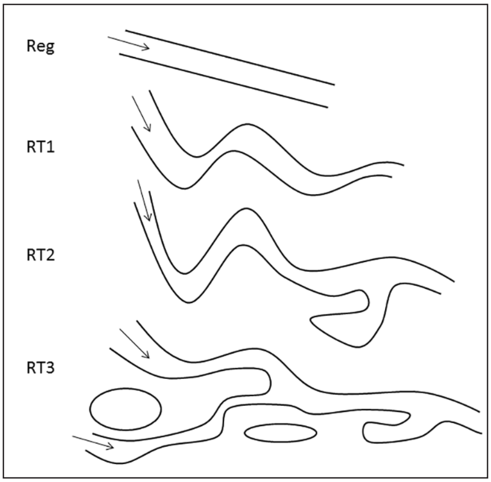

Fig. 1: Schematic illustration of a regulated stretch (Reg) and the different types of restoration measures (RT1,2, 3) carried out at the Weidenbach stream. – Abb. 1: Schematische Darstellung der regulierten (Reg) und restrukturierten Abschnitte (Restrukturierungstypen RT1, 2, 3) im System des Weidenbaches (Chovanec et al. 2014a).

Previous experience has shown that RT3 had the best results for dragonfly colonization (Chovanec et al. 2014a).

Investigation area:

A section of two kilometres upstream of the Weidenbach's mouth was restored in 2009 and 2010: Backwaters and meanders (flow velocity 0–0.3 m/s) were created in a retention area (RT3). This meandering section is followed by a section between flood protection dams, where small islands were created and the Weidenbach was widened (up to a width of about 10 m; flow velocity 0–0.4 m/s; RT2). The mouth of the Weidenbach was restructured by creating an estuary (flow velocity up to 0.5 m/s; RT2; Fig. 2). Riparian vegetation is dominated by *Phragmites* sp., *Typha latifolia*, *Alisma plantago-aquatica*, *Butomus umbellatus Lythrum salicaria*, *Mentha aquatica*, *Rumex* sp., *Persicaria hydropiper*, and young *Salix* sp. In standing water and in areas of reduced flow velocity in the stream channel large patches of *Ceratophyllum demersum* and *Potamogeton* sp. are found. According to the odonatological river typology for the bioregion Eastern Ridges and Lowlands, this Weidenbach section belongs to the type of "rivers with a catchment size >100 km^2" ("RC_{ERL}>100"; Chovanec et al. 2014b, 2015). First screening investigations in this area were carried out in 2010 and 2011 (Chovanec et al. 2012).

Weidenbach – type-specific dragonfly community:

The dragonfly fauna of the bioregion Eastern Ridges and Lowlands comprises 57 species. For defining their ecological requirements, 12 environmental parameters widely used for

Tab. 1: Traits of the rivers in the bioregion Eastern Ridges and Lowlands with a catchment area > 100 km² (RC_{ERL}>100), of the dragonfly associations A1 – A7 (further information in the text and Tab. 2) and of the species *Calopteryx splendens* (*C. spl.*). Cren.: Crenon, Rhith.: Rhithron, Pot.: Potamon, Flow vel.: Flow velocity, Stand. wat.: Standing waters, Temp. wat.: Temporary waters, Subm. mph.: Submerged macrophytes, Rip. Trees: Riparian trees. – Tab.1: Ökologische Ansprüche von *Caloptery splendens* (*C. spl*), und der Libellen-Assoziationen A1 – A7 (weitere Informationen im Text und in Tab. 2) und Ausprägung libellenkundlich relevanter Parameter beim Gewässertyp „Flüsse der Bioregion Östliche Flach- und Hügelländer mit einem Einzugsgebiet > 100 km²" (RC_{ERL}>100). Cren.: Krenon, Rhith.: Rhithron, Pot.: Potamon, Flow vel.: Strömungsgeschwindigkeit, Stand. wat.: stehendes Gewässer / Litoral, Temp. wat.: astatisches Gewässer, Size: Gewässergröße, Open water: offene Wasserfläche, Open banks: offene Ufer, Subm. mph.: Submerse Macrophyten, Reed: Röhricht, Rip. Trees: Ufergehölz; von 0 (nicht relevant / nicht ausgeprägt) bis 3 (sehr relevant / stark ausgeprägt).

