Long-term study of the macrophytic vegetation in the running waters of the Friedberger Au (near Augsburg, Germany)

Uwe Veit¹ & Alexander Kohler¹

With 8 figures and 1 table in the text

Abstract: The macrophytic vegetation of the Friedberger Ach, a tributary to the River Danube, and of three bordering ground water ditches was mapped six times within the period from 1972 to 1996 using the same method. Different characteristic features have been calculated by means of quantitative evaluation methods using the data available from this long-term study. The temporal dynamics of the macrophytic vegetation based on these studies over a 24 years period could be analysed using the "Relative Plant Quantity" (RPM) and the distribution pattern of five floristic-ecological river zones. Additionally, the recolonization of a formerly devastated macrophyte zone could be investigated by means of distribution diagrams and the "Mean Mass Indices" (MMT, MMO). From this analysis it took almost fifteen years for the macrophytic vegetation to reflect an improvement in the nutrient status of the water. In the ground water ditches examined there has been a tendency for siltation, especially in recent years. This is expressed mainly in the increasing dominance of amphiphytes and the almost total disappearance of hydrophytes. The waters of the Friedberger Au show a surprising consistency in their macrophytic vegetation over the past 24 years.

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Introduction

Since 1972 the macrophytic vegetation of several running waters in the Friedberger Au has been mapped six times always using the same method as described by Kohler (1978). Since the last mapping study in 1996 changes in the vegetation have been analyzed by calculating different characteristic features (Veit et al. 1997). This was made possible by the development of new quantitative evaluation methods by Janauer et al. (1993), Kohler & Janauer (1995) and Pall & Janauer (1995). Using these methods the macrophytic vegetation in a system of running waters could be analysed over such a prolonged period. The recolonization of a formerly devastated macrophytic zone north of Friedberg could be investigated, as well as changes in the trophic status of the waters in the Friedberger Au through the definition of floristic-ecological river zones. The influence of different local factors on the macrophytic vegetation has been examined. Furthermore, the aim was to determine the extent to which the methods used for mapping and analysis are suitable for similar long-term studies and whether or not they can be used to assess the success of applied management and possibly provide predictions of imminent changes in water quality.

Study Area

The waters of the Friedberger Au are situated in Germany, north-east of Augsburg between the Lech, an afflux to the right of the River Danube in the west and the tertiary hilly landscape (Tertiärhügelland) bordering in the east (Figure 1).

The Friedberger Au belongs to the glacial gravel landscapes and was formed especially during the Würm ice age and the following post ice age by the River Lech, with its enormous masses of water and gravel (Schaefer 1957, 1967; Bestler et al. 1989). Up to now the waters of the Friedberger Au are dominated by groundwater. The alluvial gravel covering
fine-grained flinz layers form the main horizon of the ground water. Groundwater as well as surface waters drain to the north.

The soils in the study area are comprised of loam and sandy loam. The lowland moor soils derived from the formerly high groundwater level have been almost completely mineralised due to the lowering of the groundwater since 1890. As a result of additional drainage ditches dug between 1910 and 1940, the original flood-plain forests of the Lech valley have been replaced by areas of arable land and meadow (BESTLER et al. 1989, KOHLER et al. 1989). Nowadays most areas are used mainly for intensive agriculture (BESTLER et al. 1989).

Four waters in the Friedberger Au have been examined (Figure 1): The Friedberger Ach rises south of Friedberg at the eastern edge of the Lech plain and is fed by five springs. It runs north and flows today into the River Danube at Marxheim. The present course of the Ach basically still corresponds to its natural course and has only been straightened at several places by cutting through meanders. Additional ditches have been dug which are supposed to divert floods around the villages. The drop amounts to between 1 and 2 ‰.

