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Integrating Conflicting Goals of the EC Water Framework Directive and the EC Habitats Directives Into Floodplain Restoration Schemes

Gabriele Weigelhofer[1,2]*, Eva Feldbacher[2], Daniel Trauner[1,3], Eva Pölz[1], Thomas Hein[1,2] and Andrea Funk[1,2]

[1] Department of Water, Atmosphere, and Environment, Institute of Hydrobiology and Aquatic Ecosystem Management, University of Natural Resources and Life Sciences, Vienna, Austria, [2] WasserCluster Lunz-Biological Station GmbH, Lunz am See, Austria, [3] Umweltbundesamt, Vienna, Austria

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***Correspondence:**
Gabriele Weigelhofer
gabriele.weigelhofer@wcl.ac.at

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River floodplains are among the most threatened ecosystems of the world and their protection and restoration is of key importance for river managers. In Europe, the Water Framework Directive (WFD) and the Habitats and Birds Directives (HBDs) provide a guideline for decision processes in floodplain restoration projects. While the WFD, however, represents an aggregated, multiple-species approach aiming at the restoration of the natural hydrological dynamics, the single-species focused HBDs regulate the protection of the existing fauna and flora with protection status. Thus, trade-offs between rheophilic and stagnophilic aquatic organisms may hamper the definition of a compromise solution between the ecological objectives of the restoration. We present an assessment scheme for the restoration of a degraded Danube floodplain near Vienna, which equally considers both WFD and HBDs objectives in a transparent, comprehensible, and objective way. In a first step, predictive hydrological and ecological models were generated for different hydrological scenarios considering the aquatic community composition (floodplain index according to WFD) as well as individual protected species of the taxonomic groups fish, amphibians, reptiles, and water birds (HBDs). Based on these models, we developed an assessment scheme which considered potential changes in the available habitats, the current conservation states, and priorities of the species. Thereby, we included experiences from other restoration projects. The results show that both the multiple-species and the single-species approach achieved a similar ranking of the hydrological scenarios, in which the "business-as-usual" alternative without any restoration measure was identified as the worst case. The multiple-species approach of the floodplain index provided a clear ranking of the hydrological scenarios and revealed a low potential of any target measure to restore the pre-regulation state of the floodplain. In contrast, the single-species approach required a much higher degree of decisions by experts, but provided a detailed insight into spatial effects of the measures on different species, thus revealing the potential for local compensation measures. Our study demonstrates that a combination of these two approaches can be an effective tool for river managers in the development of sustainable floodplain restoration schemes in accordance with the WFD, the HBDs, and national nature protection laws (in this case, the Nature Conservation Acts of Vienna and Lower Austria).

Keywords: EC water framework directive, EC habitats directive, floodplain index, species distribution models, decision process, nature protection

INTRODUCTION

River floodplains are among the most threatened ecosystems in the world (Tockner et al., 2010). Along the Upper Danube in Germany and Austria, more than 90% of the former dynamic floodplains have been lost due to the construction of flood protection dikes and impoundments for hydropower generation (Hein et al., 2016). During the last decades, an increasing number of restoration projects has focused on the re-integration of these floodplain areas into the hydrological dynamics of the Danube main channel (Schiemer et al., 1999; Baart et al., 2013; Stammel et al., 2016). However, floodplain restoration challenges both, river managers and decision makers, through multiple, often conflicting ecological, economic, and social demands (Buijse et al., 2002; Jungwirth et al., 2002; Preiner et al., 2018). Regarding nature protection, decision makers may additionally have to comply with different regulations in the same area, which sometimes have divergent goals. In specific, conflicts may arise from efforts to restore the former hydrologically dynamic character of the floodplain and the need to protect rare, but stagnophilic species, which have inhabited the area during the phase of disconnection (Moss, 2007; Stammel et al., 2016).

In the European Community (EC), two major directives exist, which set restoration and/or conservation aims for aquatic ecosystems and provide a guideline for decision processes in floodplain restoration projects (Moss, 2007; Gumiero et al., 2013; Hein et al., 2019). The EC Water Framework Directive (WFD) mandates members to restore or maintain the good ecological state of river systems (Council of the European Communities, 2000). The WFD represents a multiple-species approach, based mainly on benthic invertebrates and fish, which is oriented at a near-natural (historical) reference state of the respective aquatic system without human impacts. Although neither floodplains nor specific riparian or floodplain organisms are currently addressed as separate entities in the WFD, the intact structure of riparian zones necessary to support a good ecological state of the river system is mentioned (Meyerhoff and Dehnhardt, 2007; Gumiero et al., 2013). In contrast, nature protection laws are generally single-species approaches, which regulate the protection of endangered species or habitats on a defined spatial scale (e.g., local or national), independent of whether they were originally present in these areas or not. The most important regulations on European Community level are the Habitats and Birds Directives (HBD) which aim at the protection and conservation of aquatic, semi-aquatic, and terrestrial floodplain habitats and protected species within designated Natura 2000 areas as a tool of the EC biodiversity strategy (Council of the European Communities, 1992, 2009; Gumiero et al., 2013). There is an increasing awareness in the EC and the European Environment Agency (EEA) of the need to improve coherence among the different EC directives regulating floodplain management via the development of a consistent method across Europe based on a holistic river basin management perspective (European Environment Agency, 2020). In addition to the HBDs, national nature protection laws may be relevant for the setting of restoration aims for river floodplains. In Austria, nature conservation is regulated in nature conservation laws of nine autonomous federal states (Artmann, 2018).

Due to the high complexity and diversity of river-floodplain systems, conflicts may arise from the different foci of these directives to either restore the original functionality (WFD) or conserve the existing biodiversity (HBDs and nature protection laws) (Acerman et al., 2007; Gumiero et al., 2013; Janauer et al., 2015). Pristine river-floodplain systems are characterized by high lateral hydrological dynamics and alternating erosion-sedimentation processes, where large running waters with shifting lotic and lentic conditions usually dominate (Eupotamon), while stagnant, permanent or temporary water bodies may coexist in margin areas (Para-, Pleisio-, and Paleopotamon) (Amoros et al., 1987; Jungwirth et al., 2002). This creates a diverse mosaic of different terrestrial, semi-aquatic, and aquatic habitats. Disconnection from the main channel reduces this temporal and spatial dynamics severely, thereby stimulating terrestrialisation processes and favoring stagnant conditions (Schindler et al., 2016). This may change the character of the floodplain entirely, leading to the establishment of a more terrestrial, semi-aquatic, and stagnophilic flora and fauna. Nevertheless, such floodplains may harbor rare species and habitats of high nature protection value, which can be threatened by the restoration of the former lateral hydrological connectivity and dynamics of the floodplain. In many cases, a complete re-connection of the artificially disconnected floodplain with the river channel is not feasible due to a multitude of hydrological or socio-economic constraints (Jungwirth et al., 2002). However, the question arises whether and how a partial restoration of the lateral connectivity can stimulate a development toward the original dynamic conditions without threatening the existence of immigrated rare species requiring more stagnant conditions.

