Assessing the success of lowland river restoration using dragonfly assemblages (Insecta: Odonata)

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The ecological status of straightened and restored stretches of a small river system ("Weidenbach") in the lowland areas of eastern Austria was assessed based on dragonfly surveys. Restoration measures were carried out to varying extent, ranging from measures aimed at the main channel (increasing sinuosity and in-stream habitat heterogeneity) to river-type-specific restoration (RTSR) focusing also on the lateral connectivity of the system (e.g., by river widening and constructing backwaters). The assessment, which is in compliance with the EU Water Framework Directive (WFD), is based on a comparison between the current situation ("status quo") and a river-type-specific reference condition. The key elements of the assessment are species composition and the Odonata Habitat Index (OHI). Stretches of the Weidenbach subjected to RTSR were characterised by higher species numbers and a broader range of OHIs than in the other areas of the same river, indicating a wider spectrum of relevant habitats. In RTSR areas, autochthonous populations of sensitive and threatened species such as *Coenagrion scitulum* and *Aeshna isosceles* were found. These areas were ranked as class II ("good dragonfly-related ecological status"), which represents the second best class and the quality target in the 5-tiered WFD classification scheme.

Chovanec A., Schindler M. & Rubey W., 2014: Bewertung des Erfolges von Restrukturierungsmaßnahmen an einem Tieflandfluss anhand der Libellenfauna (Insecta: Odonata).
In der vorliegenden Studie wurden Restrukturierungsmaßnahmen an einem Fließgewässer-System (Weidenbach) im östlichen Tiefland Österreichs auf der Grundlage libellenkundlicher Erhebungen evaluiert. Der Bewertungsprozess orientiert sich an den Vorgaben der EU Wasserrahmenrichtlinie (WRRL) zur Bestimmung des ökologischen Zustandes und basiert auf einem Vergleich der aktuellen Gewässersituation mit einem gewässertypspezifischen Referenzzustand. Dieser entspricht Klasse 1 („sehr guter ökologischer Zustand") in dem 5-stufigen WRRL-Schema. In die Bewertung flossen insbesondere das an den einzelnen Abschnitten nachgewiesene Arteninventar und die errechneten Odonata Habitat Indices (OHI) ein. Es wurden jene Abschnitte am besten bewertet, an denen die für den Gewässertyp relevante laterale Ausdehnung durch die Errichtung von Nebengewässern, Aufweitungen und die Erhöhung der Sinuosität des Hauptgerinnes gefördert worden war. Diese Bereiche waren durch hohe Zahlen limnophiler und rheophiler Arten und das autochthone Vorkommen sensitiver bzw. gefährdeter Species (z. B. *Coenagrion scitulum* und *Aeshna isosceles*) gekennzeichnet. Breitere Bereiche von OHI-Werten indizierten das reichere Angebot an libellenkundlich relevanten Habitaten. Der libellen-ökologische Zustand wurde hier mit Klasse 2 („gut") festgelegt. Dies entspricht der Qualitätszielvorgabe der WRRL.

Keywords: Odonata, Odonata Habitat Index, Weidenbach, Austria, Water Framework Directive, ecological status, river-type-specific assessment, reference condition, ecoregion.

Introduction

Under the European Water Framework Directive (WFD; Directive 2000/60/EC; European Community 2000) an overall assessment of river systems is required, with particular reference to the term "ecological status": The assessment includes, apart from pollution aspects, disturbances of river hydrology and morphology. In order to describe the status quo of rivers and the strategies employed to reach the targets specified in the WFD, national River Basin Management Plans (RBMP) have to be drawn up by the EU Member States.

According to the RBMP published for Austria (FMAFEWM 2010), 65% of the rivers with a catchment area > 10 km² fail to reach the quality objective "good ecological status". This is mainly due to regulation and channelisation of rivers and hydropower development leading to river fragmentation, reduced habitat heterogeneity, changes in the flow regime and disrupted lateral connectivity of rivers with wetlands and tributaries.

In the WFD, five classes of ecological status are defined: high – good – moderate – poor – bad. The "good ecological status" is defined as a slight deviation from the river-type-specific reference status (i.e., high status), which is in line with other international assessment philosophies (Karr & Chu 1999, Hughes et al. 2000). The assessment process 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 also include benthic invertebrates (Wimmer et al. 2000, Moog et al. 2004). In order to define reference conditions of a particular river stretch, the situation either known or assumed to have existed prior to large-scale channel regulations and industrialization (approx., the middle of the 19th century) has to be taken into account. Historical maps and faunistic data, as well as old paintings may provide useful information (Chovanec & Waringer 2001).

In modern landscapes used by man it is neither possible nor useful to re-establish pristine riverine conditions without abandoning current uses such as settlement, flood protection and agriculture. Reaching "good ecological status" has to be interpreted as a good political and scientific compromise between the sustainable use of waters and conservation or restoration needs, provided that the key characteristics of natural processes, structures, functions and compositions are developed (SER, 2004).