The Friedberger Ach nowadays is a eurythermic running water, coming into contact with the groundwater at only a few points, which is partly dammed higher than the normal level of the surrounding area. In contrast the Forellenbach, the Hörgelaugraben and Höhgraben are cold, stenothermic ditches with permanent water regimes, which are rich in calcium carbonate and fed by groundwater. All three ditches already existed before the development of the area at the beginning of the 20th century (KOHLER et al. 1989). The Forellenbach is the only one of the three ditches, which flows into the Friedberger Ach south of Mühlhausen. The Hörgelaugraben and the Höhgraben today seep away again in the gravel underground strata after a few kilometres.
The Friedberger Ach is used as an outlet channel. Today several completely biological sewage plants discharge their effluents into the Ach downstream the mouth of the Forellenbach (Figure 1). Until 1974 the sewage plant in Friedberg was in operation, which discharged insufficiently treated sewage into the Ach. As a result a zone of macrophytic devastation occurred below this sewage plant (cf. 4.3).

**Material and Methods**

All six mappings of the vegetation, which form the basis for the present study, were undertaken using the same method as that described by Kohler (1978). The waters examined were mapped section-wise along their total length. Since the division into sections took place according to the macrophytic vegetation at the time of the individual studies as well as according to ecological criteria, several sections had to be further subdivided compared to the first mapping in 1972. For the vegetation surveys, which were always done between July and September, all macrophytes were taken into account which were rooted below the water surface at the time of examination. In addition all Characeae as well as selected water mosses were recorded. The quantitative estimation of the individual species was done using a five-step scale according to Kohler (1978). Furthermore several location factors such as water depth, water width, turbidity, shading of the water surface, type of substrate as well as the type of vegetation and the land utilization of areas adjacent to the water were recorded at nearly all sections mapped.

From the data from all six mappings vegetation tables and distribution diagrams as well as lists of the recorded species were firstly constructed and the species numbers for several water areas were determined. The following quantitative analysis of the data was performed according to Janauer et al. (1993), Kohler & Janauer (1995) as well as to Pall &
JANAUER (1995). The characteristic features "Relative Plant Quantity" (RPM), the two "Mean Mass Indices" (MMO and MMT) and the "Relative Range Length" ($L_r$ or $d$) have been calculated (VEIT et al. 1997). For the classification of the floristic-ecological river zones five species groups were distinguished following KOHLER & SCHIELE (1985), which have different trophic demands in cool stenothermic, lime-rich and originally oligotrophic waters. These species groups were already characterized at the beginning of the surveys in the Friedberger Au and in the Moosach by the use of ecological series (KOHLER et al. 1971, 1974).

Species group I: *Potamogeton coloratus*, *Chara hispida*, *Ch. vulgaris* and *Juncus subnodulosus*. These species are restricted to cleanest, unpolluted spring-fed brooks.

Species group II: *Mentha aquatica*, *Sparganium natans*, *Juncus articulatus* and *Potamogeton berchtoldii* can mainly be found in unpolluted sections.

Species group III: *Groenlandia densa* and *Potamogeton natans*. Both species extend to sections that are minimally polluted.

Species group IV: *Myriophyllum spicatum*, *M. verticillatum* and *Elodea canadensis*. They can mainly be found in moderately polluted sections and do not occur in clean water sections.

Species group V: *Callitriche obtusangula* and *Zannichellia palustris* are frequent in more heavily polluted sections and are missing in unpolluted spring sections.

The distribution pattern of these five species types characterizes five floristic-ecological river zones which mirror an increasing nutrient availability within the water (cf. SCHNEIDER 2000, SCHORER et al. 2000). Figure 2 depicts the occurrence of the respective species groups in the five floristic-ecological river zones.
Results

Development of the macrophytic vegetation during 24 years of examination

Even though the species inventory of the Friedberger Ach and of the three ground water ditches is the same, several differences could be observed. Altogether 18 hydrophytic, 17 amphiphytic, 60 helophytic macrophytes and 6 species of algae were identified over the 24 years of mapping (Table 1). However, the waters differed in relation to their dominant species. The Friedberger Ach is mainly characterized by the hydrophytes Ranunculus trichophyllus, Potamogeton pectinatus, Zannichellia palustris, Myriophyllum verticillatum, M. spicatum as well as the neophyte Elodea canadensis. In contrast, amphiphytes like Berula erecta, Mentha aquatica, Phalaris arundinacea, Veronica anagallis-aquatica and Nasturtium officinale play a main part in the ground water ditches. In these waters considerable stands of Potamogeton coloratus could also be found until 1996.

