Figure 3: Eichhornia crassipes (Mart.) Solms. Left: Flower and leaves of E. crassipes (Water Hyacinth) © georgjanauer2020. The lower part of the petioles/leaf stalks is widened with airspaces, providing buoyancy. Right: Solid canopy of Water Hyacinth. © Hans Hillewaert

helophytes into the former water-covered realm of the native aquatic plants. The additional threat of IAS eradicating the native aquatic vegetation should be counteracted with force by the respective public organisations. One important step is a higher frequency of surveying the floodplain water bodies to be on the spot when IAS are starting their invasion, and trying to 'confine/limit/eliminate' as described in the EU-Regulation.

References

EU WFD (2000): Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Community, L327.

EU IAS (2014): Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 23 October 2014 on the prevention and management of the introduction and spread of invasive alien species' (Official Journal of the European Union / L317)

EU Amending Directive (2014): Commission Directive 2014/101/EU of 30 October 2014 amending Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy. Official Journal of the European Union. L311.

EU Habitats Directive (1992): Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. L0043.

UBA (2002): Neobiota in Österreich, Umweltbundesamt Wien, 432pp.

UBA (2013): Aquatische Neobiota in Österreich Stand 2013. Pdf-Download: Lebensministerium. Umweltbundesamt Wien. Latest update: 2016 (https://www.umweltbundesamt.at/ms/neobiota-austria/neobiota_recht/neobiota_steckbriefe/eichhornia_crassipes; accessed 20200408, 20:36).

UBA (2019): Arten der Unionsliste – Steckbriefe; Umweltbundesamt GmbH, Spittelauer Lände 5, 1090 Wien https://www.neobiota-austria.at/ms/neobiota-austria/neobiota_recht/neobiota_steckbriefe/

UBA (2020): Neobiota-Bericht; Umweltbundesamt Wien. https://www.neobiota.austria.at/

Editorial note:

for further information on invasive alien species see details of the IAD-Expert Group IAS; see also Trichkova et al. 2017 (in Bulgar.): https://www.esenias.org/files/ESENIAS_Atlas_WEB.pdf

Analysis of the retention potential of restoration measures in Bavarian streams

Michael Neumayer: Technical University of Munich - Chair of Hydrology and River Basin Management, Arcisstraße 21, 80333 Munich, Germany, email: michael.neumayer@tum

Sonja Teschemacher: Technical University of Munich - Chair of Hydrology and River Basin Management, Arcisstraße 21, 80333 Munich, Germany, email: sonja.teschemacher@tum

Fabian Merk: Technical University of Munich - Chair of Hydrology and River Basin Management, Arcisstraße 21, 80333 Munich, Germany, email: fabian.merk@tum

Prof. Dr.-Ing. Markus Disse: Technical University of Munich - Chair of Hydrology and River Basin Management, Arcisstraße 21, 80333 Munich, Germany, email: markus.disse@tum

Background

The concept of restoration comprises the reestablishment of the natural state of previously anthropogenically altered ecosystems as well as the conservation of unaltered, natural ecosystems (StMUV 2014). This study focuses on examining possible restoration measures for water bodies and the surrounding floodplain ecosystems. It aims to define the possible positive effects these measures may have on the natural retention potential and thereby on flood mitigation.

Every ecosystem is defined by its location through e.g., climate, geology, tectonics, soil, and vegetation. These conditions contribute to local characteristics like run-off behavior, sediment budget, morphology, water quality, and flora and fauna, which all dynamically shape surface water bodies (Jürging 2001). During the past centuries, humans have reshaped most of the running waters in Bavaria to enable land use changes towards cultivation or even settlements. Channel straightening has eradicated many

Figure 1: Anthropogenically heavily altered (left) and barely altered, hence, quasi-natural (right) sections of the Otterbach. (left image: © Johanna Springer; right image: © René Heinrich)

water body specific characteristics and reduced the existing natural river retention. In some cases, the natural floodplains were replaced by highly water-sensitive constructions, e.g., settlements and industrial areas *(see fig. 1).*

Within this study, the retention potential of natural rivers and floodplains will be compared to the potential of the current state of streams. Therefore, one section of each of the following rivers in Bavaria was selected: Weißer Main, Roter Main, Mangfall, Glonn, and Otterbach. These sections were then analyzed with the help of the two-dimensional hydraulic model HYDRO-AS-2D.