To our knowledge, no approach has been developed so far which tries to balance the different aims of the EC WFD and the EC HBDs and combine them into a single assessment scheme as guidance for floodplain restoration concepts. In this study, we present an approach to compare the different EC directives and integrate the partly conflicting ecological aims. Our case study is a formerly dynamic floodplain of the river Danube east of Vienna, which was cut off from the main channel in the 19th century (Funk et al., 2013; Reckendorfer et al., 2013; Weigelhofer et al., 2015). While the reduced hydrological dynamics has led to the establishment of rare, highly protected species, resulting in the designation as a national park and a Natura 2000 area, it threatens the further existence of the floodplain through severe water supply deficits. Thus, besides other socio-economic demands and hydrological restrictions (described in, e.g., Sanon et al., 2012; Preiner et al., 2018), one of the main tasks of this study was to develop an assessment scheme for potential future scenarios, which equally considers both WFD and HBDs objectives in a transparent, comprehensible, and objective way. The developed approach should identify the compromise solution with the highest potential of restoring the pre-regulation conditions, while keeping losses in the established communities at a minimum. The study was based on the development of predictive hydrological and ecological models for different restoration scenarios, which were supported by long-term monitoring data within the study area as well as by experiences from other restoration projects in the vicinity (Reckendorfer et al., 2006; Hein et al., 2016). Based on these models, we developed an assessment scheme for the WFD and HBDs goals separately in a first step and then integrated these two approaches into an overall weighted evaluation of the different scenarios. In the following sections, the different steps of this approach and the evaluation results are presented for the case study and challenges and solutions for floodplain restoration schemes are discussed.

MATERIALS AND METHODS

Study Area and Scenarios

The floodplain Lower Lobau extends over an area of approximately 1,500 ha on the left bank of the River Danube east of Vienna (48°09′36.8′′N 16°32′15.0′′E). Due to the construction of a flood protection dike in the 19th century, the upstream opening of the main Lobau side arm was cut off from the Danube channel, leaving only a downstream opening for flood water entry (Funk et al., 2013; Reckendorfer et al., 2013; Weigelhofer et al., 2015). The isolation from erosive flood events has led to the transformation of the floodplain water bodies from mainly Eupotamon to Para-, Pleisio-, and Paleopotamon with numerous isolated and seepage or groundwater-fed backwaters harboring a diverse stagnophilic and semi-aquatic fauna and flora (Reckendorfer et al., 2013). The whole floodplain area lies within the jurisdiction of the two Federal states Vienna (upstream part) and Lower Austria (downstream part; **Figure 1**). The Lower Lobau has been assigned as a Natura 2000 area and is part of the National Park Donauauen (Hein et al., 2006).

A range of hydrologically feasible and socially and ecologically acceptable re-connection scenarios were defined to evaluate the restoration potential of the floodplain under different hydrological conditions, to identify trade-offs among the different legal objectives, and to find the best compromise solution. The tested scenarios comprised

1. a controlled water supply of 3 m^3s^{-1} from the Danube to raise the surface and groundwater levels in the floodplain, to increase the connectivity and the surface water exchange through the main side arm, and to establish locally restricted rheophilic conditions (abbreviated as "S3" in the following chapters). This scenario is expected to fully preserve important socio-economic demands in the area such as drinking water supply, recreation or agriculture (Sanon et al., 2012).
2. a partial re-connection with the Danube, discharging 20–80 m^3 s^{-1} into the main side arm (depending on the respective water level of the Danube) to establish permanently flowing conditions there ("S20–80"). This scenario is expected to reflect the highest possible level of reconnection that is still acceptable accounting for socio-economic demands, particularly the potential for drinking water production, as the surface water influence impacts the quality of groundwater (Sanon et al., 2012).
3. a business-as-usual scenario without restoration measures, resulting in a further loss of aquatic areas due to terrestrialisation processes in the floodplain and channel bed incision of the Danube main channel ("S0").

Due to both, hydrological limitations and socio-economic restrictions, such as, e.g., flood protection or drinking water supply, a full re-connection with the Danube, which would have resulted in a stimulation of rejuvenation and erosion processes at large scale, was not feasible and, thus, not included as restoration scenario.

The hydrological variables for the scenarios (water tables, water depths, flow velocities, and flow directions) were provided by a calibrated 2-D hydrodynamic surface water model (CCHE-2D; Univ. of Mississippi–National Center for Computational Hydroscience and Engineering; Gabriel et al., 2014). The model predicted an increase in total water area by $>25\%$ and $>30\%$ for the S3 and the S20–80 scenarios at mean water level, respectively. The hydrological model was validated by comparing the modeled *status quo* with the actual situation in the floodplain water bodies at different water levels.

The S0-scenario was estimated by extrapolating the aquatic habitat losses between 1938 and 2011 using a regression model based on the evaluation of aerial images (Böttiger, 2011). The models predicted a decrease by almost 20% of the current water body area for the S0 scenario by 2050. The prediction of the historical reference state was based on the distribution of aquatic habitats in 1817 presented in Hohensinner et al. (2004) and hydrological variables were taken from Hohensinner and Jungwirth (2016).

Floodplain Index (FI) According to WFD Principles

To compensate the lack of an official WFD assessment procedure suitable for floodplains, the "floodplain index FI" was developed by Chovanec and Waringer (2001), which assesses the intactness of floodplains via the occurrence of Odonata. This index corresponds to the WFD by using pristine conditions as reference and calculating the ecological state of the floodplain from the presence or absence of species with different habitat preferences (Chovanec et al., 2005). The FI was extended later to other groups, such as caddisflies, mollusks, amphibians, fish, and other

