Chapter 20

Eutrophication, Management and Sustainable Development of Urban Lakes: General Considerations and Specific Solutions for Alte Donau – A Synthesis

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Abstract Intensively used urban water bodies are vulnerable to eutrophication. The shallow lake Alte Donau (Vienna) can be seen as an example for the extent of anthropogenic influence. Human impacts paired with changes in environmental conditions gave way to eutrophication processes in Alte Donau. Due to the great public interest restoration concepts and subsequently management programs were established. This chapter provides a synthesis of the key aspects to evolve and implement a successful water management plan. An attempt is made to generalise our specific solutions to serve as a basis for the development of similar strategies for other urban lakes.

Keywords Restoration · Groundwater · Seepage · Management · Improvement · Shallow lake

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20.1 Introduction

Urban lakes are different types of natural or man-made water bodies within densely populated areas. For the purposes of management, these lakes can be defined by several operational criteria. They tend to be small and shallow, with surface areas of less than 2.5 km^2 and a mean depth of 6 m or less. The ratio of the watershed area to lake area can be variable but is often 10:1 or higher, meaning that their watersheds exert a strong influence on the lake. As an overall index of development, the urban lake watershed must contain at least 5% impermeable cover. The water budget often depends on ground-water and precipitation or is entirely artificially controlled. Most of these urban lakes must be managed for recreation, water supply, flood control or some other direct human use regardless whether natural or man-made (Birch and Mc Caskie 1999).

Curiously, the unique problems and conditions of urban lakes have received little attention in scientific literature. This is particularly surprising given that many of the management efforts are devoted to lakes and reservoirs that are distinctly urban in character. While the watershed management literature is filled with phosphorus budgets and watershed models, it is unusual to find overviews about the influence of watershed development on lake quality and it is exceptionally rare to find studies that have tracked changes in lake quality as a function of watershed development over time (Schueler and Simpson 2001).

However, restoration and recovery of already eutrophicated systems can only be achieved if external measures like watershed management are combined with internal measures.

20.2 Eutrophication

Small and shallow aquatic ecosystems generally have lower resilience than large, deep lakes. Urban lakes are therefore more sensitive to water pollution and eutrophication suffering from natural or anthropogenic impacts. If man-made, these environments tend to have rather regular shapes and higher shoreline development when recreationally used resulting in negative impacts on their functioning (Naselli-Flores 2008).

Metropolitan runoff flowing over impermeable surfaces collects large amounts of nutrients resulting in higher unit area phosphorus load from storm-water than other watersheds. Many urban watersheds receive additional loads from storm-water overflow, failing septic systems or pollutant seepage. Urban lakes also have unique internal nutrients sources such as water bird droppings, boat sewage and sediment release (Traut and Hostetler 2004). As a consequence, phytoplankton blooms and uncontrolled macrophyte growth may severely impair water quality and cause sanitary risks. Massive growth of submerged plants may form an obstacle to several forms of recreational use. Moreover, highly developed shorelines, including tourism exploitation (Dokulil 2014a), housing and development sites (Cappiella and Schueler 2001) may significantly contribute to eutrophication and pollution. Urban lakes may potentially be contaminated by various compounds particularly their sediments causing long-term environmental problems and human health risks. Because of these many facets impacts have on urban lakes, management efforts must be integrative and sustainable (e.g. Sorensen 1996) especially when impacts are amplified by climate warming (Dokulil 2014b).

20.3 Restoration and Management

Urban lakes are complex systems strongly influenced by disturbances within their watershed. Therefore, thorough management of urban lakes must be tightly coupled with the management of the watershed. The entire catchment must be supervised and necessary strategies developed to optimise land use, erosion, housing, wastewater treatment, public transport, recreation, tourism or any other factor which might be important in the watershed (NALMS 1988).