Two trends relating to the development of the vegetation in the Friedberger Au could be determined by analyzing the "Relative Plant Quantity". The RPM diagrams on the one hand provide information about the dominance relationships in running waters, but on the other hand they also offer details concerning the total number of species. According to these results the greatest changes in the Friedberger Ach took place between 1972 and 1978. Whereas in 1972 only twelf macrophyte species with RPM values higher than 1 % could be detected, 18 macrophytes were found in 1978. Since then the number has varied between 15 and 17 macrophyte species. The changes concerning the dominance relations are also striking. In 1972, three of the 12 species recorded showed a "Relative Plant Quantity" higher than 10 %, with Elodea canadensis at almost 30 %. In 1978 no macrophyte species with a percentage higher than 20 % were recorded and in 1982 only two species showed an RPM value higher
than 10 %. This trend continued up to 1996 when only *Potamogeton pectinatus* had an RPM value just above 10 % but 11 species had an RPM value between 5 and 10 %.

Whereas the macrophytic vegetation in the Friedberger Ach became richer in species terms within the study period, an opposite trend can be observed in the ground water ditches, especially since 1987. A clear decrease in the number of species is discernible, particularly in the Höhgraben and the Hörgelaugraben, but since 1992 also in the Forellenbach. In addition, the two amphiphytes *Berula erecta* and *Mentha aquatica* clearly dominate with a combined "Relative Plant Quantity" of more than 50 % of the macrophytic vegetation. In contrast the mass of hydrophytes has further decreased since then.

**Floristic-ecological river zones**

Figure 4 depicts the spatial extension of the five floristic-ecological river zones. For all six mapping occasions, the very similar distribution of the individual river zones is remarkable. Based on these results the ground water ditches can, with few exceptions, be assigned to zones A and B for unpolluted water habitats. Only in a period between 1972 and 1982 did macrophytes of the species type C, which characterize a slight trophic load, occur due to diffuse sewage inflows. In contrast, the Friedberger Ach can mainly be assigned to zones D and E. Only a few sections in the headwaters of the Ach have lower nutrient levels.

Attention is drawn to the slow improvement in the nutrient load within the sections of the zone where macrophytic growth had been formerly devastated. Whereas these sections have belonged to zone D since the mapping of 1978, it has become more and more difficult within the last few years to assign parts of this area and several sections situated further upstream to one of the five floristic-ecological river zones. This is because neither species of groups I and II nor of groups IV and V could be detected. However, these sections can also hardly be
assigned to zone C since the two typical macrophytes for this zone, *Groenlandia densa* and *Potamogeton natans*, are also missing. These two species have by now completely disappeared from the Friedberger Au system. Nevertheless these water sections must be assigned to a moderately nutrient loaded water type despite this negative feature. Even in 1996 the influence of different discharges into the Friedberger Ach could clearly be seen. Below the discharge of a rain catchment basin, zone D begins. From the discharge of the "Lechleite" sewage plant, at the mouth of the Forellenbach onwards, the river sections belong to zone E. From here on the discharges of further sewage plants obviously prevent an improvement in the water quality.

**Recolonization of the former macrophytic devastation zone in the Friedberger Ach**

Due to the discharge of effluents in an almost untreated state by the sewage plant of Friedberg, which was only taken out of operation in 1974, a 4.5 km long devastation zone, where no submerged macrophytes were growing within the water, had to be designated in 1972. After the closure of the sewage plant a recolonization process started, which has not yet been finally completed even after 20 years. This can clearly be shown by some details of the distribution diagram (Figure 5) and the MMO/MMT graphics (Figure 6).