Apart from big rivers, it is particularly the rivers in lowland areas whose type-specific characteristics have been heavily altered by channelisation and large-scale drainage in the catchment areas. Within Austria, the European ecoregion Hungarian Lowlands, delineated by Illies (1978), is represented by the fluvial bioregion Eastern Ridges and Lowlands (Moog et al. 2004). The rivers of this bioregion with catchment areas > 10 km² have a length of approx. 4,750 km in Austria. Of these, only 30 km (0.6%) have been assessed as having "high ecological status", while 662 km (14%) have "good ecological status" (FMAFEWM 2010). The implementation of rehabilitation measures in rivers with altered type-specific characteristics presents a major challenge for water management and has been the subject of several studies (Wiesbauer & Rubey 2006).

Natural or near-natural lowland rivers are characterised by a species-rich dragonfly fauna (Chovanec 1999, Wildermuth & Küry 2009): River-type-specific features comprise running water sections, temporary stretches, wetland areas and backwaters. All these habitat types are potential habitats for different dragonfly communities. Macroinvertebrate- or fish-related assessment methods according to the WFD may not be applicable, e.g. in the case of small fish free rivers, standing or temporal systems.

Because of their quick response to habitat changes, dragonflies are suitable indicators for assessing the ecological effect of water management activities, such as river restoration. Dragonflies belong to the biological quality element benthic invertebrates specified in the WFD; their role as bioindicator focuses on the assessment of the land-water interface, river morphology and in-stream habitats, river-floodplain connectivity and hydrological conditions (Schmidt 1985, Waringer 1989, Samways 1993, Chovanec & Waringer 2001,

Chovanec et al. 2004, D'Amico et al. 2004, Samwald 2004, Kadoya et al. 2008, Oertli 2008, Simaika & Samways 2009, Silva et al. 2010).

The investigations presented in this paper were part of a study lasting three years (2009–2011) with the aim to develop a system for assessing the ecological quality of small lowland rivers' morphology based on dragonfly surveys and to evaluate restoration measures implemented at these rivers by applying this assessment scheme (see also Chovanec & Schindler 2011). As required under the WFD, a river-type-specific approach was used, which allows generalising methodology and results presented in this paper for other running waters of the same type in other lowland regions.

Methods

River typology:

Investigations were carried out at the Weidenbach and at one of its tributaries, the Sulzgraben (Fig. 1). The Weidenbach is a third order tributary to the Morava river; it is located in the lowlands of the Austrian province Lower Austria, a region called Weinviertel, in the northeastern part of Austria. The Weinviertel belongs to the Pannonian climate zone, with warm dry summers as well as cold winters with little snow (total yearly sum of precipitation 400–600 mm). The Weidenbach originates at 250 m above sea level. The difference in altitude along its course is about 100 m. It is 34 km long and drains a catchment of 227 km^2. The total length of the Weidenbach system, including its tributaries and adjacent ditches, is 58 km. The epipotamal Weidenbach belongs to the fluvial bioregion Eastern Ridges and Lowlands within the ecoregion Hungarian Lowlands. The total length of rivers with a catchment area > 10 km^2 located in the bioregion Eastern Ridges and Lowlands is 4,750 km in Austria, which corresponds to 16% of the length of Austria's total network of rivers with a catchment area > 10 km^2 (Gerabek 1964, Illies 1978, Wimmer et al. 2000, Moog et al. 2004, Wimmer & Moog 2004, FMAFEWM 2010).

The river system is hydrologically characterised by a winter-pluvial flow regime with an average annual discharge of 0.12 m^3s^{-1} and a high water discharge of 10.8 m^3s^{-1}. The pristine channel type can be described as wandering and meandering. As can be seen from the maps of the Josephinian Cartographical Register (18th 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 the Weinviertel. A painting by Kozlowsky (1932; Provincial Museum of Lower Austria) shows large periodical wetland areas in this landscape before the river has been regulated. Flow velocity used to be slow because of the shallow slope. With a length of 8.6 km the Sulzgraben is the largest tributary to the Weidenbach. The average annual discharge is less than 5 l/s^{-1}.

From the mid 19th century onwards, the character of the landscape has changed fundamentally following large-scale drainage and river regulation for the purpose of land reclamation and flood control. River courses were straightened and degraded by trapezoidal channelisation, steep embankments and narrow riparian strips. Wetland areas adjacent to the Weidenbach were reduced from 1,200 ha to 77 ha. According to the RBMP, the current ecological status of the Weidenbach water body, in which the investigation areas are situated, has been assessed as "poor" (FMAFEWM 2010).

