Morphodynamic Effects on the Habitat of Juvenile Cyprinids (*Chondrostoma nasus*) in a Restored Austrian Lowland River

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Abstract At the Sulm River, an Austrian lowland river, an ecologically orientated flood protection project was carried out from 1998–2000. Habitat modeling over a subsequent 3-year monitoring program (2001–2003) helped assess the effects of river bed embankment and of initiating a new meander by constructing a side channel and allowing self-developing side erosion. Hydrodynamic and physical habitat models were combined with fish-ecological methods. The results show a strong influence of riverbed dynamics on the habitat quality and quantity for the juvenile age classes (0+, 1+, 2+) of nase (*Chondrostoma nasus*), a key fish species of the Sulm River. The morphological conditions modified by floods changed significantly and decreased the amount of weighted usable areas. The primary factor was river bed aggradation, especially along the inner bend of the meander. This was a consequence of the reduced sediment transport capacity due to channel widening in the modeling area. The higher flow velocities and shallower depths, combined with the steeper bank angle, reduced the Weighted Useable Areas (WUAs) of habitats for juvenile nase. The modeling results were evaluated by combining results of mesohabitat-fishing surveys and habitat quality assessments. Both, the modeling and the fishing results demonstrated a reduced suitability of the habitats after the morphological modifications, but the situation was still improved compared to the pre-restoration conditions at the Sulm River.

Keywords Habitat modeling · Restoration measures · River monitoring · *Chondrostoma nasus* · Aggradation · Juvenile fish habitats

Introduction

Since the mid-1980s, habitat modeling has been successfully used as an integrative instrument to evaluate anthropogenic hydrological interferences on aquatic habitats (Harby and others 2004). Initially, such modeling focused on minimum flow and the effects on the aquatic ecology (Milhous and others 1989). Habitat modeling has also sometimes been evaluated in combination with new methods such as telemetric investigations (Scruton and others 2002). This involves an abiotic characterization by hydrodynamic numerical modeling or field measurements as well as using biotic criteria for habitat models as defined by preference and suitability indices for fish species or age classes (Bovee 1986). Most such studies have concentrated on describing salmonid habitats (Greenberg and others 1996; Salveit and others 2001; Beard and Carline 1991; Bremset and Berg 1999; Eklöv and Greenberg 1998). Moreover, abiotic characteristics in habitat modeling studies are typically calculated with stable geometric boundary conditions (Wheaton and others 2004; Peter and others 2004; Shen and others 2004; Gard 2006). This approach neglects the dynamic linkage between variable discharge and morphodynamic processes. Analyses of early life stages in cyprinid fishes, especially in the rheophilic cyprinid nase (*Chondrostoma nasus*), mainly

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concentrate on larval drift (Reichard and others 2004; Zitek and others 2004a) and on habitat description over steady state morphological conditions. Bartl and Keckeis (2004), for example, studied juvenile nase in a restored river, whereas Schiemer and others (2002) investigated the influence of possible bottlenecks. Other studies on juvenile nase described feeding and energy intake behavior (Keckeis and others 2001) as well as spatial and seasonal characteristics (Keckeis and others 1997). Some studies have dealt with the connection between morphological characteristics and habitat use of juvenile nase (Hirzinger and others 2004; Winkler and others 1997, Spindler 1988, Dedual 1990). Here, we document the development of a restoration measure and examine how key morphodynamic processes affect the habitat quality for juvenile fish. Juvenile nase are classified in this study according to the work of Mühlbauer (2002) and Traxler (2002), who conducted a two-season monitoring survey on fish migration using fish traps. Juvenile fish are divided into the following age classes: 0+ (young of the year), 1+, and 2+. 0+ nase contain lengths of 3–6 cm (winter: 4–9 cm), 1+ fish are defined with 7–12 cm length (winter: 10–15 cm), and 2+ are 13–20 cm long (winter: 16–21 cm). We address the question how and how fast these juvenile nase (0+, 1+, and 2+) react to changing channel morphology (aggradations) which was affected by a flow split at above 10 $m^3 s^{-1}$ in the investigated area.

Study Reach

The study reach is situated in the southern-east part of Austria (-62950, 5181450; Gauss-Krüger). The Sulm River is formed by two main tributaries originating from the Central Alps and discharges into the Mur River, a tributary to the Drau River. The biocoenotic description is defined as epipotamal (Muhar and others 1998) and barbel-region (Illies and Botoseanu 1963). The riparian vegetation is defined based on the main species by Otto (1981) as *Salicetum cinereae*, *Fraxino-Populetum*, *Salicetum albea* forests. After the confluence of the two tributaries — White and Black Sulm Rivers — from the Central Alps, the Sulm River historically resembled a meandering river (Muhar and others 1998; Zitek and others 2004b). The bankfull discharge of the historical Sulm was 40–45 $m^3 s^{-1}$ with an average slope of 0.0003 m m^{-1}. River bed straightening in 1965 led to a linear course. The slope was increased to 0.001 mm^{-1} by meander cut-offs (Habersack and Hauer 2004). Within a further flood protection project in 1999, the river channel was widened, leading to an increased bankfull discharge of 80 $m^3 s^{-1}$. In the frame of the river widening and revitalization project, two small meanders were constructed. One of the meanders

(Fig. 1) at river station 12.960 km–13.356 km was modeled to analyze the habitat situation for juveniles of the rheophilic cyprinid nase (Fig. 1). The regulated river bed was cut off and serves as a backwater in low-flow situations. When the discharge increases to more than 10 $m^3 s^{-1}$, the former river bed functions as a flood channel. This study reach is located approximately 12.8 km upstream of the mouth into the Mur River. Hydrological data for the monitoring area were provided by the Regional Government of Styria (2001) and are depicted in Table 1. The flow regime is indicated as a pluvio-nivale 3, i.e., the occurrence of three equivalent flood peaks (March, June, and November) is characteristic (Mader and others 1996). Furthermore, the Pielach River will be described in this introductory chapter because biological data for the habitat modeling were taken from this Lower Austrian tributary of the Danube River (Fig. 1). The total catchment is 591 km^2, about half that of the Sulm River catchment (1113 km^2) (Table 1). The total length of the Pielach River is 67 km, with a mean annual discharge of 6.47 $m^3 s^{-1}$. Mean river width is 22.5 m, containing gravel (2–6.3 cm) as the dominant substrate type. The Pielach River was historically defined as a meandering river (and still features this characteristic) due to a lower bed slope (0.002) near the mouth (Table 1).

Methods

For the hydraulic simulations, a one-dimensional (1 D), a quasi-two-dimensional (1.5 D), and a depth-averaged two-dimensional (2 D) hydrodynamic-numerical model were used. The river bed topography was obtained by a terrestrial survey in 2001 and repeated for the modeling area in 2002 and 2003. For the terrestrial survey a total station (Leica TC805) was used. The bed topography was measured by cross sectional measurement (9–21 points per cross section/mean = 14) with distances of 9.2 m–24.7 m (mean = 22.7 m) between the 22 transects, depending on the heterogeneity of river morphology. Additional points were sampled between the cross sections to allow the generation of high-quality Digital Terrain Models (DTMs) of each monitoring year (2001–2003). Including breakline interpolation at bankfull stage, the terrain models were rendered by the Surfer$^©$ - Software based on measured and interpolated data (1385 points/2001, 2292 points/2002, and 2404 points/2003). The different modeling geometries (2001/2002/2003) allowed the influence of the morphological development on the abiotic parameters flow velocity and depth to be calculated. Furthermore, substrate maps for 2001, 2002, and 2003 were derived. These maps were completed with additional volumetric sediment samples.

Fig. 1 (**A**) Location of the Sulm and Pielach River in Austria (Europe) presented in the national grid (-62950, 5181450; Gauss-Krüger); (**B**) Investigated river section of this study (22 cross sections)
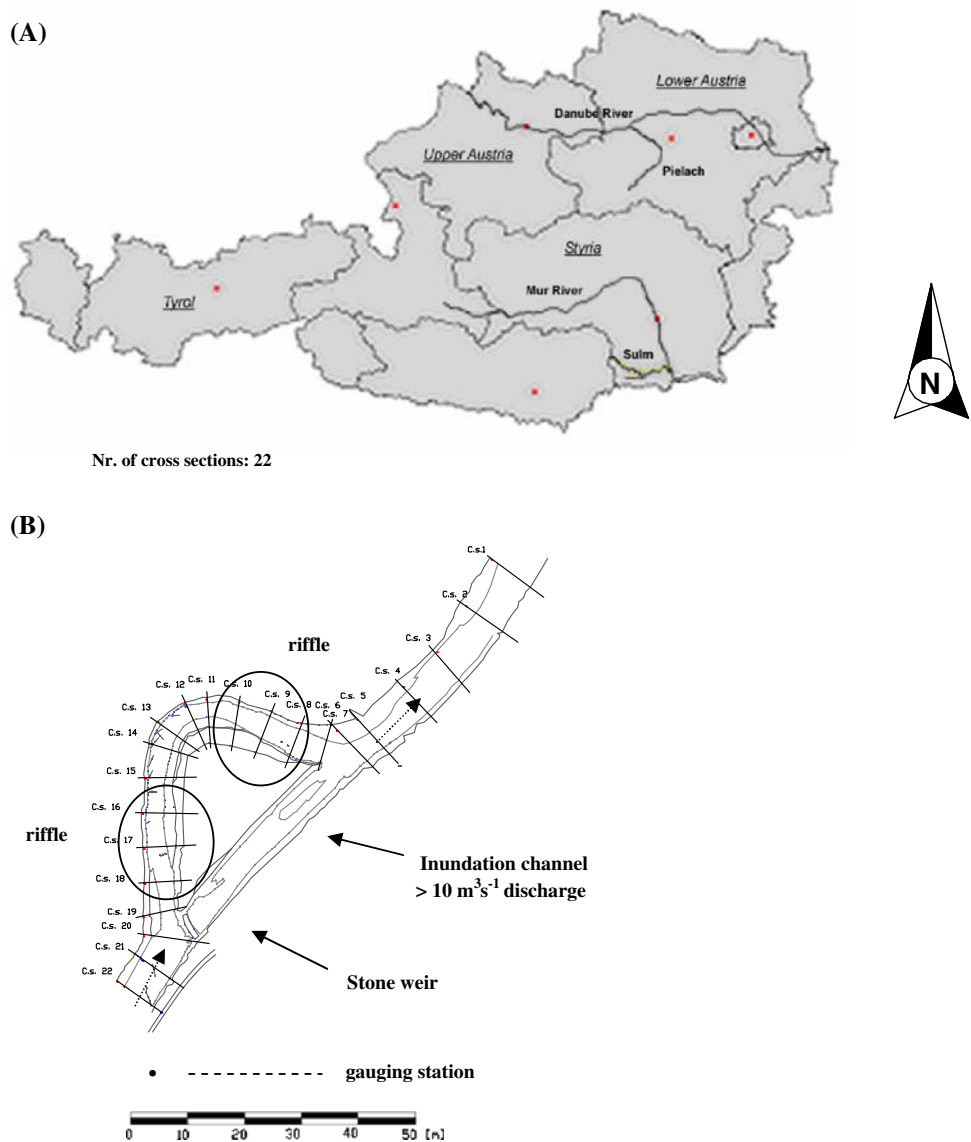

