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The Alte Donau: Successful Restoration and Sustainable Management

An Ecosystem Case Study of a Shallow Urban Lake

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Chapter 14
The Effect of Restoration Measures on the Benthic Invertebrates of a Danube Backwater (Alte Donau)

Berthold Janeček, Patrick Leitner, Otto Moog, and Katrin Teubner

Abstract Benthic invertebrates were used as bioindicators to document the effect of restoration measures in the backwater Alte Donau in Vienna, a former side-arm of the Danube. The study covers four periods of lake management: (1): the mesotrophic year before eutrophication (1987), (2): the 2 years of chemical iron chloride treatment aimed at the phosphate precipitation in the water column and the oxidization of nitrate-treated sediment surface layers (1995–1996), (3): further 3 years of other lake management measures during the restoration period (1995–1999), and (4): an early stage of the re-establishment of underwater vegetation (2000, 2003). Over eight survey years from 1987 to 2003, about 330 benthic invertebrate taxa with three most abundant systematic groups were identified: 37 species of oligochaetes, 23 species of molluscs (18 gastropods and 5 bivalves), and 190 species of the chironomids and other dipterans. The trophic classification index that refers to a habitat quality score by chironomids indicates the year 1987 as mesotrophic (3.46, the index range for mesotrophic conditions is 2.50–3.49). In this year the chironomids and oligochaet species inhabited a variety of diverse habitats ranging from soft sediments (clay and mud), sand, gravel, pebbles and stones to dense stands of macrophytes. The biomonitoring record of 15 mollusc species was significantly higher in this mesotrophic reference year than in any other following survey year. The trophic classification index denotes 1995 as the most eutrophied year. With the restoration and the re-establishment of macrophytes the values of this index decreased but remained higher than during the mesotrophic condition. In the years 1995 and 1996, when the chemical treatment with iron chloride, slaked lime and calcium nitrate was applied and the macrophytes were rare, the biomass of chironomids and oligochaets

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was particularly low. Among the three important taxonomic groups, i.e. the chironomids, bivalves, and oligochaets, only the first two groups achieved relative biomass dominance. The relative importance of chironomids over oligochaets during these both years of the Riplox-treatment might rather mirror the losses of oligochaets being affected by nitrate exposure than the re-colonization by 'new' chironomid species in the sediment. In addition, in particular active filter feeders such as bivalves seemed to adjust well to the muddy sediment environment after chemical treatment. In the following years of the restoration and the early stage of macrophyte re-establishment, oligochaets and bivalves became the dominant groups mainly contributing to the macrozoobenthic biomass, while the biomass of chironomids remained relatively low. Different from the indication by enhanced water transparency and low phytoplankton biomass achieved by restoration measures in 2004, the shift towards a mesotrophic environment seemed to be retarded when assessing Alte Donau by the chironomid habitat quality score index. The main reason why the chironomid assemblage did not follow the other indicators of mesotrophic conditions in 2004 can be seen in the disruption of the sediment (e.g. by sedimentation of precipitation chemicals) and associated loss of underwater habitat structure due to still relatively low macrophyte biomass during the last invertebrate survey. The phytophilic chironomid species still had a low abundance when only about 50% of the macrophyte biomass was recorded if compared with the mesotrophic situation in 1987. Despite the wax and wane of benthic invertebrates described during the eight-year survey, invertebrate biomass is relatively high in the long-term average and thus characterises Alte Donau as a lowland environment along habitats from low- to high altitudes.

Keywords Oxbow lake · Benthic fauna · Bio-indicator · Chironomids · Pupal exuviae of chironomids · Bivalves · Oligochaets · Re-colonization of sediment · Lake restoration · Phosphate precipitation · Riplox

14.1 Introduction

Benthic invertebrates are a diverse group, containing a large number of species of various systematic origins, widely used as bioindicators (Rosenberg and Resh 1993; Woolsey et al. 2007; Moog et al. 2018). They are important consumers for accelerating the turnover of autochthonous and allochthonous organic matter in aquatic systems and serve as substantial food source for fish (Merritt and Cummins 1996; Moog 2002; Jungwirth et al. 2003; Moog and Hartmann 2017). They are living on the sediment surface, in the interstices and also colonize underwater vegetation from littoral to deeper profundal zones in a lake. The survey of invertebrates in Alte Donau was carried out sporadically in years of varying trophic states and restoration measures and thus differs logistically from those of planktic community of bacteria, algae, ciliates and other animals described in Chaps. 9, 11, 12, and 13. Nevertheless, the macrozoobenthos surveys in Alte Donau have the advantage of being consistently studied by the same person (B. Janeček) when considering the species determination for 8 years over a whole period from 1997 to 2003.

The benthic invertebrates in Alte Donau have been described for year 1987 before the eutrophication and various periods of the restoration measures. The main aim of this chapter is to characterise the benthic invertebrate community for these different periods (the description of the four basic periods of restoration measures are described in Chaps. 5 and 6). Beside the species description, a trophic index (Fittkau 1992; Orendt 1993) is used to assess the water quality before eutrophication and along years of restoration. Other results derived from the pre-dominance pattern of individual groups within the benthic community and from shifts in the similarity of the community structure by multivariate ordination plots are used to identify the main macrozoobenthic development. Among the benthic community a strong focus is given on the chironomids because this taxonomic group represented the highest species diversity throughout the 8-year benthic community survey in Alte Donau. Chironomids are commonly used for assessing this type of freshwaters (e.g., Wolfram 1996; Moog and Chovanec 2000).

14.2 Methods and Description of the Investigation Area

The oxbow lake Alte Donau in Vienna, a former side arm of Danube River was cut off from the main river for more than 160 years (Dokulil et al. 2010). With the regulation of the Danube River 1870–1875 (Chap. 2), a new river bed was built for navigation (New Danube), while the former stretch of the Danube River was named Alte Donau. Alte Donau thus became a groundwater-seepage lake, which was used for boating, fishery, and poultry farming (goose husbandry). This oxbow lake has also a long tradition as a popular recreational area (Chaps. 2 and 19).

Macrozoobenthos biomonitoring surveys were carried out about two times a year from 1995 onward in Alte Donau. The peak season for sampling was autumn, followed by summer contributing about 40% and 30% to the data set, respectively. Taking into account the spatial heterogeneity along the elongated shape of Alte Donau, in total more than 25 sampling sites were surveyed (Fig. 14.1), which included four sites for the bottom samples and seven sampling sites for chironomid pupal exuviae. Lake bottom samples were taken by scuba diving using a hand net (625 cm^2 area, 100 μm mesh size) or with a PVC-corer (27 cm^2 area). Pupal exuviae of chironomids were sampled by sweeping the surface with a pond-net. The samples were stored in plastic bottles and preserved with 4% formaldehyde.

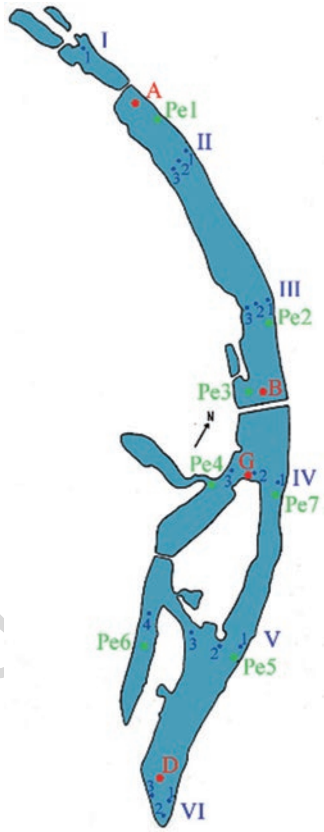

Fig. 14.1 Sampling sites. Transects of bottom samples taken in 1987 are marked by I–VI. Bottom samples at sites A and D were taken from 1995 to 2003, at B in 1995 and at G in 1999, pupal exuviae at Pe1 to Pe5 in 1996, 1997 to 2000 and 2003, at Pe6 in 2000 and 2003, and at Pe7 in August 1997 and September 1997

14.2.1 Species Identification and Determination of the Biomass

The separation of benthic invertebrate specimens was done by hand-picking, for some samples warm sucrose solution (30 °C, conc. c. 1.13 g per ml H_2O) was used to separate the invertebrates from the remaining sample (Kajak et al. 1968).

All larger animals with a length of up to 2–3 mm were collected and separately labelled according to major taxonomic affiliations. A fraction of smaller animals was obtained by sub-sampling (volumetric method) to reduce the effort required for sorting and identification. For calculating the biomass of the benthic invertebrates, the weight was measured using a precision balance (accuracy of 1 per 10.000 g). The conversion of fresh weight into ash free dry weight and caloric equivalent is described in Janeček (1985, 1995).

After taxonomic identification, the specimens have been preserved in 80% ethanol. Many chironomids and especially a lot of their pupal skins have been processed to permanent slides embedded in Euparal. For the identification of chironomids, a microscope with a magnification of at least 400x (for some details 1000x with oil immersion) was most appropriate. Some common macrozoobenthos species are shown by photographs in Fig. 14.2.

14.2.2 Graphical Display and Statistical Methods

The snapshot sampling of macrozoobenthos from 1987 to 2003 did not rely on a regular sampling frequency but took advantage of presenting a synoptic measure of species distributions and environmental situations over a long-time perspective in Alte Donau. Data were graphically and statistically treated by distribution free methods, taking into account the sporadic sampling in space and time for the benthic invertebrates described before (see non-parametric tests that are statistically satisfying large data sets by snap shot sampling in ecology in Krienitz et al. 2016).