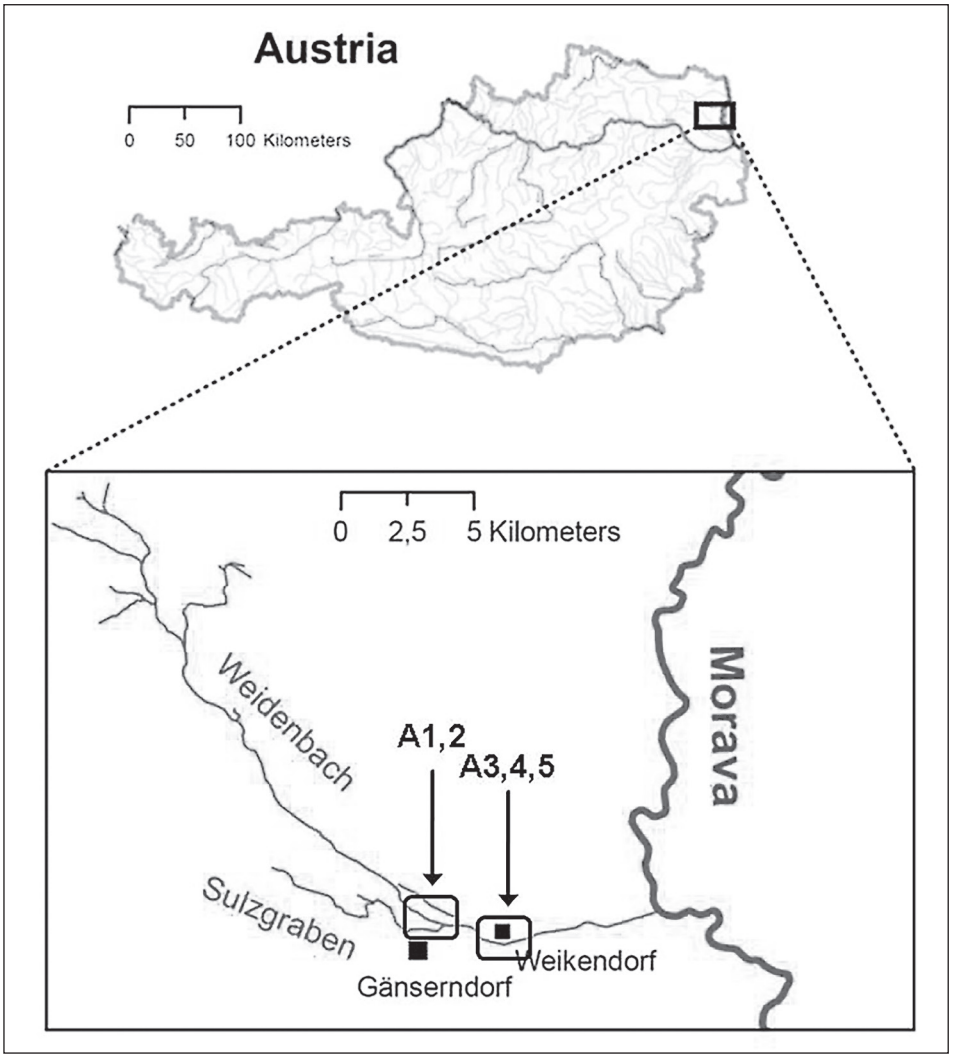

Fig. 1: Location of the investigation areas A1–A5. – Abb. 1: Lage der Untersuchungsgebiete A1–A5.

Within the last 10 years the Weidenbach was subjected to numerous restoration measures, which were aimed at an improvement of the existing flood protection 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 where the river was widened. These retention areas, which are largely free from other uses (especially agriculture), enable a certain degree of morphodynamic processes and lateral development.

In this study the ecological status of five investigation areas (A1–A5) located in the Weidenbach river system was classified (Fig. 1). In order to cover all relevant habitat types in each area, a number of representative and homogenous investigation sites (number varying

