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ASSESSMENT OF THE ECOLOGICAL STATUS OF DANUBIAN FLOODPLAINS AT TULLN (LOWER AUSTRIA) BASED ON THE ODONATA HABITAT INDEX (OHI)

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The ecological status of waterbodies situated in a Danubian floodplain section at Tulln (Lower Austria) was assessed by a dragonfly survey using the "Odonata Habitat Index" (OHI) approach suggested by CHOVANEC & WARINGER (2001, *Regulated Riv. Res. Mngmt* 17: 493-507). The investigation was carried out at 28 standing water bodies and 2 reference sites situated directly at the Danube. Stretches of 100 m shorelength were mapped and the "Representative Spectrum of Odonata Species" (SCHMIDT, 1985, *Odonatologica* 14: 127-133) was recorded. Only autochthonous spp. were used for the assessment procedure. A total of 11 Zygoptera and 20 Anisoptera spp. was recorded, 29 of them autochthonous. Site-specific Odonata Habitat Indices ranged from 1.72 to 3.67. The OHI of the only reference site where Odonata were detected directly at the Danube was 1.38. The mean OHI for the whole floodplain section was 2.79. These figures indicate a relatively high level of habitat diversity. By comparing this status quo with reference conditions derived from the overall habitat situation before the regulation and from old species inventories dating back to the 19th century, the status of the Tulln floodplain section was ranked as class II ("good ecological status") in a 5-tiered classification scheme.

INTRODUCTION

The dynamic interaction between water and land is the principal impetus that created floodplains and controls their characteristic functional processes (TOCKNER et al., 2000), thereby maintaining the ecological integrity of river-floodplain systems. Aspects of lateral connectivity are considered to be especially indicative of this ecological integrity of alluvial rivers (e.g. AMOROS & ROUX, 1988; BAYLEY, 1995; WARD & STANFORD, 1995; WARD et al., 1999), and the relevance of bioindicator groups has been comprehensively discussed (e.g. WARINGER-LÖSCHENKOHL & WARINGER, 1990; SCHIEMER & WAIDBACHER, 1992). Within this framework, dragonflies play an essential role (e.g. WARINGER, 1989; CHWALA & WARINGER, 1996; WASSERMANN, 1999; CHOVANEC & WARINGER, 2001; CHOVANEC et al., 2002). Odonata have evolved a wide range of physiological, morphological and behavioural adaptations, allowing them to colonise the wide range of lotic and lentic habitats typically present in functioning flood plain systems. This ability makes them powerful indicators for evaluating the ecological quality of land-water ecotones, habitat heterogeneity (e. g. bank morphology and aquatic vegetation) and the hydrological dynamics of water bodies (SCHMIDT, 1985; CORBET, 1993; SAMWAYS, 1993; CHOVANEC & RAAB, 1997).

The use of dragonflies as bioindicators benefits from a long tradition of ecological work on this insect group which led to an advanced knowledge of their ecological needs and offers many advantages: The relatively small number of dragonfly species is mostly identifiable in the field, by photographs or by examining exuviae, thereby matching the principles of conservation. In addition, the relatively long ontogenetic development of odonate species meets requirements for medium to long-term monitoring, and their migration behaviour enables them to rapidly colonize new habitats.

The aim of the present study was, therefore, to use the bioindication potential of Odonata for the study of poorly-investigated floodplain water bodies situated within the riverine forests of the Danube at Tulln (Lower Austria) and to assess the ecological status of this Danubian floodplain section by using the procedure suggested by CHOVANEC & WARINGER (2001).

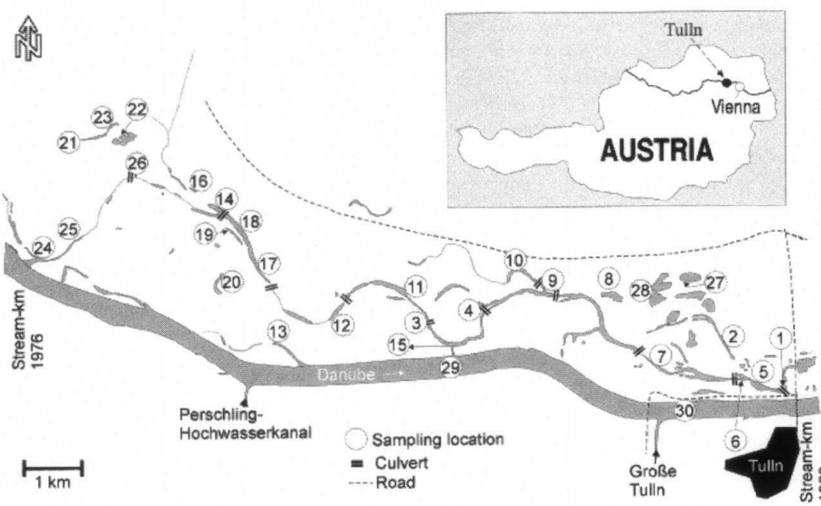

Fig. 1. Map of the study area, showing the Danube, its tributaries (Perschling-Hochwasserkanal, Große Tulln) and standing water bodies within the riverine forests along the northern bank. Encircled numbers indicate the sampling sites. The upper right insert highlights the position of the sampling area within the borders of Austria.