Developing the potentially natural model scenarios

In the beginning, the hydraulic influence of anthropogenic constructions such as crossing streets or railway lines had to be reduced. Thus, a so-called structure reduced model was created, which demonstrates the current state with reduced constructional influences on the hydraulic conditions. This is the 'starting' state to which different restoration measures are compared to. Within this step, non-removable infrastructures were identified according to the restriction analysis of the Bavarian floodplains program (PAN 2016) and therefore remained in the structure reduced models.

Based on the structure reduced models, various potential natural state scenarios were created (restoration scenarios). All scenarios aim for completely (re-)naturalized conditions of the respective water bodies with non-cultivated, forested floodplains encompassing them. The methodology of the hydrodynamic two-dimensional modelling of restoration measures has been enhanced in the course of the project, resulting in a total of four different methods *(see fig. 2)*. The enumeration of these models thereby also represents their chronological order of development.

Within Method 1, restoration concepts include alterations of the river course, changes in the cross sections, and the presence of riparian forest. These were modeled and analyzed separately as well as in varying combinations. However, following a restoration approach where measures are conceptualized individually, the result is unsatisfacto-

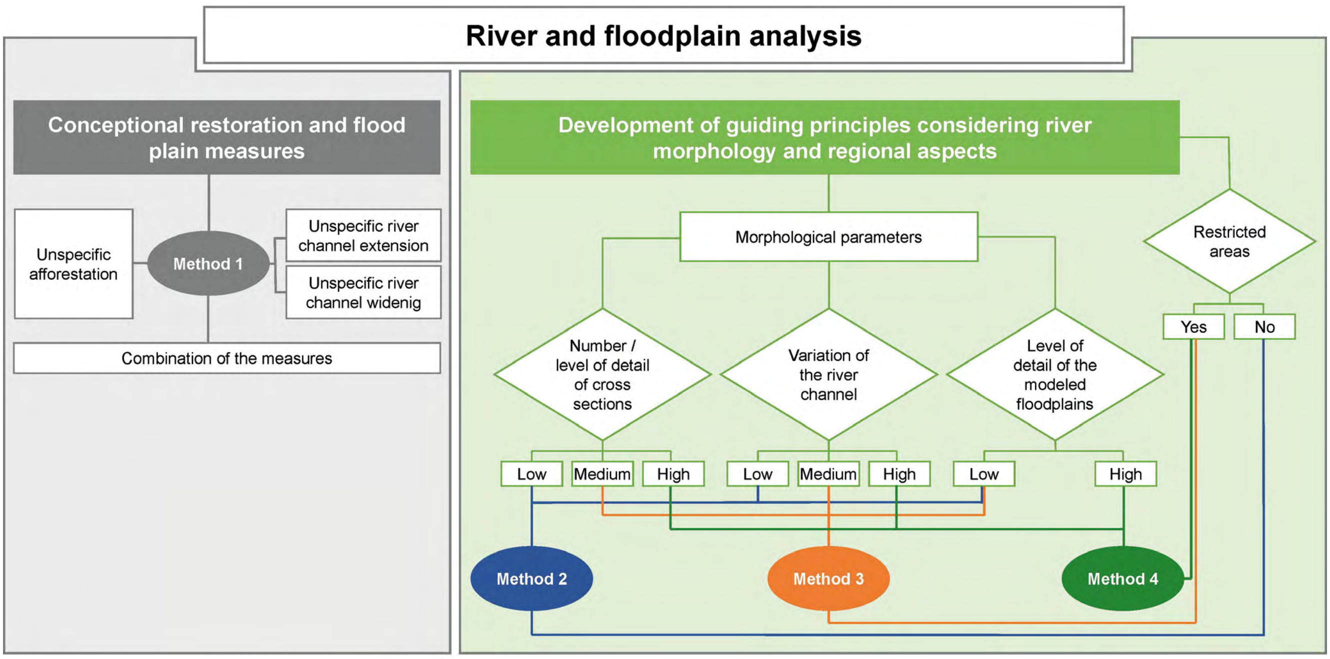

Figure 2: Different methods of modelling river and floodplain restoration measures. (Neumayer et al. 2018, modified)