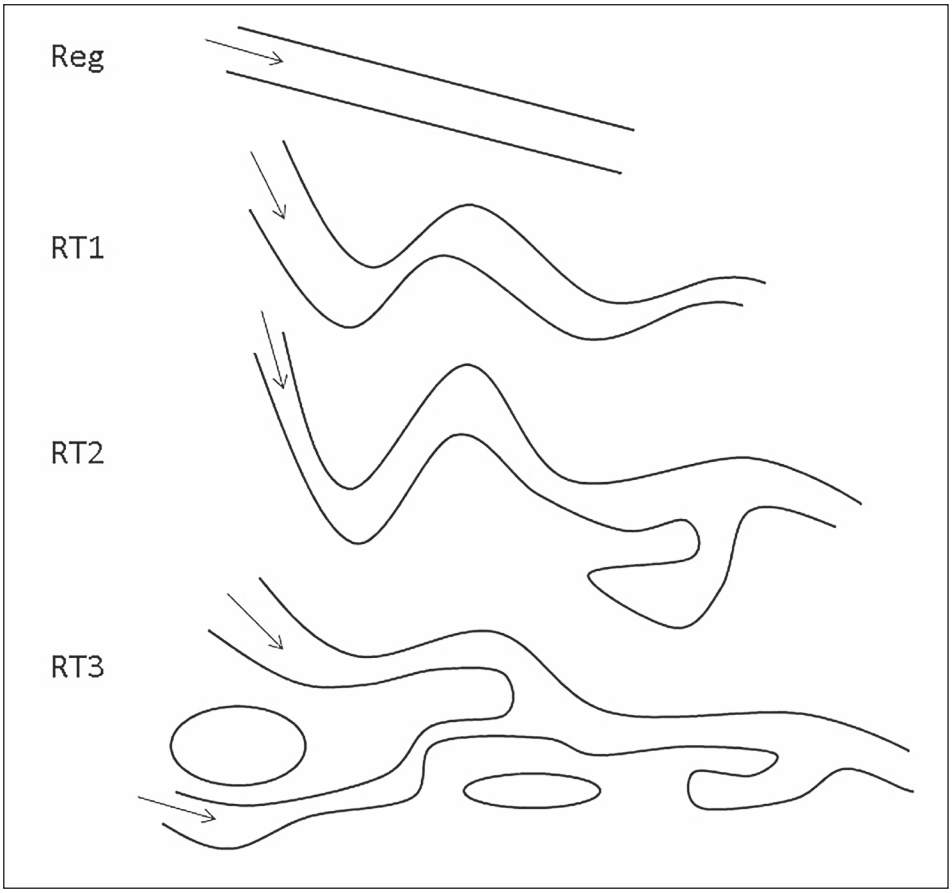

Fig. 2: Schematic illustration of the regulated stretch (Reg) and the different types of restoration (RT1, 2, 3) carried out at the Weidenbach system. – Abb. 2: Schematische Darstellung der regulierten (Reg) und restrukturierten Abschnitte (Restrukturierungstypen RT1, 2, 3) im System des Weidenbaches.

from 1 to 3 per investigation area) with a length of 100 m were chosen. The total number of investigated sites was 8 (I–VIII); all sites were exposed to the sun. Investigation areas were classified according to their morphological status, ranging from regulated stretches to river-type-specific restoration (Fig. 2).

Morphological status:

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 – investigation areas A2 and A4.

Restoration type 1 (RT1): Restoration measures along the main channel: increase of sinuosity, construction of in-stream structures (willow rootstocks, live fascines), riparian restoration, river widening – A5.

Restoration type 2 (RT2): Measures of restoration type 1 + creation of "blind" side channels connected to the main channel at the downstream end; thus considering lateral connectivity aspects to some extent – A3.

Restoration type 3 (RT3): Measures of restoration type 1 + measures to increase lateral connectivity by creating side arms and isolated backwaters, expanding riparian zones; located in retention areas – A1.

Investigation areas and sites:

The following areas were investigated. A1: Retention area with a size of about 10 ha at the confluence of Weidenbach and Sulzgraben situated in the town of Gänserndorf (48°20'N, 16°43'O; 167 m asl; Fig. 3). Restoration measures were carried out in 2006. Investigation sites were chosen at the restored sections of the Weidenbach and the Sulzgraben as well as at one of the created standing waters. The three sites (I, II, III) were characterised by riparian vegetation (macrophytes and reed) and single willows. Investigations were performed in 2010.

A2: Regulated stretch of the Sulzgraben situated in Gänserndorf, near A1, densely vegetated by terrestrial plants and helophytes. Because of the structural homogeneity only one investigation site (IV) was chosen. Investigations were carried out in 2010.

A3: Restored stretch of the Weidenbach (investigation site V), 2.5 km downstream A1, with backwater (length 100 m), connected at its downstream end with the main channel (investigation site VI). A3 is situated in the western parts of the village of Weikendorf (48°21' N, 16°46' O; 152 m asl). RT2 measures were implemented in 2004. Both sites are characterised by rush, reed and floating macrophytes. Investigations were carried out in 2009.

A4: Regulated stretch of the Weidenbach in Weikendorf, 1 km downstream A3 (investigation site VII), investigated in 2009.

A5: Restored stretch of the Weidenbach in the eastern part of Weikendorf, 2 km downstream A4 (Fig. 4). RT1 measures were carried out in 2006. Riparian vegetation is characterised by a small belt of helophytes. Investigations were performed at one investigation site (VIII) in 2009 and 2010. Data were aggregated for both years.

Data collection in the field:

In order to cover all phenological groups, five field trips were carried out at each investigation site between April and September 2009 and 2010. Sampling was performed on warm and sunny days between 11.00 and 16.00 h when dragonflies were most active at the water bodies. The investigations concentrated on counting adults and freshly hatched individuals. Specimens were identified by sight or by photographs. When necessary, individuals were caught with a handnet and released after identification.

The numbers of individuals recorded during the field investigations were converted into a five-class abundance system, for the specific purpose of calculating the Odonata Habitat Index: 1 – single, 2 – rare, 3 – frequent, 4 – abundant, 5 – extremely abundant. For allocating to abundance classes, species-specific habitat requirements and territorial behaviour patterns were considered (Tab. 1). Abundance class ranking was based on the field excursion during which the largest number of individuals was recorded.