	Cren.	Rhith.	Pot.	Flow vel.	Stand. wat.	Temp. wat.	Size	Open water	Open banks	Subm. mph.	Reed	Rip. trees
C. spl.	0	1	3	1.5	0.5	0	1.5	0	0	0.5	2.5	1.5
RC_{ERL}>100	0	0	3	0.5	1.5	1.0	2.5	2	1.5	2	2.5	1.5
A1	0	0	0.75	0	3	0	2.25	2.25	0	1.75	1.5	0.5
A2	0	0	1	0	3	1	1.5	1	0	1	1	0
A3	0	0	1	0	3	0	1.5	0	0	0.5	2	1
A4	0	0	0.5	0	3	0	1.5	0	0	2	2	0
A5	0	0	0	0	3	2	1.5	0	0	0.25	2.5	0
A6	0.5	3	0	1	0	0	1	0	0	0	1.25	2
A7	0	1	2.5	1	0.5	0	1.5	0	1	0	1.5	0

Odonata species were chosen and transformed into numerical species traits given by combinations of factor loadings in a range between 0 (= not applicable, not relevant) and 3 (= fully applicable, highly relevant) in steps of 0.5 (Chovanec et al. 2015). An example is given in the first line of Tab. 1: the ecological requirements of *Calopteryx splendens*. Hierarchical clustering based on these species traits resulted in the definition of seven dragonfly associations: A1 = Association of open waters; A2 = Association of sparsely vegetated banks; A3 = Association of reed and riparian trees; A4 = Association of reed and submerged macrophytes; A5 = Association of temporary waters; A6 = Rhithron association; A7 = Potamon association (Tab. 2; for further information see Chovanec et al. 2014b, 2015). The medians of

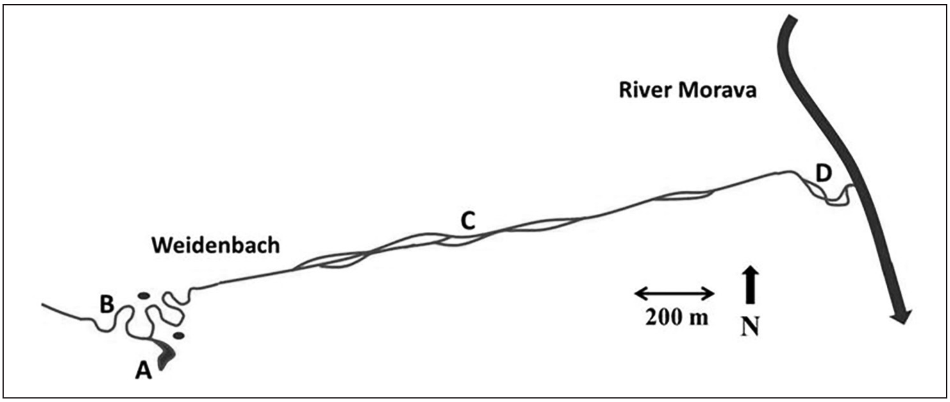

Fig. 2: Investigation area. A, B, C, D: stretches investigated. – Abb. 2: Untersuchungsgebiet. A, B, C, D: Untersuchungsstrecken.