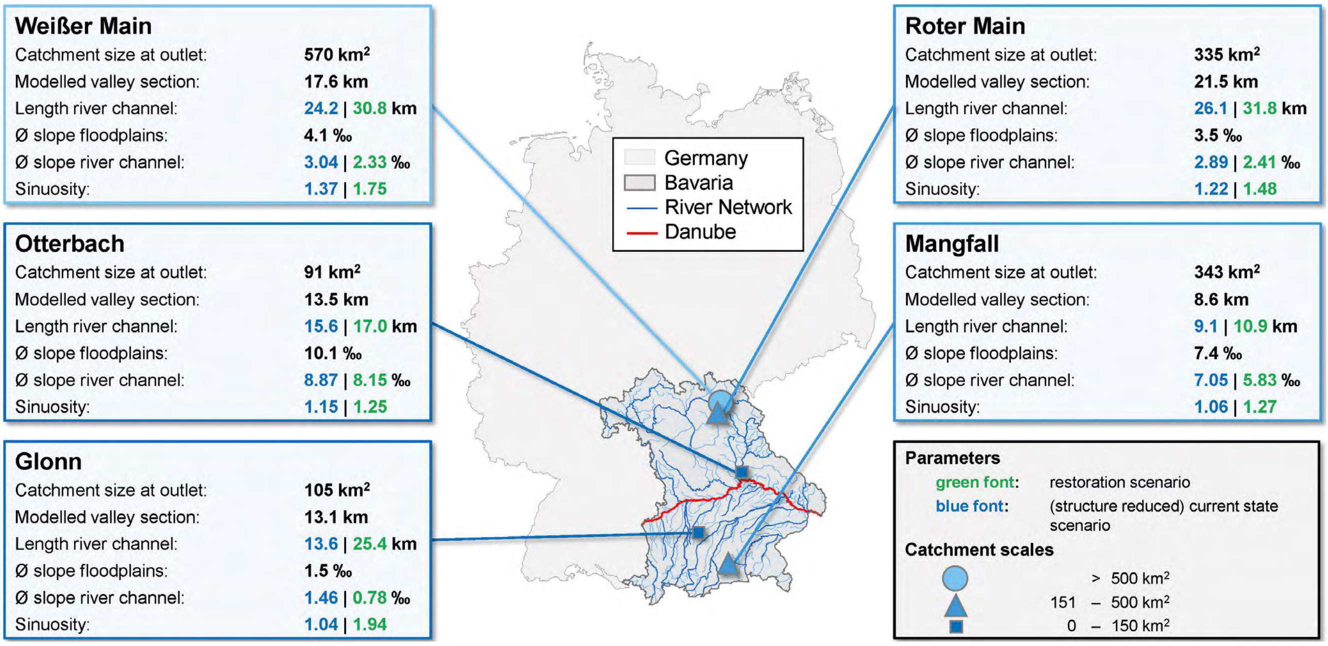

Figure 3: Overview of the most important area and model characteristics of all five investigation sections of the restoration scenarios in comparison with those of the structure reduced current state. (Neumayer et al. 2019, Bayerische Vermessungsverwaltung 2014, modified)

ry and does not represent actual natural conditions well. Because of this, Method 1 was no longer pursued.

On the contrary, Methods 2–4 regard restoration as a holistic water-body specific approach. These methods enable the derivation of specific hydromorphological conditions that represent a potential natural floodplain. The derivation of the appropriate model parameters included analysis of morphological data extracted from the streams and the floodplains as well as state-of-the-art knowledge from technical literature on surface water typology (e.g., Pottgiesser & Sommerhäuser 2008, Dahm et al. 2014, Koenzen 2005, Briem 2002).

The level of detail for the modeled floodplains and streams increases across the four methods. However, the necessary input data, the degree of parametrization, as well as the cost for preparation and computation, analogically increase.

Detailed investigations considering all of the factors mentioned above as well as the quality of the modelling results proved Method 3 to be economically most feasible.

Investigation Areas

The location as well as the values of the most important parameters are illustrated in figure 3 for the five investigated hydraulic sections. The model outlet of the induced catchment area, the center line of the valley, and the mean slope of the terrain were kept constant for the structure reduced current state model and the different restoration scenarios.

The sizes of the catchment areas at the model outlet vary between 570 km² (Weißer Main) and 91 km² (Otterbach). The restoration measures lead to an extension of the flow path in all study sections, as the water bodies were straightened by anthropogenic constructions, mostly for increasing the agricultural use in the floodplain area. Flow path extensions will therefore depend on both the current condition and the predicted sinuosity of the natural stream.