STUDY AREA

The Danube is 2850 km long and, by this, the second largest river in Europe. It rises in the German Black Forest, crosses a catchment of approximately 805300 km² and discharges into the Black Sea. The river enters Austrian territory at the German city of Passau, transverses the Federal states of Upper Austria, Lower Austria and Vienna and leaves Austria a short distance upstream of the city of Bratislava. This Austrian stretch of the Danube is 352 km long which is equivalent to 12.3% of the Danube's total length.

According to the Strahler-system the Austrian Danube is a 9th order stream (WIMMER & MOOG, 1994) with an average mean discharge of 2.000 m^3/s. The flow regime is primarily influenced by large alpine tributaries, with highest water levels in late spring and early summer. The Austrian Danube can be characterised as relatively steep stretch with an average slope of 0.44 ‰ and with high current velocities (2.0-2.65 m/s^{-1} in the line of maximum velocity of flow).

Historically, the anthropogenic influence on the Austrian stretch of the Danube may be divided into three phases: after the regulation in the 19th century (phase 1), the first dam of an hydroelectric power plant was constructed in the early 1950s (phase 2). Finally, up to now (phase 3), the Austrian Danube has been tranformed into a power-generating waterway where the former continuity of the river is now interrupted by ten dams used for hydroelectric purposes. Currently, the Wachau and the section between Vienna and the eastern border of Austria remain the only stretches of the Austrian Danube where the hydrological, sedimentological and ecological conditions of an unobstructed, natural river still apply.

Our study site (Fig. 1) is in the backwater area above the hydroelectric power plant of Greifenstein and near the city of Tulln (altitude: 180 m; 48°20'N, 16°04'E). At the study site the Danube is confined within artificial banks and paved with boulders; the river is approximately 350 m wide. Water backs up from the dam of the powerplant and therefore the maximum surface water velocity is significantly reduced when compared with the situation at the free-flowing Danube; at the study site, the mean water velocity is 0.68 m/s^{-1} at baseflow. Annual fluctuations in water temperature of the Danube are high (0-21°C). At both sides of the Danube, many pools, ponds, cut-off side arms and flooded gravel pits are located within the riverine forests of the floodplain which, in addition to two reference sampling stations directly at the Danube, were the focus of the present study. Most waterbodies investigated in the present study are part of a restoration project ("Gießgang Greifenstein") which tried to improve the water supply by artificially connecting individual waterbodies and by re-establishing river-floodplain interactions (cf. WIMMER & CHOVANEC, 1999). As the sites have been described in detail by SCHULTZ (2002), only a brief account on the environmental parameters acting at each sampling site is given in Table I.

MATERIAL AND METHODS

The evaluation of the ecological integrity of river/floodplain systems is based on a comparison between the reference condition and the status quo of a given area. The degree of deviation from the former indicates the extent of human impacts. As the procedure has been described in detail by CHOVANEC & WARINGER (2001), only a brief account is given here.

Before actual field work starts field excursions were carried out in order to select representative sampling sites reflecting the proportion of different habitat types present in the study area. A quantification of the habitat types was made by measuring shoreline lengths per habitat type by using official maps (scale = 1:25 000). Sampling sites representing different habitat types were observed occasionally at the same water body. To maintain a high degree of comparability, larger water bodies were divided into stretches of 100 m shoreline length; smaller ones were investigated in total.

Field collections were performed in optimal weather conditions for dragonflies. In order to cover all phenological groups (from early spring species to late summer/autumn species) and to record the "Representative Spectrum of Odonata Species" (SCHMIDT, 1985) 41 field trips between 25 April 2001 and 30 April 2002 were performed. Abundance estimates were ranked within a five class system: 1: single;

Table I

Habitat templates acting at the thirty sampling sites shown in Fig. 1. For each parameter, its impact at the given site is indicated by a numeral ranging from 0 to 3 (0= negligible; 3= very high importance)

