**Management challenges related to long-term ecological impacts, complex stressor interactions, and different assessment approaches in the Danube River Basin**

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**Abstract**
For centuries, rivers have experienced massive changes of their hydromorphic structures due to human activities. The Danube River, the second largest river in Europe, is a case in point for long-term societal imprint. Resulting human-induced pressures are a key issue for river management, aiming to improve the ecological conditions and guarantee the provision of ecosystem services. As the most international river basin in the world, the management of the Danube is particularly challenging and needs a well-organized cooperation of 19 nations. The recent river basin management plan has identified pollution and hydromorphological alterations as most pressing problems, but it has also acknowledged newly emerging issues. In this article, we present 3 specific examples of highly relevant issues for the future river basin management of the Danube: (a) long-term impacts in the catchment such as changes in flood patterns and potential ecological consequences; (b) complex feedback loops linking the spread of neozoa with intertwined stressor responses due to river engineering for different purposes; and (c) linkages between different assessment approaches based on European legal frameworks to analyse the specific pressures at different spatial scales. These examples highlight the need for a more integrated approach in future Danube River Basin management schemes. Furthermore, large-scale effects such as climate change and interactions of multiple pressures need to be addressed in future management to increase resilience of the river system and to allow a sustainable ecosystem-based management of rivers.

**KEYWORDS**
EU Habitat Directive, EU Water Framework Directive, hydrograph, hydropower production, multiple stressors, navigation, neozoa, river regulation

1 | INTRODUCTION

All over the world, large rivers have undergone massive alterations due to infrastructure development, such as damming and channelization, land use changes, pollution, and biotic changes (Vörösmarty et al., 2010). In some European river basins, these stressors have lasted over centuries, often causing environmental legacies, irreversible ecological impacts, system adaptions, or system shifts (Hoffmann et al., 2010; Hohensinner, Jungwirth, & Muhar S Schmutz, 2011). Moreover, stressor interactions may lead to various, often hardly predictable additive, synergistic or antagonistic effects on river ecosystems (Crain, Kroeke, & Halpern, 2008; Hering et al., 2015; Piggott, Townsend, & Matthaei, 2015).

Human populations have inhabited riverine landscapes since prehistoric times, benefiting from provisioning and other ecosystem services despite the inevitable flood hazards and risks (Hein, Bondar-Kunze, Schierner, Welti, & Pinay, 2009). Interventions into river channels and floodplains for agriculture and settlements,
urbanization, hydropower generation, and navigation date back to medieval times or at least to the early industrialization period. During the 20th century, human activities and civil engineering operations have caused river ecosystem fragmentation and habitat destruction and have modified dynamic system properties, such as the flooding regime; the longitudinal, lateral, and vertical connectivity; biogeochemical cycles; and biodiversity patterns (Gergel, Carpenter, & Stanley, 2005). Consequently, riverine ecosystems are among the most endangered ecosystems worldwide (Fryirs & Brierley, 2016).

The Danube River is such an example of a multiple-stressed, highly vulnerable riverine system, which still shows a high ecological potential despite its long-term exposure to socio-economic usage. Ongoing, partly conflicting demands within and among the different neighbouring countries, inconsistencies in legislation, and drivers of change aggravate the problem of a joint, sustainable management further. This article presents both changes of key ecosystem properties of the Danube River and management strategies for the Danube River Basin (DRB) to underline challenges for future ecosystem-based management. In particular, we focus on long-term changes in the hydrograph and the discharge regime of the Danube River as well as on the historic development of human activities, such as hydropower generation and navigation, and related changes in the dispersal of alien species. Furthermore, we highlight the interplay of different pressure assessment methods in relation to protected areas along the navigable stretch of the Danube River. The presented examples can be of valuable support in the sustainable management of river basins in Europe and around the world.

2 | CURRENT SITUATION IN THE DANUBE RIVER BASIN

The DRB is the most international river basin in the world, shared by 19 nations and draining a catchment of 807,827 km² in Central and South-Eastern Europe (Habersack et al., 2016; Figure 1). The Danube River flows from the Black Forest Mountains in Germany to the Black Sea and has a total length of 2,857 km, which is divided into three sections: the Upper (1,066 km), Middle (860 km), and Lower Danube (931 km; Figure 1: Sommerwerk et al., 2009). Exceptionally diverse ecological and socio-economic properties characterize the DRB (Sommerwerk et al., 2010). Its unique biodiversity and high ecological potential make the DRB one of the Earth’s 200 most valuable ecoregions (Olson & Dinerstein, 1998). At the same time, the DRB is listed among the world’s top 10 rivers at risk, mainly due to river engineering, navigation, pollution, and invasive species (Wong, Williams, Pittock, Collier, & Schelle, 2007).