Table 1 River typologies Sulm/Pielach

	Sulm	Pielach
Catchment area	1113 km^2	591 km^2
Altitude of study reach	272 m. a. sl.	230 m. a. sl.
Mean precipitation per year	1160 mm	875 mm
Channel slope	0.0008–0.001	0.002
River length	About 50 km	67 km
Mean river width	18.5 m	22.5 m
Dominating substrate (cm)	2–6.3	2–6.3
Morphological type (historical)	Meandering	Meandering
Mean annual discharge	8.85 m^{3}s^{-1}	6.47 m^{3}s^{-1}

The CASIMIR$^©$ (1.5 D) model was implemented in the monitoring process as one tool to simulate the habitat conditions. This model has no separate module to calculate the hydraulic conditions (Jorde 1999). The geometric boundaries and the one-dimensional (1 D) simulated water surface were therefore necessary to start the habitat modeling. For one-dimensional hydraulic modeling, the HEC RAS$^©$ software was used. To obtain the two-dimensional velocity distribution from the average value in the cross section, the habitat model uses the formula of Darcy-Weissbach (Schneider 2001).

$$v_m = \frac{1}{\sqrt{\lambda}} \cdot \sqrt{8 \cdot g \cdot R_{hy} \cdot I_E} \tag{1}$$

where v_m = average velocity (ms^{-1}), λ = resistance coefficient by Darcy-Weissbach (-), g = gravity force (9.81 m s^{-2}), R_{hy} = hydraulic radius (m), I_E = energy slope (m).

This equation can be used to describe local currents by dividing the wetted area into strips. This organization is already pre-determined by the selected width resolution z, which was defined as 0.03 m.

$$v_m = \frac{1}{\sqrt{\lambda}} \cdot \sqrt{8 \cdot g \cdot R_{hy} \cdot I_E} \qquad (2)$$

where λ_i = resistance coefficient (for all cells in the modeling transects equal) by Darcy-Weissbach (-), g = gravity force (9.81 ms^{-2}), h_i = medium water depth of each cell (m), z = width of the vertical strips (cells).

As a second habitat model the River2D$^{©}$ software was used to generate habitat time series. The River2D application is a two-dimensional, depth-averaged finite element model. It is intended for use on natural streams and rivers and has special features for accommodating supercritical/subcritical flow transitions, ice covers, and variable wetted area. It is basically a transient model but provides for an accelerated convergence to steady-state conditions. River2D uses SI standard units for all input and output (Blackburn and Steffler 2002). To generate habitat time series 32 discharges were simulated for each year (2001–2003) using the appropriate river bed topography. For low to mean flow conditions (1.5–10 m^{3}s^{-1}) a $\Delta Q = 0.5$ m^{3}s^{-1} was selected. Above the flow split up a $\Delta Q = 1.0$ m^{3}s^{-1} was applied for discharges between 10 m^{3}s^{-1} and 20 m^{3}s^{-1} and additionally 25 m^{3}s^{-1}, 30 m^{3}s^{-1}, 35 m^{3}s^{-1} and 40 m^{3}s^{-1} were simulated for each year (2001/2002/2003) of the monitoring period. Based on the modeling results a linear interpolation was done for the daily discharge/WUA relationship according to the habitat rating curves. Further two flood events (8/10/2001, 6/12/2002) were analyzed separately ($n = 13$). In total, 109 discharge simulations were performed to generate habitat time series (30 discharge simulations are advised for PHABSIM studies (Milhous and others 1989). The models (1 D, 2 D) were calibrated by adjusting the n-value in the main channel under low-flow conditions (2.66 m^{3}s^{-1}) and above mean flow (12.3 m^{3}s^{-1}). Further verification was done for 80 m^{3}s^{-1} (flood on 05/12/2002, Fig. 7)

To link the hydraulic simulation results (CASIMIR, River2D) with suitability indices, the method of Bovee (1986) was used. This method of multiplying suitability indices was also utilized in the PHABSIM model (Milhous and others 1989) and is shown in Equation 3.

$$SI_{ges} = SI_d \cdot SI_v \cdot SI_s \ or. \ concluded \ SI_{ges} = \prod_{i=1}^{I} SI_i \qquad (3)$$

where SI_d = Suitability Index depth, SI_v = Suitability Index velocity, SI_s = Suitability Index substrate, SI_{ges} = Suitability Index total, SI_i = Suitability index variable.

For measuring flow velocities the P.-EMS, developed by DELFT-Hydraulics, was used. The P.-EMS is capable of measuring velocity components in a 2D-plane (Delft Hydraulics 2006). Data were transported to data-acquisition equipment (LabVIEW). The P.-EMS allows flow velocity measuring within a range of 0–2.5 ms^{-1} (optional 0–5.0 ms^{-1}) bi-axially in a four quadrant range. Velocities

were measured in five different cross sections to validate the calculated flow velocities of the CASIMIR and the River2D model. Based on the longitudinal habitat characteristics of the study reach (Fig. 3) cross sections comprising the entire set of different habitat types had to be selected. Therefore they are situated in a well developed run — riffle — pool sequence of the study reach. The set of modeled velocities should sufficiently reflect the influence of different hydro-morphological patterns on stream hydraulics. Transects in run habitats were measured at cross section 19 and cross section 15 (Fig. 1B). Further flow velocities were measured on the peak of riffle 1 (c.s. 17) and finally for low flow discharge (2.66 m^{3}s^{-1}) in areas with water depths > 1.2 m, representing run/pool habitats (c.s. 14, c.s. 11).

Suitability Curves

Suitability curves indicate the suitability of habitats based on a single parameter. They are computed from empirical frequency distributions, which are standardized based on the most strongly occupied class (Bovee and Cochnauer 1977; Bozeck and Rahel 1992). The class with the largest frequency (highest suitability) receives a SI value of 1. All further classes are weighted after it. The unused classes have the suitability index (SI) 0.

Snorkeling observations on the habitat use of juvenile nase in the Pielach River in 1997 were used to generate suitability indices for this age-class. Water temperature during the snorkeling survey in spring ranged between 14° C and 20° C (Melcher 1999). The snorkeling approach was mainly based on the methods of Thurow (1994) and Greenberg and others (1996). The advantage of this method is that fish can be observed in their natural environment. It was possible to investigate 0+ microhabitats ($n = 723$) of nase (also described in Pokorny 2000) up to a length of 50 mm. Based on the observations, Melcher (1999) developed the suitability classes for mean velocity, water depth, and substrate shown in Table 2.