Internal restoration techniques are abundantly described particularly for shallow water bodies (Carvalho 1994; Xu et al. 1999; Morscheid and Maehlmann 2005). Methods have been summarised and classified in Fig. 20.1 after Singh (1982). Among the many methods available, chemical stabilisation of phosphorus (Welch and Schrieve 1994) and removal of lake sediment (Van der Does and Frinking 1993; Björk 1978, 1994) are most popular. In many food web oriented lake rehabilitation

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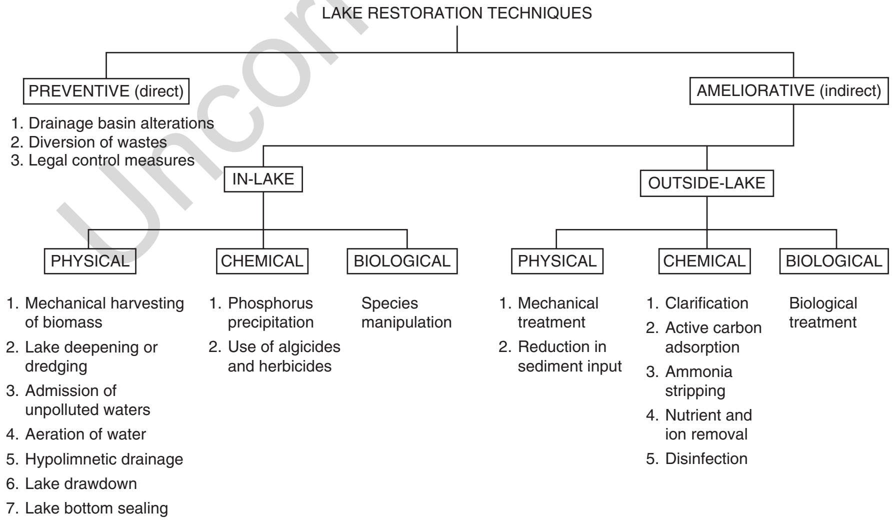

Fig. 20.1 Classification of lake restoration techniques. (Modified from Singh 1982)

activities, manipulation of the fish community is a prime focus (Hansson and Butler 1994; Berg et al. 1997; Hansel-Welch et al. 2003).

As aquatic plants may easily become a nuisance in man-made waters, management of aquatic vegetation is a major requisite usually by controlling abundant growth of macrophytes, e.g. by extensive harvesting (Pieterse and Murphy 1990; Bowmer et al. 1984; Madsen et al. 1988). More recently, macrophytes are recognised as an essential component in suppressing algal dominance during rehabilitation of eutrophic water bodies (Körner 2002). Regrowth of macrophytes was reported in a majority of lake restoration studies (Hansson and Butler 1994; Perrow et al. 1997). The re-establishment of aquatic vegetation in these studies occurred mainly by natural propagation and without any active management (Hansel-Welch et al. 2003). Under such conditions, the recovery of the water body towards the macrophyte dominated state may take long and the ecosystem is at risk to shift back to the algal dominated state.

Investigations on the essential environmental conditions promoting macrophyte growth are numerous (e.g Riis and Hawes 2002; Crisman et al. 2005; Janse et al. 1998). The complexity of ecological pressures in lake environments, ranging from sediment characteristics to herbivory, often impairs the proliferation of the aquatic plants (Lau and Lane 2002; Irfanullah and Moss 2004).

The submersed aquatic vegetation is the essential factor determining water quality by preventing the growth of phytoplankton in shallow lakes (Bailey et al. 2002; Gopal and Goel 1993; Wium-Andersen 1987; Berger and Schagerl 2003).

Several experimental approaches were developed for the transplantation of submersed plants for pools (Irfanullah and Moss 2004), lake littorals (Wychera and Humpesch 2002; IGB 2005; Hilt 2005; Gross and Hilt 2005; Morscheid and Maehlmann 2005) and for oxbows (Janauer 1995; Janauer and Pall 1998).

20.4 Sustainable Development

Water is so essential to life and the life processes of all living beings, that management of water resources requires a new paradigm, the concept of sustainability (Heintz 2004; Taylor and Goldstein 2010). This concept describes the dynamic conditions and the resiliency or robustness of complex systems to adapt and thrive in the face of change. Sustainable development shall meet the needs of the present without compromising vital ecosystems as well as the ability of future generations to meet their own needs. Application of the concept to water resources management involves integrative components. Once sustainable goals have been defined and adopted, sustainable infrastructure principles can operate. These principles must be based on the best integrated technology and institutional capacity. The outcome must then be evaluated and adapted if necessary in an iterative process. All activities in sustainable development of water resources shall rely on basin wide perspectives.