For the graphical display of the main biomass pattern among the dominant invertebrate groups along the large range of biomass (1.13–2789 g fw m^{-2}), we reduced the information of metric invertebrate biomass to a binary set of presence and absence data (Fig. 14.3). We separated the invertebrates in oligochaetes, bivalves and chironomids, which refer to the most species-rich or most persistent invertebrate groups, and in the remaining invertebrates (see species and taxonomic affiliations in Table 14.1). In addition, the predominant invertebrates among these groups for each sample were identified (the predominance of an invertebrate group is defined by contributing a higher biomass to the total biomass of macrozoobenthos than individually other groups, compare with the method of Krienitz et al. 2016). The original data averaged for each year are shown for chironomids and oligochaets in Fig. 14.4.

The trophic chironomid index (Fig. 14.5, see further method description below) was depicted as box-whisker plots using SigmaPlot 10 (SPSS Inc., Chicago, USA). The line inside the box indicates the median, both ends of the box the 25th and 75th percentile, and the error bars the 10th and 90th percentile.

Multivariate analysis was used to determine whether the sampling sites were placed into specific groups that will minimize variance within groups and maximize variance among chironomid groups. We applied NMS (Non-metric Multidimensional Scaling) as an ordination technique that seeks to explain the variation in species community data using as few dimensions as possible (Kruskal 1964). NMS was analysed based on log (x + 1) transformed benthic invertebrate data using PC-ORD version 5. In this analysis sites with similar taxa composition are plotted close to each other in the scatter plot while dissimilar sites are plotted far from each other (Fig. 14.6). The following parameters were used in NMS ordinations: distance measure = Sorenson Bray-Curtis; starting configuration = random; runs with real data = 50; step-down in dimensionality from 6 dimensions to 1 dimension; initial step length = .2; maximum number of iterations per run = 400; stability criterion = .00001; iterations to evaluate stability = 10; Monte Carlo (randomized data) runs = 50.

14.2.3 Trophic Classification Index

In addition to abundance and biomass data of invertebrates described in the method before, also habitat quality scores were applied to track the long-term habitat changes in Alte Donau. Such scores are retrieved from a meta-analysis of empirical observations of biotic community structure or other phenomena discovered across individual habitats (Karr 1991; Hofmann 1994; Brettum 1989; Moog and Chovanec 2000; Moog 2002; Henderson 2003; Blenckner et al. 2007; Moog and Hartmann 2017). Habitat scores are applied to infer an ecologically sound integrity of aquatic habitats without referring to the individual data again. The trophic classification index suggested by Fittkau (1992) and Orendt (1993) was applied because in Alte Donau (1) the chironomids were a representative and species-rich group among the invertebrates (Table 14.1), and (2) the habitat change of Alte Donau was mainly due to nutrient enrichment and subsequent nutrient reduction passing restoration measures (Chaps. 5 and 6). This habitat quality score refers to those chironomid species that are most frequently contributing to the chironomid community within a narrow trophic range. Empirical regressions described in detail in, e.g., Orendt (1993) provide evidence that the population density of many chironomid species responds significantly to the total concentration of phosphorus, i.e. to the total pool of the nutrient element which is primarily understood to control the bottom up growth in freshwaters. The chironomid trophic index displayed in Fig. 14.5 covers many species, and thus is a community metric mirroring the habitat conditions along the phosphorus gradient and associated effects. The index consists of five ranks and indicates the trophy as follows:

1.00–1.99	oligotrophic
2.00–2.49	oligo- to mesotrophic
2.50–3.49	mesotrophic
3.50–3.99	meso- to eutrophic (in some lists up to 4.49)
4.00–5.00	eutrophic

14.3 Results

14.3.1 Benthic Macroinvertebrate Species Inventory of Alte Donau

A total number of 330 benthic invertebrate taxa were identified during the extended invertebrate surveys over 8 years from 1987 to 2003 (Table 14.1). The oligochaetes (37 species), the molluscs (18 species of gastropods and 5 bivalves), and the chironomids together with other Diptera (190 species) were the three main groups of benthic invertebrates (Tables 14.1 and 14.2). Specimens from these

Table 14.1 Macrozoobenthic taxa found in Alte Donau from 1987 to 2003

TAXONOMIC AFFILIATION	TAXON
CNIDARIA:	*Hydra* sp. WARINGER in LÖFFLER, ed., *Pelmatohydra oligactis* PALLAS; *Craspedacusta sowerbii* LANKESTER
TURBELLARIA:	*Dendrocoelum lacteum* O.F. MÜLLER, *Dugesia tigrina* GIRARD
NEMATODA:	*Nematoda* Gen. sp.
GASTROPODA:	*Acroloxus lacustris* LINNAEUS, *Bithynia tentaculata* LINNAEUS, *Potamopyrgus antipodarum* GRAY, *Galba truncatula* O.F. MÜLLER, *Radix auricularia* LINNAEUS, *R. ovata* DRAPARNAUD, *Physella acuta* DRAPARNAUD, *P. heterostropha* SAY, *Gyraulus albus* O.F. MÜLLER, *G. crista* L., *G.* sp., *Planorbis planorbis* L., *Hippeutis complanatus* LINNAEUS, *Valvata cristata* O.F. MÜLLER, *V. piscinalis* O.F. MÜLLER, *V. studeri* BOETERS & FALKNER, *Viviparus acerosus* Bourguignat, *V. contectus* Millet
BIVALVIA:	*Dreissena polymorpha* PALLAS, *Casertiana nitida* JENYNS, *Anodonta anatina* LINNAEUS, *A. cygnea* LINNAEUS, *Unio pictorum latirostris* KÜSTER
OLIGOCHAETA:	*Aeolosoma sp., Criodrilus lacuum* HOFFMEISTER, *Eiseniella tetraedra* SAVIGNY, Stylodrilus heringianus CLAPAREDE, *Amphichaeta leydigii* TAUBER, *Chaetogaster diaphanus* GRUITHUISEN, *Dero digitata* MÜLLER, *D. obtusa* D'UDEKEM, *D.* sp., *Nais christinae* KASPRZAK, *N. communis* PIGUET, *N. pseudobtusa* PIGUET, *N. elinguis* MÜLLER, *N. simplex* PIGUET, *N.* sp., *Ophidonais serpentina* MÜLLER, *Pristina longiseta* EHRENBERG, *Slavina appendiculata* D'UDEKEM, *Specaria josinae* VEJDOVSKY, *Stylaria lacustris* LINNAEUS, *Vejdovskyella comata* VEJDOVSKY, *V. intermedia* BRETSCHER, *Propappus volki* MICHAELSEN, *Aulodrilus japonicus* YAMAGUCHI, *Branchiura sowerbyi* BEDDARD, *Ilyodrilus templetoni* SOUTHERN, *Limnodrilus claparedeianus* RATZEL, *L. hoffmeisteri* CLAPAREDE, *L. profundicola* VERILL, *L.* sp., *Potamothrix bavaricus* ÖSCHMANN, *P. hammoniensis* MICHAELSEN, *P. moldaviensis* VEJD. & MRÁZEK, *Psammoryctides barbatus* GRUBE, *P. moravicus* HRABE, *P.* sp., *Tubifex* cf. *ignotus* STOLC, *Tubifex tubifex* MÜLL
HIRUDINEA:	*Dina punctata* JOHANNSON, *Erpobdella octoculata* LINNAEUS, *Alboglossiphonia hyalina* MÜLLER, *Helobdella stagnalis* LINNAEUS

(continued)

Table 14.1 (continued)

TAXONOMIC AFFILIATION	TAXON
CRUSTACEA -MYSIDACEA:	*Limnomysis benedeni* CZERNIAWSKI
CRUSTACEA -AMPHIPODA:	*Chelicorophium curvispinum* SARS, *Dikerogammarus haemobaphes* EICHWALD, *D.* sp., *Echinogammarus ischnus* BEHNING, *Gammarus roeselii* GERVAIS,
CRUSTACEA -ISOPODA:	*Asellus aquaticus* LINNAEUS
ARACHNIDA-ACARINA:	*Hydrozetes lacustris* MICHAEL, *Trimalaconothrus novus* SELL., *Hydrodroma despiciens* O.F. MÜLLER, *Lebertia* sp., *Frontipoda musculus* O.F. MÜLLER, *Limnesia undulata* O.F. MÜLLER, *Hygrobates longipalpis* HERMANN, *Unionicola aculeata* KOENIKE, *U. crassipes* O.F. MÜLLER, *Neumania deltoides* PIERSIG, *Piona discrepans* KOENIKE, *P. pusilla* NEUMAN, *P. pusilla rotundoides* THOR, *Hydrochoreutes krameri* PIERSIG, *Forelia curvipalpis* VIETS, *Axonopsis complanata* O.F. MÜLLER, *Brachypoda versicolor* O.F. MÜLLER, *Mideopsis orbicularis* O.F. MÜLLER, *Arrenurus* sp., *Porolohmanella violacea* KRAMER
EPHEMEROPTERA	*Caenis horaria* L., *C. lactea* BURMEISTER, *C. luctuosa* BURMEISTER, *C. luctuosa/macrura*, *C. rivulorum* EATON, *C.* sp., *Cloeon dipterum* L., *Ephemerella* sp., *Ephemera danica* MÜLLER, *E. vulgata* LINNAEUS, *E.* sp.
ODONATA:	*Coenagrion puella* LINNAEUS, *Erythromma najas* HANSEMANN, *Ischnura elegans* Van der LINDEN *Platycnemis pennipes* PALLAS, *Orthetrum* sp.
PLECOPTERA:	*Nemoura* sp.
HETEROPTERA:	*Gerris* sp., *Ilyocoris cimicoides* LINNAEUS
PLANIPENNIA:	*Sisyra* sp.
COLEOPTERA:	*Haliplus* sp., *Oulimnius tuberculatus* MÜLLER, *Donacia* sp.
TRICHOPTERA:	*Ecnomus tenellus* RAMBUR, *Hydropsyche contubernalis* McLACHLAN, *Orthotrichia costalis* CURTIS, *Oxyethira flavicornis* PITET, *O.* sp., *Athripsodes cinereus* CURTIS, *Athripsodes* juv., *Ceraclea dissimilis* STEPHENS, *Leptocerus tineiformis* CURTIS, *Mystacides azurea* LINNAEUS, *Mystacides longicornis* LINNAEUS, *M.* sp., *Oecetis lacustris* PICTET, *Oecetis ochracea* CURTIS, *O.* sp., *Psychomyia pusilla* FABRICIUS, *Tinodes waeneri* LINNAEUS