The three parameters were taken out of a set of 9 parameters (mean velocity, water depth, cover, substrate packing, visual protection, vegetation, substrate, near bottom velocity, and submerged vegetation) which was mapped at the observed microhabitat points ($n = 723$) of juvenile nase. The data were used for preference calculation by using a logistic regression model provided by the SPSS10$^{©}$ statistical package. The highest correlation in relation to the independent variable was documented for mean velocity, water depth, and cover (substrate). These three parameters explain 90.5 percent of the overall statistical model. Altogether the model exhibits 92.4 percent as the degree of explanation using 723 fish points and 584 nonfish points (Melcher 1999). Based on these statistical
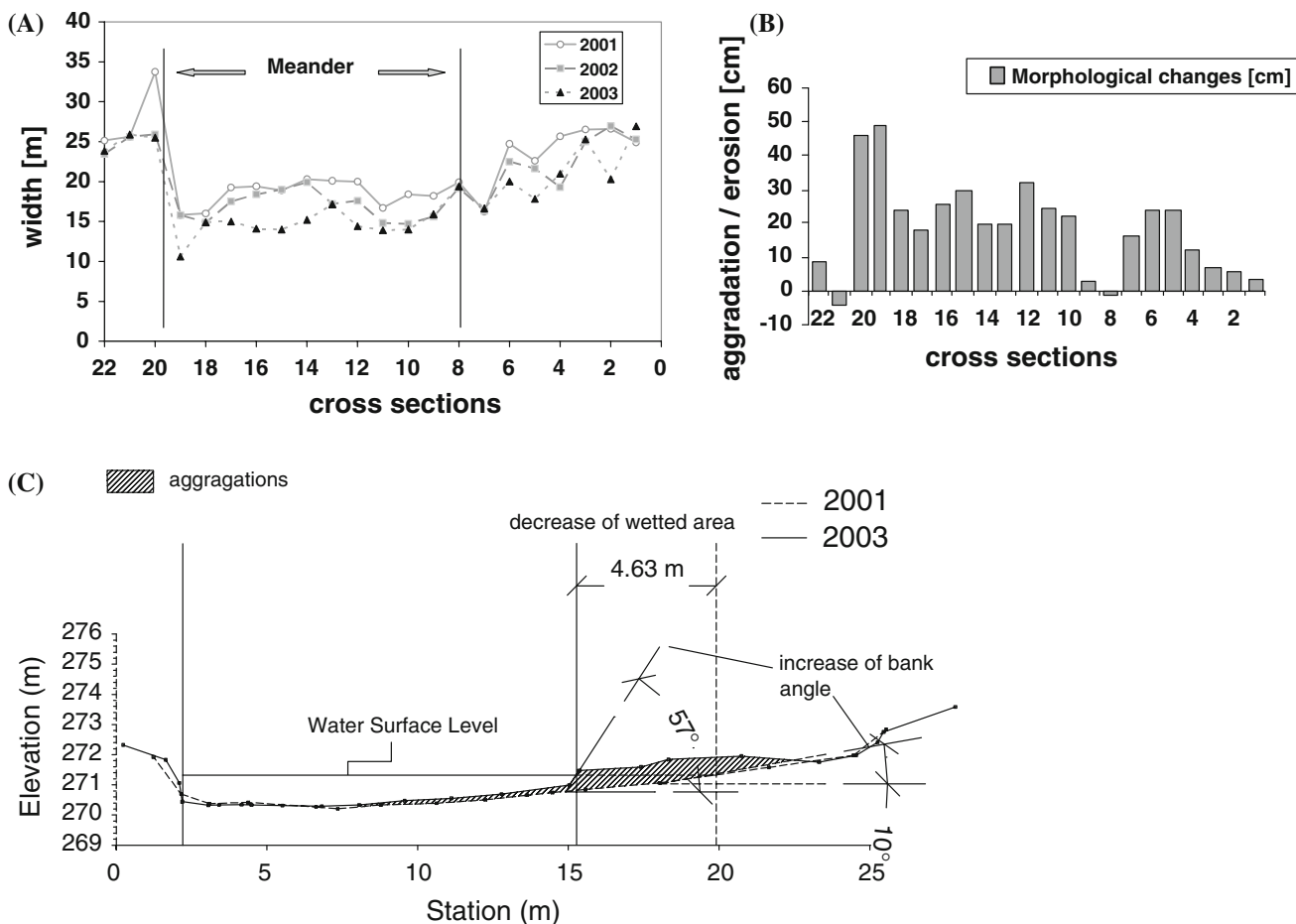
Fig. 2 Morphological development 2001–2003 of the investigation area (Sulm River); (**A**) the change of River width (m) for mean flow (8.85 m³s⁻¹); (**B**) mean aggradations and erosion (m) in the monitored cross sections for the time period 2001–2003, related to the mean flow water surface level; (**C**) development of the bank angle at cross section 16 during the monitoring period
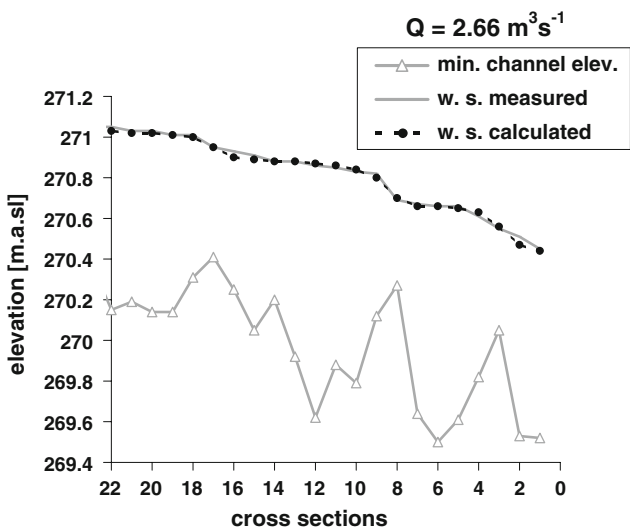

Fig. 3 Calibration of the water surface levels for 2.66 m³s⁻¹ discharge in the monitoring section (dashed line = calculated water-surface elevation; solid line = measured water surface elevation)

Table 2 Suitability Indices (SI) of *Chondrostoma nasus* developed by Melcher (1999) by snorkeling in the Pielach River

Depth (cm)	SI	Velocity (cm/s)	SI	Substrate (cm)	SI
>0	1	0	1	0	1
30	0.8	5	0.8	0.062	1
60	0.4	10	0.8	0.063	0.4
120	0.01	15	0.4	0.2	0.01
121	0	20	0.4	2	0.4
		35	0.01	2.01	1
		36	0	6.3	0.8
				20	0.01

results, mean velocity, water depth, and substrate (cover) were taken for habitat modeling of juvenile nase in the Sulm River. In both rivers—the Sulm and the Pielach—the nase is among the most abundant species. Table 1 compares the hydromorphological characteristics of the two rivers.

We calculated the development of habitats for juvenile nase over the period 2001–2003 by multiplying suitability

indices according to the PHABSIM model. A number of studies (Elliot and others 1996; Harby and Arnekleiv 1994; Huusko and Yrjänä 1996; Shuler and Nehring 1993) have used PHABSIM to evaluate the effectiveness of stream restoration projects post-construction. To gain further quantitative modeling results, the method of Weighted Usable Area (WUA) (Bovee 1986) was implemented in the modeling process (Equation 4).

$$WUA = \sum_{i=1}^{n} HSI_i.A_i \qquad (4)$$

where n = total number of grid cells (-), HSI_i = habitat suitability index (-), A_i = area of single grid cells (m^2).

The steady state modeling results were then compared with the dynamic hydrological regime in the monitored area (habitat time series). This required obtaining the distribution of the steady state modeled habitat conditions. For descriptive statistical analyses, the hydrological conditions at the juvenile habitats within the important period for growth of juvenile nase were investigated. Finally, a duration analysis was conducted for the simulated discharges during the monitoring period.

Fish Sampling

The fish community was surveyed using electrofishing gear (DC shockers with 5 kW, 400 V and 12 A). Within the modeling area, we fished 7 separated stretches (Sampling stretch 3 = cross sections 1–2 [length: 71 m]; sampling stretch 4 = cross sections 2–4 [length: 30 m]; sampling stretch 5 = cross sections 4–6 [length: 67 m]; sampling stretch 7 = cross sections 6–9 [length: 68 m]; sampling stretch 8 = cross sections 9–14 [length: 107 m]; sampling stretch 10 = cross sections 14–18 [length 80 m]; sampling stretch 11 = cross sections 18–22 [length: 57 m]). The former river bed (inundation channel) was also sampled (length 143 m). Additionally, two stretches were fished downstream and one upstream of the meandering section. These results are not presented in the study. The upstream ends of the study reaches were blocked with 1 cm mesh seines. After installing the seines, we waited for 10 minutes before fishing. Every stretch was fished by 3 runs, using 4 parallel poles. The surveys were started at the lowermost stretch (sampling stretch 1). Caught individuals were released downstream of the end of each stretch in order not to influence the sampling stretches upstream. A total of four surveys were conducted, two (2000 and 2002) during winter (December) and two during summer situations (2001 and 2003). Collected fish were identified to the species level and total length was measured to the nearest 5 mm. Age classes of the nase were distinguished based on length-frequency histograms. We define all nase < 200 mm as juveniles,

corresponding to the age classes 0+ to 2+. This group is separated from subadult and adult fish, which have different habitat preferences.

Results

Morphodynamic Processes: Deposition

This section deals with the effects of sedimentation on channel geometry and the consequences for different habitat types in the investigation area. The terrestrial surveys 2001–2003 showed strongly altered morphological characteristics of the current cross sections. The development of the river geometry is shown in Fig. 2A–C and Table 3. The dynamic processes behind these survey results were important for the boundary conditions of *Chondrostoma nasus* habitats.

The partly strong aggradation, mainly caused by a flood with a recurrence of eight years in December 2002, was not equally distributed over all cross sections. Most of the deposited sediments (fine gravel, gravel) were found on the inner bend of the artificial meander (Fig. 2C). This led to a several meter decrease of the river width at mean discharge (8.85 m^{3}s^{-1}) over the years (Table 3). The growth of willows (*Salix alba, Salix purpuraea*) on these newly accrued areas led to reduced transport of suspended sediment. The deposition of fine material $d_m < 0.005$ m and its cohesive properties built up banks with an increasing angle over the years (Fig. 2C). The effects of these aggregations on instream hydraulics as well as on bottom shear stress and maximum water depth under mean flow (8.85 m^{3}s^{-1}) conditions are presented in Table 3. The reduction of the total wetted area over the years (9609 m^2/7862 m^2/7385 m^2//discharge = 2.66 m^{3}s^{-1}) in the study reach (Table 4) increased bottom shear stress, especially in the newly created meandering section. For all 22 cross sections in the study reach, the mean increase was 4.83 Nm^{-2} (S.E.: 4.87) between 2001 and 2002 (Table 3). In the meandering section (cross section 19 - cross section 6/Fig. 1) the increase was significantly higher, amounting to a mean of 7.31 Nm^{-2} with a standard error (S.E: 3.95). The changes in bottom shear stress between 2002 and 2003 were moderate, with an increase of 1.43 Nm^{-2} (S.E.: 6.01) for the whole section and 1.22 Nm^{-2} (S.E: 4.72) for the artificially created meandering section. The changes in maximum water depth in the cross sections at mean flow (8.85 m^{3}s^{-1}) were not significantly different between the whole section and the meander. The depth increased by 8 cm/S.E.: 24 (total) and 7 cm/S.E: 22 (meander) between 2001 and 2002. Between 2002 and 2003 an increase of 12 cm/S.E: 22 (overall) and 9 cm/S.E: 13 (meander) was measured.