Tab. 2: Dragonfly associations defined for the bioregion Eastern Ridges and Lowlands (A1-A7), dragonfly associations defined for "rivers with a catchment size > 100 km²" located within the bioregion (◀), and species recorded in four stretches of the Weidenbach; A, B, C, D: stretches investigated (Fig. 2); 1: single, 2: rare, 3: frequent, 4: abundant, 5: extremely abundant; * autochthonous in the stretch or in the investigation area (Inv. Area). – Tab. 2: Libellen-Assoziationen der Bioregion Östliche Flach- und Hügelländer (A1-A7) und des Gewässertyps „Flüsse der Bioregion Östliche Flach- und Hügelländer mit einem Einzugsgebiet > 100 km²" (◀), Nachweise der Arten, die an den 4 Untersuchungsstrecken des Weidenbaches (A, B, C, D; Fig. 2) nachgewiesen wurden; 1: Einzelfund, 2: selten, 3: häufig, 4: sehr häufig, 5: massenhaft; * bodenständig an der Strecke oder im Untersuchungsgebiet (Inv. Area).

Association, Species	A	B	C	D	Inv. Area
A1 – A. of open waters ◀					
Erythromma najas					
Erythromma viridulum	5*	4*	4*	2*	*
Enallagma cyathigerum	2*				*
Aeshna grandis					
Anax imperator	2*	3*	4*		*
Anax parthenope	1	1	1*		*
Cordulia aenea					
Somatochlora metallica					
Epitheca bimaculata					
Libellula fulva					
A2 – A. of sparsely vegetated banks ◀					
Ischnura pumilio	3*	2*	2*	1*	*
Libellula depressa	2*	2*	2*		*
Orthetrum albistylum	3*	3*	3*	2	*
Orthetrum cancellatum	3*	3*	4*	2	*
Sympetrum fonscolombii					
Sympetrum pedemontanum			2		
Sympetrum striolatum	2*		2*		*
A3 – A. of reed and riparian trees ◀					
Sympecma fusca			3*		*
Lestes viridis	2*	5*	3*		*
Pyrrhosoma nymphula					
Brachytron pratense					
Aeshna cyanea					
Aeshna isosceles		2*	1*		*
Aeshna mixta	3*	3*	4*		*
A4 – A. of reed and submerged macrophytes ◀					
Lestes sponsa	2*				*
Coenagrion puella	2*	2*	3*	2*	*
Coenagrion pulchellum	2*	2	2*	1	*
Coenagrion scitulum					
Ischnura elegans	5*	5*	5*	2*	*
Aeshna viridis					
Libellula quadrimaculata	2*	1*			*
Crocothemis erythraea	3*	2*			*
Sympetrum vulgatum	5*	3*	3*	3*	*
Leucorrhinia pectoralis					

Tab. 2, cont.

Association, Species	A	B	C	D	Inv. Area
A5 – A. of temporary waters ◀					
Lestes barbarus					
Lestes dryas					
Lestes virens					
Aeshna affinis					
Anax ephippiger					
Sympetrum danae	1				
Sympetrum depressiusculum					
Sympetrum flaveolum					
Sympetrum meridionale					
Sympetrum sanguineum	3*	3*	2*		*
A6 – Rhithron association					
Calopteryx virgo					
Cordulegaster bidentata					
Cordulegaster boltonii					
Cordulegaster heros					
A7 – Potamon association ◀					
Calopteryx splendens	1	4*	3*	3*	*
Platycnemis pennipes	2*	4*	5*	3*	*
Coenagrion ornatum					
Gomphus flavipes					
Gomphus vulgatissimus		1	2*		*
Ophiogomphus cecilia					
Onychogomphus forcipatus					
Orthetrum brunneum				3*	*
Orthetrum coerulescens		1	2*		*
Total number of species	22	21	22	11	28
Number of autochthonous species	19	17	21	8	26

each of the twelve habitat parameters over the species of a given association yielded seven association traits (Tab. 1). The characteristics of the Weidenbach's river type "RC_{ERL}>100" (Wimmer et al. 2012) were transformed into the 12 habitat parameters (river type traits; Fig. 3, Tab. 1), which enables a correlation (Pearson's product moment correlation) between river type and dragonfly association and, thus, the definition of type-specific dragonfly associations. Pearson's correlation ranges from +1 (perfect fit) to -1 (complete avoidance). Correlations ≥ 0 were considered for the definition of type-specific associations. Both the highest correlation value between one association and one given river type and this value minus 0.1 were weighted with a factor of 3. Highest correlation values minus 0.2 and 0.3 were weighted with a factor of 2, lower correlation values with a factor of 1. The correlations are shown in Tab. 3 (Chovanec et al. 2014b, 2015).