The river network of the DRB has been progressively constrained for flood protection, navigation, and, during the last 100 years, for hydropower generation, resulting in 78 barriers (including barriers without hydropower production and 44 hydropower plants [HPPs]) located in the Danube and further 1,610 along the tributaries (International Commission for the Protection of the Danube River [ICPDR], 2009; Figure 1). This has affected the sediment regime of the Danube considerably, leading to significant reductions of sediment transport in upstream sections and riverbed incision in downstream reaches (Habersack et al., 2016). Point and diffuse pollution as well as the effects of land use changes have aggravated the ecological impacts of barriers, river channelization, and navigation. According to the ICPDR, less than 19% of the floodplains existing in the 19th century remain in the entire basin, equivalent to a loss of approximately 33,800 km² of floodplain area (ICPDR, 2009). Before main river regulations were conducted, the active floodplain width amounted to >10 km in the Upper and >30 km in the Middle and Lower Danube, respectively (Figure 1). In the Upper Danube, most floodplains and fringing wetlands have been converted into agricultural and urban areas or have been isolated by dams and artificial levees and are, thus, hydrologically and functionally decoupled. However, along the Middle and the Lower Danube, large, near-natural floodplain areas still exist (Hein et al., 2016).

3 | LONG-TERM CHANGES IN THE FLOOD REGIME OF THE DANUBE

Both riverine ecosystems and ecosystem services largely depend on the flood regime. Repeated floods sustain dynamic hydrological conditions in both the river and its riparian zone, supply floodplain habitats with water and nutrients, and enable the migration of organisms from the main river to side arms and backwaters (Baart, Hohensinner, Zsuffa, & Hein, 2013; Bayley, 1991; Weigelhofer, Preiner, Funk, Bondar-Kunze, & Hein, 2015). The repeated drying and rewetting of floodplain habitats often results in increased aquatic productivity compared to stable systems in temperate and tropic regions (Bayley, 1991; Tockner, Malard, & Ward, 2000). However, the rapid decline of flood...
peaks can cause stranding and subsequent dehydration of fish eggs and larvae in shallow spawning grounds, thus severely compromising the natural recruitment of fish stocks (Pintér, 1992; Welcomme & Halls, 2002). Fast water level changes, combined with high flood amplitudes, also expose semi-aquatic and aquatic plants to submergence and desiccation stress to which they may be unable to adapt (Brock, van der Velde, & van de Steeg, 1987; Welcomme & Halls, 2002). This may easily affect diverse water plant communities in riparian areas (Brock et al., 1987; Zsuffa, 2001).

The natural river hydrograph of the Danube is characterized by two major flooding periods, one in early spring (March and April), caused by snowmelt in mountainous areas, and one in early summer (May and June), which is associated with prolonged rainfalls in the Upper Danube catchment (precipitation maximum). Low water levels usually occur in late summer and early autumn due to low precipitation and in winter when the precipitation is bound in the form of snow and ice. Flood pulses during spring and early summer are especially important for river biota as they enable the spawning of typical Danubian fish species, such as pike, carp, or other cyprinids, which depend on vegetation-rich habitats in floodplains (Keresztesy & Farkas, 2005; Patak, Zsuffa, & Hunyady, 2013; Pintér, 1992).

In recent years, floods from snowmelt have increasingly coincided with early-summer precipitation (rain-on-snow phenomena), thus altering the magnitude and duration of floods especially along the Upper Danube (Lóczy, 2010). River regulation, catchment deforestation, and channelization have additionally affected the hydrograph of the Danube (Zsuffa sr, 1999). To quantify the magnitude of these changes over time, we analysed daily water levels in the Upper Danube at Vienna, Bratislava, and Baja (approximately 160 km south of Budapest) between 1829 and 2005. We focused on spring (April-June) as the main period for plant growth and fish spawning. Water levels were analysed as to long-term changes in (a) maximum, mean, and minimum water levels; (b) the rate of water level decline after flood peaks (defined as the highest daily drop in water levels); and (c) the difference between highest and lowest water levels between April and June. Four periods were defined, which represent different phases of river regulation. Between 1829 and 1848, no major river regulations were performed and almost pristine conditions prevailed. The periods 1878–1897 and 1898–1912 illustrate the hydrological regime after the major river regulation works in the Upper Danube, whereas the period 1968–2005 includes the establishment of impoundments along the main stem of the Danube (current state).