The main reason for this massive change in morphology was the regulated former river bed, which serves as an inundation channel for discharges above 10 m³s⁻¹ (Fig. 1). The enlargement of the flow area above this value reduced the bottom shear stress in the meandering section. At 80 m³s⁻¹ (bankfull discharge), a shear stress of 76 Nm⁻² was calculated for cross section 22 (upstream of the restoration section). At cross sections 20, 19, and 18, close to the flow splitting, the computed shear stress only reached values from 10–39 Nm⁻² (Table 3).

This simulated result was verified by the distribution of the aggradation in Fig. 2B: at the beginning of the meander section the sum of deposition peaked at 0.5 m (mean aggradation of the river bed in the monitored cross sections).

Based on the substrate maps (dominant size class) on each terrestrial survey point (total station TC805), the choritope distribution changed due to the aggradation processes in the study reach. The main substrate types over the whole monitoring period, with a significant reduction based on percentage of total wetted area, are gravel size classes (2–63 mm). The reduction in the percentage of gravel (26.7%) was obvious (2001 = 69.1%, 2002 = 55.1% and 2003 = 42.4% of total wetted area). Other choriotope types increased their percentage in the investigated area during the three surveys of monitoring; fine gravel (2 mm–2 cm) (13.1%), cobbles (63–250 mm) (1.1%) as well as silt (1.5%) and boulders (6.0%) mainly eroded out of river bank protection structures at the 8-year flood. These substrate changes do not significantly affect the habitats (WUAs) of juveniles because the preferred substrate size (gravel, silt; Table 2) is frequently found in shallow water areas (2001–2003); all other substrate classes are also suitable to a certain degree (Table 2).

The habitat model CASIMIR was applied to analyze the effects of these morphological developments on the abiotic parameters velocity and depth. As noted above, the water surface levels in the cross sections for specific discharges have to be defined as boundary conditions for the CASIMIR model. Determining the water surface levels required calibrating the one-dimensional model. In a first step the simulated water surface level was calculated for measured values at 2.66 m³s⁻¹ discharge (Fig. 3). The sum of roughness influences showed the best correlation with $n = 0.045$ HEC RAS/$n = 0.041$ River2D (n = manning roughness factor). At this low discharge, the influences of form roughness are much higher than the grain roughness. The calculation of n based on volumetric sediment samples using the formula of Meyer-Peter, Müller (1949) yielded $n = 0.029$ as a roughness factor with d_{90} as an input parameter.

Further measured and modeled velocities were compared in 5 cross sections (c.s.: 19, 17, 15, 14, 11; Fig. 1) using $n = 26$ measured verticals. Two cross sections are presented in Fig. 4. The mean of deviation between measured and modeled velocities by River2D was 0.054 ms⁻¹ (SE: 0.047), between measured and modeled velocities by CASIMIR 0.066 ms⁻¹ (SE: 0.048) ($n = 26$). A comparison between the two numerical models (River2D/CASIMIR) resulted in a mean deviation of 0.037 ms⁻¹ (SE: 0.038) whereby the maximum outlier (0.200 ms⁻¹) was found in a riffle cross section (Fig. 4A). In this transect (c.s. 17) also the maximum deviation between measured and modeled (River2D/CASIMIR) occurred. Differences of 0.150 ms⁻¹ and 0.170 ms⁻¹ were documented in this cross section. Additionally a comparison between one-dimensional and two-dimensional models was conducted by integrating the depth-averaged two-dimensional velocities over the selected cross sections. The mean of deviation between River2D and HEC-RAS was 0.04 ms⁻¹ (SE: 0.02). The maximum outlier (0.08 ms⁻¹) was found in cross section 19.
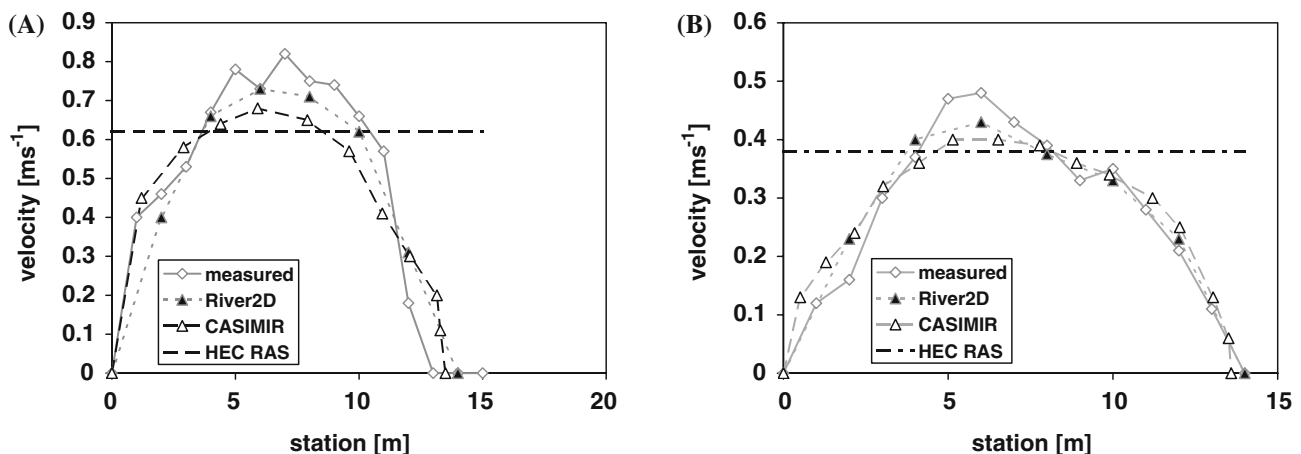

Fig. 4 Cross sectional plot of the measured and modeled velocity distributions at (A) cross section 17 and (B) cross section 19; solid grey line = measured velocities; dashed grey line = River2D; black dashed line = CASIMIR

Table 3 Summary table of yearly morphological changes, shear stress at bankfull discharge

C.s.	Change of mean aggragation (m)	Change of mean flow width (m)	Change of mean flow shear str. (Nm²)	Bankfull discharge shear str. (Nm⁻²)	Change of mean flow max. water depth (m)
22	2001–02: +0.05	2001–02: −1.68	2001–02: −4.68	76	2001–02: +0.35
	2002–03: +0.04	2002–03: +0.40	2002–03: +6.69		2002–03: +0.14
21	2001–02: −0.05	2001–02: ±0	2001–02: −2.72	65	2001–02: +0.63
	2002–03: +0.01	2002–03: +0.29	2002–03: +4.23		2002–03: −0.32
20	2001–02: +0.24	2001–02: −7.84	2001–02: +0.93	39	2001–02: +0.23
	2002–03: +0.23	2002–03: −0.41	2002–03: +5.39		2002–03: −0.31
19	2001–02: +0.06	2001–02: ±0	2001–02: +11.6	18	2001–02: −0.52
	2002–03: +0.43	2002–03: −5.20	2002–03: −9.18		2002–03: +0.07
18	2001–02: +0.04	2001–02: −1.15	2001–02: +3.21	10	2001–02: +0.21
	2002–03: +0.20	2002–03: +0.05	2002–03: +1.31		2002–03: +0.15
17	2001–02: +0.06	2001–02: −1.75	2001–02: +5.50	13	2001–02: −0.07
	2002–03: +0.12	2002–03: −2.50	2002–03: +0.50		2002–03: +0.06
16	2001–02: +0.02	2001–02: −1.00	2001–02: +4.93	9	2001–02: +0.04
	2002–03: +0.24	2002–03: −4.30	2002–03: +2.48		2002–03: −0.03
15	2001–02: +0.10	2001–02: +0.10	2001–02: +2.05	15	2001–02: +0.15
	2002–03: +0.20	2002–03: −5.00	2002–03: +2.66		2002–03: +0.08
14	2001–02: +0.07	2001–02: −0.40	2001–02: +2.28	15	2001–02: +0.22
	2002–03: +0.13	2002–03: −4.70	2002–03: +3.28		2002–03: +0.04
13	2001–02: +0.06	2001–02: −2.90	2001–02: +3.67	23	2001–02: +0.44
	2002–03: +0.13	2002–03: −0.05	2002–03: −0.77		2002–03: −0.08
12	2001–02: +0.21	2001–02: −2.40	2001–02: +4.03	26	2001–02: +0.14
	2002–03: +0.11	2002–03: −3.20	2002–03: −0.32		2002–03: −0.03
11	2001–02: +0.20	2001–02: −1.90	2001–02: +9.19	13	2001–02: +0.18
	2002–03: +0.05	2002–03: −0.90	2002–03: −1.91		2002–03: +0.42
10	2001–02: +0.12	2001–02: −3.70	2001–02: +12.28	14	2001–02: +0.12
	2002–03: +0.10	2002–03: −0.70	2002–03: −6.47		2002–03: +0.29
9	2001–02: +0.09	2001–02: −2.60	2001–02: +14.44	12	2001–02: +0.04
	2002–03: −0.07	2002–03: +0.30	2002–03: −8.05		2002–03: −0.02
8	2001–02: +0.10	2001–02: −0.70	2001–02: +10.10	10	2001–02: +0.22
	2002–03: −0.11	2002–03: +0.20	2002–03: +7.99		2002–03: +0.09
7	2001–02: +0.26	2001–02: +0.12	2001–02: +9.66	5	2001–02: −0.14
	2002–03: −0.10	2002–03: +0.29	2002–03: −1.93		2002–03: +0.16
6	2001–02: +0.25	2001–02: −2.22	2001–02: +9.44	38	2001–02: −0.10
	2002–03: −0.01	2002–03: −2.50	2002–03: −6.61		2002–03: +0.02
5	2001–02: +0.13	2001–02: −0.99	2001–02: +0.06	20	2001–02: +0.71
	2002–03: +0.10	2002–03: −3.79	2002–03: +0.34		2002–03: +3.07
4	2001–02: +0.14	2001–02: −6.36	2001–02: +1.97	18	2001–02: −0.08
	2002–03: −0.02	2002–03: +1.68	2002–03: +13.33		2002–03: +0.18
3	2001–02: +0.14	2001–02: −1.51	2001–02: +4.57	17	2001–02: +0.02
	2002–03: −0.07	2002–03: +0.30	2002–03: −3.50		2002–03: +0.48
2	2001–02: +0.03	2001–02: +0.36	2001–02: +1.03	18	2001–02: −0.12
	2002–03: −0.05	2002–03: −6.66	2002–03: +13.53		2002–03: +0.84
1	2001–02: +0.11	2001–02: +0.36	2001–02: +2.16	27	2001–02: −0.21
	2002–03: +0.00	2002–03: +1.65	2002–03: +5.82		2002–03: +0.15