	Environmental variables									
Site	Water current	Reed belts	Floating leaves	Open water surface	Riparian trees & brush	Open banks	In-solation	Tempo-rary water	Arti-ficial water	Rip-rap
1	1	0	1	3	2	1	3	0	3	1
2	0	3	1	3	2	0	3	0	0	0
3	3	1	0	0	2	0	2	0	2	2
4	1	3	1	2	1	0	3	0	0	1
5	0	1	3	3	2	1	3	0	0	0
6	3	3	1	0	1	1	2	0	0	0
7	0	3	3	3	0	0	3	0	0	0
8	0	0	0	3	1	2	3	0	3	0
9	0	3	2	3	2	0	3	0	0	0
10	0	3	1	2	3	0	2	0	0	0
11	0	2	0	0	2	0	2	0	0	0
12	0	3	0	0	3	0	2	0	0	0
13	0	3	1	0	3	1	1	2	0	0
14	1	1	2	3	2	0	3	0	0	2
15	0	3	0	3	3	0	2	0	0	1
16	0	3	1	0	2	0	3	3	0	0
17	0	3	0	0	1	0	3	0	0	0
18	0	1	3	3	2	0	3	0	0	0
19	0	1	1	3	3	0	0	0	0	0
20	0	3	1	0	2	0	3	0	0	0
21	0	2	0	0	3	1	3	0	2	0
22	0	1	2	3	2	3	3	0	3	0
23	0	3	1	0	3	0	2	3	0	0
24	2	3	0	3	3	0	2	0	3	0
25	1	2	0	0	1	0	3	0	3	0
26	0	3	3	2	3	0	2	0	0	0
27	0	0	0	3	1	3	3	0	3	0
28	0	1	1	3	2	1	3	0	3	0
29	3	0	0	3	3	0	2	0	2	3
30	3	1	0	3	3	0	2	0	2	3

2: rare; 3: frequent; 4: abundant; 5: extremely abundant. Abundance class ranking was based on the field excursion with the largest number of individuals recorded.

Since the assessment approach emphasises breeding species with self-sustaining populations, the determination of autochthony is essential. Exuviae were the most important indicators of resident populations. For collecting exuviae the riparian vegetation, emerging parts of water plants, dead wood and abiotic riparian structures such as steep banks and gravel substrate were surveyed thoroughly at each field sampling date following the time schedule of SCHMIDT (1985). Identification of exuviae was made according to HEIDEMANN & SEIDENBUSCH (1993). In addition to exuviae, newly hatched imagines, larvae, reproductive behaviour (copula, tandem, egg deposition), territorial behaviour, imagines in abundance class 3, 4 or 5, imagines observed over a period > 1 month and the record of a given species at several water bodies within the study area were used as indicators for autochthony.

The parameters necessary for the calculation of the Odonate Habitat Index (OHI) is the species inventory, the species-specific habitat value, the indication weight and the abundance for each species. In order to describe the habitat preferences numerically, a 10-point system was used. According to specific habitat preferences, 10 valency points were distributed among five habitat types. For example, a species exclusively inhabitating temporary pools is given 10 valency points in the relevant category (H5: 10); for eurytopic species occurring in a wide range of stagnant waters of a floodplain system, the 10 points available will be more or less evenly distributed between different categories (H1: 2, H2: 2, H3: 2, H4: 2, H5: 2). This valency point distribution procedure has been developed on the basis of the authors' recordings in the investigation area as well as at other sites, on autecological data and on expert consulting. Indication weights ranging from 1 for eurytopic species to 5 for stenotopic species (calculation according to SLADECEK (1964)) have been allocated to each species in order to identify sensitive species (indication weight ≥ 3).

The assessment is based on the abundance of a set of dragonfly species appearing in river/floodplain systems within specific habitat types. These habitat types (H1-H5) follow a gradient of lateral connectivity with the main river channel, ranging from H1 (Eu-/Parapotamon) to isolated floodplain waters (H5; Palaeopotamon). The definition of these types is in line with habitat templates described for dragonfly associations (JACOB, 1969; WARINGER, 1989; CHWALA & WARINGER, 1996) and with backwater classifications (WARINGER-LÖSCHENKOHL & WARINGER, 1990; WARD & STANFORD, 1995):

H1: Eupotamal permanent water bodies; the main river channel and its littoral areas and associated inshore structures; permanently connected side channels with high hydrological connectivity reflecting water level fluctuations of the main channel; no sedimentation processes; +/- lotic backwater sections downstream artificial openings of weirs; no macrophyte communities in the open water, open banks or *Phalaridetum* stands in the littoral area, riparian trees and shrubs; sand and gravel substrates are dominating.

H2: Littoral areas of parapotamal (e.g. dead arms retaining a connection to the main channel) or plesiopotamal (e.g. former braided segments that became disconnected from the main channel) standing and permanent backwaters; littoral areas of large gravel pits in the floodplain area; (significantly) reduced hydrological connectivity and dynamics; open banks; only few macrophytes (e.g. *Phalaridetum*); riparian trees and shrubs; high proportion of sand and gravel substrates.