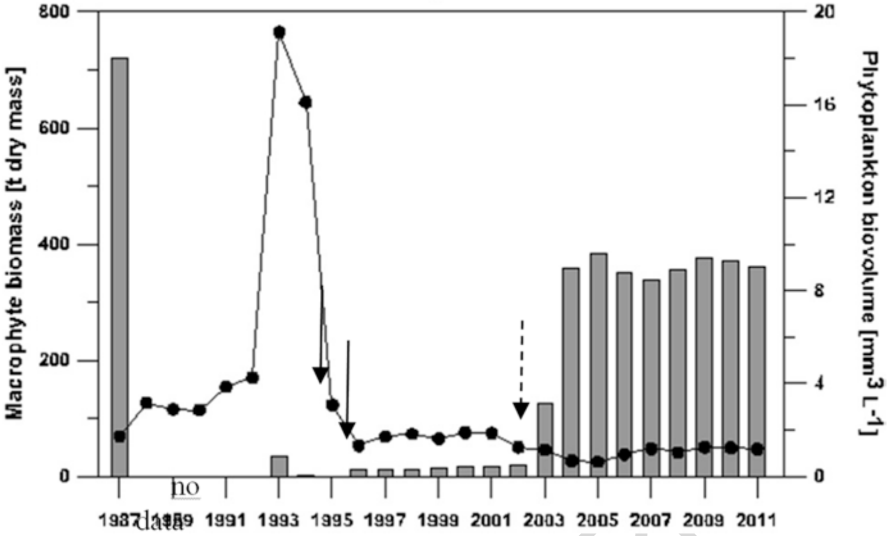

Fig. 20.2 Annual changes of macrophyte biomass (BM) in t dry mass (bars) and phytoplankton biovolume (B) as mg fresh weight per litre (line) from 1987 to 2011. Arrows with continuous line: Riplox-treatment, arrow with dashed line: start of periodical water level lowering

20.5 Specific Solutions for Alte Donau

Restoration and management measures for sustainable development of the urban lake Alte Donau were extensively described and discussed in this volume. The key measures and their results shall be briefly summarised here.

Excessive nutrient concentrations were strongly reduced by phosphorus flocculation with ferric chloride and by sediment oxidation with calcium nitrate (Chap. 5 – Riplox treatment, Chap. 6). The efficacy of this treatment was predicted to be 10 years. Algal blooms disappeared and across the years phytoplankton composition shifted from blue-greens to green algae, diatoms and later on to chrysophytes (Chaps. 9 and 10). Concomitantly the metazoan zooplankton altered from mainly filter-feeding herbivorous cladocerans under eutrophic algal-turbid state to mainly selective-feeding omnivorous and herbivorous copepods under mesotrophic transparent-water state (Chap. 11). Assemblages of microzoans (rotifers, Chap. 11) and protozoans (ciliates in Chap. 12, heterotrophic nanoflagellates in Chap.13) differed between treatment periods by lowered food supply (see also bacteria in Chap. 13 and discussion Chap. 11) or increasing grazing pressure.

With the reduction of the phosphorus concentration in the water column and associated suppression of phytoplankton development, the transparency increased significantly (Chap. 6) promoting an initial recovery of macrophyte-stands (Fig. 20.2). But in the following years the macrophytes showed no significant increase in biomass, even though regrowth was assisted by plantings. Figure 20.3 shows that the hysteresis of the year by year trajectory indicates considerable

