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Urban aquatic ecosystems: Habitat loss and depletion of native macrophyte diversity during the 20th century in four Swiss cities

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Abstract Urban areas are among the most affected by human activities. In Europe, urbanization has essentially occurred since the end of the 19th century. However, the influence of this dramatic process on aquatic ecosystems has rarely been quantified and analyzed using historical data. In this study, we investigate the evolution of the hydrological system and native aquatic macrophytes in urban areas between the end of the 19th century and the beginning of the 21st century. Four urban areas in Switzerland were chosen for the analyses, Zürich, Basel, Lausanne and Fribourg, and we analyzed the changes in aquatic plant diversity based on the historical and recent floristic data available for the same areas and the same time periods. Our results show that a significant proportion (~30 %) of aquatic habitats has disappeared from the investigated locales during the last 130 years and that the extinction rate of the aquatic plant species is notably higher in the studied cities (28 %) than in Switzerland as a whole (2 %). Thus, between the end of the 19th and the beginning of the 21st centuries, urban development in Swiss cities has prompted a degradation of aquatic habitats that resulted in a significant reduction of the aquatic biodiversity. However, our study shows that urban areas still have the capacity to shelter a large diversity of aquatic organisms, including some of the most threatened species. Thus, it is important to integrate urban areas in the conservation strategies for these species.

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Introduction

Aquatic ecosystems and aquatic organisms have been affected during the last centuries by multiple anthropogenic pressures (Egertson et al. 2004). Both flowing and standing water bodies have been regulated, dried out, affected by nutrient enrichment or directly destroyed (Roelofs 1983; Cronk and Fennessy 2001; Preston and Croft 2001; Kozlowski and Vallelian 2009). As a consequence, aquatic macrophytes, i.e., vascular plants inhabiting water, are among the most threatened group of organisms in many countries (Moser et al. 2002; Kozlowski et al. 2009).

Urban development and the associated environmental changes have been significant during the last centuries and are expected to continue during the next decades (Alberti and Marzluff 2004; UN-HABITAT 2011). Urbanization is one of the most important causes of fragmentation and degradation of natural habitats and it simplifies species composition and disrupts hydrological systems (Arnold and Gibbons 1996; Booth and Jackson 1997; Marzluff 2001; Paul and Meyer 2001; Walsh et al. 2005; Wenger et al. 2009; Francis 2012). Nevertheless, scientific literature on the theoretical and practical aspects of urban nature and conceptual works on the conservation of urban biodiversity are rather sparse (e.g., Collins et al. 2000; Savard et al. 2000; Pickett et al. 2001; Alberti and Marzluff 2004; Francis and Lorimer 2011; Kowarik 2011; Ramalho and Hobbs 2012). Thus, maintenance of biodiversity for residents and for its intrinsic value in the face of an increasing human population and expanding cities requires a better understanding, including more research on urban ecosystems (Niemelä 1999). However, scientists, especially ecologists, have historically been reluctant to study urban biodiversity because the systems have been regarded as less worthy than non-urban ecosystems (Gilbert 1989; McDonnell and Pickett 1993; McDonnell 1997; Gaston 2010).

Clearly, human-dominated ecosystems represent an insufficiently studied issue in ecological research, even though most people live in urban areas (50–60 % worldwide and 80 % in industrialized countries) (UN-HABITAT 2011). Urbanization is often a threat to many natural habitats and species, yet the depletion of species diversity in urban areas has been poorly documented. Nevertheless, predicting changes as urbanization proceeds should be an important issue for modern research (Shepherd 1994; Landolt 2001). For example, over 180 plant species have become locally extinct in the past 100 years in the German city of Munich (Riley and Page 2000), and more than 300 plant species in the city of Fribourg in Switzerland have become extinct (Purro and Kozlowski 2003). To counteract these adverse effects of urbanization and to ensure that urban expansion proceeds in a sustainable manner, further ecological data need to be collected. However, there is a scarcity of such knowledge in many countries. Furthermore, the incorporation of scientific information into urban management and planning is weak, which is surprising considering that urban nature is important for both recreation and the well being of the residents (Douglas 1992; Sukopp et al. 1995; Vandruff et al. 1995; Niemelä 1999; Francis and Lorimer 2011; Kowarik 2011).