Assessment:

Classes of association status (CAS) were defined to evaluate the recorded species numbers with respect to the structure of individual river type-specific associations. In the case of associations comprising more than eight species, a record of at least four species is required for ranking in class 1 of association status. In the case of associations comprising fewer species,

Tab. 3: Correlations between dragonfly associations (A1-A7, see also Tab.2) and "rivers with a catchment size > 100 km²" located in the bioregion Eastern Ridges and Lowlands" (RC_{ERL}>100). WF: Weighting factors (WF) for correlations ≥ 0. – Tab. 3: Korrelationen zwischen den Libellen-Assoziationen (A1-A7, siehe auch Tab. 2) und dem Gewässertyp „Flüsse der Bioregion Östliche Flach- und Hügelländer mit einem Einzugsgebiet > 100 km²"; WF: Gewichtungsfaktoren für Korrelationen ≥ 0 (CHOVANEC et al. 2014b, 2015).

	A1	A2	A3	A4	A5	A6	A7
RC_{ERL}>100	0.6	0.5	0.5	0.5	0.3	-0.4	0.5
WF	3	3	3	3	2		3

a lower number is required. Tab. 4 shows the associations, weighting factors, and species numbers per CAS for the river type "RC_{ERL}>100", according to the result of the Pearson's correlation. The numbers of autochthonous species recorded for the type-specific associations determine an association's status class. For the calculation of the ecological status, the individual association's status classes have to be weighted with the relevant factors according to the Dragonfly Association Index (DAI; CHOVANEC et al. 2014b, 2015):

$$DAI = \frac{\sum(CAS*WF)}{\sum WF}$$

(CAS – Class of association status, WF – Weighting factor).

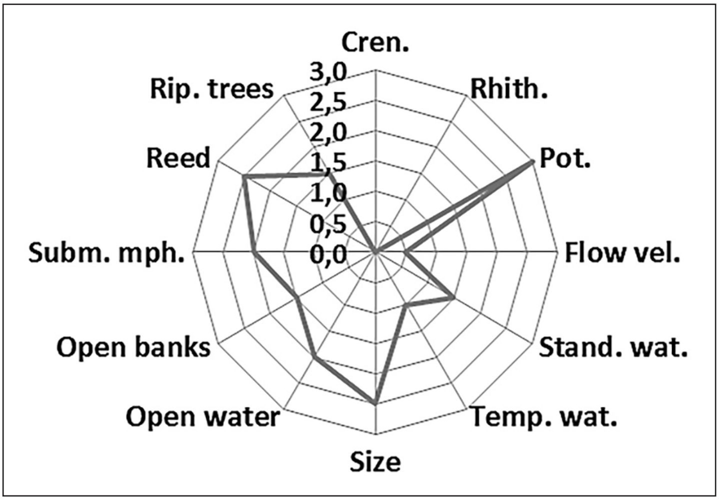

Fig. 3: Traits of "rivers with a catchment size >100 km²" located in the bioregion Eastern Ridges and Lowlands" (RC_{ERL}>100). Cren. – Crenon, Rhith. – Rhithron, Pot. – Potamon, Flow vel. – Flow velocity, Stand. wat. – Standing waters, Temp. wat. – Temporary waters, Subm. mph. – Submerged macrophytes, Rip. trees – Riparian trees; factor loadings between 0 (= not applicable, not relevant) and 3 (= fully applicable, highly relevant). – Abb. 3: Ausprägung libellenkundlich relevanter Parameter beim Gewässertyp „Flüsse der Bioregion Östliche Flach- und Hügelländer mit einem Einzugsgebiet > 100 km²". Cren. – Krenon, Rhith. – Rhithron, Pot. – Potamon, Flow vel. – Strömungsgeschwindigkeit, Stand. wat. – stehendes Gewässer / Litoral, Temp. wat. – astatisches Gewässer, Size – Gewässergröße, Open water – offene Wasserfläche, Open banks – offene Ufer, Subm. mph. – Submerse Macrophyten, Reed – Röhricht, Rip. trees – Ufergehölz; 0 nicht relevant / nicht ausgeprägt) bis 3 (sehr relevant / stark ausgeprägt).