The results show a decrease in mean, minimum, and maximum water levels of the Upper Danube. At Bratislava, for example, these decreases amount to 340, 300, and 140 cm, respectively, since 1878. These changes are responsible for the severe loss of aquatic and semi-aquatic habitats along the river (Zsuffa, 2001). In addition, the rate of the water level decline after flood peaks has increased during the past two centuries by a factor of more than two in the Upper Danube (Figure 2). Although water levels dropped by about 35 cm d⁻¹ on average during receding floods in 1878–1897, this value is about 75 cm d⁻¹ today. Likewise, differences between the highest and the lowest water levels have increased (Figure 3). The increased variability of the hydrological regime has contributed to the decline of fish stocks and water plants (Pintér, 1992; Zsuffa, 2001).

**FIGURE 2** Means and standard deviations of maximum daily water level decreases. (Gaps are due to lack of recorded water levels from the particular periods.)

**FIGURE 3** Means and standard deviations of the differences between highest and lowest water levels for the four periods.

The main reason for the overall decrease in water levels is riverbed incision, which is a general phenomenon in the Danube (Habersack et al., 2016). Incision was triggered by increasing water velocities caused by meander shortcuts, side channel closures, and main channel trainings conducted in the 19th and 20th centuries (Habersack et al., 2016). A chain of HPPs built along the German and Austrian Danube, especially in the second half of the 20th century, additionally contributed to channel incision, as the dams reduced bed load transport (Habersack et al., 2016; Beckendorfer et al., 2005). River straightening, reductions of floodplains, and decoupling of the remaining floodplains from Danube floods have severely intensified the dynamics of flood pulses in the Danube (Zsuffa, 2001; Zsuffa sr, 1999). Although current restoration efforts try to compensate some of the effects of former river regulation (Schmutz et al., 2014), the above-mentioned changes in both, the overall water supply and the flood dynamics, may be further aggravated by the ongoing climate change and soil sealing in the catchment (Beniston & Stoffel, 2014; Lóczy, 2010).

### 4 DISPERSAL OF ALIEN SPECIES IN RELATION TO THE HISTORIC DEVELOPMENT OF HYDROPOWER GENERATION AND NAVIGATION

Modified biotic interactions caused by an increasing number of alien species represent another challenge for the management of the Danube
investigated was based on data found in Bódis et al. (2012) and comprised molluscs, peracarid and eucarid crustaceans, fish, and reptiles. These data covered the period from 1861 to 2010 in the Middle Danube in Hungary. The temporal evolution of inland navigation from 1959 to 2014 is reflected by transport freight on the Danube River in Austria, representing the transition of the Upper to the Middle Danube (data source: Statistik Austria). Although the amounts of transported goods differ between the Upper, Middle, and Lower Danube, the general pattern of the development through time is similar for all river sections. Additionally, we compared the relative portion of native and alien macroinvertebrate species in different mesohabitats along the Danube based on the data from the Joint Danube Survey 3 (for more details see Graf, Csányi, et al., 2015).

The construction of HPPs in the Danube started at the end of the 19th century. Until 1950, nine HPPs existed in the Upper Danube (Figure 4, Table 1). Within the next 50 years, the number of HPP constructions increased dramatically. Currently, there are 44 HPPs in the Danube, whereby the majority is located in Germany and Austria. Likewise, the amount of transported goods continuously increased in the Upper and Middle Danube from the 1950s onwards (Figure 4). In the 1990s, a sharp increase of transport freight can be observed due to the fall of the Eastern Bloc, which was followed by a sharp decrease at the beginning of the 2000s. Concurrent to the development of hydropower generation and navigation, the number of alien species has continuously increased in the Middle Danube since 1910, whereby the sharpest increase has occurred after 1980. However, the decrease in freight transport after 2000 is not reflected in the recordings of invaders. Besides, early species invasions in the Middle Danube cannot not be directly linked to the early constructions of HPPs in the upper reach. It seems likely that other factors related to anthropogenic alterations are relevant, further complicating management interventions (Orendt et al., 2009).