*Elodea canadensis* and *Ranunculus trichophyllus* were the first hydrophyte colonizers in 1978. Quite surprisingly their distribution in the former devastation zone was very uniform after four years, which is shown by the almost identical values for MMO and MMT (Type I) according to JANAUER et al. (1993). Unfortunately it was unclear as to whether or not these two species had been able to recolonize these sections from areas upstream or downstream since in 1972 only few sections above the area of impacted by the discharge had been mapped. Whereas both species were already distributed below the devastation zone as early as
in 1972, this could be proved for the sections further upstream only for *Elodea canadensis*. Four years later *E. canadensis* had already quite distinctly lost its importance when two further eutrophendent, hydrophytic species, *Myriophyllum spicatum* and *Potamogeton pectinatus*, appeared but in contrast to the primary colonizers only spot-wise (Type II) according to Janauer et al. (1993). In 1987 the spatially limited occurrence of *Myriophyllum spicatum* on a huge massive scale is striking. Additionally isolated stands of *Potamogeton crispus* could be found. Furthermore two amphiphytes, *Myosotis scorpioides* and *Phalaris arundinacea*, became increasingly important. In the interim *Elodea canadensis* had completely disappeared. By 1996 the vegetation had almost stabilized. It now consists of *Potamogeton crispus*, *P. pectinatus*, *Agrostis stolonifera*, *Myosotis scorpioides*, *Phalaris arundinacea* and *Veronica anagallis-aquatica* as well as individual occurrences of *Myriophyllum spicatum* and *Ranunculus trichophyllus*. Furthermore, the first discovery of the meso- to oligotraphent species *Potamogeton berchtoldii* in the former devastation zone is quite remarkable.

**Siltation trends in the ground water ditches**

Since mapping in 1987 a clear change of the macrophytic vegetation in the ground water ditches has taken place. Even though amphiphytes have already played an important role in the groundwater ditches since the first mapping in 1972, they have replaced the existing hydrophytic species almost completely over the last ten years. Only three hydrophytic macrophytes with an RPM higher than 1 % could be found in the three ditches examined in 1996 (Figure 3). At the same time amphiphytes made up more than 80 % of the macrophytic vegetation (Figure 7).

On closer examination a dependence of the "Relative Plant Quantity" of different growth habit classes on the depth of water can be discerned (Figure 8). For the analysis of this
interrelationship, sections of all waters and all mappings between 1978 and 1996 have been analysed. For depths of water more than one metre amphiphytes represent about 40 to 45 % of the vegetation. With decreasing water depth the amphiphytic ratio rises up to 90 %. Increasing siltation may be the cause of the vegetation development observed in these groundwater ditches. This is the result of a lack of management measures, which have hardly been carried out since the end of the 1980s and corresponds temporally with the obvious increase in amphiphytes of the "Relative Plant Quantity". To what extent variations of the groundwater level play a role remains to be seen.

Discussion

The present investigation shows to what extent macrophytes, in conjunction with quantitative evaluation methods can be used to describe and investigate the state, as well as the development of running water over longer periods of time. Macrophytes are mainly used as trophy indicators (Kohler et al. 1989, Melzer 1988, Schneider 2000). They therefore, represent indicator organisms (definition according to Arndt et al. 1996) which primarily facilitate statements concerning the nutrient status of waters.

Different studies have investigated the influence of further environmental factors such as shading, current etc. on the macrophytic vegetation using different characteristic features and taking into consideration the trophic situation (Kohler et al. 1996, SIPOS 2000, Sonntag et al. 1999, 2000, Veit et al. 1997, Würzbach et al. 1997). Despite the mostly obvious correlations between individual location factors and the mass of distribution of the individual macrophytic species, it has always to be taken into account that these correlations are first of all only relevant for the specific running water system examined. To what extent a transfer to similar types of running waters is possible is currently being examined (SIPOS et al. 2001a).
The methods used have proved very suitable for this long-term study. With the original data of the vegetation mappings the new evaluation methods could be used in the future and without any problems. The only problem in this study was posed by the increasing subdivision of the sections during the course of the examination period, which became necessary due to changing ecological parameters or in the macrophytic vegetation. Therefore, the accuracy of the more recent mappings was broadly more detailed than that of earlier mappings. It must therefore be recommended that in the future short sections should be used from the beginning even if ecological conditions and the macrophytic vegetation do not change over longer stretches of the running water.