DIPTERA:	*Bezzia* sp., *Monohelea* sp., *Chaoborus flavicans* MEIGEN, *C.* Sp.,
	Ablabesmyia longistyla FITTKAU, *A. monilis* LINNAEUS,
	A. cf. *monilis* LINNAEUS, *Acricotopus lucens* ZETTERSTEDT,
	Brillia bifida KIEFFER, *Bryophaenocladius* cf. *nidorum* EDWARDS, *B.* sp., *Chironomus acutiventris/obtusidens*, *C.* cf. *annularius nec* DE GEER,
	C. balatonicus DÉVAI W. & S., *C. balatonicus/plumosus*,
	C. longipes STAEGER, *C. longistylus* GOETGHEBUER,
	C. luridus STRENZKE, *C. nudiventris* RYSER S. & W., *C. nuditarsis* KEYL, *C. plumosus* LINNAEUS, *C. plumosus*, *C. pseudothummi* STRENZKE,
	C. sp., *Cladopelma bicarinata* BRUNDIN, *C. goetghebueri*,
	C. virescens MEIGEN, *C. viridula* LINNAEUS, *C.* sp.,
	Cladotanytarsus atridorsum KIEFFER, *C. lepidocalcar* KRÜGER,
	C. mancus WALKER, *C. mancus*, *C. nigrovittatus* GOETGHEBUER,
	C. vanderwulpi EDWARDS, *C. wexionensis* BRUNDIN, *C.* sp., *Corynoneura arctica* KIEFFER, *C. carriana* EDWARDS,
	C. coronata EDWARDS, *C. gratias* SCHLEE, *C. scutellata* WINNERTZ, *C.* sp., *Cricotopus albiforceps* KIEFFER, *C.* cf. *arcuatus* HIRVENOJA,
	C. bicinctus MEIGEN, *C. cylindraceus* KIEFFER, *C. festivellus* KIEFFER,
	C. flavocinctus KIEFFER, *C. fuscus* KIEFFER, *C. intersectus* STAEGER, *C.* cf. *laricomalis*, *C. pilitarsis* ZETTERSTEDT, *C. reversus* HIRVENOJA,
	C. ricotopus FABRICIUS, *C. sylvestris*, *C. trifasciatus* MEIGEN,
	C. sp., *Cryptochironomus albofasciatus* STAEGER, *C. obreptans* WALKER, *C. psittacinus* MEIGEN, *C. supplicans* MEIGEN, *C.* sp., *Cryptotendipes*
	holsatus LENZ, *C. ryptotendipes usmaensis* PAGAST,
	C. sp., *Demicryptochironomus vulneratus* ZETTERSTEDT,
	Dicrotendipes lobiger KIEFFER, *D. nervosus* STÆGER,
	D. notatus MEIGEN, *D. pulsus* WALKER, *D. tritomus* KIEFFER, *D.* sp., *Einfeldia pagana* MEIGEN, *Endochironomus albipennis* MEIGEN,
	Glyptotendipes mancunianus EDWARDS, *G. lyptotendipes glaucus/pallens*, *G. pallens* MEIGEN, *G. paripes* EDWARDS, *G. signatus* KIEFFER,
	G. viridis MACQUART, *G.* sp., *Harnischia curtilamellata* MALLOCH, *H. arnischia fuscimana* KIEFFER, *H.* sp.,

(continued)

Table 14.1 (continued)

	TAXONOMIC AFFILIATION	TAXON
t1.82		*Heterotrissocladius marcidus* WALKER, *Hydrobaenus lugubris* FRIES, *Kiefferulus tendipediformis* GOETGHEBUER,
t1.83		*Labrundinia longipalpis* GOETGHEBUER,
t1.84		*Limnophyes minimus* MEIGEN, *L.* sp., *Microchironomus tener* KIEFFER, *Microtendipes britteni* EDWARDS, *M. britteni/confinis*,
t1.85		*M. chloris* MEIGEN, *M. icrotendipes pedellus* DE GEER,
t1.86		*Nanocladius balticus* PALMÉN, *N. anocladius bicolor* ZETTERSTEDT, *N. anocladius rectinervis* KIEFFER, *Nilotanypus dubius* MEIGEN,
t1.87		*Orthocladius consobrinus* HOLMGREN, *O. rthocladius fuscimanus* KIEFFER, *Parachironomus arcuatus* GOETGHEBUER, *P. biannulatus*
t1.88		STAEGER, *P. mauricii* KRUSEMAN, *P. tenuicaudatus* MALLOCH,
t1.89		*P. varus* GOETGHEBUER, *P. vitiosus* GOETGHEBUER,
t1.90		*P. conversus* WALKER, *P.* sp., *Parakiefferiella bathophila* KIEFFER,
t1.91		*P. coronata* EDWARDS, *P.* sp., *Paralauterborniella nigrohalteralis* MALLOCH, *Paramerina cingulata* WALKER,
t1.92		*Paratanytarsus bituberculatus* EDWARDS, *P. dimorphis* REISS,
t1.93		*P. dissimilis* JOHANNSEN, *P. aratanytarsus inopertus* WALKER,
t1.94		*P. laetipes* ZETTERSTEDT, *P. tenellulus* GOETGHEBUER,
t1.95		*P. tenuis* MEIGEN, *P.* sp., *Paratendipes albimanus* MEIGEN,
t1.96		*Paratrichocladius rufiventris* MEIGEN, *Phaenopsectra* cf. *flavipes* MEIGEN, *P.* sp., *Polypedilum bicrenatum* KIEFFER, *P. convictum* WALKER,
t1.97		*P. cultellatum* GOETGHEBUER, *P. nubeculosum* MEIGEN,
t1.98		*P. sordens* V.D. WULP, *P.* sp., *Procladius choreus* MEIGEN,
t1.99		*P. lugens* KIEFFER, *P. rufovittatus* V.D. WULP (*Psilotanypus rufovittatus*), *P. sagittalis* KIEFFER, *P. signatus* ZETTERSTEDT, *P.* sp., *Prodiamesa*
t1.100		*olivacea* MEIGEN, *Psectrocladius limbatellus* HOLMGREN, *P. sectrocladius* cf. *brehmi* KIEFFER, *Psectrocladius oxyura* LANGTON,
t1.101		*Psectrocladius oxyura/sordidellus*,
t1.102		*P. psilopterus* KIEFFER, *P. sordidellus* ZETTERSTEDT,
t1.103		*P. schlienzi* WÜLKER, *P.* sp., *Pseudochironomus prasinatus* STAEGER, *P.* sp., *Schineriella schineri* STROBL, *Stempellina almi* BRUNDIN,
t1.104		*S. subglabripennis* BRUNDIN, *S. minor* EDWARDS,
t1.105		*Stenochironomus gibbus* FABRICIUS, *Stictochironomus* sp., *Synorthocladius semivirens* KIEFFER, *Tanypus kraatzi* KIEFFER, *T. punctipennis*
t1.106		MEIGEN, *T.* sp., *Tanytarsus bathophilus* KIEFFER, *T. chinyensis* GOETGHEBUER, *T. cretensis* REISS, *T. ejuncidus* WALKER, *T. eminulus*
t1.107		WALKER, *T. excavatus* EDWARDS, *T. glabrescens* EDWARDS, *T. gregarius* KIEFFER, *T. heusdensis* GOETGHEBUER,

t1.108		*T. inaequalis* GOETGHEBUER, *T. lactescens* EDWARDS,
t1.109		*T. lestagei* GOETGHEBUER, *T. lestagei*-Agg. Typ 1&2,
t1.110		*T.* cf. *longitarsis* KIEFFER, *T. mancospinosus* EKREM & REISS,
t1.111		*T. medius* REISS & FITTKAU, *T. mendax* KIEFFER, *T. mendax/occultus*, *T. nigricollis* GOETGHEBUER, *T. nigricollis/usmaensis*,
t1.112		*T. occultus* BRUNDIN, *T. pallidicornis* WALKER, *T. sensu* Langton,
t1.113		*T. signatus* V.D. WULP, *T. smolandicus* BRUNDIN,
t1.114		*T. sylvaticus* V.D. WULP, *T.* cf. *usmaensis* PAGAST,
t1.115		*T. verralli* GOETGHEBUER, *T.* spp., *Thienemanniella* sp., V*irgatanytarsus* sp. sensu Langton & Visser,
t1.116		*Xenochironomus xenolabis* KIEFFER, *Zavreliella marmorata* V.D. WULP

t1.117 Sites and sampling period see Fig. 14.1

Table 14.2 Number of collected species of the seven main taxonomic affiliations (n.c. not collected, * only bottom samples). The number of chironomid species, which were newly found in Alte Donau when compared with the survey in 1987 are listed from 1995 onward (last row)

	1987	1995	1996(97)	1997 (98)	1998	1999	2000	2003
Gastropoda	13	5	7	4	4	2	2	3
Bivalvia	2	3	3	2	1	4	1	2
Oligochaeta	7	13	10	16	16	21	8	14
Crustacea – Malacostraca	n.c.	3	2	3	3	4	4	2
Ephemeroptera	3	3	3	2	2	3	3	3
Trichoptera	5	5	8	5	3	12	5	2
Chironomidae	68	39*	91	77	67	114	114	90
Chir. spp., new for AD		15	24	10	6	31	18	5

systematic units have been found in all years of the habitat surveys in Alte Donau. Eighty species of other taxonomic affiliations such as Cnidaria, Turbellaria, Nematoda, Hirundinea, Crustacea (Ostracoda), Mysidacea, Amphipoda, Isopoda, Arachnida-Acarina, Ephemeroptera, Odonata, Plecoptera, Heteroptera, Planipennia, Coleoptera, and Trichoptera were further recorded during this study (Table 14.1). Comparing the chironomid species inventories of 1987 with those of each following year, 5–24 chironomid species were found that haven't been observed during the very detailed initial survey in the mesotrophic year 1987 (Table 14.2). The settlement of this countable number of newly observed chironomid species illustrates the dynamic and also the persistence of chironomids throughout surveys during restoration and macrophyte re-establishment in Alte Donau.