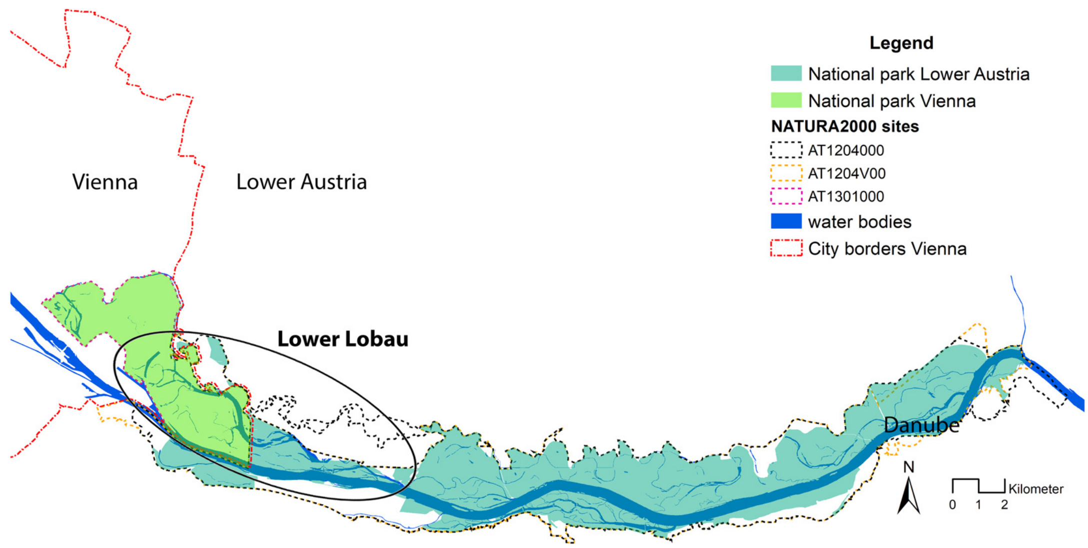

FIGURE 1 | Map of the study area Lower Lobau, showing its location within the two Natura 2000 sites in Vienna (Site code 1301000) and Lower Austria (Site codes 1204000 and 1204V00) and as part of the National park "Danube wetlands" (parts in Vienna and Austria marked in different colors).

invertebrate taxa, to enable a more holistic view of the floodplain's ecological state (Waringer and Graf, 2002; Chovanec et al., 2004; Chovanec et al., 2005; Waringer et al., 2005; Šporka et al., 2009; Funk et al., 2017). In short, 10 valency points are assigned to each target species within a system of five floodplain water body types, Eu- and Parapotamal (types H1, H2 according to Amoros et al., 1987, respectively), isolated permanent water bodies with low to high macrophyte coverage (H3 < 20% and H4 > 20% coverage, respectively) and isolated astatic waterbodies (H5). These valency points represent habitat preferences of species similar to the saprobic index (Brabec et al., 2004), thus, enabling a more accurate assessment of the ecological state of the floodplain water bodies via the community instead of hydro-morphological or chemical parameters. An indicator weight is allocated to each species, ranging from 1 for eurytopic to 5 for stenotopic species, and the floodplain index FI is calculated based on the presence of all species for each water body type. Finally, the ecological state of the floodplain is determined by the current or potential availability of the five floodplain water body types in comparison to natural or near-natural (historical) reference conditions (for details, see Chovanec et al., 2005).

To derive a prediction of the FI for the different scenarios as well as for the historical state, species presences were modeled related to seven environmental parameters (upstream hydrological connectivity, downstream hydrological connectivity, sun exposure, maximal relative water depth at low, mean, and high water levels as well as current velocity at an annual flood event) using Surface Range Envelopes (SRE, Busby, 1991; **Figure 2**). Surface Range Envelope is analogous to Bioclim (Busby, 1991) and uses only occurrence data to define a multi-dimensional environmental space, in which a species can occur, resulting in a multi-dimensional rectilinear envelope, using 5 and 95% percentiles (see also Reckendorfer et al., 2006). This is a fast, simple and intuitive approach which allowed us to model a total of 204 species (33 fish, 7 amphibians, 24 Trichoptera, 38 Odonata, 40 mollusks, and further 62 invertebrate species).

Based on the presence predictions of the different taxonomic groups, the FI was calculated for each scenario and compared to the predictions for the historic reference state (**Figure 2**). The modeling approach was validated by comparing the calculated FI for the *status quo* with field data. The assessment of the ecological state of the floodplain for each scenario followed the protocol provided by Chovanec and Waringer (2001) (**Table 1**). For a more detailed spatial information, the FI was calculated separately for the different basins of the main channel and the individual side-arms (examples shown in **Supplementary Figure S1**).

HBDs and Nature Protection Approach

The EC HBDs aim at the conservation or restoration of a "good conservation status" of each relevant protected species as listed in the standard data form for the respective Natura 2000 area (Gumiero et al., 2013; Hein et al., 2019). Likewise, regional conservation laws in Austria aim for the good status of the protected species. In the case of trade-offs between species, i.e., if a particular conservation measure will support one species, but discriminate against another, it requires the assessment and balancing of potential positive and negative impacts of an envisaged measure via, e.g., smart spatial and temporal planning. For this purpose, 41 aquatic and semiaquatic protected species of the taxonomic groups water birds, fish, amphibians, and reptilians (**Supplementary Table S2**) were divided into habitat guilds based on preferences for flow velocities (e.g., flow guilds according to Schiemer and Spindler, 1989) and water body permanence (i.e., permanent vs. temporary water bodies). For selected species (**Supplementary Table S2**) with sufficient data availability, predictive species distribution models were developed based on a generalized linearized model (GLM) approach (**Figure 2**). From these models, weighted usable areas