c.s. = cross section; mean flow = 8.85 m^3s^{-1}; shear str. = bottom shear stress

Table 4 (A) Results of the mesohabitat electrofishing for the different sampling stretches (3–11) presenting the absolute numbers of caught fish (B) and Weighted Useable Areas for the different modeling reaches at the modeling discharges (2.66 m^3s^{-1}, 6.3 m^3s^{-1}, and 10 m^3s^{-1})

Season date	Winter 2000 12/12/2000	Summer 2001 16–17/7/2001	Winter 2002 26–27/11/2002	Summer 2003 8–9/7/2003
(A)				
Discharge (m^3s^{-1})	5.87	2.26–2.66	5.34–5.59	5.21–7.47
	t. 2+ 1+ 0+	t. 2+ 1+ 0+	t. 2+ 1+ 0+	t. 2+ 1+ 0+
3 (c.s. 1–2)	2/0/0/2	7/0/7/0	10/0/5/5	17/0/0/17
4 (c.s. 2–4)	–/–/–/–	79/1/66/6	4/1/1/1	20/3/3/4
5 (c.s. 4–6)	5/2/0/3	15/0/11/1	–/–/–/–	41/12/0/1
Flood channel	329/16/260/52	1/0/1/0	108/0/51/57	1/0/0/1
7 (c.s. 6–9)	1/1/0/0	38/1/37/0	1/0/0/1	9/1/0/8
8 (c.s. 9–14)	37/15/0/7	180/14/143/4	206/6/149/36	54/1/0/0
10 (c.s. 14–19)	1/0/1/0	28/1/27/0	12/0/4/6	37/16/4/2
11 (c.s. 20–22)	4/4/0/0	8/0/5/0	12/6/3/1	2/0/0/0
Total	379/38/261/64	356/17/297/11	353/13/213/107	181/33/7/33

Section	Q modeling [m^3s^{-1}]	WUA 2001 [m^2]	WUA 2002 [m^2]	WUA 2003 [m^2]	total 2001 [m^2]	total 2002 [m^2]	total 2003 [m^2]
(B)							
3	2.66	23.66	21.83	25.44	760	593	671
	6.3	12.35	16.69	7.58	933	731	747
	10	0.83	9.06	8.52	958	840	826
4	2.66	78.54	28.83	21.34	1554	1270	1256
	6.3	23.76	17.4	16.09	1833	1597	1561
	10	5.31	13.78	15.34	1875	1765	1730
5	2.66	20.61	10.87	11.32	995	896	829
	6.3	4.23	5.03	6.02	1209	1005	992
	10	1.08	2.27	2.89	1263	1195	1127
7	2.66	22.55	21.55	11.23	1047	983	1008
	6.3	6.21	2.87	8.31	1150	1126	1092
	10	5.11	4.68	5.85	1198	1181	1152
8	2.66	78.03	19.10	11.20	1237	1130	1033
	6.3	23.92	7.54	3.61	1460	1268	1160
	10	6.82	3.61	7.03	1518	1402	1253
10	2.66	47.56	31.80	10.38	1406	1384	1087
	6.3	18.45	15.49	9.43	1639	1586	1278
	10	10.38	5.26	13.83	1737	1699	1405
11	2.66	34.20	26.75	18.61	1730	1606	1501
	6.3	22.42	21.53	6.66	1910	1809	1718
	10	18.61	10.56	7.26	1970	1901	1851

t. = nase total; 2+ = nase juvenile (130 mm–200 mm); 1+ = nase juvenile (70 mm–120 mm); 0+ = nase (−60 mm)

Three geometry input files were generated for each of the years 2001, 2002, 2003. In combination with discharge simulations at 2.66 m^3s^{-1}, 6.3 m^3s^{-1}, and 10 m^3s^{-1} for each year, the effect of morphodynamics on depth and velocity conditions is shown (Fig. 5). These three specific discharges were selected because 2.66 m^3s^{-1} represents a typical low flow situation and is defined as the bottom boundary for the discharge simulations. At 10 m^3s^{-1} the inundation channel causes the flow to split. Discharges above 10 m^3s^{-1} cannot be simulated exactly by the habitat model, defining this value as the upper limit. The mean value of 6.3 m^3s^{-1} between bottom and upper discharge limit was also simulated. The modeling results and the effects on the abiotic conditions for 2.66, 6.3 and 10 m^3s^{-1} are shown in Fig. 5.

The flow velocities over the monitoring period clearly increased due to the reduced wetted area. The water depth at low flow (2.66 m^3s^{-1}) shows an extension of the classes 0.1–0.4 m (Fig. 5B). The simulations at higher discharge values show continuously reduced differences (Fig. 5D, F).
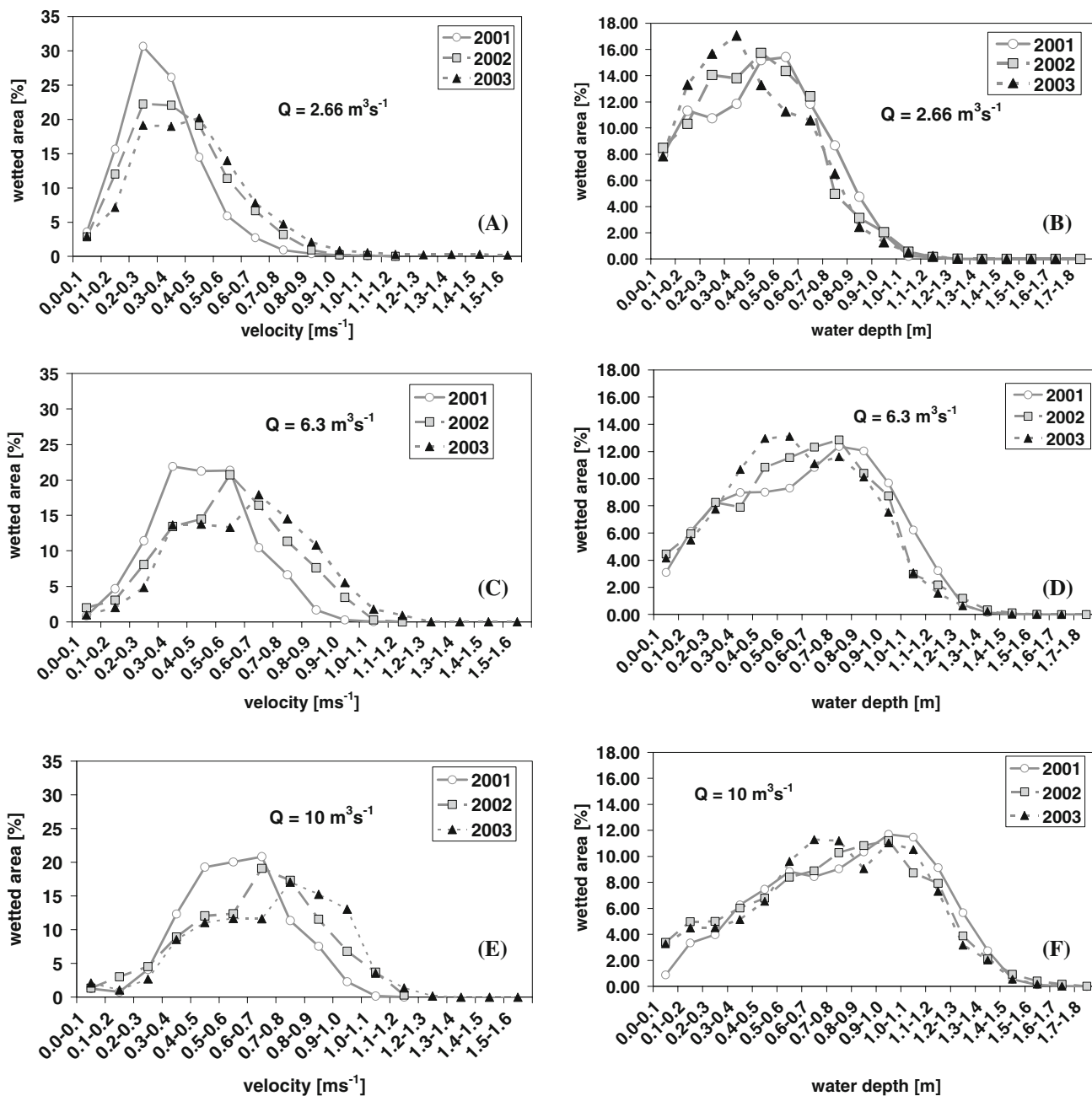
Fig. 5 Development of the abiotic parameters velocity and depth for 2.66 m³s⁻¹, 6.3 m³s⁻¹, and 10 m³s⁻¹ during the monitoring period 2001–2003; (**A**) = development of velocity for 2.66 m³s⁻¹; (**B**) = development of water depth for 2.66 m³s⁻¹;