The aim of this study was to quantify the changes in urban water bodies and the native aquatic vascular plants inhabiting them between the end of the 19th century and the beginning of the 21st century. The following questions were addressed: (1) What was the change in the river and stream lengths in the chosen urban areas during the last 130 years? (2) What was the alteration of the standing water surfaces (i.e., lakes and ponds)? (3) What was the level of persistence of pre-urban aquatic macrophytes in areas under intensive urbanization pressure? The results of our study will provide a basis for more effective conservation measures of aquatic habitats and organisms and appropriate conservation priority settings in urban areas.

Methods

Four urban areas in Switzerland, Zürich, Basel, Lausanne and Fribourg, were chosen for the analyses. The choice of these cities was justified by the existence of detailed local floras describing the past and present occurrence of native aquatic plants and by the existence of ancient and recent maps for the regions under consideration. The main characteristics of the locations are given in Table 1.

To analyze the change in water bodies (rivers, streams, lakes and ponds) during the last century, two digital map sets, ancient and recent, were utilized for each study site. The hydrography at the end of the 19th century was analyzed using so-called Siegfried maps (Swisstopo 2010), which showed the geographical situation between 1873 and 1902. These ancient maps were scanned and digitized. The hydrography at the beginning of the 21st century was analyzed using the current national maps of Switzerland (scale 1:25000, Swisstopo 2006), which are available in electronic form. All of the maps were further arranged, geo-referenced and assembled using Idrisi (Eastman 1987–2006). The delimitation of the studied zones corresponding to the areas covered by flora was performed using CartaLinx (Eastman 1998–1999). Lastly, we digitalized and measured the lengths of the rivers and streams and the surfaces of the lakes and ponds for both time periods and each city.

Among the 3000 vascular plants occurring naturally in Switzerland (Aeschimann and Burdet 1994; Lauber and Wagner 2007), 104 native species are making part of the ecological group of aquatic macrophytes following the classification of the Swiss flora of Moser et al. (2002) (Appendix S1). The nomenclature of botanical names follows the synonymic index of the Swiss flora (Aeschimann and Heitz 2005). Using the available literature, we generated a databank that included all native aquatic plants of Switzerland and recorded the presence or absence of all 104 studied taxa for two time periods: (1) the end of the 19th century to the beginning of the 20th century and (2) the end of the 20th century to the beginning of the 21st century. The information was extracted mainly from recently published local floras and detailed ancient data (Zürich: Landolt 2001; Basel: Brodtbeck et al. 1997, 1999; Lausanne: Hoffer-Massard et al. 2006; Fribourg: Purro and Kozlowski 2003). Additional information was extracted from Binz (1901), Schneider (1880), Cottet and Castella (1891), Jaquet (1930), Durand and Pittier (1882), Cruchet (1933) and Naegeli and Thellung (1905).

Results

At the end of the 19th century, a total of 669 km of running water (rivers and streams) existed in the four Swiss cities investigated in this study (Fig. 1), with the longest hydrographic systems found in the largest cities, Basel (349 km) and Zürich (220 km). However, 36 % (243 km) of these running bodies of water were absent at the beginning of the 21st

Table 1 Study sites and their general characteristics

Site	Coordinates (N/E)	Area (km^2)	Population	Inhab./km^2	Altitude (m a.s.l.)	Precipitation (mm/year)
Zürich	47°22′/8°32′	122	350000	2869	391–871	1000
Basel	47°34′/7°34′	300	360000	1200	256–875	788
Lausanne	46°31′/6°38′	54	200000	3704	372–830	1051
Fribourg	46°48′/7°09′	10	33000	3300	540–700	999