The observation of these invertebrates is attributed to four periods: (1) the mesotrophic reference condition in 1987, before the oxbow lake has undergone the strong eutrophication in the early nineties, (2) the 2 years of chemical phosphate precipitation (iron chloride treatment, 1995, 1996), (3) a 3 year period of further restoration treatments (1997–1999) and (4) 2 years of the re-establishment of macrophytes (2000, 2003) (more details about the periods see Chap. 6). In addition to a description of particular species and habitat change during these lake periods, the main pattern of invertebrate development is graphically shown in Figs. 14.3, 14.5 and 14.6.

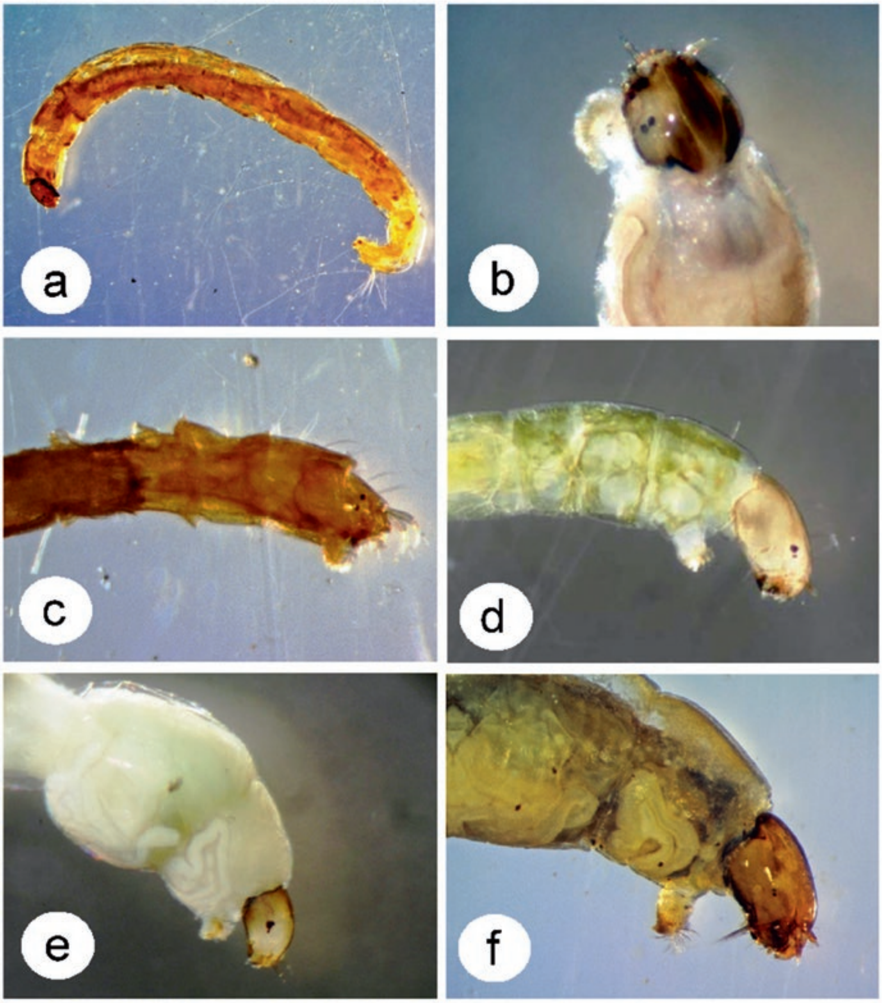

Fig. 14.2 Chironomidae found in Alte Donau – (**a**) Larva of *Polypedilum* sp. (Chironominae – Tribus Chironomini), (**b–f**) Heads of larvae, (**b**): *Paratendipes* cf. *albimanus* (Chironominae – Tribus Chironomini), (**c**): *Virgatanytarsus* cf. *arduennensis* (Chironominae – Tribus Tanytarsini), (**d**): *Cricotopus sylvestris* (Orthocladiinae), (**e**): *Nanocladius rectinervis* (Orthocladiinae), (**f**): *Prodiamesa olivacea* (Prodiamesinae). (Photos **a**, **c** and **f** by Wolfram Graf; **b**, **d** and **e** by Sabine Schiffels)

14.3.2 Year 1987 – Mesotrophic Conditions

The survey in year 1987 characterises the period before eutrophication of Alte Donau with luxuriant stands of macrophytes, which were mainly built up by water-milfoils (*Myriophyllum* spp.) and stoneworts (charophytes, most widespread species was *Nitellopsis obtusa*) (macrophyte survey see Chap. 8). In the extended surveys in spring (April, May) and early summer (June), the Naididae, which can occur on both, the sediment and the macrophytes, dominated the Oligochaeta community. The motility of these species is well recognised as they can leave the sediment climbing up to higher parts of the plants when faced with oxygen deficiency near the lake bottom. *Stylaria lacustris* and *Pristina aequiseta* were the most abundant species of Naididae, followed by *Nais communis*, *N. elinguis* and *N. pseudobtusa*. In contrast to the years after the iron chloride treatment, Tubificidae (*Tubifex tubifex*, *Potamothrix hamoniensis*) were rarely found in the sediments in 1987. An explanation for the lack of these Oligochaeta species under mesotrophic conditions may be the relatively coarse-grained to sandy sediments, the large fraction of coarse-textured detritus of plant material (further details see e.g., Learner et al. 1978; Schneider et al. 1988; Bauer and Waringer 1987; Hauer et al. 2018).

The record of 15 mollusc species (spp.) in 1987 was higher than in any of the following survey years of this study (Table 14.2) (Haberlehner 1987). In comparison to the benthic fauna of some larger sized backwaters in the alluvial forests east and west of Vienna (e.g. floodplain of Stopfenreuth: 34 spp., Lobau floodplains: 27 spp., Haberlehner 1986), however, Alte Donau serves as fragmented and modified habitat for a smaller number of species and lower animal densities (history of river cut-off Alte Donau see method and Chap. 2).

The Chironomidae were the third important benthic invertebrate group, with respect to abundances (individual numbers and biomass) and a large variety of species during the whole study period. In general, the chironomid communities in the fine sediment exhibited low species numbers even though high densities of 4200 individuals m^{-2} were found in January (1357–12,995), 13,650 individuals m^{-2} in March (3. March: 5913–31,490 ind. m^{-2}), 3060 individuals m^{-2} in May (27. May: 1676–5579 ind. m^{-2}) and 2810 individuals m^{-2} in June (15. June: 1410–5599 ind. m^{-2}). The biomass values ranged from 0.81 in May to 2.02 in June and thus were moderate despite the peak abundances. The comparably low total biomass of chironomids was due to the small size of the abundant species, e.g., belonging to the Tanytarsini (*Tanytarsus glabrescens*, *T.* spp., *Paratanytarsus tenuis*, *P.* spp.) and Orthocladiinae (*Parakiefferiella bathophila*, *Psectrocladius sordidellus*). Merely two Chironomus species (*C. plumosus*, *C. balatonicus*) were of large size and were only common at single sites. Chironomini were in general not numerous, with the exception of up to 480 individuals m^{-2} for *Chironomus plumosus* and up to 560 individuals m^{-2} for *Parachironomus arcuatus* in June. Tanypodinae mainly consisted of *Procladius* (*Holotanypus*) spp. and *Tanypus punctipennis*. Only a few species have been found exclusively on sediments, for example *Cryptochironomus* spp., *Stictochironomus* spp. or *Cladotanytarsus mancus*. A larger number of species,