(**C**) = development of velocity for 6.3 m³s⁻¹; (**D**) = development of water depth for 6.3 m³s⁻¹; (**E**) = development of velocity for 10 m³s⁻¹; (**F**) = development of water depth 10 m³s⁻¹

The flow velocities for 2.66 m³s⁻¹ showed a reduction of the flow velocity classes 0.2–0.4 ms⁻¹ over the years (Fig. 5A). On the other hand, velocities exceeding 0.5 ms⁻¹ increased over time (Fig. 5A). The maximum value in 2003 was 1.65 ms⁻¹ for the low-flow situation instead of a computed maximum value of 1.15 ms⁻¹ in 2001. The velocities developed similarly for 6.3 m³s⁻¹ and 10 m³s⁻¹ (Fig. 5C and E).

The Weighted Useable Areas (WUAs) could then be evaluated in combination with the multiplication of the Suitability Indices on the predefined grid (z = 3 cm) (Fig. 6, Table 4).

The morphological changes clearly negatively influenced the availability of physical habitats for juvenile nase. The WUAs for juvenile nases declined at 2.66 m³s⁻¹ discharge from 325 m² to 110 m². The reduction of suitable habitat
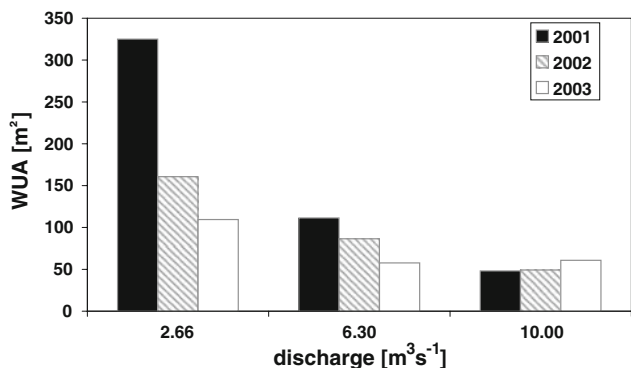
Fig. 6 WUAs of juvenile habitats of nase for different discharges (2.66 m^{3}s^{-1}, 6.3 m^{3}s^{-1}, 10 m^{3}s^{-1}) over the monitoring period 2001–2003

Fig. 8 Duration analysis in percent for the characteristic discharges over the monitoring period

areas at 6.3 m^{3}s^{-1} was less distinct, with values ranging from 111 m^2 in 2001 to 58 m^2 in 2003, whereas the modeling at 10 m^{3}s^{-1} showed little increase of juvenile habitat. This is because, at 10 m^{3}s^{-1} discharge, shallow-water areas as suitable habitats for juvenile nase occur on the top of aggradations. The steady state modeling results were then compared with the dynamic hydrological regime in the monitored area. Therefore habitat time series (Fig. 7) were implemented in the study related to 109 modeling discharges

based on the flow hydrograph for the study reach (gauging station, Fig. 1). Figure 7 further provides the hydrograph for the whole monitoring period 2001–2003, including the dates of morphological surveys and fish samples.

The duration analysis of the discharges showed that 72.9% of the discharges were below 6.3 m^{3}s^{-1} between June 1st and October 1st (Fig. 8). A further 51.2% were between 2.66 and 6.3 m^{3}s^{-1}, 16.3% between 6.3 and 10 m^{3}s^{-1}, and in 10.8% of the time the flow exceeded 10 m^{3}s^{-1}. These 10.8% were responsible for the
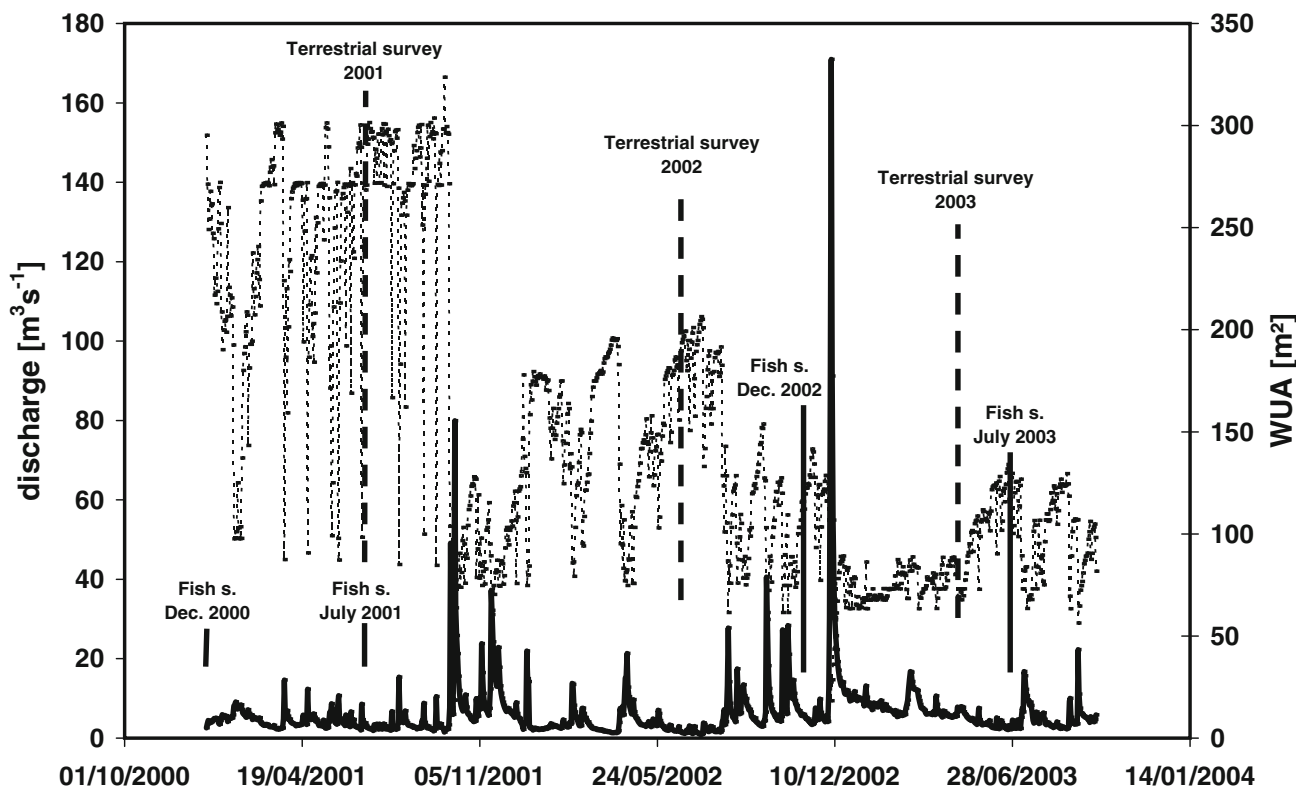

Fig. 7 Hydrograph of the Sulm River during the monitoring period 2001–2003 showing the dates of fish sampling and the terrestrial surveys of the monitoring area (solid line); Habitat time series of Weighted Useable Areas (WUAs) (dashed line); Fish s. = fish sampling; Dec. = December

aggradation in the meandering section. Flow splitting above 10 m^3s^{-1} discharge (Fig. 1) and the subsequently reduced bottom shear stress (Table 3 for 80 m^3s^{-1}) defined the special morphological characteristics of this section over the monitoring period.

The effects of those morphological developments on physical habitats of juvenile nase can be seen in Fig. 7 where suitable areas decline over the whole monitoring period depending on flood frequencies. As described in Fig. 6, for three specific discharges (2.66 m^3s^{-1}, 6.3 m^3s^{-1}, 10 m^3s^{-1}) the artificially created meander section provided the best habitats (323.66 m^2–270.18 m^2) for low flow conditions (1.5 m^3s^{-1}–3.37 m^3s^{-1}) in 2001. Caused by the artificially created morphologic boundaries of the monitoring year 2001, a steep gradient of calculated WUAs between low- and above mean flow conditions (323.66 m^2/1.5 m^3s^{-1} and 97.80 m^2/8.04 m^3s^{-1}) can be seen in Fig. 7. Discharges above 10 m^3s^{-1}, which cause a flow split up, exhibit no significant enhancement of available physical habitats. In contrast, a constant decline in WUAs is documented as well (e.g., −14.51 m^2 between 9.09 m^3s^{-1} and 14.62 m^3s^{-1}), originated by the fact that the former regulated river bed (steep bank angles) provides no morphological structures with available habitat for juvenile nase during discharges above mean flow. Similar results (decrease of WUA for discharges >10 m^3s^{-1}) are documented for the monitoring period in 2002. Exceptions are the modeling results related to the river morphology of 2003, which was strongly influenced by the December flood 2002. The findings of the habitat modeling present an enhancement of physical habitat for discharges above and below the flow split up (e.g., +9.89 m^2 between 9.08 m^3s^{-1} and 14.03 m^3s^{-1}). The partially considerable mean aggradations (up to 0.43 m) in the meandering section (Table 3) are responsible for the minor habitat improvement because shallow-water areas, as suitable habitats for juvenile nase, occur on the top of aggradations (Figs. 6, 7). Interestingly the differences (WUAs) between the best available habitats under low flow conditions and physical habitats above mean flow (10 m^3s^{-1}–15 m^3s^{-1}), which are clearly documented for 2001 (artificial meander geometry), decrease constantly depending on flood frequency. This development is related to river morphological regime processes. Regime processes are influenced by eight major variables including channel width, depth, flow velocity, discharge, channel slope, roughness of channel material, sediment load, and sediment size (Leopold and others 1964). The interaction between flood magnitude, flood frequency and transported sediments at the Sulm River generate a cross sectional shape of the artificially created meander which is defined through the existing boundary conditions (see 8 major variables). As it could be documented in Fig. 7 and Table 4, the quantity of available physical habitats in a river system is strongly related to these hydrological/hydraulic processes.