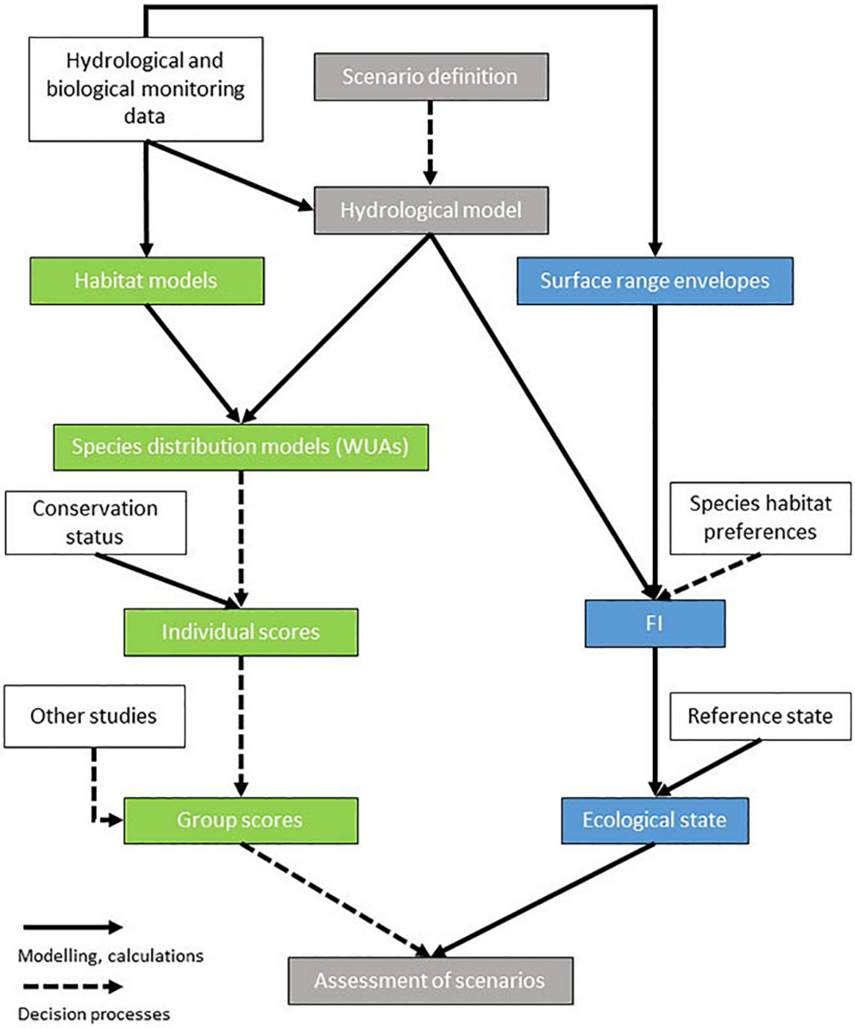

FIGURE 2 | Work flow diagram for the assessment of the restoration scenarios according to the Habitats and Birds Directive and nature protection laws (left, green boxes) and the Floodplain Index (relating to the Water Framework Directive; right, blue boxes). Full lines indicate modeling and calculations, dotted lines decision processes. White boxes indicate data necessary for the modeling and decision processes.

(WUAs) were calculated for each modeled species and each scenario as described in Funk et al. (2013). This approach allowed us to predict quantitative losses or gains of total habitat area in the floodplain for the different species groups and scenarios.

In a second step, the potential change of the conservation status was estimated based on the existing conservation status according to the Natura 2000 assessment (A excellent, B good, and C average or reduced) or regional conservation law (Vienna Nature Conservation Act and Lower Austrian Nature Conservation Act, I excellent, II good, III not satisfying) and the predicted change in WUAs for each species (**Figure 2**). Unfortunately, the assessment had to be performed separately for the upstream part in Vienna and the downstream part in Lower Austria, as these areas are protected under the two different federal laws and are part of two different Natura 2000 sites (**Figure 1**). While the floodplain represents >50% of the Natura 2000 area in Vienna, the Lower Lobau is only a small part of the National Park Donauauen in Lower Austria, covering less than 10% of the Natura 2000 area there. Consequently, species have a different protection and conservation status in the respective Natura 2000 sites. The evaluation was supplemented by local expert knowledge and experiences from other re-connection schemes in adjacent floodplains (Reckendorfer et al., 2006; Hein et al., 2016). Here, our assessments and predictions were checked and – if necessary – slightly adapted for each species by experts of the National Park and the environmental protection agency regarding the actual situation (e.g., potential over- or under-estimation of occurrence) and the potential development (e.g., higher or lower potential due to factors not considered in the model, such as, e.g., predation). We defined the aim of the restoration for each species or habitat by either maintaining the existing good or excellent state or establishing a good state in the case of an existing average or reduced state. Thus, five scores could be achieved for each species and scenario depending on the

TABLE 1 | Definition of the ecological state based on the occurrence of floodplain habitat types according to Chovanec and Waringer (2001) and adaptions for the restoration scheme in the Lower Lobau

Ecological state	Description	Adaptions
I (high)	All habitat types exist, dominance of H1	
II (good)	Small deviation from reference state, all habitat types exist, H1 does not dominate	H1 at least 15% of reference conditions
III (moderate)	Significant deviation from reference state; H1 is missing or two habitat types are missing	
IV and V (bad)	Only 2 habitats types exist; low number of type-specific species	

existing status of the species and the predicted status after the implementation of the measures (**Table 2**).

Significant changes in the conservation status were expected, if (a) the distribution data predicted by the models were consistent with experiences from other restoration projects, (b) the predicted changes in WUAs had a significant influence on the overall distribution of this species in the floodplain, and (c) the floodplain was or may become a distribution hotspot of this species for the whole Natura 2000 area. Consequently, predicted changes with minor consequences did not influence the overall evaluation score. The individual scores were weighted according to the priority and the protection state of the respective species provided by the HBDs (value 4 for all species listed in Annex I or II of the HBDs) and the nature protection law effective in this region (Vienna Nature Conservation Ordinance and Lower Austrian Species Protection Ordinance, value 3, 2, and 1 for priority species, strictly protected, and protected species, respectively; **Figure 2**). The average score for each taxonomic group was calculated via the equation:

$$Average\ score\ per\ group = \frac{\sum(Ni \times Gi)}{\sum Gi}$$

Where Ni is the score and Gi is the weight of each species. For the comparison and evaluation of the different scenarios across all groups, only positive and negative effects were considered. Consequently, three cases were distinguished:

a) the scenario will have only negative effects on one or more groups (worst case scenario)
b) the scenario will have positive and negative effects on different groups
c) the scenario will have only positive effects on one or more groups (best case scenario)

In the case of (b), the magnitude and spatial extend of the potential negative effects as well as potential compensation measures to reduce the negative effects were included in the assessment. To give an example, the increase in water tables in the S3 and S20–80 scenarios were predicted to lead to a loss of isolated shallow water bodies, the dominant habitats for amphibian larvae. However, this negative effect can be easily compensated at low costs as the increase in water tables offers the chance for the creation of new stagnant water bodies in former terrestrial areas, eventually induced by small-scale excavation measures.

Combination of WFD and HBDs Assessments

We used a modification of the evaluation scheme of the HBDs (**Table 2**) to combine the assessments of the two approaches into one recommendation for the water management. Here, scores were assigned to each scenario for both WFD and HBDs, considering whether the overall aim of the Directives could potentially be achieved by the scenario (good ecological state for WFD, average good conservation state for HBDs) and/or a further improvement or deterioration of the *status quo* was likely. For the average scores of the HBDs assessment, taxonomic group scores were weighted (4 for amphibians, reptiles, and fish and 1 for water birds due to their larger areal distribution).

The scores ranged from 1 (aims fully achieved and further improvement) to 5 (aims not achieved and further deterioration) corresponding to the HBDs scores in **Table 2**. For the combination, both assessment schemes had equal importance, thus, no weights were assigned. We only used the assessment of the upstream part of the floodplain located in Vienna in this final step because of the higher proportion of floodplain area represented and the low discriminative power of the assessment in Lower Austria (see scores in **Table 4**).