One option of tackling species invasion in the Danube would be to focus on strengthening the competitive power of the native river community. The current macroinvertebrate communities reflect the different mesohabitat preferences of alien and native species (Figure 5). Native taxa prefer organic and rather fine substrates, whereas alien taxa represent a biological response to human interventions in the river and act as stressors for native species. Alien species compete with the indigenous fauna for habitats and resources and, thus, may severely impair the entire functioning of aquatic ecosystems (Statzner, Bonada, & Dolédec, 2008). Due to their usually high densities, alien species may dominate the benthic community, act as bioengineers, and can intervene in the nutrient cycle (Nakano & Strayer, 2014). Hence, the establishment of alien species represents an irreversible shift in the ecosystem state. Restoration and rehabilitation measures may enhance habitat diversity and enable a coexistence of native and nonnative species. However, the extirpation of alien species seems unmanageable in the long term (Orendt, Schnitt, Liefferinge, Wolfram, & Deckere, 2009).

Vessels are considered as the main vectors of alien species, which are transported by ballast water and on vessel hulls. Regarding fish, fishery (including aquaculture) and animal trade were responsible for early invasions, whereas waterways are the main pathway for recent invaders, such as gobies (Rabitsch et al., 2013). Changes of habitat conditions additionally favour the establishment of invasive species that may fill up available environmental niches after outcompeting impaired native populations. In the Upper Danube, for example, river regulation and damming for hydropower generation have severely impaired habitat conditions through morphological degradation and homogenization, hydrological alterations, and increased sedimentation upstream of dams (Banning, 1998; Reid, 2004). Damming technically complements navigation as it stabilizes flows, ensures controlled water levels, and supports a wide navigation line. In summary, these influences reduce habitat diversity, disturb sediment equilibrium, and induce adverse and short-term hydrological disturbances due to vessel-induced waves. The resulting irregular, high shear stress at the river banks is particularly negative for the sensitive land–water interface (Liedermann et al., 2014), which is essential for hemilimnic organisms during metamorphosis.

Our analysis focused on the simultaneous development of hyromorphological impacts, inland navigation, and the dispersal of alien species along the Danube to demonstrate the close interaction of these stressors. We collected construction dates of HPPs, identified by Habersack et al. (2016), to characterize the temporal development of hydropower generation. Our information covered the period from 1877 to 2013 for the whole Danube River. The number of alien taxa investigated was based on data found in Bódis et al. (2012) and comprised molluscs, peracarid and eucarid crustaceans, fishes, and reptiles. These data covered the period from 1861 to 2010 in the Middle Danube in Hungary.
species favour larger, stabile substrates, especially rip-rap-dominated habitats (Borza, Huber, Leitner, Remund, & Graf, 2017; Graf, Csányi, et al., 2015). Riverbank restoration can create more lentic areas, such as shallow riverbanks with fine sediments and large woody debris accumulations, which support the distribution of the indigenous fauna (Graf, Hartmann, & Leitner, 2011).

Species distributions oscillated in the past and will show fluctuations and shifts in the future, but human activities support the dispersal of alien species and reduce dynamic processes that are inherent to natural ecosystems. The increasing occurrence of invasive species in combination with the loss of indigenous fauna in large rivers is a pressing problem, which needs further consideration at European-wide scale (e.g., Graf et al., 2008; Graf, Leitner, et al., 2015; Moog et al., 2008).

5 | EUROPEAN STRESSOR ASSESSMENT APPROACHES AFFECTING THE DRB

Currently, there are two main legal frameworks for assessing the ecological integrity of riverine ecosystems in Europe: the European Commission (EC) Water Framework Directive (WFD), which aims at restoring and maintaining a good ecological state of all surface and subsurface water bodies in the EC (EC, 2000), and the EC Habitat and Birds Directives (HBD), which focus on the protection and conservation of a wide range of natural habitats and endangered species to maintain biodiversity (EC Birds Directive, 2009a; EC Habitats Directive, 1992). Both approaches can be used for the assessment of key stressors in the DRB. However, their different focus and administrative spatial scale may yield divergent results in terms of stressor relevance. Although in the WFD, human pressures on aquatic ecosystems are assessed at national level (ICPDR, 2016), the management of protected Natura 2000 sites according to the HBD is organized at local or regional level (Ostermann, 1998). In addition, the WFD assessment is based on data analyses, whereas the HBD assessment relies on expert judgement. We compared local identifications of stressors (HBD approach) with large-scale assessments at the catchment scale (WFD approach) for protected riparian areas along the navigable stretch of the Danube River (length 2,415 km) and complemented these results with data from European land use monitoring to (a) investigate potential consensus among the different approaches and (b) extrapolate main drivers and stressors for the Upper, Middle, and Lower Danube.