Evaluation by Electro Fishing

The length frequency histograms of the nase are shown in Fig. 9, whereby Fig. 9A represents the first sampling survey in winter 2000; the further sampling dates follow chronologically. The population structure from the first to the last monitoring survey changed clearly. In winter 2000, juvenile 0+ fish, as well as 1+ and 2+ nase, are represented. In the following summer (2001), the class 2000 was found in high numbers. In summer 2003, primarily 3+ individuals (length 210–280 mm) were documented. The main reason for this difference is assumed to be the change in the river morphology and consequently the change in the availability of juvenile habitats. Adult nase (>350 mm), however, are represented at all sampling dates (Fig. 9). In summer 2001, the highest numbers of juvenile fish occurred in the meander stretches. In winter 2000, juveniles were abundant only within lentic cut-off waters of the inundation channel, with few individuals in other habitats (Table 4). Table 4 clearly shows that, beyond the decrease in total numbers of juveniles between summer 2001 and summer 2003, juveniles vanished in the inner bend of the meander (sampling stretches 7, 8, and 10). Especially the curved sampling stretch Nr. 8 showed a reduction from 161 juveniles (2+, 1+, 0+) to 1 (2+) in 2003. This reflects the morphological development and the change of abiotic habitat conditions there. The possible impact of physical habitat loss on the total number of fish is shown by comparing Weighted Usable Areas (WUAs) and the total numbers of juvenile nase for the sampling stretches ($n = 7$). Different age classes of juvenile nase were compared with available habitats (Table 4) at the discharges occurring during the fish surveys (summer 2001 = 2.66 m^3s^{-1}/summer 2003 = 6.3 m^3s^{-1}). The results show a good correlation for summer 2001, where $r^2 = 0.67$ is calculated for all juveniles ($n = 324$), related to the percentage of WUA in the 7 sampling stretches (flood channel excluded). The analysis of 0+ and 1+ nase grouped as the second combination of age classes (1+, 0+) shows an $r^2 = 0.68$ using 307 individuals. Finally, 0+ nase as the third, singly evaluated size class features an $r^2 = 0.76$ ($n = 11$) for the relation between the simulated amount of habitats and individuals sampled by mesohabitat-electrofishing (Fig. 11). In summer 2003 theses correlations were less clear than documented two years before. Especially the analysis of all juveniles combined shows an $r^2 < 0.1$ ($n = 72$ juvenile nase), i.e., no correlation is present between simulated habitats and total numbers of sampled fish (Table 4). A poor correlation $r^2 < 0.2$ was evident for the second age group, 0+ and 1+ combined, ($n = 39$) and 0+ ($n = 32$) as well (Table 4). One explanation for the difference between the two years might be the hydrologic situation during, before, and after the electro-fishing (Fig. 10). 2001 was
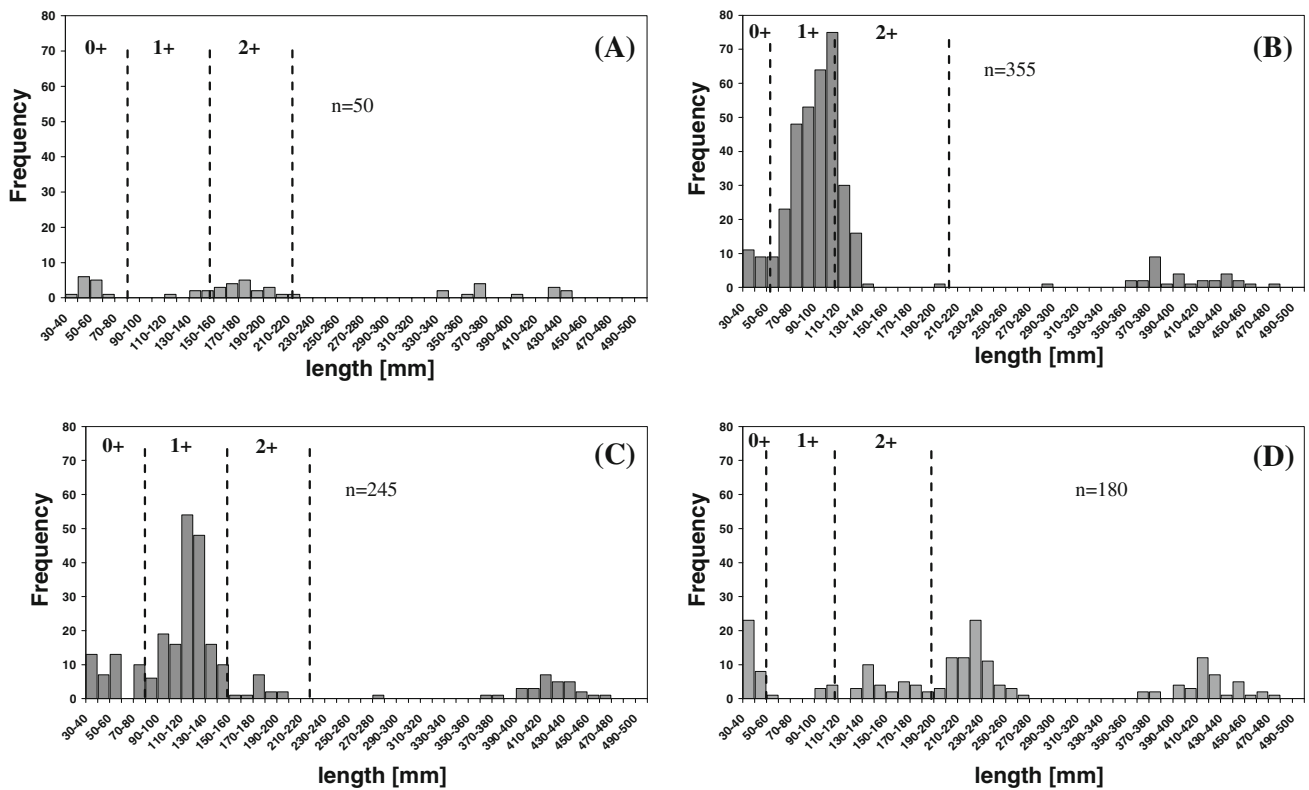
Fig. 9 Population structure of nase in the modeling area (cross sections 1–22/excluding flood channel); (**A**) winter 2000; (**B**) summer 2001; (**C**) winter 2002; (**D**) summer 2003

characterized by lengthy low-flow situations (<3 m^{3}s^{-1}) in June and July. The juvenile nase were able to use the shallow water habitats in the inner bend of the meandering section without any hydrologic interference. Accordingly, the juveniles were documented in high densities in areas with shallow water over gravel bars with suitable abiotic conditions (Table 4). During the fish sampling in 2003, higher discharges (5.21 m^{3}s^{-1}–7.47 m^{3}s^{-1}) occurred at the

beginning of increasing discharge (maximum discharge = 17.7 m^{3}s^{-1}) three days after the sampling (Fig. 10). Especially 2+ nase exhibited certain mobility at this time and were more abundant in areas with less suitable habitats (section 10 with 16 nase 2+). The age classes 0+ and 1+, which are not mobile at this life stage, continued to be documented in sections with suitable habitats (Table 4).
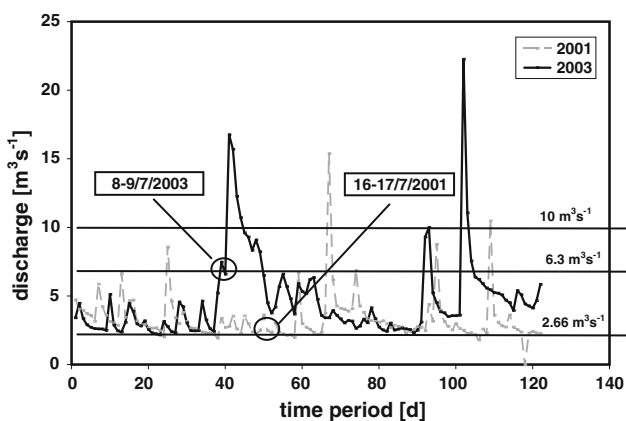