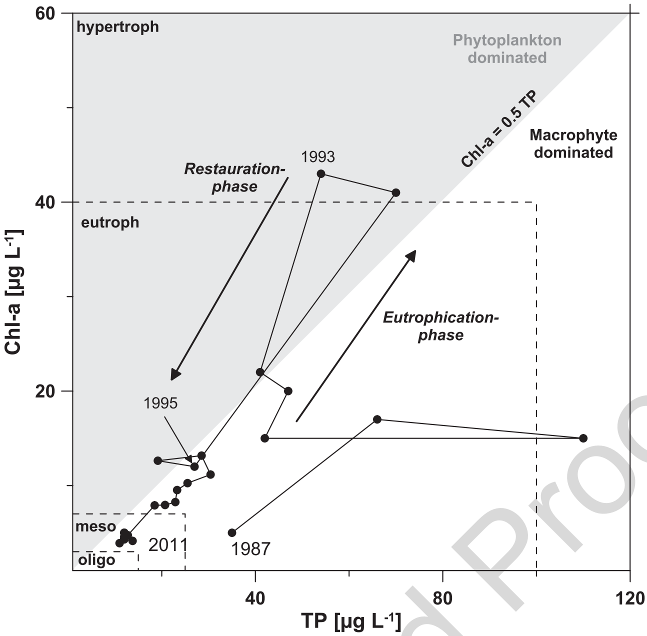

Fig. 20.3 Trajectory of total phosphorus (TP) versus chlorophyll-a (Chl-a) in Alte Donau during eutrophication and restoration (1987–2011). Years with macrophyte or algal domination are indicated by white and grey background respectively separated by a line equivalent to Chl-a = 0.5TP. TP and Chl-a as annual averages. Trophic delineations are indicated by dashed lines

resilience after perturbation. The starting point for intensive regrowth of macrophyte was given by an intervention into the hydrological regime of Alte Donau (Fig. 20.2). From 2002 onwards every spring the water level was lowered in the range of 15–30 cm to improve the light availability at the lake bottom at the beginning of the growing season and to imitate partly the former natural hydrological dynamic. The watermilfoil started to grow as well from planted areas as spontaneously in other lake areas. Other species that have been planted showed initially good growth but were more and more suppressed by shading due to the dense stands of *Myriophyllum spicatum*.

Seven years after the Riplox treatment the system switched back to the macrophyte dominated clear-water state. The response of macrophyte biomass to the increase and subsequent decrease in TP concentrations is shown in Fig. 20.4. The trajectory indicates large hysteresis in the loss and re-colonization of under-water vegetation. Management plans to stabilise rehabilitated ecosystems need to take hysteretic behaviour and return time into consideration.

Water quality in terms of total phosphorus and chlorophyll-a is now, 22 years after the forward shift, better than it was back in 1987 (Fig. 20.3, details in Chap. 6), but the quantity and composition of submerged vegetation is still quite different.

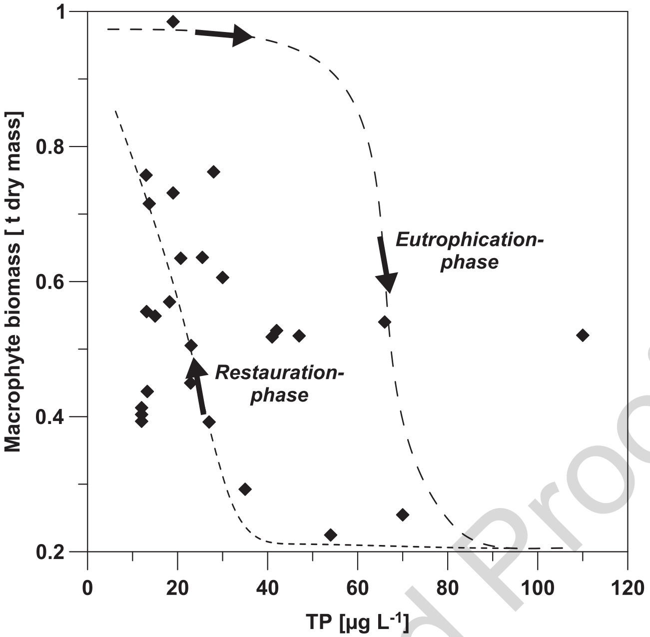

Fig. 20.4 Hysteresis in the decline and recovery trajectories of macrophyte biomass versus total phosphorus concentration (TP) in the open water during the eutrophication and rehabilitation phases between 1987 and 2011. Macrophyte biomass as in Fig. 20.2, TP as in Fig. 20.4

Macrophyte beds are dominated up to more than 90% by *Myriophyllum spicatum*, whereas the ground-covering charophytes are under-represented.

The relative contribution of different plant groups to total macrophyte biomass is documented for the period before eutrophication with macrophyte domination for the year 1987 and for the years 1993, 2002 and 2015 following treatment (Fig. 20.5, see also Fig. 20.2).