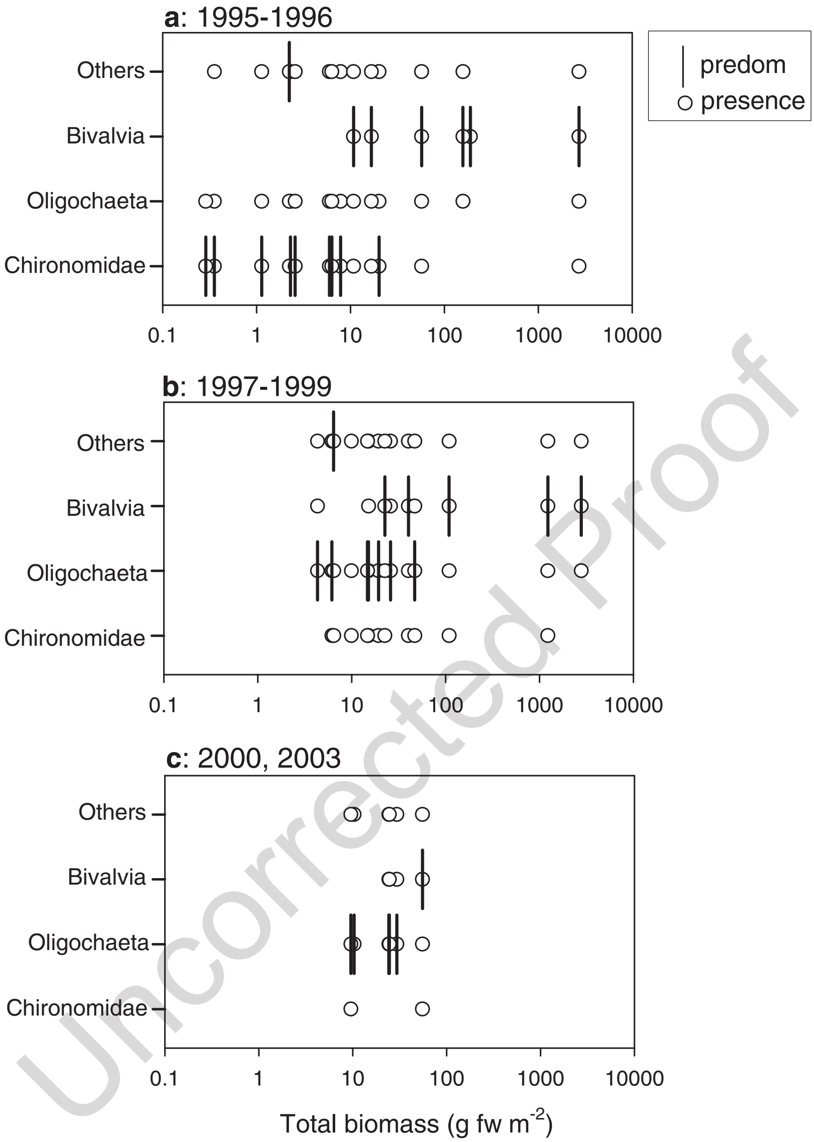

Fig. 14.3 Presence of invertebrates displayed along the total invertebrate biomass during three periods of restoration: (**a**) – chemical phosphate precipitation by RIPLOX-method, (**b**) – further restoration measures, (**c**) – re-establishment of macrophytes (n = 36). The composition of invertebrates is depicted by the three groups Chironomidae, Oligochaeta and Bivalvia that are mainly and most persistently contributing to the invertebrate biomass in addition to remaining invertebrates (others) (species see Table 14.1). An invertebrate group is displayed as present (dots) if the contribution to the total invertebrate biomass exceeds 5%. Note that each invertebrate sample can be represented by all four groups. A bar indicates the predominant invertebrate for each sample. Note the log-scale of the total biomass of invertebrates. Further description see methods

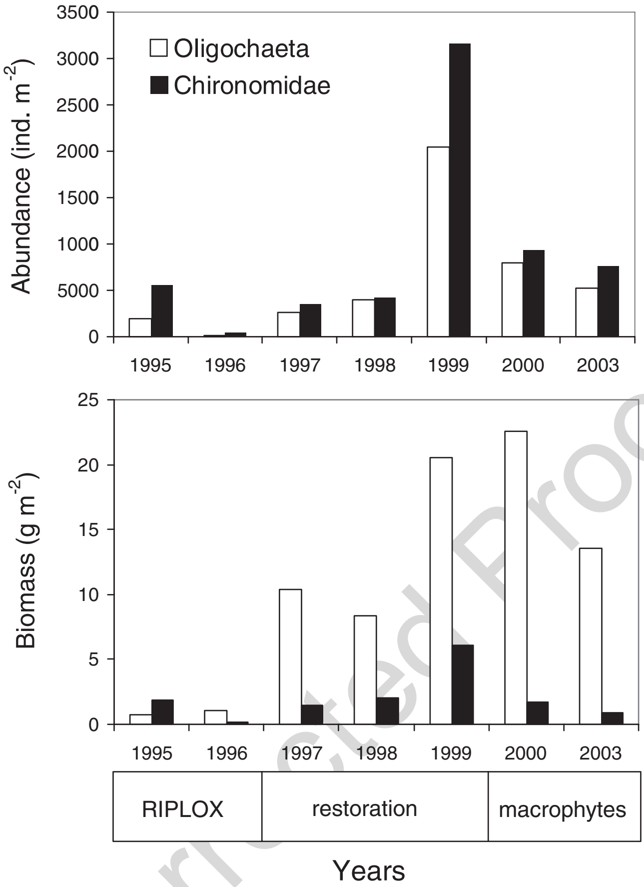

Fig. 14.4 Abundance and biomass of oligochaetes and chironomids displayed as bar charts covering the main three periods of restoration as in Fig. 14.3

however, was found on both the macrophytes and the bottom sediments and was thus able to use the diverse habitat structure during this mesotrophic period with dense macrophyte stands. Members of this transition group were *Ablabesmyia monilis*, *Parakiefferiella bathophila*, *Psectrocladius sordidellus*, *Dicrotendipes tritomus* and some species of *Paratanytarsus* and *Tanytarsus* (e.g., *T. glabrescens*). *Polypedilum nubeculosum* was found on the submerged plant species *Ceratophyllum demersum* and *Myriophyllum spicatum*, and even *Chironomus plumosus* can occur on macrophytes such as *Chara tomentosa*, *Nitella obtusa* and *Myriophyllum spicatum*. The following species were collected exclusively from macrophytes *Chara tomentosa* and *Nitella obtusa* or from periphyton: *Nanocladius bicolor*, *Cricotopus* sp., *Dicrotendipes lobiger*, *Endochironomus albipennis*, *Parachironomus*

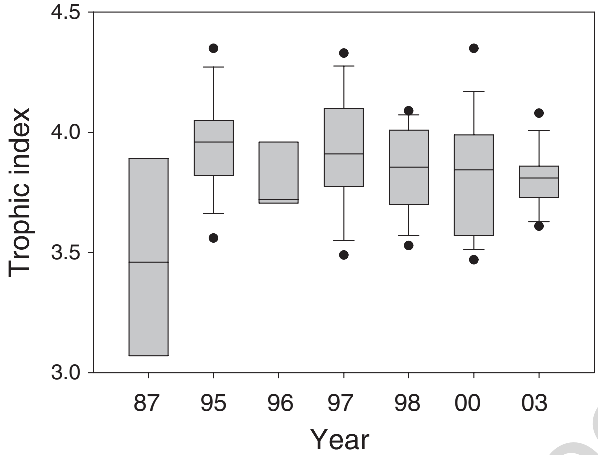

Fig. 14.5 Chironomid assemblages used as bioindicators: Trophic index calculated from the abundance of chironomid species for individual years (1987–2003)

tenuicaudatus and *Glyptotendipes viridis* (mining in macrophytes *Sagittaria* and *Alisma*, see Kalugina 1975). *Glyptotendipes signatus* refers to the same habitat behaviour but is also known to settle on the bryozoans such as *Plumatella fungosa* (Janeček 2005).

The trophic indices were calculated from the pupal exuviae collections and refer three times to mesotrophic and another three times to meso-eutrophic conditions. The range of variability in the trophic index is much larger in 1987 when compared with later years (Fig. 14.5). In the following survey years mesotrophic conditions could only be identified for certain sites and only twice: site Pe3 sampled on 14.8. 1998 (value for the trophic index = 3.49) and site Pe1 on 19.8. 2000 (value for the trophic index = 3.47) (sites see Fig. 14.1).

The NMS ordination plot of scores illustrating the similarity or dissimilarity of chironomid assemblages is shown in Fig. 14.6. One symbol represents an investigation site. The benthic communities of the scores from 1987 (depicted as black triangles) are not overlapping with the scatterplots of the other years and thus confirm the unique status of chironomid community structure. They are separated most distant from those of the other years along the first NMS axis mirroring substantial differences in the community structure (Fig. 14.6). These main changes in the chironomid species composition can be well verified when going back to the original survey information. In the years after 1987 and with chemical treatment of phosphate precipitation, some of the most abundant species such as of the Tanytarsini (*Tanytarsus glabrescens*) completely disappeared.

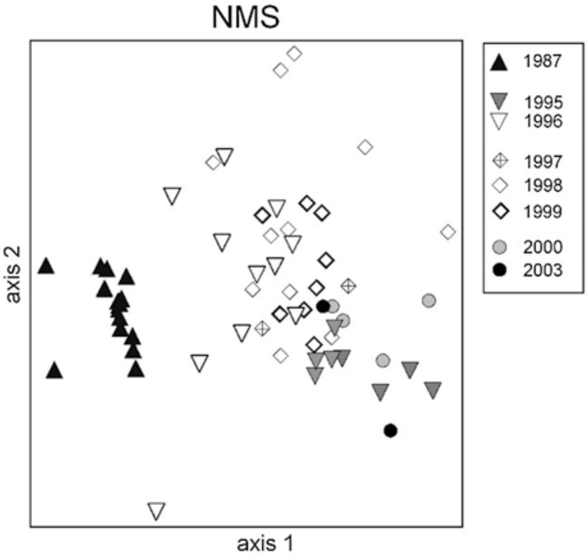

Fig. 14.6 Ordination scatter plot for data points that refer to the chironomid species communities in benthic samples from individual years (1987–2003)

14.3.3 Years 1995 and 1996 – Chemical Treatment for Phosphate Precipitation

In the period of strong eutrophication of Alte Donau in 1992 and 1993, the formerly clear-water oxbow lake turned into a turbid water body with large biomass blooms of phytoplankton (mainly *Cylindrospermopsis raciborskii* and *Limnothrix redekei*, see Chap. 9). The submerged water plants almost disappeared under low underwater light availability (Chaps. 5 and 8), the annual mean Secchi depth was 0.85 and 0.89 m (shown in Fig. 11.5 in Chap. 11). The benthic invertebrate surveys for 1995 and 1996 were conducted weeks to months after the chemical precipitation treatment with iron chloride (April 95 and April 96). With the deposition of sedimentary layers rich in organic carbon (biodegraded material formed during eutrophication together with precipitate containing phosphate, slaked lime and calcium nitrate by chemical treatment, Ripl 1976), large areas of the sediment surface were then covered by sapropel while sandy river sediments of a grain diameter 100–250 µm became rare (Janeček 2000). In accordance with the sparse underwater vegetation in 1995 (Fig. 8.1 in Chap. 8, 1.6 m annual mean Secchi depth in Fig. 11.5 Chap. 11), in particular, the phytal macrozoobenthos species of the Chironomidae and Trichoptera were rarely found. The abundance of the phytal species, however, immediately increased again when the submerged vegetation started to recover due to elevated water transparency in 1996 (Chap. 8, 2.1 m annual Secchi depth in Chap. 11). Particular abundant macrozoobenthic species observed in 1987, such as the