Fig. 10 Hydrograph (detail) during, before and after the fish monitoring in summer 2001 and 2003 including the exact date of sampling
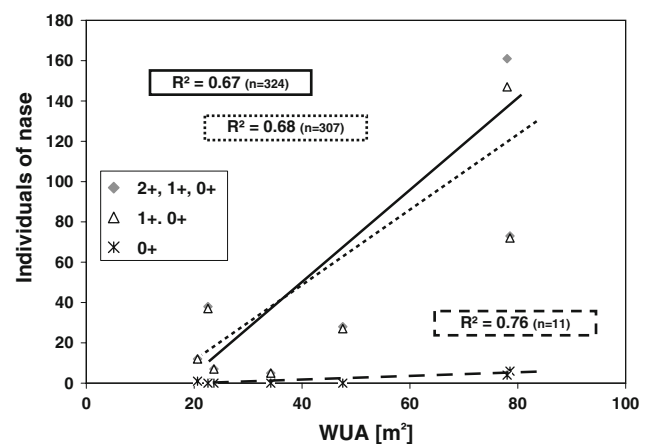

Fig. 11 Correlation between physical habitat and the numbers of caught nase, analyzed for different groups of age classes in summer 2001 (discharge = 2.66 m^{3}s^{-1})

Furthermore, the impact of higher discharges, especially of floods, is clearly evident in Table 4. Seven days after the fish sampling in December 2002, an 8-year flood occurred at the Sulm River and reduced 0+ nase drastically. In summer 2003, only 7 nase 1+ could be detected compared to 107 fish 0+ in winter 2002. The cold water temperatures during the winter season and the swimming performance are responsible for this massive loss of individuals. Older life stages (1+) had a higher survival rate during the flood event: they were still found (n = 33) in most of the sampling sections of the study area in 2003. Comparing the available habitats and the total number of fish, however, does show the influence of morphodynamic processes on the habitat use of fish, especially for 0+ and 1+ nase. The sections containing the highest densities of juveniles in 2001 (sampling stretches 4 and 8) also provided the best physical habitats. In summer 2003, sampling stretch 8, on the inner bend of the meander, showed the second worst physical habitat conditions and was no longer used by the juvenile nase (Table 4). In contrast, section 3, on the downstream end of the study reach, featured steadily improving habitat conditions over the monitoring period; it contained the highest number of individuals (n = 17) during the summer 2003 sampling period.

Discussion

This study applies the PHABSIM method to analyze the habitat quality of juvenile nase. PHABSIM, in general, assesses the habitat "performance" of a reach by defining its usable area for a particular (target) species or age class, based on a function of discharge or across channel structures. The decision to apply the method of multiplying suitability indices (PHABSIM) at the Sulm River was based on the fact that the habitat demands of this specific life-stage are well described with 3 parameters: velocity, depth, and substrate (Melcher 1999). The importance of these three abiotic parameters for classifying habitat quality was also documented in other scientific papers. Water velocity was suggested as the principal variable determining microhabitat use by juvenile cyprinids by Santos and others (2004). Other studies, however, reported water depth as the primary parameter influencing microhabitat use (Grossmann and Freeman 1987). Substrate was also identified as an important parameter for juvenile nase habitats, from which the velocity pattern can be estimated (Spindler 1988; Dedual 1990). The results of snorkeling at the Pielach River showed that velocity, depth, and substrate are decisive in the habitat use of juvenile nase (Melcher 1999). Therefore, the PHABSIM method of multiplying suitability indices (Bovee 1986) is an adequate tool to describe the abiotic habitat quality of

juvenile nase, despite criticism of this method for fish habitat analysis (Ghanem and others 1996; Scruton 1996; Railsback 1999).

The present study also shows that morphodynamic processes, especially bed load transport, are essential for understanding the long-term development of aquatic habitats. In the investigated area the aggradation of bed load and suspended sediments and their interaction with vegetation caused a rapid change in channel morphology and flow characteristics. The electro fishing results, which were part of the three years monitoring program, allow to argue that juvenile nase react to the modified abiotic conditions. Nevertheless by comparing the area occupied by fish, which is in some cases much less than the amount of available habitat (e.g., year 2001/section 3 = 23.55 m^3/7 specimen of 1+ nase (Table 4)), we assume that physical habitat is not the only limiting factor for the recruitment of juvenile nase but among the most important parameters. Especially the habitat niche of 0+ nase is related to specific physical habitat characteristics. Larval nase are not as mobile as older year classes and therefore occupy suitable areas in high densities. Those areas are not larger than several square decimetres, described as shallow water habitats (<10 cm) with preferred substrate (pelal, microlithal) (Keckeis and others 1997). From these habitats the juvenile nase shift towards gravel bars with shallow water and low flow velocities on the gravel bars. Based on these additional aspects in habitat use we might conclude that in most of the modeled sections suitable habitat area (m^2) is available to a much larger extent than occupied by the juvenile nase. Moreover the increase of habitat needs in terms of space, which is related to the ontogenesis, has to be considered in our case study. However, not only the amount of habitat is decisive, which was positively correlated in this study to fish frequency, further other parameters like food availability might have an influence on the habitat use of juvenile nase. The importance of one single meander in context of a nase population in a river stretch should also be considered. It is obvious that fish move in and out of the meander. Especially older life stages of nase (2+) are much more mobile than the younger fish (0+, 1+). Nevertheless even single restoration measures like the observed meander section resemble "hot spots" for the fish fauna, especially if the adjacent river stretches are regulated and therefore not suitable for single life-stages such as larvae or juveniles. Hence, the mid- to long term development of the hydraulic patterns within such sections is important for the development and future sustainability of fish populations (e.g., the spawning and recruitment of nase is always related to the availability of riffle habitats; Hauer and others 2007). For a better understanding of habitat dynamics, we also applied time-related habitat modeling (habitat time series) with morphodynamic aspects for mid-term habitat modeling. It was obvious that hydrologic interferences have a

recognizable impact on the available physical habitats and the fish population as well. Especially, floods with the recurrence interval of eight years in December 2002 caused a decline of all juvenile fish in the monitored section. This reflects the bankfull discharge conditions in relation to the historical "Leitbild" situation. Historically, overbank flow was found at 40–45 m^3s^{-1} instead of today's 80 m^3s^{-1}. Juvenile fish therefore have no opportunity to shift into refuge habitats. This problem persists in many rivers despite restoration measures. Other studies describe morphodynamic processes to predict habitat development. Kerle and others (2000) modeled the habitats for cross section enlargement of the Rhine River for the coming 30 years. There, a simulation discharge of 1500 m^3s^{-1}, coupled with sediment transport calculations by the model DELFT3D, yielded minor improvements for rheophilic fish species. These results, however, have no bearing on the rapid and massive physical habitat changes of nase described in this study over a mere 3 years of monitoring. Langler and Smith (2001) investigated another lowland river, the Hunspill River, for the effects of restoration on the habitats of 0+ fish. Within one year they documented a significant improvement for juvenile fish in shallow-water areas and bays. Similarly designed structures were once used by juvenile nase in the Sulm River in 2001 before they vanished due to morphological changes. Decisive features for juveniles occupying such areas are the low flow velocity and higher temperatures of the shallow waters (Mills and Mann 1985; Melcher 1999; Nunn and others 2003). The water velocity tolerance not only determines the capacity of fish to resist a current (Facey and Grossmann 1990; Kaufmann 1990; Young and Cech 1994), but also defines their escape response and feeding efficiency (Dabrowski and others 1988; Meng 1993).

The habitats of the juveniles (concerning the flow velocities) are also bound by close borders (Spindler 1988; Hofer and Kirchhofer 1996). The relative importance of shallow, slow flowing, and marginal habitats for small fishes is described by Copp (1992) and Scheidegger and Bain (1995). Shallow areas of the river littoral zone represent refuges both from the elevated water velocities and predation risk in the deeper areas of the mid-channel (Power 1987; Copp 1992; Copp and Jurajda 1993). The loss of such areas invariably affects recruitment, as has been shown for another rheophilic cyprinid species *Barbus barbus*, which is particularly sensitive to river regulation (Philippart 1987; Baras and Cherry 1990). Santos and others (2004) observed the association between larger fish and deeper habitat in all seasons: larger nase and chub always occupied deeper water, whereas smaller individuals were mainly found in shallow water areas.

Here, we also document that the flood event in winter 2002 reduced the juvenile nase. Such events in the early life of fishes may be major determinants of year class strength (Balon 1984, 1985; Snyder 1990) because the fish pass through several critical phases during this period and because fitness at the end of the growing season influences over-winter survival (Mills and Mann 1985; Mann and Mills 1986; Hederson and others 1988). Small fish size makes the availability of suitable habitat and food during this period important (Lightfoot and Jones 1979; Heggenes 1988; Rozas and Odum 1988; Mann 1997). Nevertheless, a certain percentage of the juveniles survived and found less physical habitat available through the morphological changes during the monitoring period in the restored river section. To predict such potential morphological development processes, Shields and others (2003) suggest applying numerical models in planning phases. They mention 13 steps from defining targets to monitoring the restoration area. Estimating river bed stability is fundamental to the morphodynamics of riverine systems (Kondolf and Sale 1985; USACE 1994), and stability is directly coupled to the increase or decrease of potential aquatic habitats (Shields and others 2003). River regulation and the associated altered river discharges have drastically reduced suitable habitat, especially for 0 + fish (Spindler 1988; Petts 1994; Shirvell 1994). This calls for further work on early larval and juvenile stages of cyprinids and their interaction with morphodynamic processes.

Conclusion

Revitalization projects are one crucial step to reach the good ecological condition required by the European Water Framework Directive (WFD) by 2015 by improving physical habitat conditions. The Sulm River, however, clearly demonstrates that — apart from the short-term improvement in the aquatic ecology by such measures (artificial meander, river widening) — mid-term morphological developments can change the artificially created habitats. This calls for mid-term and long-term monitoring of abiotic and biotic data. Integrative evaluation methods are eminently suited to study mid-term and long-term developments initiated by a revitalization measure, whereby habitat modeling can serve as a successful tool.

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