Aquatic molluscs (Gastropoda et Bivalvia) in a marsh lake of Upper Austria: How does agricultural and touristic use of the lake and its environment affect local species diversity and abundance?

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Abstract. In the present study, the distribution of molluscs in the Höllerersee, a marsh lake 30 km north of the city of Salzburg, was investigated. At 40 sample points, which are characterized by equal distances of 50 m, a total number of 19 species could be collected, including 14 freshwater gastropods and 5 bivalves (2 mussels and 3 pill clams). For each determined species, specific distribution patterns could be worked out, reflecting either a preference for a certain part of the lake (e.g. *Viviparus contectus*) or a constant occurrence along the lakeshore (e.g. *Pisidium casertanum*). Besides natural factors (ground substrate, shading, vegetation), biotope descriptions also included anthropogenic influences of the lake due to extensive tourism and economic use. Possible relationships between mollusc distribution and natural/anthropogenic parameters are discussed.

Kurzfassung. Aquatische Mollusken (Gastropoda et Bivalvia) in einem Moorsee in Oberösterreich: Inwieweit werden Artendiversität und Abundanz durch landwirtschaftliche und touristische Nutzung des Sees und seiner Umgebung beeinträchtigt? – In der vorliegenden Studie wurde die Molluskenausbreitung im Höllerersee, einem Moorsee 30 km nördlich der Stadt Salzburg, untersucht. An den 40 Probenpunkten, welche durch identische Abstände von jeweils 50 m charakterisiert sind, konnten insgesamt 19 Arten aufgesammelt werden, davon 14 aquatische Schnecken und 5 Muscheln (2 Großmuscheln und 3 Erbsenmuscheln). Für jede Spezies wurde ein Verteilungsmuster entlang des Seeufers erstellt, aus welchem entweder die Präferenz eines speziellen Uferabschnittes (z.B. bei *Viviparus contectus*) oder ein konstantes Auftreten entlang des Ufers (z.B. bei *Pisidium casertanum*) ersichtlich werden sollte. Die Biotopbeschreibung an den Probenpunkten beinhaltete neben der Erfassung natürlicher Faktoren (Bodensubstrat, Beschattung, Vegetation) auch eine Quantifizierung anthropogener Beeinträchtigungen des Sees infolge von extensivem Tourismus oder wirtschaftlicher Nutzung. Mögliche Zusammenhänge zwischen der Verteilung einzelner Mollusken und natürlichen/anthropogenen Parametern werden diskutiert.

Key words. Aquatic molluscs, marsh lake, distribution, biotope, tourism, agriculture.

Introduction

Aquatic gastropods and bivalves have been recently recognized as valuable bioindicators, showing a considerable sensitivity to physical and chemical changes of their environment (FALKNER 1990). Due to this specific quality, many freshwater molluscs have been already included in the saprobia system which is currently used to describe the water quality of rivers and brooks (PATZNER 1994). According to the recent level of knowledge, some freshwater snails and mussels are adapted to very specific habitats, while others show a wider tolerance concerning the colonization of aquatic biotops. Without a doubt, numerous aquatic gastropods of Middle Europe can be assigned to the group of specialists with high requirements on their habitat. A rather extreme case is, for instance, represented by *Bythinella austriaca* which exclusively occurs in small brooks with moderate flow velocity, low water temperature (< 10° C; stenotherm), considerable content of $CaCO_3$, and low input of organic components (GLÖER & MEIER-BROOK 1998, STURM 2000a). If only one of these parameters is changed, the *Bythinella* population may become extinct within a rather short period of

time. Another behaviour can be described for most representatives of the pond snails (e.g. *Radix peregra*, *R. ovata*, *Galba truncatula*) which are found in very different types of aquatic habitats, ranging from small ponds with extensive vegetation to alpine rivers and lakes with low content of nutrients (TURNER et al. 1998, STURM 2001). Within the group of freshwater bivalves, specialization has not yet reached the same extent as for some gastropods. As a special characteristic, most mussels colonize puddles, ponds or lakes, whereas only few species exclusively live in running waters (e.g. *Magaritifera magaritifera*; GLÖER & MEIER-BROOK 1998). For many species of the genus *Pisidium*, a similar generalistic behaviour as for the pond snails can be observed (TURNER et al. 1998).