Fig. 3: Investigation area A1 (restoration type RT3). Photo: A. Chovanec. – Abb. 3: Untersuchungsgebiet A1 (Restrukturierungstyp RT3), Foto: A. Chovanec.

Fig. 4: Investigation area A5 (restoration type RT1). Photo: A. Chovanec. – Abb. 4: Untersuchungsgebiet A5 (Restrukturierungstyp RT1). Foto: A. Chovanec.

Calculations and assessments were made on the basis of self-sustaining, autochthonous (resident, breeding) populations. According to an adapted scheme of Chovanec & Waringer (2001), the following criteria were considered to determine the autochthony of a species at an investigation site: Records of

– newly hatched specimens, and/or
– reproductive behaviour (copula, tandem, egg deposition), and / or
– imagines in abundance class 3, 4 or 5, and / or
– imagines at a site over a longer period of time (at least two surveys).

Species were classified as autochthonous in a particular area, if their autochthonous status was confirmed at least at one site situated in this area, or if, during a single survey, individuals of one species were recorded at two or more sites within this area.

Assessment:

Tab. 1: Allocation of individual numbers/100 m to abundance classes. – Tab. 1: Zuordnung der nachgewiesenen Individuenzahlen/100 m zu Abundanzklassen.

	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

Pursuant to the requirements of the WFD, an assessment method was developed for the investigated river type, based on a comparison between the status quo of the investigated river stretch and a river-type-specific dragonfly-related reference status ("high dragonfly-related ecological status"; class I). Since natural or near-natural stretches of the Weidenbach or another river of the same type are no longer existent, a potential dragonfly-related reference status was defined on the basis of river-typological characteristics (see above), historical faunistic data and zoogeographical aspects (Raab et al. 2007). Based on this potential reference status, the other classes of the ecological dragonfly-related status were described (class II–V).

To achieve "good ecological status" with regard to benthic invertebrates, the requirement according to WFD is that the following parameters deviate only minimally from type-specific biotic communities: taxa composition and abundance, proportion of type-specific, disturbance-sensitive taxa, and diversity of biotic community (FMAFEWM 2010). Hence, the assessment method developed for this study takes the following parameters into account:

– total number of autochthonous species
– number of sensitive autochthonous species: To consider species' sensitivity indication weights ranging from 1 to 5 are included in the Odonata Habitat Index (OHI) based on the algorithm according to Sladecek (1964); the values can be derived from the literature

about the OHI cited below. Sensitive species are defined as those with an indication weight classed as 3, 4 or 5.
– Odonata Habitat Index (also taking into account abundances).

The Odonata Habitat Index (OHI, Chovanec & Waringer 2001, Chovanec et al. 2004) was developed for the assessment of river floodplain systems, using an algorithm based on existing macrozoobenthic analyses such as the assessment of biological water quality and the calculation of longitudinal stream zonation patterns and functional feeding groups (Zelinka & Marvan 1961, Moog & Chovanec 2000). Further details on the OHI calculation can be found in the literature mentioned above.

The Index, which has to be calculated for each investigation site, may range between values of 1 and 5 and shows a species community's preference for a specific habitat type (Tab. 2). The habitat types H1–H5 follow a gradient of lateral connectivity with the main river channel, ranging from H1 (Eu/Parapotamon) to isolated temporary floodplain waters (H5, Palaeopotamon). The habitat types, shortly described below, are explained in detail in Chovanec & Waringer (2001). H1: Littoral areas of permanent, flowing waters or side arms with strong hydrological dynamics. H2: Littoral areas of permanent standing waters (backwaters) retaining a connection to the main channel; reduced hydrological dynamics; sedimentation low; open riparian area; poorly developed macrophyte communities. H3: Open water areas of permanent, standing backwaters with floating macrophytes; significantly reduced hydrological dynamics; sedimentation high. H4: Littoral areas of permanent standing waters with reed belts; significantly reduced hydrological dynamics; sedimentation high. H5: temporary pools drying up at least once throughout the year (mostly during late summer, autumn).

Tab. 2: Habitat types indicated by the values of the Odonata Habitat Index (OHI; Chovanec & Waringer, 2001). – Tab. 2: Werte des Odonata Habitat Index (OHI) und durch sie indizierte Habitattypen (Chovanec & Waringer 2001).