Tab. 4: Type-specific associations (Assoc.; see also Tab. 2) for "rivers with a catchment size >100 km²" located in the bioregion Eastern Ridges and Lowlands, relevant weighting factors (WF) and classes of association status. – Abb. 4: Gewässertyp-spezifische Libellen-Assoziationen für den Gewässertyp „Flüsse der Bioregion Östliche Flach- und Hügelländer mit einem Einzugsgebiet > 100 km²" (siehe auch Tab. 2); Gesamtzahl der Arten pro Assoziation, Gewichtungsfaktoren und assoziations-spezifische Statusklassen (Chovanec et al. 2014b, 2015).

Assoc.	Species	WF	Class of association status				
			1	2	3	4	5
A1	10	3	≥ 4	3	2	1	0
A2	7	3	≥ 3	2	1		0
A3	7	3	≥ 3	2	1		0
A4	10	3	≥ 4	3	2	1	0
A7	9	3	≥ 4	3	2	1	0
A5	10	2	≥ 4	3	2	1	0

The result obtained is a value between 1 and 5 indicating the ecological status of an investigated site with special regard to hydro-morphological aspects. In many cases, it is not possible (due to topographical conditions) that all type-specific habitat features are present at one and the same site. Therefore a correction factor has been introduced in the assessment procedure: If at least 50% of the type-specific associations are represented by at least two autochthonous species (for A6 one species is sufficient), the DAI value has to be reduced by a correction factor of 0.5 (= $DAI_{corr.}$). This is why DAI values < 1 are possible. The values of the DAI or $DAI_{corr.}$ indicate the class of ecological status: 0.50–1.49 indicating high ecological status (class I); 1.50–2.49 good ecological status (II); 2.50–3.49 moderate ecological status (III); 3.50–4.49 poor ecological status (IV); ≥ 4.50 bad ecological status (V; Chovanec et al. 2015).

Data collection in the field:

The method is based on counting adult and freshly hatched individuals. In order to cover all phenological groups, eight field trips were carried out between 30 April and 9 September 2012. For the purposes of a practice-oriented approach, larvae and exuviae were not sampled (see also Bried et al. 2012). Specimens were identified by sight or by photographs. Where necessary, individuals had to be caught with a handnet and released after identification. Because the assessment approach is based on records of breeding species with self-sustaining populations, it is essential to estimate autochthony. According to an adapted scheme of Chovanec & Waringer (2001), the following criteria were to be considered in order to determine whether a species is autochthonous within an investigated stretch: Records of

- newly hatched specimens, and/or
- reproductive behavior (copula, tandem, egg deposition), and/or
- imagines in abundance class 3, 4 or 5, and/or
- imagines (also in lower abundance classes) on a given stretch of river over a longer period of time (at least two surveys).

The following criteria were to be considered in order to determine whether a species is autochthonous in an area with several stretches investigated:

- autochthony in at least one stretch according to the criteria as noted above, and/or
- imagines (also in lower abundance classes) on two or more stretches within a given area.

The numbers of individuals recorded during the field investigations were converted into a five-class abundance system. To allocate numbers of individuals to abundance classes, species-specific habitat requirements and territorial behavior patterns were to be considered (CHOVANEC et al. 2012; Tab. 5). The abundance class considered for this assessment approach was the class determined during the field excursion, where the largest number of individuals was recorded.

Tab. 5: Allocation of individual numbers/100 m to abundance classes. – Tab. 5: Zuordnung der nachgewiesenen Individuenzahlen/100 m zu Abundanzklassen (CHOVANEC et al. 2012).