The most extensive lengthening of the flow path, both relative and absolute, could be seen for the section of the river Glonn, where the length increased by 11.8 km, which is equal to 87 % of the original length. The Otterbach river which mainly flows through U- and V-shaped valleys experienced the least change concerning the length of the flow path with an increase of 1.4 km (ca. 9 %).

The increase in the over-all flow path correlates with a more pronounced sinuosity of the path as well as a flatter bottom slope compared to the current state. The correlation between the degree of sinuosity and the flow path length can be observed very well for the river Glonn which experienced the maximum change in flow path length. The degree of sinuosity nearly doubled, changing from 1.0 to 1.9. For both investigation areas in the Main catchment, the degree of sinuosity increased by 0.3, with the Roter Main showing the smaller absolute degree of curving. This can be explained with the overall narrower profile of the valley.

For the river Mangfall as well as the Otterbach, the degree of sinuosity increased from 1.1 to 1.3. Again, the reasons for the comparably small increase in curving and in the over-all flow path length can be found in the shape of the valley and the hydromorphological characteristics of the streams.

Comparison of the resulting peak flow attenuations and translations

Five flood events of varying return periods and precipitation events were simulated for each of the investigated

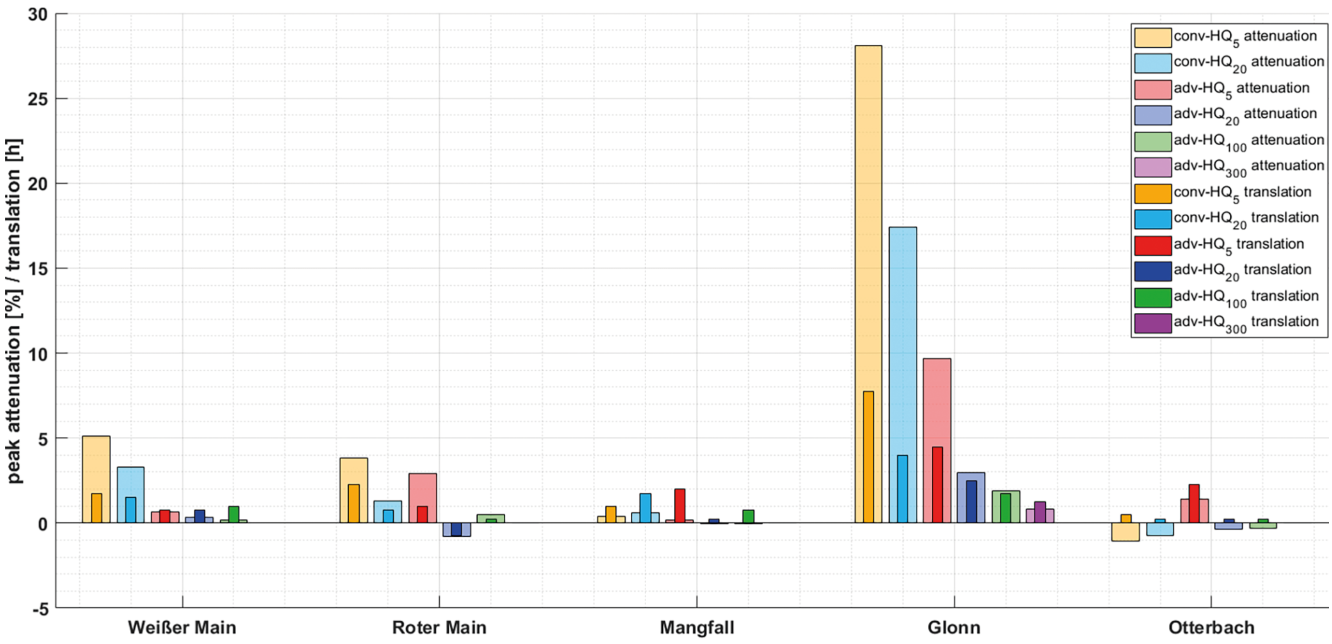

Figure 4: Cross-area representation of the peak attenuation and translation effects between the structure reduced current state and the restoration scenario at the model outlet.

river sections. The precipitation events were categorized in convective events (high intensity over a comparably short period of time; 'summer thunderstorms') and advective events (comparably low intensity over a long period of time; 'persistent rain'). For the river Glonn, an additional advective extreme precipitation event with a return period of 300 years was simulated. Figure 4 presents the attenuation and translation of the flood peak at the outflow when comparing the structure reduced current state of the catchment areas with the respective restoration scenario. A positive flood peak reduction expresses a decrease of the peak discharge for the restoration scenario. Consequently, a positive translation in the peak translates to a delayed flood peak for the restoration scenario. If the values in figure 4 are negative, the effects simulated are vice versa. Note that regardless of the catchment area or flood event, the total inundation area increases for the restoration scenarios due to the higher water levels in the floodplains and more favorable conditions for overflowing.