OHI value	Habitat type
1.0 – 1.7	H1
1.8 – 2.5	H2
2.6 – 3.3	H3
3.4 – 4.1	H4
4.2 – 5.0	H5

Results

Reference status and assessment scheme

The potential dragonfly-related reference status of the river-type investigated in this study can be described as follows: *Calopteryx splendens* is the rheophilic species found to be characteristic of the wider flowing river segments. Records of other rheophilic species (also in the wider river segments) include for example Gomphid species and rheophilic *Orthetrum*-species (*O. brunneum*, *O. coerulescens*). *Coenagrion ornatum* is a species characteristic of small, vegetated lenitic water bodies such as ditches (Chovanec et al. 2010, Waldhauser

& Mikat 2010). Autochthonous populations of species which are ecologically less specialized and also occur in running waters – such as *Platycnemis pennipes*, *Ischnura elegans* and *Sympetrum sanguineum* – can be found. The potamal features of the river's winding or meandering course favor the development of backwaters and flooded areas, whose hydrological connectivity with the main river varies depending on the status of their development and terrestrialisation. These habitats are colonised by lestid, coenagrionid, aeshnid, corduliid and libellulid species.

Due to the broad habitat spectrum associated with this river-type, which comprises flowing sections, standing and intermittent waters, the dragonfly fauna can be described as being rich in species (at least 15 autochthonous species). OHI values indicate the whole spectrum of habitat types: H1 which is dominant, representing flowing sections and H2–H5 indicating water bodies characterised by different levels of hydrological connectivity, terrestrialisation and water permanence.

Five classes of dragonfly-related ecological status were defined, on the basis of the reference status (i.e. class I; Tab. 3; see also Chovanec & Schindler 2011). This assessment scheme was applied to the individual areas investigated in this study. The assessment results there-

Tab. 3: Scheme for assessing the dragonfly-related ecological status of investigation areas belonging to the type "small epipotamal running waters of the bioregion Eastern Ridges and Lowlands within the ecoregion Hungarian Lowlands" (see also Chovanec & Schindler 2011). – Tab. 3: Schema zur Bewertung des libellenökologischen Zustandes von Untersuchungsgebieten, die dem Typ „Epipotamal-klein der Bioregion Östliche Flach- und Hügelländer der pannonischen Tiefebene" zuzuordnen sind (vgl. auch Chovanec & Schindler 2011).

High dragonfly-related ecological status Class I	**Good dragonfly-related ecological status Class II**	**Moderate dragonfly-related ecological status Class III**	**Poor dragonfly-related ecological status Class IV**	**Bad dragonfly-related ecological status Class V**
The number of autochthonous species (>15) and the proportion of sensitive autochthonous species are high.	The number of autochthonous species is reduced, sensitive autochthonous species occur.	The number of autochthonous species is distinctly reduced, sensitive autochthonous species occur.	Small number of autochthonous species; sensitive autochthonous species occur in very small numbers or are missing	No autochthonous species, therefore calculation of OHI is not possible.
Inventory of autochthonous species and calculated OHIs indicate dragonfly- relevant habitat diversity in the main river and at backwaters: stretches with flowing river character (H1), which are dominant, as well as stretches with varying terrestrialisation character (H2–H4) and temporary waters (H5) occur.	Inventory of autochthonous species and calculated OHIs indicate dragonfly-relevant habitat diversity in the main river and the presence of dragonfly-relevant habitats at backwaters. Habitat diversity is reduced compared to Class I.	Inventory of autochthonous species and calculated OHIs indicate dragonfly- relevant habitats in the main river with varying character, dragonfly- relevant backwaters are missing.	Inventory of autochthonous species and calculated OHIs indicate a reduction of dragonfly- relevant habitats in the main river, dragonfly- relevant backwaters are missing.	

fore refer specifically to these investigation areas rather than to the entire water body as delineated in the RBMP. Not all of the criteria listed in the descriptions have to be fulfilled for an area to be allocated to one of the classes; the class to be selected is the one whose description corresponds best to the overall aspect determined for the investigated area.

Status quo and assessment

In the five investigation areas a total of 28 dragonfly species were recorded, representing 36% of the Austrian Odonata fauna. Twenty-three species were found to be autochthonous in at least one of the investigation areas (Tab. 4). Of the 28 species 11 are classified as sensitive, with 9 of them being autochthonous. Six species (5 of them autochthonous) are listed in one of the threatened categories of the Austrian Red List (critically endangered, endangered, vulnerable; Raab et al. 2007). None of the species found is listed in the European Red List (Kalkman et al. 2010). *Platycnemis pennipes* and *Ischnura elegans* occurred at all investigation sites in autochthonous populations.

The results obtained at the regulated, straightened stretches show a dragonfly community poor in species: At site IV (located in A2) 6 species were recorded (4 of them autochthonous) and at site VII (in A4) 3 species (all autochthonous). The species spectrum is characterised by rheophilic and euryoecious species, therefore the values of the OHIs (1.83 and 1.48) indicate habitat type H1 and a transitional habitat type between H1 and H2, respectively. According to the criteria listed in Tab. 2, both areas are ranked as class IV ("poor dragonfly-related ecological status").

In A5 (restoration type RT1) 12 species were found, 7 of them autochthonous. The species inventory consists of rheophilic, euryoecious and limnophilic species characteristic of both open banks (*Orthetrum cancellatum*) and terrestrialisation zones (*Sympetrum sanguineum*). The OHI value (2.47) indicates H2. The number of individuals was found to be low for most species. According to the assessment criteria, the area meets the requirements for class III ("moderate dragonfly-related ecological status").