	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

Surveys were performed along the banks of four homogenous 100 m stretches, which represented the hydro-morphological characteristics of the whole studied site: one stretch at a large standing backwater (A in Fig 2; Fig. 4), one stretch in the meandering stream section (B; Fig. 5), one stretch in the section with increased sinuosity between the dams (C; Fig. 6) and one in the estuary (D; Fig. 7). The situation of the Weidenbach's mouth prior to restoration is shown in Fig. 8. For the assessment procedure the autochthonous species recorded on all investigated stretches were put in one site-specific species inventory and processed in the DAI.

Fig. 4: Stretch A, backwater. Photo: A. CHOVANEC. – Abb. 4: Untersuchungsstrecke A am stehenden Gewässer, Foto: A. CHOVANEC.

Fig. 5: Stretch B, meandering stream section, photo: A. Chovanec. – Abb. 5: Untersuchungsstrecke B in der Mäanderstrecke, Foto: A. Chovanec.

Fig. 6: Stretch C in the stream section between the dams with islands and increased sinuosity, photo A. Chovanec. – Abb. 6: Untersuchungsstrecke C im pendelnden Abschnitt mit Inseln zwischen den Dämmen, Foto A. Chovanec.

Fig. 7: Stretch D, estuary, photo: A. CHOVANEC. – Abb. 7: Untersuchungsstrecke D im Mündungstrichter, Foto: A. CHOVANEC.

Fig. 8: Confluence of Weidenbach with River Morava prior to restoration, photo: LAND UND WASSER (2008). – Mündungsbereich des Weidenbaches vor der Restrukturierung, Foto: LAND UND WASSER (2008).

Results

With the exception of the Rhithron Association A6, the river type-specific dragonfly community of "RC_{ERL}>100" comprises species of all associations. On the investigated section of the Weidenbach all associations are represented by at least one autochthonous species. A total of 28 dragonfly species were recorded, representing 36% of the Austrian Odonata fauna (Holzinger et al. 2015). Twenty-six species were found to be autochthonous in at least one of the investigated stretches and were therefore classified as autochthonous in the investigation area as a whole (Tab. 2). Six autochthonous species from four associations were found in all four stretches (*Erythromma viridulum*, *Ischnura pumilio*, *Coenagrion puella*, *Ischnura elegans*, *Sympetrum vulgatum*, and *Platycnemis pennipes*; in the order of association to which they are allocated). Eleven autochthonous species were detected on both the standing water (A) and the slow flowing stretches B and/or C (*Anax imperator*, *Libellula depressa*, *Orthetrum albistylum*, *Orthetrum cancellatum*, *Sympetrum striolatum*, *Lestes viridis*, *Aeshna mixta*, *Coenagrion pulchellum*, *Libellula quadrimaculata*, *Crocothemis erythraea*, and *Sympetrum sanguineum*). Two breeding species were found only on the standing water stretch A (*Enallagma cyathigerum* and *Lestes sponsa*). Five species (*Erythromma viridulum*, *Lestes viridis*, *Ischnura elegans*, *Sympetrum vulgatum*, and *Platycnemis pennipes*) were allocated to the highest abundance class 5 on at least one of the stretches.

At the stretches A and C the highest total numbers of species were recorded (22), with C being the stretch with the highest number of autochthonous species (21). Association A2 (comprising 7 species) was represented by 5 autochthonous species, A4 (10 species) by 7 autochthonous species. Only one breeding species of A5 was found. All four *Orthetrum* species that occur in Middle Europe were found to occur autochthonously in the investigation area: *O. albistylum*, *O. brunneum*, *O. cancellatum*, and *O. coerulescens*.