This study has tried for the first time to show the correlation between the depth of water and the quantitative ratio of different growth habits of the macrophytic vegetation. According to our results extraordinary amounts of amphiphytes occur in very shallow waters. Due to their ability to grow submerged as well as in emergent forms they have a clear advantage compared to hydrophytes even in low water-bearing times. In a long-term study like the present one, the opportunity exists to detect enhanced levels of siltation early in the process as demonstrated in the groundwater ditches. In deeper waters, amphiphytes are normally very dominant only in bank areas. This fact opens up the possibility of recording integrity of the banks. Waters with structurally rich banks should clearly have more amphiphytes than very deep waters with steep banks. The latter are structurally poor due to hydraulic engineering measures (Kohler et al. 1996, 2000, Siros et al. 2001b).

The macrophytic vegetation in the Friedberger Au shows a remarkably high consistency with regard to the macrophytic vegetation as well as the distinctiveness of the floristic-ecological river zones. The most obvious changes undoubtedly took place within the area of the former devastation zone in the groundwater ditches. The first eutraphent macrophytic species could be detected in this area as early as 1978, only four years after the discharge ceased. These
sections nevertheless offered no suitable habitat for mesotraphent and oligotraphent species over a long period of time even though the quality of the water was classified as only moderately polluted after only a few years due to its saprobity (source: Government of Swabia). It might also have been the case that the immigration of the respective species could not take place up to that time. Despite the clearly improved water quality there are quite often large amounts of nutrients fixed within the sediment which still affect the macrophytic vegetation even after the end of direct pollution (SCHORER et al. 2000). An improvement in the macrophytic vegetation in relation to trophic conditions could be observed no earlier than 1987, about fifteen years after the ending of the discharge of only mechanically treated sewage. An unsolved problem is still posed by the temporally high turbidity of the waters of the Friedberger Ach (KOHLER et al. 1989). Its influence on the macrophytic vegetation cannot be definitively established at this time (VEIT et al. 1997).

Despite the huge progress concerning the treatment of sewage, the effects of the discharge of sewage plants and rain catchment basins are still recognizable due to the indicator organisms identified. This is one reason why this very sensitive system of stenothermic, originally oligotrophic running waters, is worth preserving since its macrophytic vegetation contains hardly any oligotraphent species despite the considerably lower volumes of effluent discharged.

This long-term study shows the opportunities, as well as limitations that bioindication with macrophytes in running waters offers in connection with quantitative evaluation methods. Despite the complex interaction of different location factors, an assessment of the present status of a water and its further development is possible. Since the distinctiveness of the macrophytic vegetation in relation to individual environmental factors sometimes incurs a time delay, more emphasis should be put on the absence of individual species. However, this is only possible within a framework of repetitive mappings, since a missing species does not
inevitably point to a certain local factor (KOHLER 1995). In future it should be possible to detect the impending decline in water quality and channel structure earlier due to the disappearance of individual macrophytic species, which react sensitively towards a certain factor. It should then be possible to initiate countermeasures as long as a recolonization of these species is still possible due to the potential of the diaspores present.

Acknowledgement

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References


Figure captions

Fig. 1: Examination area.

Fig. 2: Classification of the floristic-ecological river zone by five different species groups.

Fig. 3: "Relative Plant Quantity" (RPM) in the Friedberger Au and the ground water ditches between 1972 and 1996. The bar "residual" sums up all species with an RPM value <1%. The figure above the bar represents the number of species considered.

Fig. 4: Floristic-ecological river zones in the Friedberger Au.

Fig. 5: Part of the distribution diagram for selected macrophytic species which played an important role during the recolonization of the former macrophytic devastation zone.

Fig. 6: "Mean Mass Indices" (MMO, MMT) of selected macrophytic species in the sections of the former macrophytic devastation zone.

Fig. 7: "Relative Plant Quantity" (RPM) of different growth habits in the upper and lower course of the Hörgelaurabren.