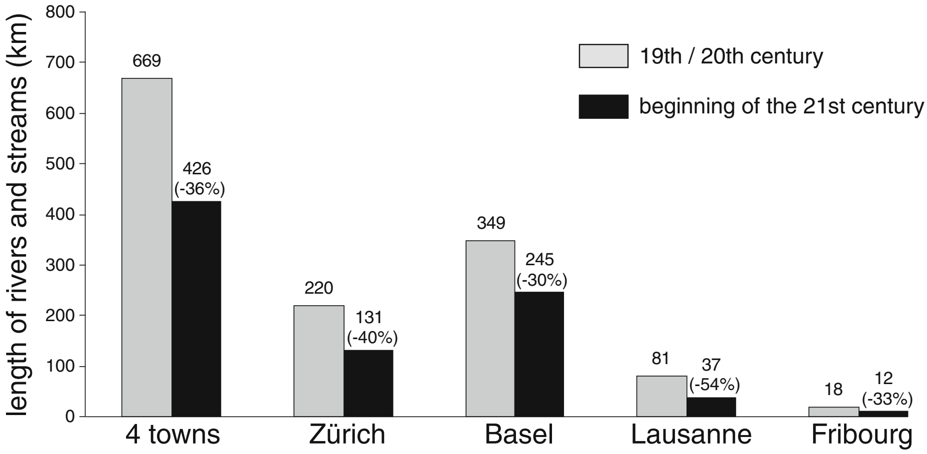

Fig. 1 Cumulative lengths of the rivers and streams in the four investigated Swiss cities and changes between the end of the 19th century and the beginning of the 21st century

century; the highest percentage of habitat depletion occurred in Lausanne (−54 %) and Zürich (−40 %), whereas the loss was approximately 30 % in Basel and Fribourg. The most extensive kilometric losses were detected for Basel (a loss of 104 km of running water) and Zürich (89 km). The majority of the running water bodies that disappeared were small streams, mainly in the intensively developed central regions of each of the studied cities (see the comparative maps in Appendix S2).

The surface areas of the lakes and ponds in the four studied urban areas were already relatively low in the past (11.8 km^2, thus 2.4 % of the total studied area) (Table 1, Fig. 2). Due to large lakes included into their administrative borders, the largest surface area existed in Zürich and Lausanne. However, during the last ~130 years, only 2 % of this standing water area was lost when considering all four of the cities together. Figure 2 shows that this loss occurred almost exclusively in Zürich where more than 0.6 km^2 disappeared. In contrast, our survey

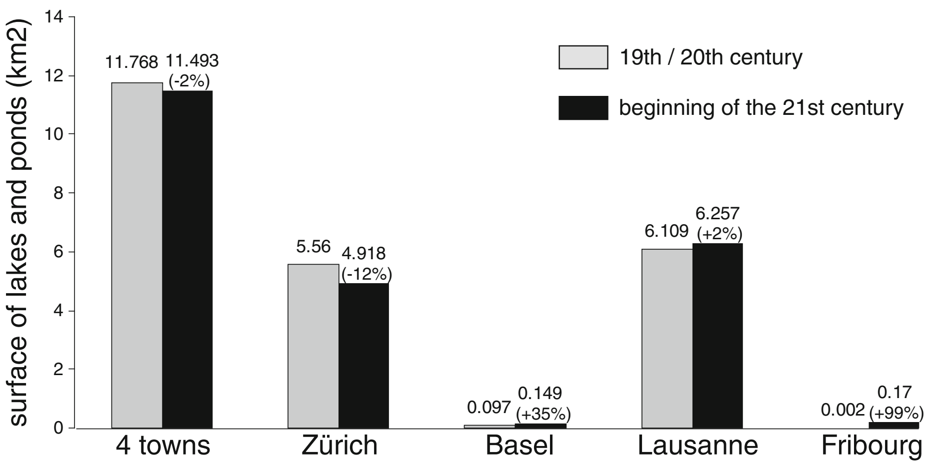

Fig. 2 Cumulative surface areas of the lakes and ponds in the four investigated Swiss cities and changes between the end of the 19th century and the beginning of the 21st century

detected an increase in the standing water surface area in all of the other cities. The most accentuated increases were in Basel and, especially, Fribourg (due to dam construction and the creation of artificial lakes). See also the comparative maps in Appendix S2.