The restoration measures show larger decreases for the peak discharge in case of low-volume convective precipitation events for all catchment areas. The effects of the restoration measures decrease with an increase in return periods regardless of the characteristics of the precipitation event. The delay of the peak discharge thereby follows a similar trend as the attenuation. The maximum reduction of 28.1 % and delay of 7.75 h occurred for a convective HQ5 event in the catchment area of the Glonn river which is characterized by a relatively wide and flat foreland. This contributes to the reduction of the flood peak which is five times higher than that of the Weißer Main (catchment area 570 km²) which showed on average the second highest peak reduction at the outlet. The smallest catchment areas include the area of the Otterbach (91 km²) along with the area of the Glonn (104 km²). While the catchment sizes of the Otterbach and Glonn are fairly similar, the effects of the restoration measures on the peak discharge are not. In contrast, the peak discharge is often increased at the outlet of the Otterbach catchment. A detailed analysis showed that the inflow of the Sulzbach, which has a comparably high discharge, into the Otterbach close to the model outlet significantly reduces the positive effects of the restoration measures along the Otterbach. Prior to the estuary, reductions of the peak discharge reached up to 8.2 %.

Table 1 lists the development of the peak discharge attenuation and translation along the course of the Otterbach. It shows the large influence of the Sulzbach which joins the Otterbach between section five ('Vor Unterlichtenwald') and six ('Outflow') *(see fig. 5)*.

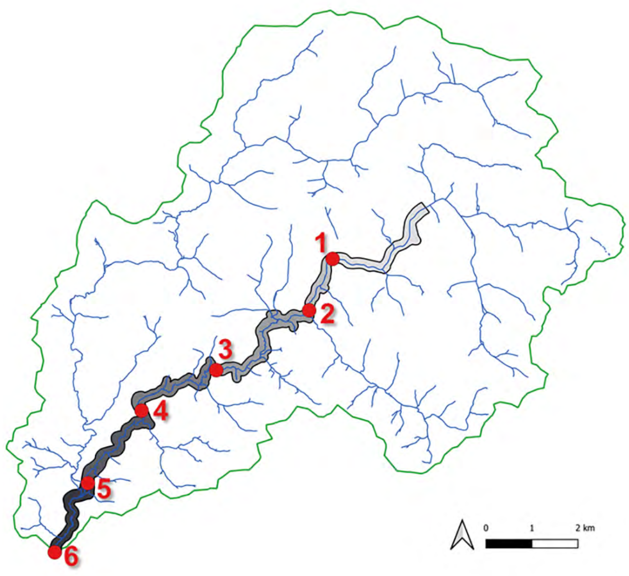

Figure 5: Locations of the control cross-sections at the Otterbach.

Flood Event	ID	Control Cross Section	Catchment Size [km²]	Peak Discharge [m³/s]		Peak Attenuation [%]	Peak Translation [h]
				IstOhne	Renat	Renat / IstOhne	Renat / IstOhne
adv HQ5	1	Steinsölden	24	5.71	5.68	0.6	0.75
	2	Vor Himmelmühlbach	26	6.12	6.06	0.9	0.75
	3	Vor Steinseige	41	10.30	9.94	3.4	0.75
	4	Vor Diebsgraben	45	11.47	11.04	3.8	0.50
	5	Vor Unterlichtenwald	50	13.20	12.60	4.5	1.00
	6	Outflow	91	18.30	18.04	1.4	2.25
adv HQ20	1	Steinsölden	24	8.36	8.32	0.4	1.00
	2	Vor Himmelmühlbach	26	8.92	8.87	0.5	0.25
	3	Vor Steinseige	41	14.01	13.86	1.1	0.25
	4	Vor Diebsgraben	45	15.32	15.23	0.6	-0.25
	5	Vor Unterlichtenwald	50	17.36	17.12	1.4	1.00
	6	Outflow	91	26.41	26.50	-0.4	0.25
adv HQ100	1	Steinsölden	24	12.18	12.10	0.6	0.00
	2	Vor Himmelmühlbach	26	12.94	12.90	0.3	0.25
	3	Vor Steinseige	41	19.55	19.47	0.4	0.25
	4	Vor Diebsgraben	45	21.24	21.11	0.6	-0.25
	5	Vor Unterlichtenwald	50	23.34	23.26	0.4	0.25
	6	Outflow	91	37.60	37.71	-0.3	0.25
conv HQ5	1	Steinsölden	24	8.89	8.80	1.0	0.25
	2	Vor Himmelmühlbach	26	8.98	8.94	0.5	0.25
	3	Vor Steinseige	41	12.30	11.69	4.9	1.50
	4	Vor Diebsgraben	45	12.63	11.86	6.0	1.50
	5	Vor Unterlichtenwald	50	13.08	12.01	8.2	1.75
	6	Outflow	91	16.87	17.05	-1.0	0.50
conv HQ20	1	Steinsölden	24	13.06	12.90	1.3	0.25
	2	Vor Himmelmühlbach	26	13.28	13.12	1.2	0.00
	3	Vor Steinseige	41	18.03	17.57	2.5	0.25
	4	Vor Diebsgraben	45	18.27	17.88	2.1	0.25
	5	Vor Unterlichtenwald	50	18.83	18.20	3.4	0.50
	6	Outflow	91	24.91	25.09	-0.7	0.25