RESULTS

FI Assessment According to WFD Principles

The results of the modeling based on the taxonomic groups relevant for the FI (Chovanec et al., 2005; Funk et al., 2017) indicated that the scenario S20–80 had the potential to restore the "good ecological status" of the floodplain according to **Table 1**. S20–80 was the only scenario, where a significant proportion of H1 habitats (eupotamon) was predicted (**Figure 3**). However, even this scenario deviated considerably in both quantity and quality of floodplain habitats from the historic reference state. S3 was predicted to achieve a moderate to good ecological state (H1 habitats present, but covering only a very small part of the floodplain), while S0 would still achieve a moderate state (all habitats present except H1). H5 habitats were present in the floodplain, but could not be displayed by the model due to their extremely low areal coverage and their temporary character. The spatial analyses of the different water bodies (see **Supplementary Figure S1** for examples) revealed obvious differences in impact strength on the potential development of habitat types for water bodies of the main floodplain channel connected via surface discharge and isolated water bodies connected only via the groundwater aquifer (**Figure 4**). While directly impacted water bodies showed a clear tendency toward more dynamic conditions in the S20–80 scenario, indicating the potential to foster the rheophilic community, isolated water bodies were predicted to maintain their character and typical stagnotopic

TABLE 2 | Evaluation scheme for the HBDs and nature protection approach for each species based on the respective conservation status and the predicted improvement or deterioration of this status.

Scores	Conservation status	Change of current situation	Examples
1 (best)	The aim of at least a good conservation status is reached	AND the current situation is improved	A species with status A/I gains in WUAs A species with status C/III (or B/II) will reach status B/II (or A/I)
2	The aim of at least a good conservation status is reached	No change	Species with status A/I and B/II maintain their status
3	The aim of at least a good conservation status is NOT reached	BUT the current situation is improved	A species with status C/III will gain more WUAs, but not enough to improve its state to B/II
4	The aim of at least a good conservation status is NOT reached	No change	Species with state C/III maintain their state
5 (worst)	The aim of at least a good conservation status is NOT reached	AND the current situation is deteriorated	Species with state A/I or B/II will be reduced to state C/III

community across all scenarios, corresponding to the results of the HBDs approach.

HBDs and Nature Protection Approach

The HBDs and nature protection approach showed distinct trade-offs between the rheophilic community, such as, e.g., rheophilic fish and water birds dependent on erosion/deposition processes, and the stagnophilic community, such as, e.g., amphibians, bird species of stagnant water bodies, the pond turtle, and stagnophilic fish (**Figure 5**).

In general, fish were positively affected by both S3 and S20–80 scenarios due to the creation of new aquatic habitats and the increased connectivity among existing habitats (**Figure 5**). Species, which clearly gained from the enhanced water supply according to the models, were rheophilic species like *Aspius aspius* (asp), *Barbus barbus* (barbel), and *Romanogobio vladykovi* (white-finned gudgeon), which had already shown to benefit from an increased re-connection with the Danube in other restoration projects (Hein et al., 2016). However, comparisons with the estimated historical species distributions revealed that even the S20–80 scenario did not support the creation of conditions necessary for endangered, strongly rheophilic Danube fish. The scenario S0 had mostly negative effects (e.g., on species dependent on large permanent and connected water bodies like *Aspius aspius*) and only positive effects on stagnotopic fish typical for backwaters with high siltation rates (e.g., *Misgurnus fossilis*, weatherfish).

The effects of the different scenarios on the amphibians were diverse. For most species, significant losses of available habitat area were predicted for the S0 scenario due to the increasing terrestrialisation of the floodplain and the drying-out of small temporary ponds (**Figure 5**). The S3 and S20–80 scenarios were expected to initiate flowing conditions in some of the current amphibian habitats and to increase the connectivity with the main side arm colonized by fish, thereby increasing the predation pressure on tadpoles. However, these scenarios showed the potential to create new, isolated and temporary water bodies in margin areas of the floodplain due to the improved water supply. Besides, compensation measures were expected to reduce potential habitat losses through the construction of new isolated habitats. Thus, most amphibian species were positively affected by S3 and S20–80 depending on their respective sensitivity to water current and predator pressure as well as on their actual occurrence.

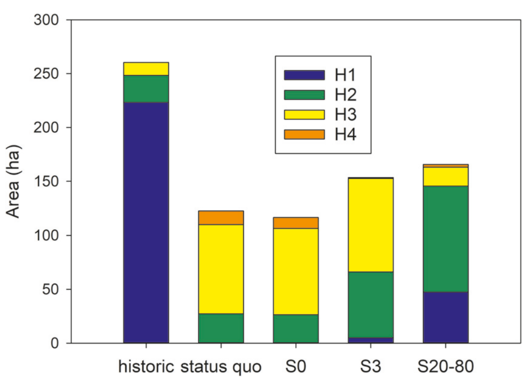

FIGURE 3 | Quantitative representation (area in ha) of the four different habitat types (H1–H4) defined under the FI according to Chovanec et al. (2005) for the four different scenarios as well as the historic state. H5 habitats were present, but could not be displayed by the model due to their low areal coverage.

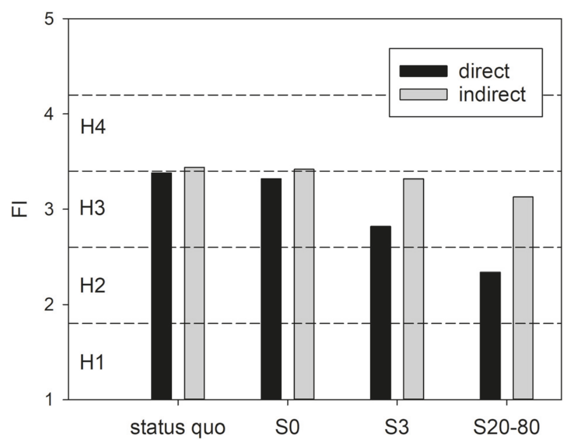

FIGURE 4 | Mean predicted value of the FI (habitat types H1-H5 according to Chovanec et al., 2005 are marked in the graph) in water bodies directly impacted by the respective restoration measure via surface discharge (direct) and indirectly due to increase in groundwater levels (indirect).