H3: Open water areas of plesio- and palaeopotamal permanent standing waters and gravel pits, typically with floating macrophytes; significantly reduced hydrological connectivity and dynamics; high degree of sedimentation; dominating macrophyte associations: *Myriophyllo-Nupharetum.*

H4: Littoral areas of plesio- and palaeopotamal permanent standing waters and gravel pits with reed belts; significantly reduced hydrological connectivity and dynamics; sedimentation high; dominating macrophyte associations: *Phragmitetum, Typhetum, Sagittario-Sparganietum*; sludgy sediments dominate.

H5: Temporary pools; hydrological connectivity and dynamics significantly reduced; sedimentation high; at least one dried-up period per year (mostly summer-autumn); dominating macrophyte associations: *Phragmitetum, Typhetum, Sagittario-Sparganietum, Magnocaricetum*; terrestrial vegetation.

As this classification refers to potential dragonfly habitats and not to whole water bodies, several types may occur at one water body: e.g. littoral and open water areas of a disconnected backwater may be classified as H2, H3, and H4.

Individual species-specific habitat values (HV) are calculated by the following equation:

$$HV = \frac{(1 \times H1 + 2 \times H2 + 3 \times H3 + 4 \times H4 + 5 \times H5)}{10}$$

with HV-values ranging from 1 to 5 (rheotopic species: HV = 1; species preferring temporary waters: HV = 5).

Table II
Dragonfly species so far reported from floodplain waterbodies of the Austrian Danube, showing habitat valencies, habitat values (HV) and indication weights (IW). H1-H5 refers to habitat types defined in the methods section

Species	H1	H2	H3	H4	H5	HV	IW
CALOPTERYGIDAE							
Calopteryx splendens (Harris)	9	1				1,1	5
Calopteryx virgo (Linnaeus)	10					1,0	5
LESTIDAE							
Lestes barbarus (Fabricius)				2	8	4,8	4
Lestes dryas Kirby				2	8	4,8	4
Lestes sponsa (Hansemann)	1	1		4	4	3,9	1
Lestes virens Charpentier				4	6	4,6	3
Lestes (Chalcolestes) viridis (Vander Linden)	1	2		3	4	3,7	1
Sympecma fusca (Vander Linden)	1	1	2	5	1	3,4	1
PLATYCNEMIDIDAE							
Platycnemis pennipes (Pallas)	4	3	2	1		2,0	1
COENAGRIONIDAE							
Coenagrion hastulatum (Charpentier)			2	6	2	4,0	3
Coenagrion puella (Linnaeus)	1	2	2	4	1	3,2	1
Coenagrion pulchellum (Vander Linden)	1		2	7		3,5	3
Coenagrion scitulum (Rambur)			6	4		3,4	3
Cercion lindeni (Selys)	1		6	3		3,1	3
Enallagma cyathigerum (Charpentier)	2	1	5	2		2,7	1
Erythromma najas (Hansemann)	1		8	1		2,9	4
Erythromma viridulum (Charpentier)	1		8	1		2,9	4
Ischnura elegans (Vander Linden)	1	3	2	3	1	3,0	1
Ischnura pumilio (Charpentier)		1		2	7	4,5	3
Ceriagrion tenellum (De Villers)		1	1	7	1	3,8	2
Pyrrhosoma nymphula (Sulzer)	2		2	6		3,2	3
AESHNIDAE							
Aeshna affinis Vander Linden				9	1	4,1	5
Aeshna cyanea (Mueller)	1	2	3	4		3,0	1
Aeshna grandis (Linnaeus)		1	6	3		3,2	3
Aeshna isosceles (Mueller)			3	7		3,7	4
Aeshna juncea (Linnaeus)			3	7		3,7	4
Aeshna mixta Latreille		1	3	6		3,5	3
Aeshna viridis Eversmann			6	4		3,4	3
Anax imperator Leach	1	1	5	3		3,0	1
Anax parthenope Selys			5	5		3,5	3
Brachytron pratense Mueller	1		1	8		3,6	4
Hemianax ephippiger (Burmeister)			5	5		3,5	3