Myriophyllum spicatum is characterised by a very successful growth strategy but the dominance was also triggered by additional effects. At the beginning of the 1990th the plant stands regularly died back in the winter months. By the end of the 1990th the *Myriophyllum* stands started to overwinter as green plants, possibly due to a series of mild winters in the last decade that might be an effect of global warming. The impact of global change on Alte Donau was verified by the correspondence between the climate signal (North Atlantic Oscillation Index) and water temperature (WT) in winter and early spring, the increase of 1.52 °C per decade for surface water temperature in April and the prolongation of warm period in summer (Chap. 11).

Two years after full recovery of macrophytes and due to intensive photosynthesis of macrophytes and also of phytoplankton (algal primary production see Chap. 10) and low ground water influx especially into the main basin of Obere Alte Donau, pH-values tended to rise up to 10 in the summer months. Water from the impoundment

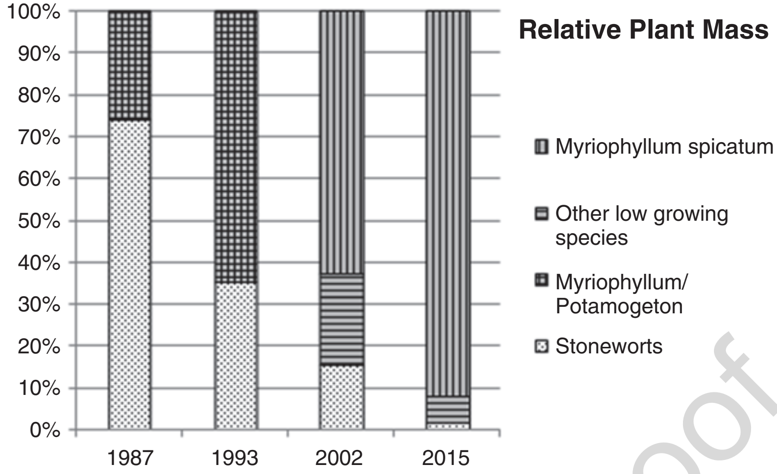

Fig. 20.5 Relative shares of different plant groups in the years 1987 (last documented good status before the eutrophication phase), 1993 (nearly total loss of macrophyte vegetation), 2002 (7 years after the Riplox treatment at the starting point of the periodical water level lowering in spring) and now (2015)

Neue Donau with a higher buffer capacity was used to exchange with water from Alte Donau to overcome this problem. This measure was done regularly from 2006 up to now in summer or autumn, exchanging quantities of 1.5–4.5 Mio m^3 within several weeks. The buffer capacity in Alte Donau could thus be raised sufficiently and the pH-values settled between 8 and 9.

A special soil filter, which is in use since 2016, was constructed in the northwestern part of Alte Donau (Wasserpark) to find a sustainable solution to stock up the main basin of Obere Alte Donau with calcium and to raise alkalinity. This soil filter can be fed with water from Neue Donau. Phosphorus, suspended materials and chlorophyll-a are reduced when passing the soil filter. The water from Neue Donau is marked by higher calcium concentrations and by higher alkalinity than the water of Alte Donau. But the special feature of the soil filter is, that the Ca content can be stocked additionally by passing a reservoir that is filled with calcium carbonate before entering the system of Alte Donau. The filter allows a constant discharge of 2500 m^3 per day, which should be sufficient to raise buffer capacity of Alte Donau permanently. This prototype of a soil filter was planned and built within an EU-Life project (EU-Life 12 ENV/AT/000128).

Because of the overall dominance of the high-growing species *Myriophyllum spicatum* intensive mowing is necessary to ensure bathing and other activities (Chaps. 8 and 19). Mowing the macrophytes also enhances the availability of light in deeper zones stimulating the growth of the low-growing vegetation. To support the proliferation of stoneworts intensive plantings have been done (Chap. 8). In contrast to helophyte planting, which turned out to be feasible with reasonable effort (Chap. 18), planting and re-establishing dense stonewort stands was a great