When calculating the $DAI_{corr.}$ a value of 0.85 is obtained, which classifies the water body as being at "high ecological status". The correction factor has to be applied because 5 of the 6 type-specific associations are represented by at least two autochthonous species.

$$DAI_{corr.} = \frac{1x3+1x3+1x3+1x3+1x3+4x2}{17} - 0.5 = 0.85$$

Discussion

Particularly in heavily altered landscapes where pristine running waters and, therefore, reference sites are lacking, the results of stream classification and typology are of crucial importance as they provide a basis for the description of reference conditions, for the definition of deviations, and for an assessment of the success of restoration measures (e. g., Hughes et al. 2000, Ehlert et al. 2002, Wimmer et al. 2000). Depending on the river type, an increase in species numbers is not necessarily positively correlated with an improvement of the ecological status. In the case of rhithral zones for example, a lower number of species is considered to be river type-specific (Wildermuth & Küry 2009, Chovanec et al. 2015). Near-pristine lowland rivers typically contain high dragonfly species numbers (e. g., Raab 1998, Staufer & Schulze 2011). This is due to their heterogeneous habitat structures, which are suitable for Odonata, particularly floating macrophytes in slow flowing or standing river sections, riparian vegetation and sandy or gravel substrate. In addition, open banks in sections with higher flow velocities and temporary waters in floodplain areas tend to increase habitat heterogeneity.

In the case of the river type investigated in this study, species richness conforms to the reference situation ("high ecological status") and is a necessary requirement for achieving "good ecological status". The results obtained in this study underline the importance of river typology-based restoration measures and of sound methods for their assessment. The RT2 and RT3 measures implemented in this stream section have led to significant ecological improvements, as shown by the response of the dragonfly assemblage and by the "high ecological status": The stream's lateral expansion is more pronounced, which is typical of this river type. The increase in river sinuosity and in-stream habitat restoration, combined with river widening, has led to a mosaic of stream velocities and diverse riparian vegetation structures in the main channel, which have a positive effect on the river's structural diversity and encourage the development of a habitat rich in niches for Odonates: The dragonfly community, which colonizes the river channel comprises not only rheophilic and flow-tolerant euryoecious species, but also limnophilic species in flow-free, densely vegetated patches (e. g. Schmedtje & Colling 1996, Hardersen 2008, Chovanec et al. 2012). Of the 19 autochthonous species recorded on the standing water stretch A, 17 were also found to occur autochthonously on at least one of the running water stretches. Hence, autochthonous species of all five "standing water associations" (A1-A5) have been found to occur in the flowing sections of the investigated areas. The occurrence of the four species of the genus *Orthetrum*, which can be found in Central Europe and which have different habitat requirements (Raab et al. 1996, Schmedtje & Colling 1996, Sternberg & Buchwald 2000) indicates a variety of micro-habitats suitable for dragonflies, which are provided at the restored river section. In 2012, no high water levels occurred and, therefore, there were no inundations in the retention area. This may be the reason why only one species of A5 was found.

Regulated sections of the Weidenbach and other streams of the same type are colonized by no more than five autochthonous species and thus have "poor ecological status" (Chovanec et al. 2014a, 2015). As already shown in other studies (Chovanec 2014b, Chovanec et al. 2014a, b, 2015), RT1 measures lead to an improvement of habitat heterogeneity in the main channel, which can be seen from the higher species numbers found there, but these measures are not sufficient for this river type to reach "good ecological status": The habitat conditions are enhanced only for A7 species rather than for the whole type-specific species inventory.

The assessment method presented in this paper is based on ecological knowledge applied through a concise and sound calculation procedure, which includes an assessment scheme for lowland rivers. It meets the bioindication requirements (Noss 1990, Cairns et al. 1993, New 1993, Samways et al. 2010), which are also set out in the WFD and serves as a tool, which measures biological responses to human activities. As described in this study, the DAI-based approach has proved to be a sound and sensitive instrument for evaluating the success of mitigation measures. It is a system-oriented approach, which includes an assessment of all micro-habitats that characterize the lowland river type that has been investigated. Focusing exclusively on channel morphology may lead to a limited view of the ecological situation as a whole, particularly in the case of river types with a pronounced lateral dimension.

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