Fig. 8: "Relative Plant Quantity" (RPM) of different growth habits in different classes of water depth: 1:0-<20 cm; 2:20-<40 cm; 3:40-<60 cm; 4:60-<80 cm; 5:80-<100 cm; 5:≥100 cm.
Tables

Tab. 1: List of observed species in the running waters of the Friedberger Au during the period of investigation between 1972 and 1996; ap: acro-pleustophyte, sa: submersed anchored macrophytic plant with roots or rhizoides, am: amphiphyte, he: helophyte
Fig. 1
Species group | Zone A | Zone B | Zone C | Zone D | Zone E
--- | --- | --- | --- | --- | ---
I | Potamogeton coloratus, Juncus subnodulosus, Chara hispida, Chara vulgaris, Nitella opaca | | | | |
II | Mentha aquatica, Juncus articulatus, Sparganium natans, Potamogeton berchtoldii | | | | |
III | Groenlandia densa, Potamogeton natans | | | | |
IV | Myriophyllum spicatum, Myriophyllum verticillatum, Elodea canadensis | | | | |
V | Callitriche obtusangula, Zannichellia palustris | | | | |
Indiff. species | Ranunculus trichophyllus, Ranunculus x glueckii, Potamogeton pectinatus, Potamogeton crispus, Berula erecta | | | | |
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### Potamogeton berchtoldii
- 1972: 24, common
- 1978: 20, frequent
- 1982: 30, not found
- 1987: 25, rare
- 1992: 30, common
- 1996: 25, frequent

### Myriophyllum spicatum
- 1972: 824, common
- 1978: 550, frequent
- 1982: 400, not found
- 1987: 850, rare
- 1992: 550, common
- 1996: 1025, frequent

### Myriophyllum verticillatum
- 1972: 250, common
- 1978: 750, frequent
- 1982: 225, not found
- 1987: 175, rare
- 1992: 575, common
- 1996: 425, frequent

### Potamogeton berchtoldii
- 1972: 24, common
- 1978: 20, frequent
- 1982: 30, not found
- 1987: 25, rare
- 1992: 30, common
- 1996: 25, frequent

### Potamogeton crispus
- 1972: 824, common
- 1978: 550, frequent
- 1982: 400, not found
- 1987: 850, rare
- 1992: 550, common
- 1996: 1025, frequent

### Potamogeton pectinatus
- 1972: 250, common
- 1978: 750, frequent
- 1982: 225, not found
- 1987: 175, rare
- 1992: 575, common
- 1996: 425, frequent

### Ranunculus trichophyllus
- 1972: 225, common
- 1978: 725, frequent
- 1982: 225, not found
- 1987: 550, rare
- 1992: 550, common
- 1996: 1025, frequent

### Agrostis stolonifera
- 1972: 225, common
- 1978: 725, frequent
- 1982: 225, not found
- 1987: 550, rare
- 1992: 550, common
- 1996: 1025, frequent

### Myosotis scorpioides
- 1972: 225, common
- 1978: 725, frequent
- 1982: 225, not found
- 1987: 550, rare
- 1992: 550, common
- 1996: 1025, frequent

### Nasturtium officinale et microphyllum
- 1972: 225, common
- 1978: 725, frequent
- 1982: 225, not found
- 1987: 550, rare
- 1992: 550, common
- 1996: 1025, frequent

### Phalacrine anadinae
- 1972: 225, common
- 1978: 725, frequent
- 1982: 225, not found
- 1987: 550, rare
- 1992: 550, common
- 1996: 1025, frequent

### Sparganium emersum et erectum
- 1972: 225, common
- 1978: 725, frequent
- 1982: 225, not found
- 1987: 550, rare
- 1992: 550, common
- 1996: 1025, frequent

### Veronica anagallis-aquatica
- 1972: 225, common
- 1978: 725, frequent
- 1982: 225, not found
- 1987: 550, rare
- 1992: 550, common
- 1996: 1025, frequent

### Fontinalis antipyretica
- 1972: 225, common
- 1978: 725, frequent
- 1982: 225, not found
- 1987: 550, rare
- 1992: 550, common
- 1996: 1025, frequent

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**Helophytes (continued)**

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**Other vascular plants**

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**Haptophytes**

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\[1\] = *Ranunculus circinatus x trichophyllus* (according to WIEGLES 1995)