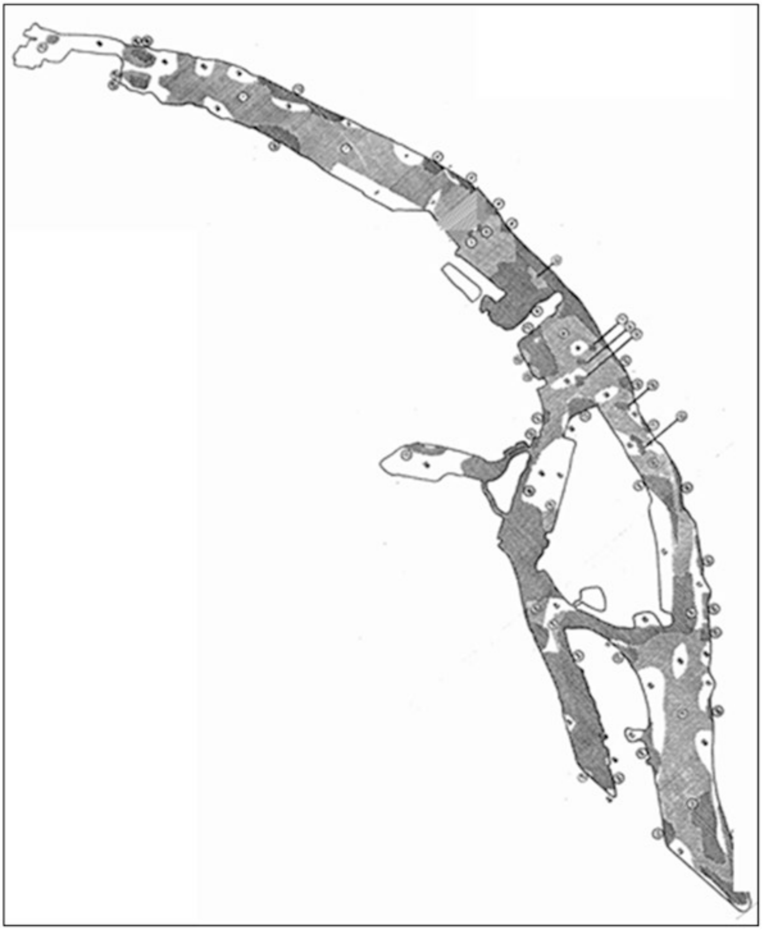

Fig. 20.6 Macrophyte cover in the Alte Donau in 1987 after Löffler (1988) – light grey: charophytes, dark grey: *Myriophyllum* ssp. and *Potamogeton* spp. – serving as objective of the macrophyte management

challenge. As well-documented by an automatic underwater video-trap (Chap. 8) fish effectively hindered the growth of charophytes by grazing (amur and rudd) or by digging out the new planted stoneworts (bream and carp, fish assemblages in Chap. 15). In order to allow a successful re-establishment of charophytes in the Alte Donau fish management has to be optimised. Charophytes can preserve a good water quality equally well as the currently dominating high-growing vegetation (Van den Berg et al. 1998), therefore the stoneworts are an ideal aquatic weed group for water quality management of intensively used urban lakes. The conditions in the Alte Donau in the 1980ies (Löffler et al. 1988) can serve as a benchmark for a sufficient cover of charophytes in a mesotrophic urban lake (Fig. 20.6).

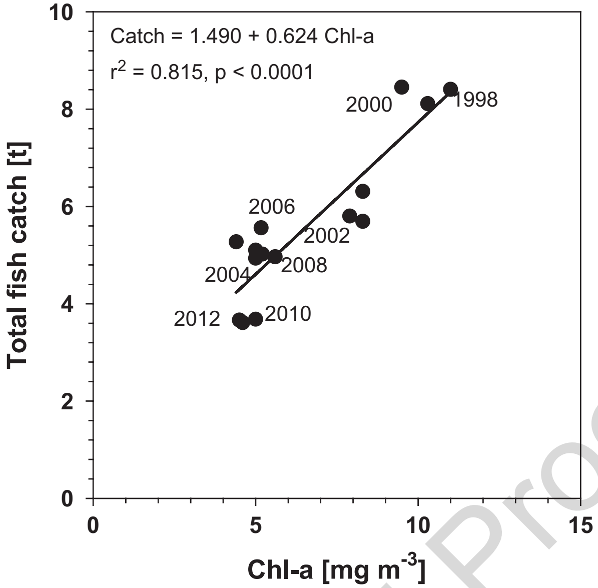

Fig. 20.7 Dependence of total fish catch (tons) on phytoplankton chlorophyll-a (mg m^{-3}) for the post-restoration years (1998ff.). Chl-a data from DWS-Hydro-Ecology, total fish catch data from Austrian Fishery Association