Table II, continued

Species	H1	H2	H3	H4	H5	HV	IW
GOMPHIDAE							
Gomphus flavipes (Charpentier)	10					1,0	5
Gomphus vulgatissimus (Linnaeus)	7	3				1,3	4
Onychogomphus forcipatus (Linnaeus)	9	1				1,1	5
Ophiogomphus cecilia (Fourcroy)	10					1,0	5
CORDULEGASTRIDAE							
Cordulegaster boltoni (Donovan)	10					1,0	5
CORDULIIDAE							
Cordulia aenea (Linnaeus)		5	2	3		2,8	2
Epitheca bimaculata (Charpentier)		2	6	2		3,0	3
Somatochlora flavomaculata (Vander Linden)		1	2	7		3,6	3
Somatochlora meridionalis Nielsen	9	1				1,1	5
Somatochlora metallica (Vander Linden)		5	2	3		2,8	2
LIBELLULIDAE							
Crocothemis erythraea (Brullé)		5	3	2		2,7	2
Leucorrhinia pectoralis (Charpentier)				8	2	4,2	4
Libellula depressa Linnaeus		4	2	1	3	3,3	1
Libellula fulva Mueller	6	2		2		1,8	3
Libellula quadrimaculata Linnaeus		1	2	7		3,6	3
Orthetrum albistylum (Selys)	1	7	1	1		2,2	2
Orthetrum brunneum (Fonscolombe)	7	3				1,3	4
Orthetrum coerulescens (Fabricius)	6		1	2	1	2,2	2
Orthetrum cancellatum (Linnaeus)	1	7	1	1		2,2	2
Sympetrum danae (Sulzer)				4	6	4,6	3
Sympetrum depressiusculum (Selys)				7	3	4,3	4
Sympetrum flaveolum (Linnaeus)				3	7	4,7	4
Sympetrum fonscolombei (Selys)		6		2	2	3,0	3
Sympetrum meridionale (Selys)				5	5	4,5	3
Sympetrum pedemontanum (Mueller)	1	2		6	1	3,4	2
Sympetrum sanguineum (Mueller)		2		5	3	3,9	2
Sympetrum striolatum (Charpentier)		4	1	3	2	3,3	1
Sympetrum vulgatum (Linnaeus)		2	1	5	2	3,7	1

The Odonate Habitat Index is based on the summation of the habitat values, abundances and indication weights of all species present at the sampling site and is calculated using the following equation:

$$OHI = \frac{\Sigma\ (HV \times A \times IW)}{\Sigma\ (A \times IW)}$$

where HV is the habitat value, A is the estimated abundance (classes 1-5) and IW is the species-specific indication weight. This results in a number between 1 and 5, indicating habitat preferences of the dragonfly community breeding at the investigation site. CHOVANEC & WARINGER (2001) have compiled a reference species list for the Austrian Danube based on the results of recent investigations, and the ecological requirements of potential species characteristic of floodplain systems (Tab. II). This inventory corresponds to a large extent to the species inventory obtained from historical data (BRAUER, 1851, 1856; BRAUER & LÖW, 1857; VORNATSCHER, 1938). Therefore, this species list consisting of 60 species from 9 families can be used as target or reference list for this area. 60 % of these species can be classified as sensitive species.

By comparing the status quo of a river/floodplain system with reference conditions, deviations caused by disturbances become visible and have to be classified into five classes. Most importantly, the definition of reference criteria – such as abiotic habitat criteria and potentially occurring species – must take into account the specific characteristics of each river type. This is why only general criteria for this dragonfly-based approach are given, leaving room for adaptations to specific conditions (Tab. III).

RESULTS

SPECIES COLLECTED

During the investigation period, a total of 11 Zygoptera and 20 Anisoptera species was recorded (Tab. IV); this number is equivalent to 51.7% of the species inventory so far reported from Danubian floodplains in Austria (Tab. II) and to 40.3% of the Austrian Odonata species. With the exception of *Pyrrhosoma nymphula* and *Ophiogomphus cecilia*, the autochthony of the remaining species could be confirmed by records of larvae or exuviae and/or by the criteria summarized in the methods section. In addition, fifteen species belong to the group of sensitive (stenotopic) species (indication weights ≥3) with *Calopteryx splendens* (maximum abundance class = 5) and *Gomphus vulgatissimus* (maximum abundance class = 4) being the only truly rheophilic species. Abundant and/or widespread odonates in the study area were *Calopteryx splendens*, *Platycnemis pennipes*, *Lestes viridis*, *Coenagrion puella*, *Enallagma cyathigerum*, *Ischnura elegans* and *Sympetrum sanguineum*. Red-list species classified as "regionally extinct", "critically endangered" or "endangered" in Lower Austria (RAAB & CHWALA, 1997) include *Coenagrion pulchellum* (maximum abundance class at the study area = 3), *Aeshna isosceles* (2), *Anax parthenope* (2), *Brachytron pratense* (3) and *Leucorrhinia pectoralis* (maximum abundance class = 4) (Tab. IV).