Table 1: Peak discharges and related attenuation and translation for characteristic river sections within the hydraulic model of the Otterbach.

The least effect of the restoration measures on the peak discharge could be seen for the river Mangfall, with a maximum reduction of 0.6 % and delay of 2 h. With a catchment area size of 343 km², the Mangfall is one of to the medium sized hydraulic areas investigated. The measures along the Roter Main show similar effects to the ones along the Weißer Main; however, they are more influenced by the interaction with joining rivers, which even results in an increased peak discharge for the advective HQ20 event.

Conclusions

It could be shown that local superposition of flood waves has a significant impact on the effectiveness of the modeled restoration measures throughout all investigated areas. The situation of the estuary of the Otterbach and Sulzbach proves this particularly well. Based on this analysis, it can be assumed that both the location of the estuary as well as its relative share of the total discharge significantly contribute to the impact of the superposition effects. Whether a superposition of flood waves supports flood peak attenuation or not depends on the river network of the catchment and the characteristics of the flood event (e.g., peak timing at the confluence, ratio of the flood wave volumes). Finally, the study showed that the efficacy of restoration measures concerning flood mitigation is based on a complex interaction between location and waterbody specific factors. As the prediction of these factors is quite limited, an appropriate modelling of the area to be investigated is necessary. The results of the simulations ran for this project only show a comparably small effectiveness in flood control (except for the river Glonn). This correlates with the moderate increase in additionally activated retention volumes. The retention effect of the modeled scenario on the Glonn river, which is relatively large for small flood events, can be explained by several factors. On the one side, the anthropogenically altered river and floodplains, in combination with wide and flat forelands, positively contribute to an activation of additional retention volumes for the restoration scenario. On the other side, the wave superposition effect that occurs during the investigated flood events has positive impacts on the reduction of the peak discharge.

Besides of flood retention effects, natural surface waters and floodplains have positive synergy effects on the surrounding ecosystems as new wetland habitats can be created through improved river-floodplain interaction.

Acknowledgements

We would first like to thank the Bavarian Environmental Agency ('Landesamt für Umwelt') and the Bavarian Ministry of the Environment and Consumer Protection ('Bayerisches Staatsministerium für Umwelt und Verbraucherschutz') for the cooperation as well as financial support of the ProNaHo-Project. We would further like to express our gratitude for the Hydrotec Ingenieurgesellschaft für Wasser und Umwelt mbH and the Leibniz Rechenzentrum for kindly assisting us with the simulations carried out within this project. Furthermore, we would like to thank Sandra Zimmermann.

Further Information

This article contains extracts from the conference article Neumayer et al. 2018 as well as from the journal article Neumayer et al. 2020.

References

Bayerische Vermessungsverwaltung (2014). Gewässernetz, Grundlage: ATKIS Basis-DLM25. URL: https://www.lfu.bayern.de/wasser/gewaesserverzeichnisse/fachlicher_hintergrund/index.htm.

Briem E & Mangelsdorf J (2002): Fließgewässerlandschaften in Bayern. Hg. v. Bayerisches Landesamt für Wasserwirtschaft. Wasserwirtschaftsamt Deggendorf.