Thirteen species (12 autochthonous) were recorded in A3 (RT2) with two investigation sites. At one of the sites, situated within the flowing section of the Weidenbach (site V), 9 autochthonous species were found. Besides the occurrence of rheophilic species, limnophilic species appeared at lenitic or standing patches within this river stretch. Therefore the OHI calculated for this site was 2.38 (H2). At the standing backwater of the Weidenbach (site VI) euryoecious and limnophilic species were recorded with an OHI of 2.92 indicating H3. The data collected in this investigation area correspond to class II ("good dragonfly-related ecological status").

A1 (RT3) was the area where the most species were recorded: 26, with 21 of them autochthonous. The restored section of the Sulzgraben (site II) was the flowing section with the highest species number (17/10) investigated in this study. The backwater investigated in this area (site III) was characterised by very high species numbers (19/17) and a high number of individuals. Four of the 5 endangered autochthonous dragonfly species and 7 of the 9 sensitive autochthonous species recorded in this study were found in this area, e.g. *Coenagrion scitulum* and *Aeshna isosceles*. The OHI values range from 2.11 to 3.09 (H2, H3). According to the criteria listed in Tab. 2, A1 is ranked as class II ("good dragonfly-related ecological status"), coming close to class I.

Tab. 4: Dragonfly species recorded at Weidenbach (WB) and Sulzgraben (SG). * autochthonous species. Reg regulated stretch. RT restoration types. S sensitive species. BW backwater. RLA Red List Austria: CR - Critically Endangered; EN - Endangered; VU - Vulnerable; NT - Near Threatened; LC - Least Concern. Abundance classes: 1 – single; 2 – rare; 3 – frequent; 4 – abundant; 5 – extremely abundant. – Tab. 4: Libellennachweise an Weidenbach (WB) und Sulzgraben (SG). * bodenständige Arten. Reg regulierter Abschnitt. RT Restrukturierungstypen. S sensitive Arten. BW Nebengewässer. RLA Rote Liste Österreich: CR – vom Aussterben bedroht; EN – stark gefährdet; VU – gefährdet; NT – Gefährdung droht; LC – nicht gefährdet. Abundanzklasssen: 1 – Einzelfund; 2 – selten; 3 – häufig; 4 – sehr häufig; 5 – massenhaft. UB: Untersuchungsgebiet.

Investigation area restoration type			**A1 RT3**				**A2 Reg**	**A3 RT2**			**A4 Reg**	**A5 RT1**
Investigation site	S	RLA	I	II	III	I–III	IV	V	VI	V–VI	VII	VIII
			WB	SG	BW		SG	WB	BW		WB	WB
Calopteryx splendens (Harris)	☑	NT	4*	3*		*	3*	4*	2	*	3*	3*
Sympecma fusca (Vander Linden)		VU		4*	5*	*						
Lestes barbarus (Fabricius)	☑	EN										1
Lestes sponsa (Hansemann)		LC		1								
Lestes viridis (Vander Linden)		LC	2	3*	3*	*						1
Platycnemis pennipes (Pallas)		LC	2*	3*	3*	*	4*	4*	5*	*	5*	5*
Coenagrion puella (Linnaeus)		LC	3*	4*	4*	*	4*	2*	2*	*		2*
Coenagrion scitulum (Rambur)	☑	CR			3*	*						
Erythromma najas (Hansemann)	☑	NT			3*	*						
Erythromma viridulum (Charpentier)	☑	LC	2		5*	*		4*	5*	*		
Ischnura elegans (Vander Linden)		LC	3*	4*	4*	*	4*	4*	4*	*	2*	4*
Ischnura pumilio (Charpentier)	☑	NT			2*	*						2
Aeshna cyanea (Müller)		LC	1		2	*						
Aeshna isosceles (Müller)	☑	VU		2	1	*	1					
Aeshna mixta (Latreille)	☑	LC		1				2*	2*	*		
Anax imperator (Leach)		LC		1*	2*	*			2*	*		1
Cordulia aenea (Linnaeus)		LC			3*	*						
Somatochlora metallica (Vander Linden)		LC		1								
Epitheca bimaculata (Charpentier)	☑	EN	1*			*						
Libellula depressa (Linnaeus)		LC		1								
Orthetrum albistylum (Sélys)		LC	2*		3*	*			2*	*		
Orthetrum brunneum (Fonscolombe)	☑	NT							1			
Orthetrum cancellatum (Linnaeus)		LC	3*	2	3*	*		2*	2*	*		3*
Crocothemis erythraea (Brullé)		LC		2	3*	*						
Sympetrum meridionale (Sélys)	☑	CR	2									2*
Sympetrum sanguineum (Müller)		LC	3*	3*	5*	*	2	2*	2*	*		3*
Sympetrum striolatum (Charpentier)		LC		1*	2*	*			2*	*		
Sympetrum vulgatum (Linnaeus)		LC	1	2*	2*	*		2*	2*	*		2
No. of spp.	11	6	13	17	19	26	6	9	13	13	3	12
No. of autochth. spp.	9	5	8	10	17	21	4	9	11	12	3	7
Odonata Habitat Index			2.11	2.54	3.09		1.83	2.38	2.92		1.48	2.47