Our survey shows that 87 native aquatic plant species were found in all four of the investigated urban areas at the end of the 19th century and at the beginning of the 20th century (Fig. 3, Appendix S1). The highest diversities of native macrophytes were recorded in Zürich (76 species) and Lausanne (58 species), in contrast to the urban area of Basel where only 17 species were found. Figure 3 also demonstrates that the four urban areas faced much higher extinction rates of the aquatic plants (loss of 28 %) in comparison with relatively low extinction rate of Switzerland as a whole (2 %). The differences between the specific cities are, however, very high. During the 20th century, Basel lost almost 60 % of its aquatic plants, and Lausanne and Fribourg each lost approximately 45 %, whereas Zürich only lost 26 % of its macrophytes. Numerically, Lausanne and Zürich lost the highest number of native aquatic plant species (26 and 20 species, respectively).

Discussion

To meet the needs of humans, urban environments and, especially, urban water bodies and their shores were dramatically transformed during the recent centuries (Duncan et al. 2011). Although the degradation of aquatic habitats and their fauna and flora was described in many urban areas, the extent of this phenomenon was rarely measured using historical data (Booth and Jackson 1997; Purro and Kozlowski 2003; Tait et al. 2005). Accordingly, our study provides very valuable account of the depletion of aquatic habitats and native macrophytes during the 20th century in a selection of European cities. The most dramatic changes were detected for small urban streams and rivers: more than 35 % of these water bodies were buried (covered and moved underground) or completely destroyed and dried out during the last 130 years. In the large Swiss cities, the aquatic organisms lost more than 100 km of running waters and their shores. Moreover, in certain Swiss cities (e.g., Lausanne) the covering of streams had already begun at the beginning of the 19th century (Bondallaz 2010); therefore, the original lengths of streams and the total historical loss of running water

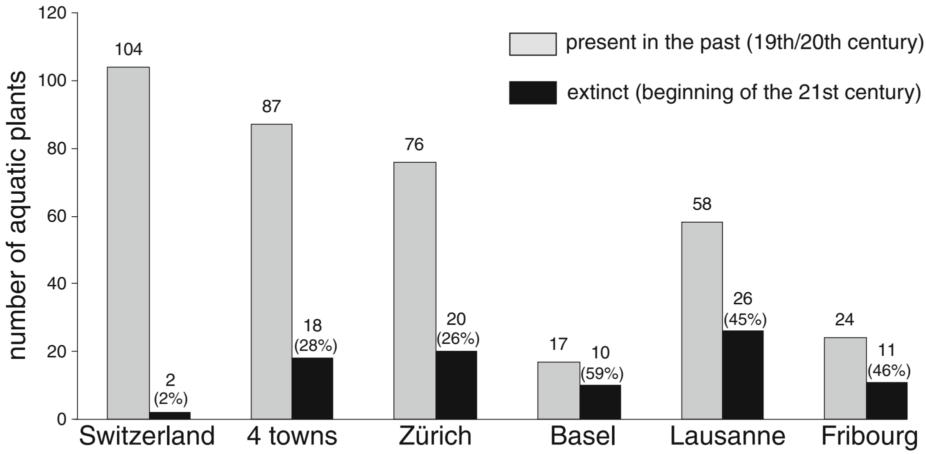

Fig. 3 Level of extinctions among aquatic plants in Switzerland and in the four investigated cities between the end of the 19th century and the beginning of the 21st century

length should be even higher than measured in our study. Additionally, more than 80 % of the running waters still existing in Swiss cities exhibit a very low ecomorphological quality, which is especially true for the large rivers, e.g., the Rhine and Birse in Basel and the Limmat in Zürich (Zeh Weissmann et al. 2009).

The dramatic decrease in the length of running water contrasts with the minimal overall loss of the surface areas of urban lakes and ponds in the four investigated cities. In fact, due to the transformations of riverbeds, the construction of dams (e.g., in Fribourg) and creation of small ponds for amphibian conservation (e.g., in Basel), some cities actually gained relatively large amounts of standing water areas (Brodtbeck et al. 1997; Bondallaz 2010). Fribourg has the most important augmentation of the standing water surface (+99 %) due to the new large lakes created after the construction of two dams by Maigrauge (year of construction: 1874) and Schiffenen (year of construction: 1963). Surprisingly, the highest percentage of aquatic plant extinctions during the 20th century was measured for Basel and Fribourg, that is, in the cities with significant increases in the surface area of standing water.