DIVERSITY

Odonata species diversity was highest at sites 22, 2, 4, 5, 9, 14 and 10 where up to 18 species (including up to 6 sensitive species) were recorded (Tab. IV). This may be explained by the fact that habitat requirements for three of the four Odonata associations valid for the Danubian floodplains in Austria (= the limnophilic *Erythromma-Anax imperator-*, *Lestes-Sympetrum-* and *Orthetrum-Libellula depressa*-coenosis; WARINGER, 1989) were clearly met by these sites. Such requirements encompass the combination of reed belts, open water zones, sub- and emerged aquatic macrophytes (including floating leaves) and unobstructed, open riparian zones; in addition, a high degree of insolation must also be given. At sites where one or the other of these five basic requirements was lacking, species diversity was significantly lower. For example, at site 15, reed belts and unobstructed bank sections were present, but aquatic macrophytes with floating leaves were lacking and insolation was obstructed by riparian trees, resulting in a decrease of diversity down to 9 species (one of them a sensitive species). In Table IV can be seen that at site 15 members of the *Erythromma-Anax imperator*-coenosis (e.g. *Erythromma najas*, *E. viridulum*, *Anax imperator*, *A. parthenope*, *Aeshna grandis*) were clearly adversely affected by the restricted habitat requirements listed above. Diversity was lowest at sites 11, 24 and 19 (3-4 species, 1

Table III

Classification scheme for the dragonfly-based assessment of river/floodplain systems (CHOVANEC & WARINGER, 2001)

Criteria	Ecological status				
	I / high	II / good	III / moderate	IV / poor	V / bad
General description	Dragonfly community (nearly) totally corresponds to the type-specific reference condition; ecological integrity (nearly) undisturbed	Dragonfly community slightly deviates from the type-specific reference condition; ecological integrity slightly disturbed	Dragonfly community significantly deviates from the type-specific reference condition; ecological integrity significantly disturbed	Only remnants of the type-specific dragonfly community; ecological integrity heavily disturbed	Few if any species are present that correspond to the type-specific reference community; ecological integrity completely disrupted
Autochthonous species	Species of all or nearly all families of the reference community occur; total number of species is high	Species of all or nearly all families occur; number of species is slightly reduced	Few or some families are missing; some or many expected species are missing	Few or some families are missing; many expected species are missing	Some families are missing; most of the expected species are missing
OHI	OHI range high (> 1.5); all habitat types +/- equally represented or H1 dominating; mean OHI ≤2.5	OHI range high (> 1.5); 4 or 5 habitat types are present, at least H1 has to be found, but is not dominating; mean OHI ≤3.5	OHIs indicate that 1 or more habitat types are missing, range of OHIs < 1.5	OHIs indicate that more than 1 habitat types are missing, range of OHIs < 1.5	OHIs indicate that more than 1 habitat types are missing, range of OHIs < 1.5
Sensitive autochthonous species	Species number high, proportion of sensitive species corresponds to that in the reference community or is slightly reduced	Number of sensitive species high or slightly reduced	Number of sensitive species slightly or significantly reduced	Only few sensitive species	No sensitive species

Table IV

Dragonfly species collected at floodplain waterbodies of the Danube at Tulln, Lower Austria, showing their status as autochthonous (a) and/or sensitive species (s). 1-5 indicate abundancy classes (1: single, 2: rare, 3: frequent, 4: abundant, 5: extremely abundant)

Species	a	s	Sampling site															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Zygoptera																		
Calopteryx splendens	+	+	5		3	4	3	4	3				4			3		
Lestes sponsa	+																3	
Lestes viridis	+				2	3					2	3	3				2	
Platycnemis pennipes	+		5	4	4	4	5	5	5	3	3	4	4	5		4	5	4
Coenagrion puella	+			4		3	4				3	4			5		3	3
Coenagrion pulchellum	+	+		2							3							
Enallagma cyathigerum	+									3								
Erythromma najas	+	+				1	2		2		3	4						
Erythromma viridulum	+	+		4			3		2			4						
Ischnura elegans	+		4	4	3	3	5	3	3		3	4		3		4	4	3
Pyrrhosoma nymphula		+													2			
Anisoptera																		
Aeshna affinis	+	+													2			3
Aeshna cyanea	+					2	2								2	2		2
Aeshna grandis	+	+	2	2		2	2				2	2			2	2		
Aeshna isosceles	+	+							2							2		
Aeshna mixta	+	+		2		2	2			2				1		2		
Anax imperator	+			2		2	2		1		2					2		
Anax parthenope	+	+		2			2											
Brachytron pratense	+	+				1			2	1	2	2				2	2	
Gomphus vulgatissimus	+	+	2		3	2		1		3						2		
Ophiogomphus cecilia		+																
Cordulia aenea	+			1					2		3					2		
Somatochlora metallica	+		2	2	2		2							2			2	