Discussion

Particularly in profoundly altered landscapes where actual reference sites are lacking, results of stream classification and typology are of crucial importance in that they provide a basis for the set-up of reference conditions, the definition of deviations and the assessment of restoration success (Ehlert et al. 2002). Depending on the river type, increasing species numbers are not necessarily positively correlated with an improvement of the ecological status. In the case of rhithral zones, of running waters for example, a lower number of species has to be defined as river-type-specific (Wildermuth & Küry 2009, Küry & Christ 2010). However, in the case of the river type investigated in this study, species richness conforms to the reference situation ("high ecological status") and has to be required for achieving "good ecological status". The results obtained in this study underline the importance of both typologically based restoration measures and their sound assessment.

River-type-specific restoration performed in A3 and particularly A1 have led to an improvement of the ecological conditions, as expressed by the dragonfly assemblage response (Fig. 5). The measures implemented in these investigation areas can be considered successful: The river system has a more pronounced lateral expansion, which corresponds to the river-type with backwaters and a variety of relevant dragonfly-related habitat types. River widening and increasing sinuosity have resulted in gradients of water flow and terrestrialisation conditions with a positive effect on structural diversity and the development of a habitat rich in niches for Odonata assemblages. The species spectrum and OHI values of A1 indicate a mosaic of standing waters and lotic and lenitic running water sections with a diverse riparian vegetation and high sinuosity. The near-natural, extensively managed water-related terrestrial system in the retention area of A1 also has a positive effect on the dragonfly fauna.

The data illustrate that restoration type 1 leads to an improvement of the habitat heterogeneity in the main channel, expressed by higher species numbers. The increase of 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. At all investigation sites of RT1, enhanced habitat heterogeneity has led to an increased number of autochthonous species (between 7 at site VIII and 10 at site II): The odonata assemblage is not only comprised of rheophilic and euryoecious, flow-tolerant species, but also of limnophilic species colonising flow-free, densely vegetated patches, which is also clearly expressed by corresponding OHI values >2. However, the implementation of RT1 is not

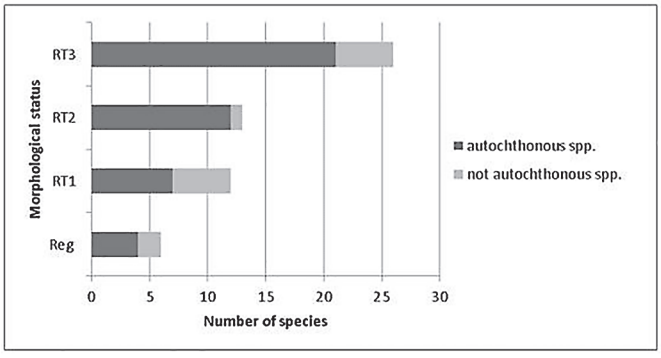

Fig. 5: Number of dragonfly species recorded at regulated sections (Reg) of Weidenbach and Sulzgraben and sections subjected to different restoration types (RT1–3). – Abb. 5: Anzahl der an den regulierten (Reg) und restrukturierten (RT1–3) Abschnitten von Weidenbach und Sulzgraben nachgewiesenen Libellenarten.

enough to reach "good dragonfly-related ecological status". But stretches subjected to RT1 may serve as important ecological stepping stones within the river system, for example between RT3 areas.

For the straightened river stretches, the species lists and OHI values (A2: 1.83; A4: 1.48) indicate – corresponding to the homogenous morphological structures and the limited range of habitats – a dragonfly assemblage dominated by a few rheophilic and flow tolerant species: In A2 and A4 only one sensitive autochthonous species was found.

The evaluation method presented in this study is based on the implementation of ecological knowledge in a concise calculation procedure and assessment scheme. The OHI (Chovanec & Waringer 2001) has been developed to extend existing metrics, to meet the requirements of bioindication set out in the WFD and to provide a sensitive tool reflecting biological responses to human activities (see also Karr & Chu 1999). Carrying out dragonfly surveys to assess rehabilitation measures at lowland rivers has proved to be a successful methodical approach: Different habitat patches are colonised by dragonfly assemblages which differ significantly from each other, both in terms of species composition and the parameters derived thereof (OHI). With regard to the river-type-specific reference status, which also includes temporary, fish-free and stagnant waters, dragonflies are reliable indicators since they inhabit all these habitat types and meet the requirements of biological indicators (Cairns et al. 1993, New 1993, Samways et al. 2010). As a further step, the approach described in this paper will be applied not only to evaluate individual measures but also to assess the morphological status of water stretches of this river type as a whole.

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