In the time frame of the restoration process of Alte Donau a lot of efforts have been made to trigger changes in the fish community. Structure of fish assemblages was modified by biomanipulation in 1998 in 'Kaiserwasser' (Chap. 15) and changes in fisheries management and practice. Predators like pike-perch, asp and later on pike were intensively stocked to reduce the planctivorous and non-predatory fish population (Chap. 15). Since macrophyte stands recovered pike is the main predator in Alte Donau. Restructuring of the fish community promoted also changes in the zooplankton assemblage (Chap. 11), stimulating the upgrowth of mainly copepods and some large species of macophyte-habitat associated cladocerans.

As a result of a consequently performed fish management, total fish catches have declined considerably and became significantly dependent on chlorophyll-a concentrations ($r^2 = 0.81$, $p < 0.001$, $n = 15$, see also Chap. 15) since 1998, the post-restoration period (Fig. 20.7.). A recent study of the fish biocenosis according to the European Water Framework Directive methodology (Gassner et al. 2013) attested the Alte Donau a "good ecological status" (Gassner et al. 2014). Since 2007 phytoplankton is also assessed according to the WFRD and the results also indicate the "good ecological status".

20.6 Conclusions

It can be concluded that suitable concepts and methods exist to establish and stabilise a macrophyte-dominated state in shallow lakes. Successful re-introduction of the aquatic macrophyte vegetation must be accompanied by adjusting the overall nutrient balance and the protection of the young aquatic plants against the negative influence of fish (herbivory, enhanced turbidity, nutrients) and waterfowl (herbivory, nutrients). Public awareness for the importance of ‘aquatic weeds’ has to be raised because of the potential of macrophytes to compete successfully with phytoplankton. Using macrophytes to keep water bodies transparent may include macrophyte management and short term restrictions to water sports.

According to Heintz (2004) and Taylor and Goldstein (2010) the management of water resources requires a new paradigm, the concept of sustainability. Restoration of the eutrophied urban lake Alte Donau was achieved by the implementation of an integrated management plan. Seven years after chemical treatment and after introduction of biomanipulation and other ecotechnical measures a switch back to a macrophyte dominated clear water stable state was observed. Routine monitoring of water quality and hydrology was essential for fine tuning and performing of a continuous management. Macrophyte domination and associated with this – a good water quality – could be stabilised for more than 20 years, demonstrating the quality of our management. In case of the urban lake Alte Donau the concept of sustainability is suitable and successful. Actually, in the frame work of the EU-Life project – Urban Lake Alte Donau (Life 12 ENV/AT/000128), two plans are compiled for maintaining and ensuring the “good ecological status”. The Integrated Lake Management Plan will include all management measures and a plan for monitoring. The Risk Management Plan will give advices how to reduce the vulnerability of the ecosystem to effects like climate change and other anthropogenic pressures. This plan will be made accessible to authorities in other cities and can serve as a model for management of urban lakes in Europe.

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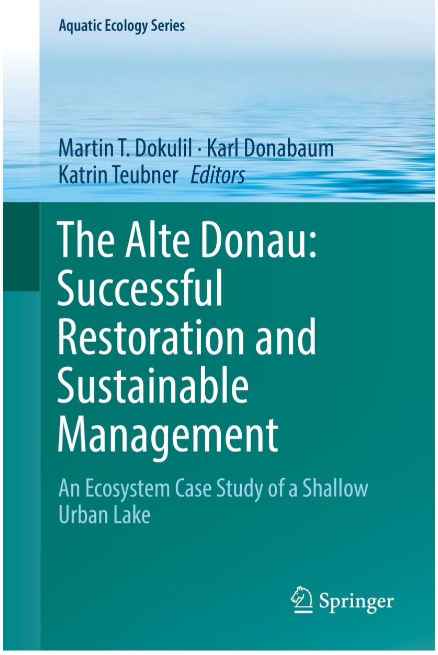

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