Dahm V, Kupilas B, Rolauffs P, Hering D, Haase P, Kappes H, Leps M, Sundermann A, Döbbelt-Grüne S, Hartmann C, Koenzen U, Reuvers C, Zellmer U, Zins C & Wagner F (2014): Hydromorphologische Steckbriefe der deutschen Fließgewässertypen. Anhang 1 von „Strategien zur Optimierung von Fließgewässer-Renaturierungsmaßnahmen und ihrer Erfolgskontrolle". Hg. v. Umweltbundesamt. Dessau-Roßlau.

Jürging P (2001): Wasserbauliche Aspekte bei der Renaturierung von Fließgewässern, Fließgewässerdynamik und Offenlandschaften. In: Bayerisches Landesamt für Umwelt (Hg.). Fachtagung, 7–18.

Koenzen U (2005): Fluss- und Stromauen in Deutschland – Typologie und Leitbilder. Ergebnisse des F+E-Vorhabens "Typologie und Leitbildentwicklung für Flussauen in der Bundesrepublik Deutschland" des Bundesamtes für Naturschutz; FKZ: 803 82 100. Zugl.: Köln, Univ., Diss., 2005. Bonn-Bad Godesberg: Bundesamt für Naturschutz (Angewandte Landschaftsökologie, 65).

Neumayer M, Heinrich R, Rieger W & Disse M (2018): Vergleich unterschiedlicher Methoden zur Modellierung von Renaturierungs- und Auengestaltungsmaßnahmen mit zweidimensionalen hydrodynamisch-numerischen Modellen. – Forum für Hydrologie und Wasserbewirtschaftung 39.

Neumayer M, Teschemacher S & Disse M (2019): Modelling river restoration and floodplain measures in Bavaria on different scales. Poster. European Geosciences Union, Vienna.

Neumayer M, Teschemacher S, Merk F & Disse M (2020): Retentionspotenzialanalyse von Renaturierungsmaßnahmen an bayerischen Gewässern. Auenmagazin, Heft 18.

PAN (2016): Planungsbüro für angewandten Naturschutz GmbH. Entwicklung und Anwendung einer Methodik zur Analyse der innerhalb der Auenkulisse wirkenden Restriktionen (Restriktionsanalyse). Hg. v. Bayerisches Landesamt für Umwelt, Referat 64. München.

Pottgiesser T & Sommerhäuser M (2008): Beschreibung und Bewertung der deutschen Fließgewässertypen -Steckbriefe und Anhang. Hg. v. Umweltbundesamt, Bund / Länder-Arbeitsgemeinschaft Wasser (LAWA).

StMUV (2014): Hochwasserschutz: Aktionsprogramm 2020plus. München: StMUV.

The vegetation of water bodies in the floodplain of the Danube in Serbia – comparative analysis and assessment of water quality using existing evaluation methods

Johanna Weidendorfer: Student of BSc Geography, Catholic University of Eichstätt-Ingolstadt, Germany, e-mail: johanna.weidendorfer@gmx.de

Rather by chance I got the opportunity to participate in a research project between six universities from Serbia, Croatia and the Czech Republic. During the site surveys in July 2019 data on species communities occurring in 17 backwaters along the Danube were collected (fig. 1 and 2). Using the metacommunity concept influences such as environmental parameters or inter-species competition on the occurrence of individual species should be explored (see Árva et al. 2017; Alahuhta & Heino 2013). A subtask included the recording of macrophytes, about which I could write my bachelor thesis.

Evaluation of Serbian backwaters using aquatic macrophytes

Eutrophication is one of the main problems maintaining good water quality in open waters today (Laketić et al. 2013). Impacts such as structural impoverishment or the discharge of toxic substances also have far-reaching consequences for lakes and rivers (Schneider 2004). In order to implement targeted measures for the improvement of water quality a regular assessment of the status of a body of water is necessary (Stelzer 2003). The bioindication is a simple way to determine the nutrient content of a waterbody as far as possible without using chemical and physical measurements. With aquatic plants in particular, changes in the nutrient balance can be derived from growth behavior and species composition (Laketić et al. 2013). Over the past few years, many indices for the evaluation of rivers and lakes using aquatic macrophytes have been developed, ranging from a simple description of macrophyte distribution to a complete ecological evaluation of the water (Schneider 2004).

Within Serbia, which is traversed by the Danube for a length of 588 km (Takić et al. 2012), the Danube has a