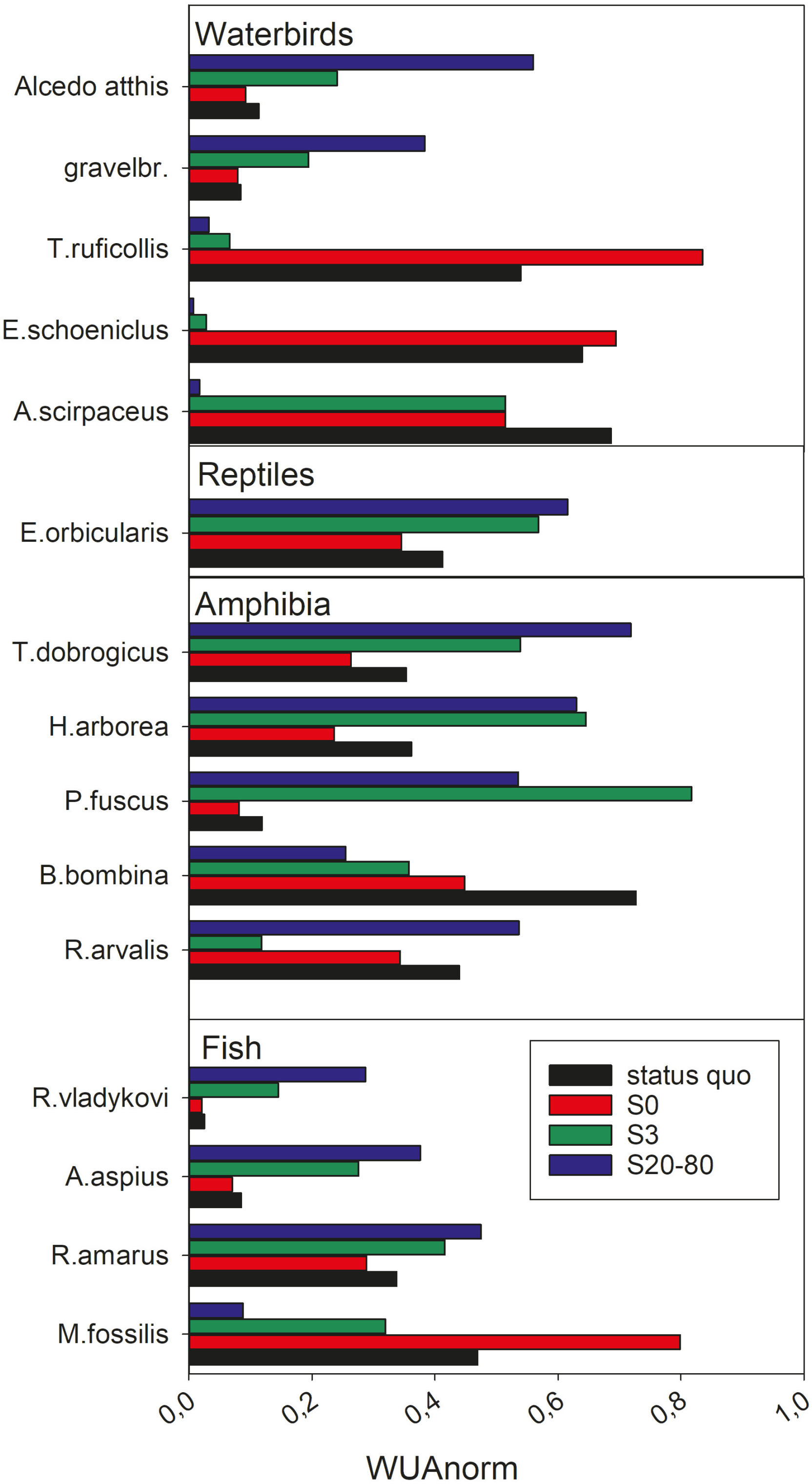

FIGURE 5 | Summarized normalized WUA values for selected species protected by the HBDs for the three scenarios and the modeled *status quo*. *Alcedo atthis* (kingfisher), gravelbr.: gravelbreeding water bird species (common sandpiper, *Actitis hypoleucos* and little ringed plover, *Charadrius dubius*), *Tachybaptus ruficollis* (little grebe), *Emberiza schoeniclus* (reed bunting), *Acrocephalus scirpaceus* (reed-warbler), *Emys orbicularis* (European pond turtle), *Triturus dobrogicus* (Danube crested newt), *Hyla arborea* (European tree frog), *Pelobates fuscus* (common Eurasian spadefoot toad), *Bombina bombina* (fire bellied toad), *Rana arvalis* (moor frog), *Romanogobio vlaycovi* (white-finned gudgeon), *Aspius aspius* (asp), *Rhodeus amarus* (European bitterling), *Misgurnus fossilis* (weatherfish). Only species protected under HBDs are displayed.

The S0 model revealed declining water tables in habitats for *Emys orbicularis* (pond turtle), which already had a low conservation status in the floodplain (**Figure 5**). Thus, the S0 scenario was predicted to decrease the habitat suitability further, while S3 and S20–80 showed a high potential of improving the situation due to the increased water supply and stabilization of water levels.

Regarding the water birds, a strong trade-off between species typical for isolated, macrophyte-rich water bodies dominated by siltation (Palaeopotamon) and species typical for dynamic water bodies (dependent on erosion patterns) was visible (**Figure 5**). An increase of habitat area in the S0 scenario was predicted especially for species which nest in emergent vegetation like extensive old reed belts (e.g., *Ixobrychus minutus*). In contrast, species breeding in young and dynamic reed zones benefited more from the increased water velocities in S20–80 (e.g., *Acrocephalus arundinaceus*). The S20–80 scenario showed positive effects due to the creation of local erosion zones, such as, e.g., gravel bars and erosion banks (*Actitis hypoleucos* and *Alcedo atthis*).

The grading of the scenarios for each species did not only consider the gains or losses in WUAs relative to the actual distribution (i.e., if losses occurred in key distribution areas or not), but also the chance for immigration from the surroundings (e.g., from other floodplains in the National Park in Lower Austria), the possibility of compensation measures (e.g.,excavations or constructions of dams to create/protect isolated water bodies) as well as experiences from other restoration projects within this area (Hein et al., 2016). Furthermore, the division into two different Natura 2000 sites with different areal extensions of the floodplain resulted in quite different scores for the two floodplain parts (**Table 3**). In Vienna, the Lower Lobau covers not only more than 50% of the Natura 2000 area there, it also represents the most valuable part, as the rest of the Natura 2000 site is surrounded by dense settlements and, thus, is heavily degraded. In contrast, the downstream section of the Lower Lobau situated in Lower Austria is only a small part of the much larger and less degraded national park and Natura 2000 area "Danube wetlands," which will buffer most of the predicted restoration effects (**Figure 1**). Consequently, only the grading for the Viennese part yielded differences among the scenarios (**Table 3**). Overall, the differences between the restoration scenarios S3 and S20–80 were usually small, because gaining and losing species partly outweighed each other. While S20–80 achieved better scores for fish and water birds due to the increase in water area and connectivity, the S3 scenario ranked higher for amphibians. The S0 scenario was identified as the worst-case scenario for all groups due to the continued drying-out of the floodplain and the low potential of compensating these water supply deficits.

Combined Assessment of the Scenarios

Considering the low predicted occurrence of H1 habitats and the still high deviation from the historic reference state even in the S20–80 scenario, we decided for the combined assessment that S20–80 only partly accomplished the WFD aim to establish a good ecological state in the floodplain, while S3 and S0 failed (**Table 4**). This was done to avoid over-estimating the subtle positive effects of an increased water supply or a partial re-connection by the WFD assessment compared to the much stricter HBDs assessment.

TABLE 3 | Overall scores per group for the different scenarios, based on both HBDs species and species protected by nature conservation laws and divided between the upstream part in Vienna and the downstream part in Lower Austria.