Chironomidae *Tanytarsus glabrescens*, *Paratanytarsus laetipes*, *P. tenuis*, nonetheless, could not be detected in 1995 and 1996 (Janeček 2000). In turn, many new species of oligochaets and Chironomidae were recorded in these 2 years, when compared with the macrozoobenthos survey in year 1987 (Table 14.2). 14 species of Chironomidae were identified for the first time in Alte Donau and three of them became quite frequent in the sediments: *Procladius rufovittatus* (*Psilotanypus rufovittatus*), *Stempellina subglabripennis* and *Stempellinella minor*. An even higher number of newly found species were recorded for the second year of chemical treatment (Table 14.2). Some of the newly found species in Alte Donau prefer sediments (e.g. *Cryptotendipes* sp., *Glyptotendipes paripes*, *Microtendipes* cf. *britteni*, *Polypedilum sordens* and *Tanytarsus medius*) or even live on water plants or stones (e.g. *Glyptotendipes pallens*, *G. viridis* and *Polypedilum sordens*). *Procladius rufovittatus* (*Psilotanypus rufovittatus*) is known for migration and was found in larger densities. Some species newly found in these 2 years might be called pelophilic and are more or less tolerant to oxygen deficiency. They are typical species of eutrophic waters. Large species such as *Chironomus plumosus*, *Ch. balatonicus*, *Tanypus punctipennis* and *T. kraatzi* could reach peak abundances of up to 520 individuals per m^2 and thus became dominant in terms of individual species biomass. According to the large distance of data point for 1987 and 1995 along the first NMS axis (Fig. 14.6) the species composition of the chironomids shifted largely from mesotrophic conditions to the first year of chemical treatment. Despite the high number of species observed, the abundance and biomass of chironomids and also of Oligochaets were in general low in 1995 and 1996 (Figs. 14.3a and 14.4), which can be seen as an initial negative effect of the chemical phosphate precipitation treatment. When comparing the biomass of these two macrozoobenthos groups, the chironomids became predominant against the oligochaets (Fig. 14.3a). Beside the chironomids, which were often pre-dominant when low total biomass of macrozoobenthos was found, bivalves became also often the most dominant group during both years of the chemical treatment (Fig. 14.3a) but stand for sampling dates and sites of high total biomass of macrozoobenthos. It thus seems that bivalves, as active and efficient filtrating collectors, can cope well with the chemical phosphate flocculation. In this view the two iron chloride treatments had some positive effects on Bivalvia and Chironomidae as the large number of species at low abundance increased the diversity in the macrozoobenthic community in particular for the latter. When looking at the trophic index, which is calculated from the abundance of chironomid species, the community indicated eutrophic conditions in 1995 and a meso-eutrophic environment in 1996 (Fig. 14.5).

A clearer picture of the compositional shifts in the macrozoobenthos community is recognised when assessing the functional feeding groups. In accordance with large sediment surface areas that are covered by fine particulate organic matter, detritivorous macrozoobenthos became the most important feeding group in 1995 and 1996. Filtrating collectors that are able to accumulate sinking organic particles were quite abundant too. We further found macrozoobenthic predators especially among the Chironomidae, namely Tanypodinae and *Cryptochironomus* spp. that are known to be at least partially carnivorous.

The compositional changes in the chironomids toward species that are primarily living in gravel and sandy sediment slightly altered the values of the trophic index (Fig. 14.5) and the overall species composition (Fig. 14.6) toward a chironomid community structure that was described under mesotrophic conditions

14.3.4 Years 1997–1999– Further Restoration Measures

In the 3 years of the "restoration period" after chemical phosphate precipitation, the annual Secchi depth reached values from 1.7 to 2 m (Fig. 11.5 in Chap. 11). The macrophyte cover did not increase substantially and remained at moderate biomass levels comparable with the year 1997. The abundance and biomass of both the oligochaets and chironomids increased when compared with the 2 years of chemical phosphate precipitation (Fig. 14.4). In view of the biomass contribution of species groups allocated to large taxonomic affiliations, the macrozoobenthos community changed from the predominance of chironomids and bivalves during the chemical treatment to a community dominated by oligochaets and bivalves in subsequent years (Fig. 14.3b). From 1997 to 1999 the muddy sediment in particular at the deeper parts of the lake seemed to build up a stable environment that provides an ideal habitat for large mussels such as *Anodonta cygnea* and *Unio pictorum*. Among the chironomids a number of species such as *Parakiefferiella bathophila* and *Paratanytarsus* spp. could reach higher densities on less muddy sediments, i.e. gravel and sand. In case of oligochaets the Naididae became dominant again as commonly described for mesotrophic conditions in 1987. In 1999, the number of species and biomass of chironomids and oligochaets was highest when compared with those of the previous and the following years (Fig. 14.4). The peak abundance and biomass for four main taxonomic affiliations for individual sampling sites were 36,900 individuals per m^2 with a corresponding biomass of 42.20 g fw per m^2 for the oligochaets, 81,790 individuals per m^2 with a corresponding biomass of 19.42 g fw per m^2 for the chironomids, 4200 individuals per m^2 with a corresponding biomass of 1.53 g fw per m^2 for the Ephemeroptera, and 900 individuals per m^2 with a corresponding biomass of 1.75 g fw per m^2 for the Trichoptera. In eutrophic lakes annual averages of macrozoobenthos biomass can reach up to 650 g fw per m^2 in the profundal zone (Brinkhurst 1974). In such ecosystems the biomass of Chironomidae usually contributes from 30 to more than 100 g fw per m^2 (Janeček 1985, 1987).

Beside active filterers also predators were found such as the free-living flatworm *Dugesia tigrina* and the leech *Helobdella stagnalis*. Among the Chironomidae a number of carnivorous (or at least partially carnivorous) species have been observed: *Ablabesmyia longistyla*, *A. monilis*, *Procladius* spp., *Cryptochironomus* spp., *Tanypus kraatzi* and *T. punctipennis*. Some species that are commonly known for running waters have been observed in 1999 in Alte Donau, such as *Propappus volki* belonging to the Oligochaeta (this oligochaet species occurred also in the Danube River, see Moog 2002; Moog and Hartmann 2017), *Hydropsyche contubernalis* of the Trichoptera and *Polypedilum convictum* of the Chironomidae. Most species of the Chironomidae, but also of the Oligochaeta and Trichoptera, were living on the open bottom areas and thus became quantitatively important whereas phytophilic species (such as for example *Ophidonais serpentina* belonging to the Naididae) did not contribute significantly to abundances and biomass within the macrozoobenthic community. In case of the chironomids this result is also supported by the percentages of pupal exuviae: Here the most phytophilic species did not even reach 1% of the total drift. The dominance of macrozoobenthos species that are living in the sediment in association with rarely found phytolitic species indicates that the sediment surface had recovered as valuable habitat for the benthic fauna while macrophytes were still missing during this period in Alte Donau.

The compositional changes in the chironomids shifted toward species that were primarily living in gravel and sandy sediment. These changes correspond to a slight decrease of the trophic index indicating eutrophic-mesotrophic conditions (Fig. 14.5). The overall species composition displayed in the NMS-ordination plot shows that the chironomid community structure tends to be less different from mesotrophic conditions than in year 1995 (Fig. 14.6, along the first NMS-axis points for 1997–1999 are less distant to points of the mesotrophic year 1987 than compared with the distance of points of mesotrophic year 1987 and eutrophic year 1995).

14.3.5 Years 2000 and 2003 – Period of the Re-Establishment of Macrophytes

The 2 years of macrozoobenthos surveys within the period of re-establishment of macrophytes (2000–2006, Fig. 5.4 in Chap. 5) are in the beginning and middle of the 7-year period. In 2000 and 2003 the annual mean Secchi depth was 1.9 and 2.3 m, respectively. The water transparency in these years was thus similar to that in 1999 (Fig. 11.5 in Chap. 11). While the macrophyte biomass surveyed for the whole basin of Alte Donau had increased consecutively from 1996 to 1999 by 10 to almost 15 tons dry weight (Figs. 8.1 and 8.7 in Chap. 8), the biomass did not exceed 15 tons in 2000. The second year of macrozoobenthic survey, year 2003, however, is the first "macrophyte transition" year with a significant increase to 125 tons dry weight biomass of underwater vegetation. From 2004 onward the annual mean Secchi depth increased significantly from 2.8 to 3.9 m and macrophytes reached remarkable stands of 300–500 tons dry weight in Alte Donau (under mesotrophic conditions in 1987 macrophytes reached 721 tons dry weight, Chap. 8). Macrozoobenthos surveys, however, are only described for 2000 and 2003 and, thus, relate to an environment of still low water transparency and a moderately enhanced macrophyte biomass in 2003. The abundance was much lower than in the years before. In 2000 and 2003 about a half of the oligochaets and a third of the chironomids of the peak abundance in 1999 could be reached (Fig. 14.4). Nevertheless, the biomass of oligochaets was still high while the biomass of chironomids was considerably low. The oligochaets dominated the benthic community most frequently when comparing the biomass of the main taxonomic affiliation groups (Fig. 14.3c) even though the total macrozoobenthos biomass was relatively low when compared with previous periods of restoration (Fig. 14.3a, b). More subtle differences in compositional shifts were found when considering single macrozoobenthic species. *Stempellinella minor* was a common chironomid species in the years of chemical phosphate precipitation inhabiting the littoral sediment areas without submerged vegetation. Their abundance declined slowly in years of stepwise re-establishment of macrophytes. Some chironomids that are commonly found at less nutrient rich habitats, such as *Cladotanytarsus nigrovittatus* (trophic index 3.6), for example, became more abundant in Alte Donau while *C. mancus* (trophic index 4.0) declined. Large profundal living Chironomus species such as *C. balatonicus* and *C. plumosus* that are commonly found under eutrophic conditions and that are expected to survive even in anoxic periods became less often observed. They reached lower abundances in 2000 and 2003 than compared with the restoration period in Alte Donau before. The profundal chironomid fauna typically associated with sustained mesotrophic conditions (e.g., *Tanytarsus bathophilus*, *T. gregarius* and *T. inaequalis*) were, nevertheless, quantitatively still of minor importance. When assessing the whole chironomid community, the median values of the trophic index for 2000 and 2003 tended to decrease slightly (Fig. 14.5) indicating a slow development toward eutrophic-mesotrophic conditions. In addition, the chironomid species composition did not differ considerably from those in 1997–1999 (see NMS-ordination plot in Fig. 14.6) and thus indicates again that the chironomid community structure is still very different from observations in mesotrophic 1987.