Furthermore, the majority of the extinct plants are typical inhabitants of lakes and ponds. This seemingly paradoxical result suggests the poor ecomorphological quality of these artificial water bodies. Although relatively old, such urban lakes and ponds remained less attractive for native aquatic organisms, perhaps because they are affected by pollution, eutrophication, shore transformation and recreational activities. The high level of aquatic plant extinction in Lausanne and Zürich, both possessing large natural lakes, additionally indicates a strong deterioration of the quality of natural water bodies in the urbanized environments. One of the most important problems is the filling up and transformation of shores. As a consequence, the majority of the large lakes in urbanized areas no longer possess natural shore fragments (Bondallaz 2010). Delarze et al. (2006) demonstrated that less that 3 % of the total 200 km of Geneva Lake shorelines can be described as natural: 40 % are completely artificial, in the form of concrete or rocky wall constructions, and an additional 34 % have been transformed into roads, railways, bridges and harbors. Furthermore, even in Switzerland, which has a very well-functioning network of sewage systems, the majority of lakes are affected by pollution and eutrophication (Armin 2006). Additionally, the temperature of the Swiss lakes increased during last 50 years by 2 °C (Perritaz and Mayerat Demarne 2007), which might negatively influence their suitability for aquatic macrophytes. More research is clearly needed to ascertain which factors are playing the most important role in the degradation of the suitability of urban lakes and ponds for aquatic plants and other organisms that are inseparable from a water source.

All of the four studied cities have lost an important proportion of their aquatic plants during the 20th century. Our results clearly demonstrate that urbanization had a negative effect on the persistence of pre-urban aquatic organisms. However, the differences between the cities are very important and further indicate that many other factors not specifically analyzed in this study are playing important roles in the deterioration of urban nature (e.g., the history of a given city and the speed and character of urbanization). For example, in Basel, which possesses the largest area, only 17 aquatic plants have been observed in the past (in spite of intensive historical floristic studies in this area), and almost 60 % of them were lost during the 20th century. On the one hand, this particularity of Basel can be explained by the absence of large lakes and the karstic geology of this area. On the other hand, Basel has a very small density of streams and rivers, with 1.16 km of running water per km^2, much less than Lausanne (1.5 km/km^2) and Fribourg (1.8 km/km^2).

Urban areas have been often described as hotspots of neophyte distribution (Klotz and Kühn 2010). Interestingly, the loss of native aquatic macrophytes in Swiss cities cannot be explained by introductions of non-native species. Only six alien aquatics have been observed in the four studied urban areas during the last 130 years: *Aldrovanda vesiculosa* (Zürich), *Acorus calamus* (Basel and Zürich), *Sagittaria latifolia* (Basel and Zürich), *Elodea canadensis* (all four cities), *E. densa* (Basel) and *E. nuthallii* (Lausanne, Basel and Zürich) (Brodtbeck et al. 1997, 1999; Landolt 2001; Purro and Kozlowski 2003; Hoffer-Massard et al. 2006). Some of them, such as *Aldrovanda vesiculosa* in Zürich, disappeared soon after its introduction in 1907 (Landolt 2001). For *S. latifolia*, *A. calamus* and *E. densa* the time of their introduction in Zürich and Basel is not known but the species are very rare. Only *E. canadensis*, widespread in certain cities (e.g. Zürich) already at the end of the 19th century, may be perhaps the only aquatic neophyte responsible for local extinction in the studied cities. Interestingly, the species itself is becoming rarer, partially due to spread of the other *Elodea* species (*E. nuthallii*), e.g. in Lausanne since 1960 (Hoffer-Massard et al. 2006).

Regardless, our results show that the urban areas did and still possess a high potential for aquatic macrophytes. More than 84 % of all of the Swiss aquatic plants were previously found in the four studied Swiss cities, that is, in merely 1.2 % of the total area of Switzerland (Brodtbeck et al. 1997, 1999; Landolt 2001; Purro and Kozlowski 2003; Hoffer-Massard et al. 2006). Even today, Swiss cities are home to 69 species of native aquatic macrophytes, some of them endangered with extinction at the Swiss level (e.g., *Trapa natans* in Lausanne, Moser et al. 2002). This result demonstrates that urban areas are important for the conservation of this plant group and should be, therefore, integrated into both local and national conservation plans and strategies.

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