The assessment of hydromorphological alterations (Schwarz, 2014) was conducted according to the WFD in 2013 by integrating information on engineering structures and floodplains with adjacent land use, navigation maps, hydrological and morphological background data, and available field records. Land cover or land use data were obtained from the European riparian zones dataset developed by the local component of Copernicus Land Monitoring Services (land.copernicus.eu; assessed 20.4.2017). Data reported on drivers and stressors of 125 Natura 2000 sites within the riparian zone of the river Danube were extracted from the database and Geographical Information System (GIS)-based maps from the European Environmental Agency (www.eea.europa.eu; accessed 20.4.2017) and were used. All geographical data as well as associated tabular data were linked in ArcGIS 10.3 (ESRI) at the spatial scale of Natura 2000 sites to make the different spatial scales of the approaches comparable. Natura 2000 sites currently stretch over approximately 1,700 km of the river; this corresponds to about 70% of the navigable section of the Danube.

In general, the two different approaches, WFD and HBD, as well as the land use data showed high concordance, as land cover within the Natura 2000 sites changes along the course of the Danube. From Upper to Lower Danube, the proportion of cropland increases, whereas woodland and forest shares decrease (land use data; Figure 6). In accordance, agriculturally used areas (impacted land cover, WFD approach) and agricultural area expansion (HBD approach) within the riparian zones are higher in the Lower Danube than in the

| TABLE 1 | The number of hydropower plants per country and time period along the Danube River |
|----------|---------------------------------|----------|----------|----------|----------|----------|-----------|
| Period   | Upper Danube | Middle Danube | Lower Danube | Total |
| <1910    | 6            | 7            | 1          | 14      |
| 1910–1950| 3            | 11           | 2          | 16      |
| 1950–1980| 14           | 22           | 1          | 37      |
| 1980–2010| 8            | 13           | 2          | 23      |
| Total    | 31           | 44           | 2          | 79      |

| FIGURE 5 | Percentages of native (grey column) and neozoa (black column) taxa occurring in the different mesohabitats for the Upper, Middle, and Lower Danube based on Joint Danube Survey 3 data |
Upper and Middle Danube. Land use data and land use categories according to HBD are significantly correlated ($R = .27, p < .01$). Forestry (HBD approach) is more relevant in the Upper Danube, reflected by its high forest cover. Coverage of urban areas within protected areas is generally low (land use data), but urbanization is a driver for impacting protected sites in the Lower Danube and significantly correlates with the percentage of urban areas ($R = .27, p < .01$), the intensity of engineering (WFD, $R = .34, p < .01$), bank stabilization (WFD, $R = .31, p < .01$), and flood protection measures (WFD, $R = .22, p < .05$).

There is also a high congruence of local (HBD) and catchment (WFD) approaches regarding hydromorphological alterations (Figure 6). According to the WFD approach, the Upper and Middle Danube are heavily impaired by instream engineering structures, artificial bank structures, and flood protection dikes. Only three free-flowing sections remain in Germany and Austria, expanding over approximately 150 km river length in total (Habersack et al., 2016). In the Lower Danube, flood protection measures are the main stressors. Hydropower generation has the highest impact in the Upper Danube and is of no significance for the Lower Danube. Likewise, the HBD approach shows a decreasing impact of hydromorphological alterations from the Upper Danube to the Lower Danube. The impacts of instream engineering structures and of artificial bank structures (WFD) are significantly correlated with the hydromorphological alterations of the HBD approach ($R = .39, p < .01$ and $R = .40, p < .01$, respectively). According to the HBD, additional threats for protected riparian areas are recreation (mainly nautical sports), fisheries (recreational in the Upper Danube vs. more commercial in the Lower Danube), invasive species, and pollution (Figure 6).

On the basis of our comparison of different assessment approaches, we are able to provide a deeper insight into main stressors along the three sections of the navigable Danube River. Our results supplement and support the information reported by Hein et al. (2016) for the Lower and Upper Danube. Stressors can be ranked in their importance for the three Danube sections as follows (see Figure 6, grey bars): (a) Upper Danube: hydromorphological alterations due to hydropower generation, navigation, and flood protection; forestry; disturbance due to recreational activities; recreational fisheries; and pollution; (b) Middle Danube: hydromorphological alterations due to hydropower, navigation, and flood protection; invasive species; disturbance due to recreational activities; and forestry; (c) Lower Danube: forestry; agriculture; urbanization; commercial fisheries; pollution; and hydromorphological alterations.