In patchy sediment areas where the bottom structure clearly indicated the approved iron chloride treatment to reduce phosphate availability by precipitation, a community of active filter feeders was reaching high biomasses in the two survey years. *Dreissena polymorpha* that was in particular found in 2000 and *Pisidium nitidum* and Pea mussels that were commonly observed in 2003 thus seem to be the most persisting active filter feeders which can still occur under more stable conditions after the restoration period has been passed.

14.3.6 Comparison of Macrozoobenthos Biomass across Habitats

The abundance and biomass of benthic fauna varied among large taxonomic affiliations corresponding to the environmental disturbance by restoration measures and different trophic states in Alte Donau. It must be stated here that the relatively low trophic index of 1987 (3.46) representing mesotrophic conditions (2.50–3.49, Fittkau 1992) was never reached again during the following years of the investigation. The habitat biomass of macrozoobenthic communities, however, can also vary across altitudes (Jungwirth et al. 1980), (Fig. 14.7). The biomass of macrozoobenthos increases exponentially when following the aquatic habitats from the source at high altitude to the river mouth at low altitudes in Austria. Among Austrian water

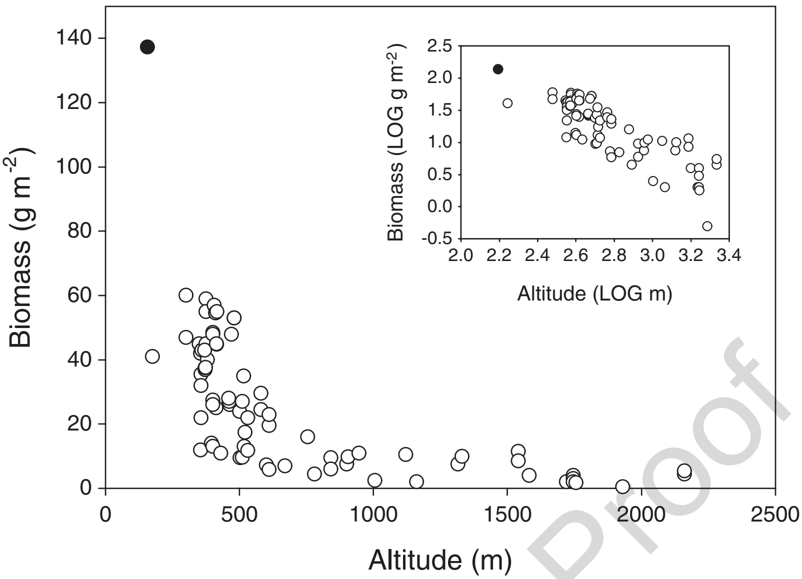

Fig. 14.7 Biomass of invertebrates sampled from benthic habitats across altitudes. Inset displays the same data but on double logarithmic scale. The black dot refers to the median biomass of Alte Donau (1995–2003). The white dots are from Dückelmann 2001 in Jungwirth et al. 1980, 2003

bodies, Alte Donau represents an ecosystem at particular low altitude that is located in the lowland close to the Danube river flood plain in Vienna. The enhanced biomass for Alte Donau (137 g per m^2) thus corresponds well to the exponential increase of macrozoobenthic biomass at low altitude habitats (see also the correspondence of the data point for Alte Donau in the log-log plot in the inset of Fig. 14.7).

14.4 Discussion

14.4.1 Species Inventory of Alte Donau

The knowledge on the benthic invertebrate fauna of the Austrian Danube section has shown a remarkable input in the last 15 years of the twentieth century. Nine years after Russev (1985) who reported 167 species, Humpesch and Moog (1994) observed 897 species of the macrozoobenthos for the River Danube in Austria. Of these, 306 species were restricted to the free-flowing main river channel, 354 species to the backwaters of impoundments and 683 to the backwaters of the riverside forests. A couple of years before the European Water Framework Directive was put into practice, the upcoming European environmental water policy stimulated a number of Danube and large river studies with a focus on environmental status assessment and discussions about mitigation measures of flood protection, navigation and hydropower use effects. As a result, Moog et al. (1995) published a list with 1142 invertebrates species in the Austrian Danube followed by a total of 1289 species 5 years later (Moog et al. 2000).

The study on the benthic fauna of Alte Donau contributes valuably to the knowledge of the biodiversity of the Austrian Danube system. A total of 330 benthic invertebrate taxa were recorded by Löffler et al. (1988) and during the current invertebrate surveys from 1995 to 2003. This is a comparably high number if one takes into consideration, that the entire water body of Alte Donau is located in the urban area close to the centre of Vienna. The importance of Alte Donau as an urban diversity hot spot is also confirmed by the fact that from the whole floodplain area around Vienna (downstream Greifenstein, river-kilometre 1940, to Vienna-Freudenau, river-kilometre 1920) a total of 511 species and 625 species have been reported in 1995 and 2000 respectively (Moog et al. 1995, 2000; Moog and Hartmann 2017). This means that the comparatively small water body Alte Donau offers a habitat for 65% and 53% respectively of the benthic invertebrate species that are known from the floodplains around Vienna.

14.4.2 Impact of Habitat Disturbance on Benthic Community in Alte Donau

Benthic invertebrates are the most preferred biomonitoring organisms studying stressors and drivers in freshwaters from temperate to subtropical and tropical zone (e.g., McLachlan 1974; Wolfram et al. 1999; Stendera et al. 2012; Mengistou 2016; Cai et al. 2017; Moog et al. 2018). Despite their high value as bioindicator in natural habitats (e.g., for chironomids in Fittkau 1992 and Orendt 1993) and their metric-based differences in benthic invertebrate communities between restored and non-restored sites (Sundermann et al. 2011), several studies emphasise the difficulties of tracking the success of restoration by retarded re-colonization of benthic invertebrates (Langford et al. 2009; Stendera et al. 2012). It is rather argued that the linkage between habitat change and structural change in the invertebrate community is less pronounced than assumed by restoration practitioners (Jähnig et al. 2010; Sundermann et al. 2011). Our results of benthic invertebrate biomonitoring surveys are in accordance with these studies as the improvement of water quality indicated by these organisms is much slower than expected by other restoration indicators. In case of Alte Donau, however, the delay in the recovery of the benthic community might be mainly due to coating of biota and sediment surface by chemical precipitants, on the one hand, and a too abrupt habitat shift by drastic nutrient reduction on the other. In the year 2004, when periods of chemical phosphate precipitation (1995–1996) and the moderate recovery of submerged macrophyte stands have been passed, the chironomid trophy index indicated only a slight recovery of the species composition compared with the mesotrophic conditions in 1987 in Alte Donau. Other organisms than benthic invertebrates, such as phytoplankton, that are commonly used to assess water quality, indicate the “success” of a restoration more rapidly. Already from year 2001 onward, the chlorophyll-a concentration revealed low values indicating a decrease of phytoplankton biomass under mesotrophic conditions in Alte Donau (Fig. 5.5 in Chap. 5, see period 3 in Fig. 9.10 and 9.11 in Chap. 9). An assessment by phytoplankton relies on species that have a short generation time ranging from hours to few days. Only phytoplankton taxa living in a more persistent environment in deep chlorophyll layers in deep lakes (Teubner et al. 2003b) are known to have a longer life span of up to 5–7 days (e.g., Gervais 1998, Zotina et al. 2003). The rapid decline of phosphorus in the water column due to phosphorus flocculation in Alte Donau thus immediately suppressed the growth of short-lived phytoplankton and was associated with significant compositional shifts from the dominance of cyanobacteria to mainly eukaryotic algae (Teubner et al. 2003a). Different from these planktonic primary producers, all other planktonic organisms such as heterotrophic bacteria, protozoans and metazoans, responded differently and also not necessarily coherently to the shortage of the total phosphorus pool (Teubner et al. 2003a). Unlike these planktonic assemblages the benthic invertebrates are taxonomically and ecologically a very heterogeneous group. On the one side, they are comprised of species that may live for only a few weeks to months as part of their life as larvae (e.g. chironomids larvae in warm bodies). On the other side, this group also includes species with a life span of five to ten or even much more years (for tubifex see e.g., Jónasson and Thorhauge 1972, for Bivalvia Cummings and Graf 2009). In view of an ecological perspective the habitat structure of benthic species is much more complex than of planktonic organisms and, thus, benthic invertebrates were affected in different ways by the restoration measures in Alte Donau. Taking into account this ecologically heterogeneity, the resettlement of benthic invertebrates after the Riplox-treatment toward species that are associated with mesotrophic conditions might have been driven by three aspects:

– Suppression by **the initially abrupt and further lasting shortage** of planktonic food that was primarily achieved by the growth control of phytoplankton under reduced phosphorus availability.
– Vulnerability to the **short-time habitat destruction** and toxicity from the chemical sediment treatment and the settlement of the phosphorous precipitate on sediment surface aimed at reducing internal phosphorus load and thus to reduce the total phosphorus pool in the water column and.
– Colonization of the new habitats by the **long-term re-settlement of macrophytes** concomitantly with the increasing water transparency.