As outlined in several studies (e.g. PATZNER & MÜLLER 1996, STURM 1999), changes of the colonized habitats including physical and chemical changes of the water are the result of direct or indirect influences by man in most cases. Due to an extensive economic, agricultural or touristic use of many lakes and running waters, aquatic molluscs are removed from their natural habitats and, as a consequence, dramatically reduced in number. In the last decades, this process has reached a considerable extent, causing the incorporation of more than 50 % of all resident freshwater gastropods and bivalves into the Red List of threatened animals in Austria (FRANK & REISCHÜTZ 1994). Some of these species are already 'endangered by extinction' (endangerment category 1) and can be only found within protected areas or natural landscapes. Contrary to the reduction of numerous native freshwater molluscs, species which have been brought in due to human inadvertance are partly subject to an inexorable dispersal (e.g. *Dreissena polymorpha*; PATZNER & MÜLLER 1996).

Recently, many lakes of the alpine foreland in Salzburg and Upper Austria have been studied malacologically, providing a good overview of the aquatic mollusc distribution in this area (e.g. JÄGER 1974, PATZNER et al., 1992, STURM 2000b). Most of these contributions have mainly included the determination of species diversity and abundance, while possible correlations between the number/abundance of species and agricultural or touristic use of the respective biotope have been only discussed very marginally (e.g. PATZNER & MÜLLER 1996). In the present study, the dependence of aquatic mollusc distribution on the anthropogenic influence of available habitats will be investigated more in detail. For doing this successfully, a marsh lake in Upper Austria (Höllerersee) has been selected which, on the one hand, shows a sumptuous colonization by molluscs (STURM 2000b) and, on the other hand, can be subdivided into parts which are subject to an extensive use by man and parts which have mainly preserved their natural appearance.

Study Area and Methods

As shown in Fig. 1, the Höllerersee is situated within the alpine foreland of Upper Austria, about 30 km north of the city of Salzburg. The lake covers an area of about 20 ha and reaches a maximum depth of 21 m. The lakeshore is lined by a sumptous vegetation with high species diversity, including e.g. *Salix purpurea, Alnus incana, Acer pseudoplatanus, Betula pendula,* and *Phragmites communis*. While in the East the lake is accompanied by a forest consisting of beeches and oaks, in the West a mixed forest with beeches, oaks, spruces, and isolated pines can be recognized (Fig. 1). The ground substrate of the Höllerersee is subject to a remarkable variation. Near the lakeshore, the substrate either consists of organic components (mud, plant fragments), mineralic components (peebles, stones, fragments of shells) or a mixture of both. In deeper regions, the ground substrate mainly includes grey- to black-colored sapropel with extremely low porosity. While in the North and West two brooks discharge into the lake and therefore represent the main water providers, the only outflow is posited at the southern end of the lake. Due to the low number of in- and out-flowing waters, a complete water replacement needs about 3 years.

Sampling and determination of aquatic molluscs. Sampling of freshwater molluscs was carried out according to the descriptions published by PATZNER (1994) and GLÖER & MEIER-BROOK (1998). Around the lake, the mollusc population was investigated qualitatively and quantitatively at 40 locations with constant distances of 50 m. For an effective collection of gastropods and bivalves, the sediment was sampled with a hand-sieve (mesh size: 0.5 mm), and single shells were sorted with feather tweezers and stored in film boxes or glass phials