#### 6 CURRENT MANAGEMENT STRATEGIES IN THE DRB AND FUTURE IMPLICATIONS

Since 1998, 14 DRB countries have been cooperating on water protection and conservation issues through the ICPDR. The ICPDR implements the “Convention on Cooperation for the Protection and
Sustainable Use of the Danube River” from 1994, known as the “Danube River Protection Convention”. This convention aims at achieving sustainable and equitable water management, including the ecological integrity, conservation, improvement, and sustainable use of surface and ground waters in the DRB (Chapman et al., 2016).

The main management targets are specified in the “Danube River Basin Management Plan” (DRBMP; ICPDR, 2009), which guides the implementation of the WFD on the catchment scale (EC, 2000). The DRBMP addresses significant water management issues, namely, pollution of different origins and hydromorphological alterations caused by longitudinal fragmentation and lateral disconnection of floodplain areas. Invasive species, climate change, and the effects of multiple stressors are also addressed in the most recent update of the management plan (ICPDR, 2016). Other European policies, such as the EC Habitat Directive (EC, 1992), the EC Floods Directive (EC, 2007) and the EC Renewable Energy Directive (EC, 2009b) are also relevant for the river basin management. Each of these legal frameworks need to be considered in the DRBMP (e.g., the Floods Directive in 2016) to achieve more harmonized actions in fulfilling the different objectives.

For the conservation and protection of biodiversity, the integration of the EC Habitat Directive will be an important next step to avoid conflicting views in the future (ICPDR, 2016; Janauer, Albrecht, & Stratmann, 2015). In addition, strategic planning tools should be included in future integrated river basin management to help decision makers governing the implementation of the various EC directives (Seliger et al., 2015). Likewise, recent scientific findings have to be considered, which address the problems of reestablishing reference conditions (Dufour & Piégay, 2009) and restoring human modified ecosystems, including the notion of novel ecosystems or no-analogue communities (Hobbs et al., 2006; Williams & Jackson, 2007).

As highlighted by our three examples, long-term impacts in the catchment, complex feedback loops and interactions within and among different ecosystem components, and linkages between different assessment approaches require more attention in an integrated management of the DRB (Figure 7). Various stressors interacting over several decades to centuries have modified key ecosystem features of the Danube irreversibly. Thus, a sustainable management approach can no longer rely on historic reference conditions but requires new or modified targets for key ecosystem characteristics (Dufour & Piégay, 2009). Human uses of the DRB have not only intensified, as our examples of hydropower generation and navigation show, but also diversified over the past centuries. Previous interventions have caused long-term environmental legacies, and their adverse effects on biota may become visible with delays (Dullinger et al., 2013; Haidvogl, Hoffmann, Pont, Jungwirth, & Winiwarter, 2015). Modern management concepts can no longer exclusively focus on the mitigation of single stressors, as they often did in the past, but have to envisage stressor interactions and develop strategies to counteract multiple stressor effects (Nõges et al., 2016; Schinegger, Palt, Segurado, & Schmutz, 2016). At the same time, management schemes need to consider complex interactions and feedback loops and cannot limit their measures to single ecosystem components or species groups (Figure 7). For international rivers, such as the Danube, an additional challenge is the need for harmonized approaches at catchment scale, whereas both human uses and ecosystem management often act at regional or local scale and vary among nations (Seliger et al., 2015). Global climate change adds to the problem of sustainable river basin management as it requires urgent global actions, thus enlarging the spatial and temporal scale further (Pont, Logez, Carrel, Rogers, & Haidvogl, 2015).

Collaborative biophysical assessments and economic valuations could boost awareness and inclusion of the interdependence of nature and people for a sustainable management of water resources (Grizzetti, Lanzanova, Liquete, Reynaud, & Cardoso, 2016). Thus, for the future, explicit and well-defined ecosystem-based targets need to be formulated and adequate measures need to be defined to achieve more resilient ecosystems, guarantee the provision of a broad range of ecosystem services, and increase the resilience against emerging stressors and large-scale changes such as climate change in river basins.

FIGURE 7 A conceptual scheme for the Danube River, including main stressors, ecosystem functioning, and the cascade of management activities. EU WFD = European Union Water Framework Directive [Colour figure can be viewed at wileyonlinelibrary.com]
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