	Vienna			Lower Austria		
	S0	**S3**	**S20–80**	**S0**	**S3**	**S20–80**
Fish	2.8	2.5	1.8	2.9	2.9	2.3
Reptiles	5.0	1.0	1.0	2.0	2.0	2.0
Amphibians	5.0	2.0	2.3	2.4	2.4	2.4
Water birds	2.6	2.2	1.8	1.2	1.2	1.2

Overall, the S0 scenario scored worst in both assessment schemes, whereby the affects were assumed to be less severe in the WFD assessment as the FI did not predict huge changes in the current distribution of habitat types (**Table 4**). Regarding the other two scenarios, the WFD assessment showed a clear preference for S20–80. This scenario also scored slightly better in the HBDs assessment, which is why S20–80 was identified as the best ecological scenario for the floodplain.

DISCUSSION

Comparison of the Two Assessment Approaches

The FI approach corresponding to the WFD principles represents a relatively fast whole-system aggregated multi-species approach for riverine species, which provides a target vision for restoration aims and, thus, facilitates an effective evaluation and clear ranking of the scenarios (Jungwirth et al., 2002). It helps to identify deficits in comparison to a defined reference state and reveals the potential of different management scenarios to reverse the current development and restore the original floodplain conditions similar to the WFD assessment (Janauer et al., 2015). However, one major drawback of the FI approach is the rather generous definition of the good ecological state as suggested by Chovanec et al. (2005). This allows to assign the good ecological state for the floodplain, if H1 habitats (eupotamon) are just present, but not dominating, without providing a threshold for a "significant deviation" from the reference state. Here, we suggest the definition of a maximum deviation from the reference state in H1 habitat occurrence (e.g., at least 15% of the original coverage of H1 habitats reached; **Table 1**) as target for the good ecological state, as it is also often done for other WFD indicators (Birk et al., 2013). Furthermore, the FI approach does currently neither include the aquatic vegetation nor terrestrial species, which are at least temporarily associated with water bodies, such as e.g., water birds, and could provide a more holistic representation of the ecological status. Including those groups would strengthen the explanatory power of the assessment further and also improve the comparability of the FI with the HBDs approach (Janauer et al., 2015). The calculation of the FI is based on a multitude of

TABLE 4 | Combined evaluation of the different scenarios for the floodplain Lobau based on the WFD and HBDs assessments of the floodplain area located in Vienna.

Scenario	Assessment	Aim reached	Probable development	Score
S0	WFD	No	No change/slight deterioration: further loss of aquatic areas highly probable, but distribution of habitat types not affected	4(−5)
	HBD	No	No change/slight deterioration: Loss of habitats for reptiles and amphibians, but no changes for fish and water birds	4.1
S3	WFD	No	No change/slight improvement: increase in water supply will maintain existing habitats; short flowing sections (H1) may support colonization by rheophilic macrozoobenthos	3(−4)
	HBD	Partly	Improvement for existing species: increase in water levels will create new habitats for amphibians and reptiles and support eurytopic fish and water birds	1.9
S20–80	WFD	Partly	Improvement: Establishment of H1 habitats for rheophilic species, but not for strongly rheophilic Danube fish; H1 still underrepresented compared to historic reference state	2
	HBD	Partly	Improvement for existing species: Fish and water birds supported, creation of new amphibian habitats	1.7

Aims were defined as the establishment or maintenance of the good ecological state for the WFD (based on the Floodplain Index FI) and the establishment or maintenance of an average good conservation state for fish, amphibians, reptiles, and water birds according to the HBDs. Colors mark the best (green) and worst (red) compromise solution.

species showing the full spectrum of habitat preferences and does not originally allow any omissions as, otherwise, the assessment would become strongly biased. However, if information is not available for all species of the FI, we suggest to use a balanced mixture of rheophilic and limnophilic species, such as, e.g., only the macroinvertebrate community or a combination of fish and amphibian species. Finally, the definition of a reference state may present a problem in heavily modified floodplains in urbanized areas, where the reversibility toward pristine conditions has been long-lost (Jungwirth et al., 2002).

In contrast to the FI/WFD assessment, the HBDs represent a single-species approach, which does not aim at one desirable scenario for the entire floodplain, but focuses on the conservation status of individual species (Janauer et al., 2015). Consequently, this approach does not yield a clear ranking of scenarios, but rather reveals losers and winners for each individual scenario. It requires more individual decisions about the priority and weighing of species than the FI approach, but also provides more information on species level with a higher spatial resolution, including even terrestrial species. This facilitates the definition of compensation measures in the case of habitat losses under a certain scenario. In our case study, amphibian-rich side-arms were predicted to suffer a severe deterioration in the S20–80 scenario due to migration of eurytopic predatory fish, without offering habitat for other threatened species (e.g., rheophilic fish). Thus, for these water bodies, the construction of dams was planned, which facilitated the entry of seepage water, but prevented the migration of predators. One major drawback of the HBDs approach is the tendency to prefer already existing species over those, which originally inhabited the floodplain, but were significantly reduced or lost during the floodplain degradation, as those are often not listed in the standard data forms of the respective sites. This may lead stakeholders to protect existing values rather than try to restore pre-regulation conditions (Moss, 2007). Another drawback is that the HBDs only aim at species and habitats listed in the directives, but ignore others, which contribute to the biodiversity and ecosystem functioning of the floodplain. For example, macro-invertebrates are currently under-represented by the HBDs, despite their key role in floodplain food webs and matter cycling (Gladden and Smock, 1990). Finally, the different spatial scope of application of the directives may challenge the formulation of a compromise solution. While the holistic WFD-related FI approach (Chovanec et al., 2005) treats the river-floodplain system as an entity, the species-centered HBDs consider the regional context of the respective Natura 2000 area, which may not necessarily coincide with the floodplain area. This different spatial focus may not only result in divergent assessments between the directives, but it may also create problems, if the planned measures and the assessment do not cover the same area.

Despite the differences mentioned above, both approaches clearly ranked S0 as the worst-case scenario in our study. This was due to the predicted general loss of aquatic habitats in the future without any obvious gains for the aquatic flora and fauna and also due to the restricted options for compensation measures. Furthermore, both approaches revealed the low potential of restoring near-natural conditions in the floodplain even with the larger discharge of Danube water in the S20–80 scenario. Regarding the best-case scenario, the FI approach clearly ranked the scenario S20–80 best, while the HBDs approach showed almost similar values for S3 and S20–80. However, the differences between the two scenarios were subtle.

Decision Support Tools

A high proportion of floodplain areas along large European rivers are protected by the HBDs (Funk et al., 2019) and all are included in the WFD objectives. These floodplains are widely threatened by diverse human pressures, including hydromorphological alterations, and restoration and conservation measures are, thus, gaining in importance. In such human altered river-floodplain systems, the achievement of the targets of the WFD and the HBDs requires a detailed planning of different, ecologically, commercially, and socially acceptable compromise solutions (Rouquette et al., 2011). In our case study, for example, an ecologically significant full re-connection with the Danube was not considered as potential scenario due to economic and social restrictions (e.g., threatening the drinking water supply and nearby settlements due to increased groundwater levels and flooding events). Thus, the decision process has to focus on realistic and hydrologically feasible options.