Table IV, continued

Species	a	s	Sampling site 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Crocothemis erythraea	+											2						
Leucorrhinia pectoralis	+	+																
Libellula depressa	+		3	3		3	3				3	2			3	3	2	2
Libellula quadrimaculata	+	+	1	2							3	3			2			
Orthetrum cancellatum	+		2	3	1	3	3		2	3	3	3				3		
Sympetrum sanguineum	+		4	3		3	3	3	3		4	3	3	4	4	3	3	5
Sympetrum striolatum	+		*1*			2				*3*					*3*			
Sympetrum vulgatum	+		2						2			2			2			
# of species / sensitive species			12/4	15/6	7/2	16/6	15/6	5/2	12/5	7/3	14/5	14/5	4/1	5/1	10/4	14/6	9/1	7/1
OHI			2.22	3.12	1.72	2.46	2.97	1.83	2.70	2.38	3.20	3.09	1.96	3.13	3.56	2.62	3.26	3.58

Table IV, continued

	a	s	Sampling site 17	18	19	20	21	22	23	24	25	26	27	28	29	30
Zygoptera																
Calopteryx splendens	+	+								3	3					
Lestes sponsa	+								5							
Lestes viridis	+						5	4	3			2				
Platycnemis pennipes	+		3	4	3			4		4	5	5	3	4	3	
Coenagrion puella	+					5	5	5	4		2	5				
Coenagrion pulchellum	+	+														
Enallagma cyathigerum	+							4					4	5		
Erythromma najas	+	+						3				5				
Erythromma viridulum	+	+		5				5								
Ischnura elegans	+		2					5	3			5	3	4		

Table IV, continued

	a	s	Sampling site 17	18	19	20	21	22	23	24	25	26	27	28	29	30
Pyrrhosoma nymphula		+														
Anisoptera																
Aeshna affinis	+	+							3							
Aeshna cyanea	+								3			2				
Aeshna grandis	+	+		1	1	3	2		2			2				
Aeshna isosceles	+	+				2										
Aeshna mixta	+	+				2		2								
Anax imperator	+					2		3				2	2	2		
Anax parthenope	+	+						2					1	2		
Brachytron pratense	+	+		2		3			2							
Gomphus vulgatissimus	+	+	3								4					
Ophiogomphus cecilia		+													1	
Cordulia aenea	+				2	2		2				2				
Somatochlora metallica	+		2							2				2		
Crocothemis erythraea	+							3				1				
Leucorrhinia pectoralis	+	+				4										
Libellula depressa	+		3	3		3	3	3								
Libellula quadrimaculata	+	+				4		2								
Orthetrum cancellatum	+		3	3				4			1		3	3		
Sympetrum sanguineum	+		4			3	3	3	5	2	3	4	2			
Sympetrum striolatum	+						3	3	3		2			3		
Sympetrum vulgatum	+					3	3	3	2							
# of species / sensitive species			7/1	6/3	3/1	12/6	7/1	18/5	11/3	4/1	7/2	11/2	7/1	8/1	2/1	0/0
OHI			2.45	2.90	2.68	3.61	3.48	3.05	3.67	1.90	1.84	3.04	2.84	2.79	1.38	0.00

sensitive species) where either insolation was completely lacking due to the dense riverine forest at both sides or vegetation was restricted to dense reed belts, favouring only species belonging to the *Lestes-Sympetrum*-coenosis. In addition to the 28 sites situated within the riverine forests, two reference sites directly at the Danube were chosen. Whilst at site 30 no dragonflies were recorded, two species of the rheophilic *Gomphus-Calopteryx splendens*-coenosis (*Ophiogomphus cecilia, Platycnemis pennipes*) were collected at site 29 (Fig. 1, Tab. III). At both sites, the banks of the fast--flowing Danube consisted of riprap, bordered by patches of riparian trees, shrubs and meadows. Autochthonous elements of this coenosis (e.g. *Gomphus vulgatissimus* up to abundance class 4) were also recorded in floodplain waterbodies (e.g. sites 1, 3, 4, 6, 14, 17, 25) where water flow was present.

ODONATA HABITAT INDEX (OHI)

On a scale from 1 (dynamic waterbodies, water current present) to 5 (temporary standing waters) the 28 floodplain sampling stations ranged from 1.72 (site 3) to 3.67 (site 23) (Tab. IV). In addition, the OHI of the only reference site where Odonata were detected directly at the Danube (site 29) was 1.38. Sampling site 3 was close to a culvert, connecting two sections of a plesiopotamic dead river branch; due to the narrow cross section of the culvert, water velocity was artificially increased at this site. On the other hand, site 23 was a temporary dead river branch, drying up in summer and leaving only layers of wetted fine sediments at the deepest sections of this site. Dense reed and sedge belts covered the whole cross section. The mean OHI for the Tulln floodplain area was 2.79. Based on this OHI mean, the high OHI range of 1.95, the presence of all habitat types (H1-H5), the species inventory and the high number of sensitive species, the investigation area meets the requirements for ecological status class II (good ecological status; Tab. III).