The impact of these three aspects of habitat disturbance by Riplox-treatment 1995/96 and other restoration measures on benthic invertebrates acted concurrently and cannot be detangled by analysing snap shot surveys during 7 years of observations in Alte Donau. As submerged macrophyte vegetation was sparse, most invertebrates were found in the sediment in Alte Donau. The majority of these species observed during the eutrophication and Riplox-treatment were not able to live attached to submerged macrophytes as an alternative. The bottom sediment was thus the main habitat for species of the benthic community in Alte Donau before macrophytes were successfully re-establishment in Alte Donau in year 2003 onwards (Chap. 8).

It is generally agreed that anthropogenically generated fine sediment deposition by terrestrial degradation, eutrophication or restoration (e.g., Naden et al. 2016) can rapidly change the sediment's habitat structure and thus impact the benthic invertebrates in manifold ways (Wood and Armitage 1997; Gundacker 2000; Jones et al. 2012; Schröder et al. 2013; Leitner et al. 2015; Murphy et al. 2015; Graf et al. 2016; Hauer et al. 2018). Such rapid fine sediment settlement alters not only the sediment architecture due to the small grain size (clogging of sediment and embeddedness of larger grains) but also the associated sediment properties such as hydrological exchange at the water-sediment interface, the oxygen content and related redox-chemical characteristics. In Alte Donau, the quality of fine sediments has been changed. During the eutrophication period, the fine sediment was built from subsequent sequestering of huge biomass of planktonic cyanobacteria, algae and other organisms and contained chemical precipitates due to the Riplox-treatment (Ripl 1976) in 1995/1996. The total biomass of benthic invertebrates and also the biomass and abundances of individual groups such as the chironomids and the oligochaets were particularly low during the chemical treatment with iron chloride, slaked lime and calcium nitrate in Alte Donau. The rapid and sustained oxidization of the sediment by nitrate that aimed at phosphate precipitation in the water column and a suppressed P-release from sediment, seem to enhance microbial activity (e.g., Wauer et al. 2005) on the one hand but is also described to be toxic for benthic invertebrates on the other hand. According to mesocosm experiments by Sueitt et al. (2015) that were designed for assessing the ecological risk of the calcium nitrate exposure to benthic invertebrates, the abundance of benthic community mainly composed by oligochaetes and chironomids was significantly lowered after 25 days of incubation. During their experiments the abundance of 900 oligochaets was *reduced* by 87%, those of about 50 chironomids by 20%. The relative importance of chironomids over oligochaets at generally low biomass of benthic invertebrates during both years of the Riplox-treatment in Alte Donau thus might rather mirror the losses of oligochaets by nitrate exposure than the re-colonization by 'new' chironomid species in the sediment. It is worth mentioning that oligochaetes are known to be particularly hypoxia resistant (*Tubifex* species are surviving 10–11 weeks in the hypoxic sediment under ice in winter and 2 weeks in hypoxic sediments at around 16 °C during stratification in summer, see review by Grieshaber et al. 1993), and thus seem to be especially vulnerable to superficial over-saturation of oxygen by access of nitrate in the sediment. Remediation experiments by Janke et al. (2011) and Sueitt et al. (2015) that were designed to tackle the time schedule of re-colonization by benthic invertebrates after sediment treatment with nitrate confirm laboratory experiments by Ripl (1976) 'that the restored sediment can support chironomids, tubificids and other animals'. After the decline of the population densities of benthic invertebrates due to the disturbance of benthic sediments by chemical or mechanical treatment (e.g., dredging declines 82% of benthic biomass, Moog et al., 2015), chironomids and oligochaets are commonly the primary or early secondary colonizers. The re-settlement of invertebrate animals after restoration is strongly supported by invertebrates from the surrounding environment (Langford et al. 2009; Sundermann et al. 2011). According to Graf et al. (2015) the Diptera with 174 taxa and the oligochaets with 53 taxa are the most heterogeneous groups within the benthic invertebrate community in the Danube River (see also Moog et al. 1995, 2000 and Sect. 14.4.1). Although it can be assumed that chironomid species that inhabit mesotrophic freshwaters in the nearby Danube River floodplain would have a major contribution to the recolonization, the species composition of chironomids did not significantly alter from 1995 to 2003 in Alte Donau. A concurrent increase of the abundance of phytophilic chironomids and the re-settlement of submerged macrophytes, however, was observed during this period and supports the importance of macrophytes as habitat for benthic invertebrates (Cyr and Downing 1988; Cheruvelil et al. 2002; Kirby and Ringler 2015). The invertebrate survey ended in 2003 before a more stabilized macrophyte biomass has been developed from 2004 onward in Alte Donau. While the macrophyte biomass was still relatively low in 2003 (17% of the biomass in 1987) about 50% macrophyte biomass of the mesotrophic reference year 1987 has been observed from 2004 onward (Figs. 8.7 and 8.11 in Chap. 8).

The invertebrate activity by feeding and bioturbation mediates detritus processing and subsequently affects the properties of the sediment habitat (McCall and Fischer 1980; Mermillod-Blondin et al. 2002; Nogaro et al. 2006, 2009, Hunting et al. 2012). The shift from the predominance of chironomids during both years of the Riplox-treatment (1995/96) to a predominance of oligochaets (1997–1999 and 2000, 2003) might have altered the sediment structure as the mode of bioturbation by these two invertebrate groups affects the water-sediment exchange in aquatic ecosystems differently. While the tubificids are described as upward conveyors feeding on deeper sediment but ejecting the faecal pellets at the sediment-water interface, the chironomids are rather known as biodiffusors living in U-shaped tubes at the near surface layer of the sediment (e.g., McCall and Fischer 1980; Mermillod-Blondin et al. 2002; Nogaro et al. 2006, 2009). The tubificid worms are thus seen as the more efficient benthic animals for reducing interstitial clogging when compared with chironomids.

In Alte Donau, mussels occurred during all three phases from the chemical treatment onward, which might relate to an alternate environmental adjustment of single species. According to Gundacker (2000), fine sediment habitats are preferred by *Anodonta* sp., while *Unio pictorum* is rather found in patchy areas of low fine sediment deposition in the Danube River. Both bivalve species were also observed during the invertebrate surveys in Alte Donau. These efficient filtrating collectors seemed to cope well with both fine sediment types, i.e. the particles sequestered from planktonic biota and those deposited by chemical treatment.

Despite the variation of benthic invertebrates between years of different trophic state and restoration measure, the relatively high biomass and the large number of species discussed above, characterise Alte Donau as lowland habitat. The exponential biomass increase of macrozoobenthos from high to low attitude habitats might be a function of a number of indirect local effects (e.g., nutrient enrichment in the lowland ecosystems, lower flow velocity might favour large-bodied benthic animals and stable potamal habitat conditions and thus might also protect the animals against washing out during floods) superimposed by global impacts (e.g. decreasing atmospheric pressure and less exposure to UV radiation across high to low attitude habitats).

The different effects modifying macrozoobenthic biomass and community structure thus need to be disentangled when further assessing Alte Donau compared with other habitats across altitudes. An increase of both, the invertebrate biomass and the number of benthic invertebrate orders and families from high to low altitude habitats, however, are commonly observed in stream ecology and are mainly discussed as direct impact of temperature and associated habitat characteristics (e.g. heavy metal concentration, 'stream hydraulics') (e.g., Clements and Kiffney 1995; Jacobsen et al. 1997; Jungwirth et al. 2003; Schmutz and Moog 2018).

14.5 Conclusion

The macrozoobenthos biomonitoring surveys covered the year 1987 before eutrophication and years of restoration (including the 2 years of chemical treatment of phosphate precipitation) and an early stage of the period of re-establishing the submerged vegetation in the oxbow lake Alte Donau. Despite the rapid decrease of phytoplankton biomass associated with an increase of water transparency and a subsequent growth of macrophytes along restoration measures, the chironomid assemblage did not clearly show a species shift towards a mesotrophic habitat. A main reason can be seen in the still relatively low macrophyte biomass during the last recent invertebrate survey in 2004, when only about 50% of the macrophyte biomass was recorded compared to the mesotrophic situation in 1987. Thus in 2004 many invertebrates living in the sediment have been found while phytophilic species, which typically live attached to the submerged vegetation, were still less common. It can be expected, however, that with an increase of submerged water plants in Alte Donau also more clean-water colonizers as found in 1987 will further resettle in Alte Donau. Despite the wax and wane of benthic invertebrates described during the 8 years of observation, the relatively high long-term average of invertebrate biomass characterises Alte Donau well as lowland environment across low- to high altitude habitats.

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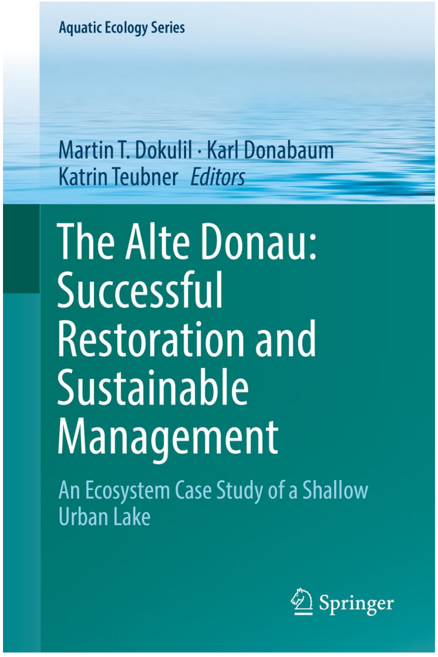

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