Although both WFD and HBDs offer some flexibility of action to find an environmentally sound compromise solution in individual cases, there is currently no general regulation about how to deal with conflicts between the different directives (Janauer et al., 2015). This study presents an approach to consider the partly conflicting goals of the WFD and the HBDs as objectively and as transparently as possible by (a) basing the species-specific assessments on a combination of long-term monitoring data, spatial modeling, and expert judgment (**Figure 2** and **Supplementary Figure S1**) and (b) developing a comprehensible scoring scheme for the scenarios applicable throughout all species, groups, and floodplain levels (**Tables 1–4** and **Supplementary Table S2**). However, we are aware that our approach depends on the quality of the available hydrological and biological data and the long-term expertise on the floodplain's state and development, including information about the historic reference state. Thus, depending on the respective situation, adaptions may be necessary for both the definition of the desired future state of the floodplain as well as for the assessment of the current ecological state and deviations from this desired state. Besides, the applicability of a classification scheme via species-based habitat distributions has to be tested and alternative classifications schemes may have to be developed for other river-floodplain systems.

The trade-offs between the stagnotopic and rheotopic community protected under the HBDs (Sanon et al., 2012; Funk et al., 2013) as well as potential trade-offs between targets of the WFD and the HBDs have already been described in detail for different floodplain systems (Janauer et al., 2015). In this context, Species Distribution Models (SDMs) are gaining in importance for the evaluation of potential restoration measures related to both the WFD (e.g., Bennetsen et al., 2016; Zucchetta et al., 2016) and the HBDs (e.g., Funk et al., 2013). Using SDM predictions for a variety of species differing in their habitat requirements can help to predict winners and losers of different restoration and conservation scenarios and, thus, help to find solid compromise solutions (e.g., Funk et al., 2013; Heuner et al., 2016; Remm et al., 2019). However, as our case study shows, predictive models do not necessarily provide a clear result in relation to preference ranking of the scenarios, as the gain of habitats for certain species may be associated with habitat losses for others. Assigning a specific weight to individual species in the analysis is therefore an important step forward in the decision process, especially if the assessment shows both winners and losers. In this case, high weights for winners and low weights for losers would show a clear preference for the respective management measure, while the reverse would entail rejection. Another important item is the consideration of the status of the individual species according to the respective legislation on European and national level (De Nooij et al., 2005). We have developed a transparent decision tree based on the actual and the predicted distribution and conservation status of the relevant species according to the HBDs and regional nature protection laws to assess the significance of potential habitat changes for the state of the different species in the future. Within our approach, we are able to account for the importance of the species in the system, the likeliness that the status is deteriorated or improved due to different restoration measures, and the potential for compensation measures.

An SDM approach can also give river managers a first insight into which measures are feasible to achieve an improved ecological status as required by the WFD (Bennetsen et al., 2016). In our case study, we used SDMs to predict the potential impact of proposed restoration measures on the ecological status of the floodplain using the FI developed by Chovanec et al. (2005). The FI includes a direct comparison with the reference state and clearly ranks the scenarios according to their potential to reach the good ecological state. However, the WFD does not refer to single floodplain sections. Instead, a water body is defined as a whole "discrete and significant" section of a river. In our case, this refers to the whole remaining free flowing stretch of the Danube between Vienna and the national border to Slovakia, which constitutes the National park Donau-Auen (**Supplementary Figure S2**). Our study shows that the inclusion of this area into the analyses, as it was done for Lower Austria, buffered the impact of the different scenarios (compared to the Viennese part) and offered the opportunity for spatial compromises. Thus, habitat losses as well as gains in the Lower Lobau were mostly neglectable when considering the entire National Park. A more detailed spatial resolution of the FI based on SDMs, may help to identify local impacts better. Water bodies, which were located within the main water course and were dominated by a eurytopic community, for example, were expected to gain from a reconnection with the Danube due to the improved water supply and the increased range of flow conditions. In contrast, our spatial models revealed that valuable lentic and temporary water bodies outside the main water course should not be included in the reconnection scheme, but rather kept isolated from inflowing Danube water by local compensation measures, such as, e.g., protection dikes, to protect the stagnotopic community from increased predation (Schmidt-Mumm and Janauer, 2016; see **Supplementary Figure S1**). This would keep losses of valuable amphibian habitats small, without affecting the eurytopic community. Thereby, seemingly negative impacts on the large-scale can be relativized. Consequently, the combination of a large-scale re-connection scheme and local protection measures may improve the ecological status of the floodplain as well as increase the overall biodiversity, thereby meeting the aims of both EC WFD and EC HBDs in a well-balanced approach.

CONCLUSION

The combination of multiple-species and single-species approaches provides a solid basis for decision processes in floodplain restoration in accordance with the EC WFD, the EC HBDs, and local legislation. Further, we could show that the "business-as-usual" alternative (i.e., no implementation of any restoration measure) is the worst scenario and that restoration actions are required to preserve at least the existing aquatic and semi-aquatic habitats in such systems. Our case study demonstrates that a detailed spatial resolution of the effects of management measures offers the opportunity to protect isolated water bodies and restore lotic conditions at the same time in the case of trade-offs between stagnophilic and rheophilic species. Therefore, detailed spatial planning is an important next step in floodplain restoration to find the optimal combination of spatially distinct large- and small-scale measures to increase the habitat availability for all relevant species as well as the overall biodiversity (e.g., Maire et al., 2015; Heuner et al., 2016; Remm et al., 2019).

Apart from the ecological challenges addressed in this paper, the management and restoration of riverine floodplains usually concerns a variety of other economic and social demands, such as, e.g., food production, tourism, or flood protection. The development and application of a Decision Support System to equally consider all demands in a transparent and reproducible way has been widely acknowledged in river floodplain management, but requires both the assessment and the weighing of the individual demands in the most objective way (e.g., Rouquette et al., 2011; Sanon et al., 2012; Stepniewska and Sobczak, 2017; Richards et al., 2018; Stammel et al., 2020). Our study provides such an approach for the aims of the WFD and HBDs, based on objective criteria and decision trees, which can be integrated into such a Decision Support System to help finding the best-compromise solution for a more holistic and, thus, sustainable management of these highly complex river-floodplain systems.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

GW and AF were responsible for the manuscript outline, the graphs, and the writing. EF, EP, and DT contributed to the data analyses, the interpretation, and the collection of background information about nature protection states. TH contributed with revisions and comments. All authors have read and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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