DISCUSSION

The regulation of the Danube in the 1870s resulted in a complete cut-off of former meandering elements of the braided river type typical for the Danube in the investigation area, transforming them into stagnant waters which were subsequently filled up by sedimentation. Besides this, hydroelectric powerplant construction starting in the 1950s transformed the Danube into a power-generating waterway where the river continuum is interrupted by ten dams. Today, only the most scenic deep river valley of the Wachau and the river stretch downstream of Vienna to the eastern national border of Austria are remains of the original free-flowing situation. These changes led to a loss of riverine inshore habitats, reduced hydrological connectivity between river and floodplain waters, a lowered water table, a reduction of aquatic floodplain areas and to a concentration of erosive forces on the Danube channel (SCHIEMER, 1999; SCHIEMER et al., 1999). As a consequence, floodplain communities changed because species associated with running waters gradually disappeared (e.g. *Gomphus flavipes*). In addition, Odonata species known from moorland pools, fens and heathland waters (*Coenagrion hastulatum*, *Aeshna juncea*) and from shallow waters created by flooding events (e.g. *Ischnura pumilio*) vanished due to human activity (BRAUER, 1851, 1856; BRAUER & LÖW, 1857; VORNATSCHER, 1938). This results today in the absence of many species well documented in the 19th century at the study site (cf. Tab. II).

Odonata species diversity was highest at sites 22, 4, 5, 9 and 10 and lowest at sites 11, 24 and 19 (Tab. IV), reflecting the ecological significance of habitat structures. The effects of insolation, vegetational structure and geomorphology for adults, as well as of water temperature, aquatic plant structure, current velocity, water chemistry and permanence of water for larval Odonata have been clearly shown by BUCHWALD (1989), GERKEN (1988) and SCHMIDT (1983). BANSE & BANSE (1985) and BRÄU (1990) demonstrated that species richness at standing water bodies was positively correlated with insolation, shallow bank inclination and the abundance of aquatic and semiaquatic plant species. In addition, the diversity of plants suitable as substrates for oviposition was positively correlated with species richness of dragonflies (LENZ, 1991). This could be also shown by SCHWEIGER-CHWALA (1994), who observed seven species of aquatic macrophytes, four species of semiaquatic plants and nine species of trees at a permanent water body within the Danubian riverine forests; insolation was also possible throughout the day and bank inclinations were shallow, resulting in the highest ranking of the Shannon and Simpson indices at this study site (2.60 and 11.26, respectively). On the other hand, a temporary site completely shaded by trees, combined with a very steep bank inclination and almost lacking aquatic vegetation yielded only one larva of *Ischnura elegans* and one adult of *Sympecma fusca* throughout the study period.

The relatively high numbers of species and sensitive species (31 of the 77 Austrian species, including 13 „Red List"-species (RAAB & CHWALA, 1997) and 52% of the reference species inventory) as well as the mean OHI and the OHI ranges listed above show that, despite of regulation, the construction of flood control devices and a multitude of recreational activities taking place in the riverine forests, all habitat types are present in the Tulln floodplain section of the Danube. Habitat types characterised by terrestrialisation processes due to reduced hydrologic dynamics (H3 and H4 types: Plesio- and Palaeopotamon) are dominating. Therefore, attempts have been made to improve connectivity and dynamics in the area investigated by the construction of weirs connecting parts of floodplain waterbodies with the Danube and by the construction of culverts which increased current speed at a very small scale and which favoured habitats of type-specific rheophilic dragonfly communities. These measurements, however, are insufficient, as can be seen by the low proportion of truly rheophilic dragonflies recorded in the present study.

The basis of the dragonfly-based approach for assessing river-floodplain systems is the comparison of a status quo with an actual or reconstructed reference situation. Within this framework, the approach is applicable at different scales: at the microscale, single waterbodies or even individual sites can be evaluated by characterizing the local dragonfly community and comparing it with a reference condition; at the mesoscale, landscape elements such as floodplain areas can be assessed; at the macroscale, issues such as landscape pattering or greenway functioning can be addressed. Besides applying the OHI approach as a stand-alone tool in cases where the hydrological connectivity between a river and the adjacent floodplain is not significantly modified by secondary hydrological influences from tributaries or man-made channels (e.g. CHOVANEC et al., 2002), we plan to include also other indicator groups listed in the Water Framework Directive of the European Union, e.g. other macroinvertebrates such as caddisflies (e.g. WARINGER & GRAF, 2002), molluscs and fish.

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