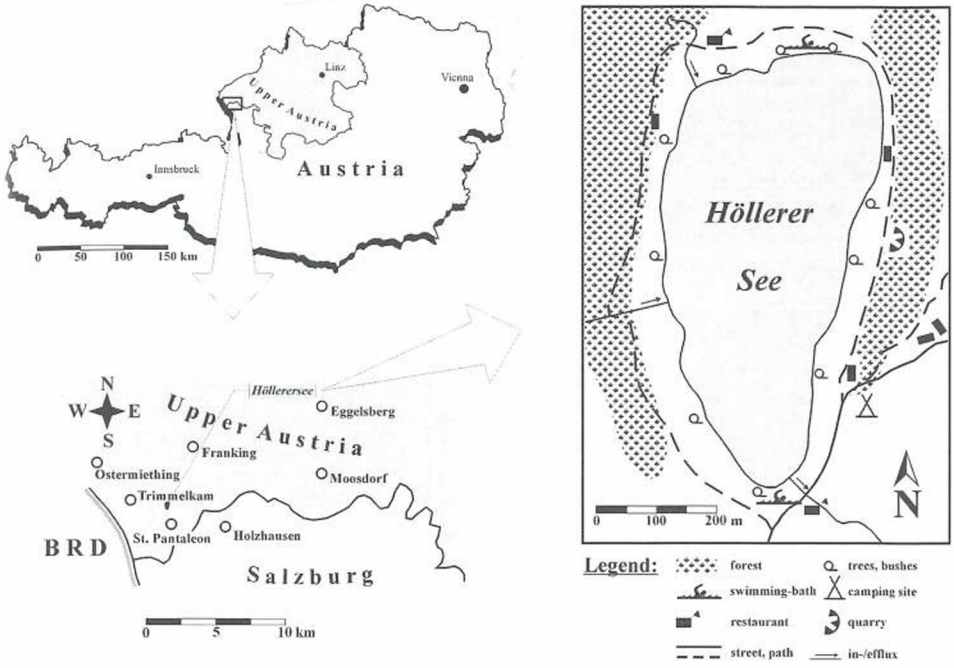


Fig. 1. Geographic position of the Höllerersee within the alpine foreland of Upper Austria. The lake is located about 30 km N of the city of Salzburg and about 150 km WSW of Linz. In the detail map, the Höllerersee and its direct environment are displayed.

filled with ethanol (70 %). Additionally to the sediment samples, molluscs were also collected from stones, wood fragments, and surrounding macrophytes. Abundances of locally occurring species were assigned to four typical classes (PATZNER 1994): 1 = rare, 2 = moderately frequent, 3 = frequent, 4 = abundant (very frequent). Besides living animals, also empty shells of recently or previously died molluscs were included into the study. Determinations of the species were carried out after GLÖER & MEIER-BROOK (1998) as well as TURNER et al. (1998).

Physico-chemical water analysis. Specific characteristics of water were investigated at selected sample points on the eastern and western shore of the Höllerersee. While temperature (° C), pH, electric conductivity (µS cm^{-1}), and oxygen content (mg L^{-1}) of water were measured in situ by using portable instruments (STURM 2000b), total and carbonate hardness (° dH) as well as nitrate contents (mg L^{-1}) were analyzed in the laboratory after storing water samples in specific 0.5-L bottles with airproof screw caps. Collected results were evaluated statistically by a computation of the mean value and the standard deviation.

Biotope description: For a comprehensive description of the ecology of single gastropods and bivalves, also the vegetation at the lakeshore as well as possible occurrences of submerse macrophytes were subject to qualitative and quantitative studies. Unknown macrophyte species were determined according to the key of SCHMEIL & FITSCHEN (1995). The quantity of different plants was distinguished in the following way: 1 = rare, 2 = frequent, 3 = abundant, 4 = in mass. Shading produced by the locally present vegetation (assuming vertical light) was also assigned to four classes (0–25 %, 25–50 %, 50–75 %, and 75–100 %). Concerning the ground substrate, a crude distinction between three categories (mud, stones, and mixed ground) was judged as meaningful (see above). Biotope description was completed with an estimation of the influence by man. Besides the frequency of tourist's visits, also the economic use of the lake and its direct environment was evaluated and expressed by two categories (low frequency/economic use, high frequency/economic use).

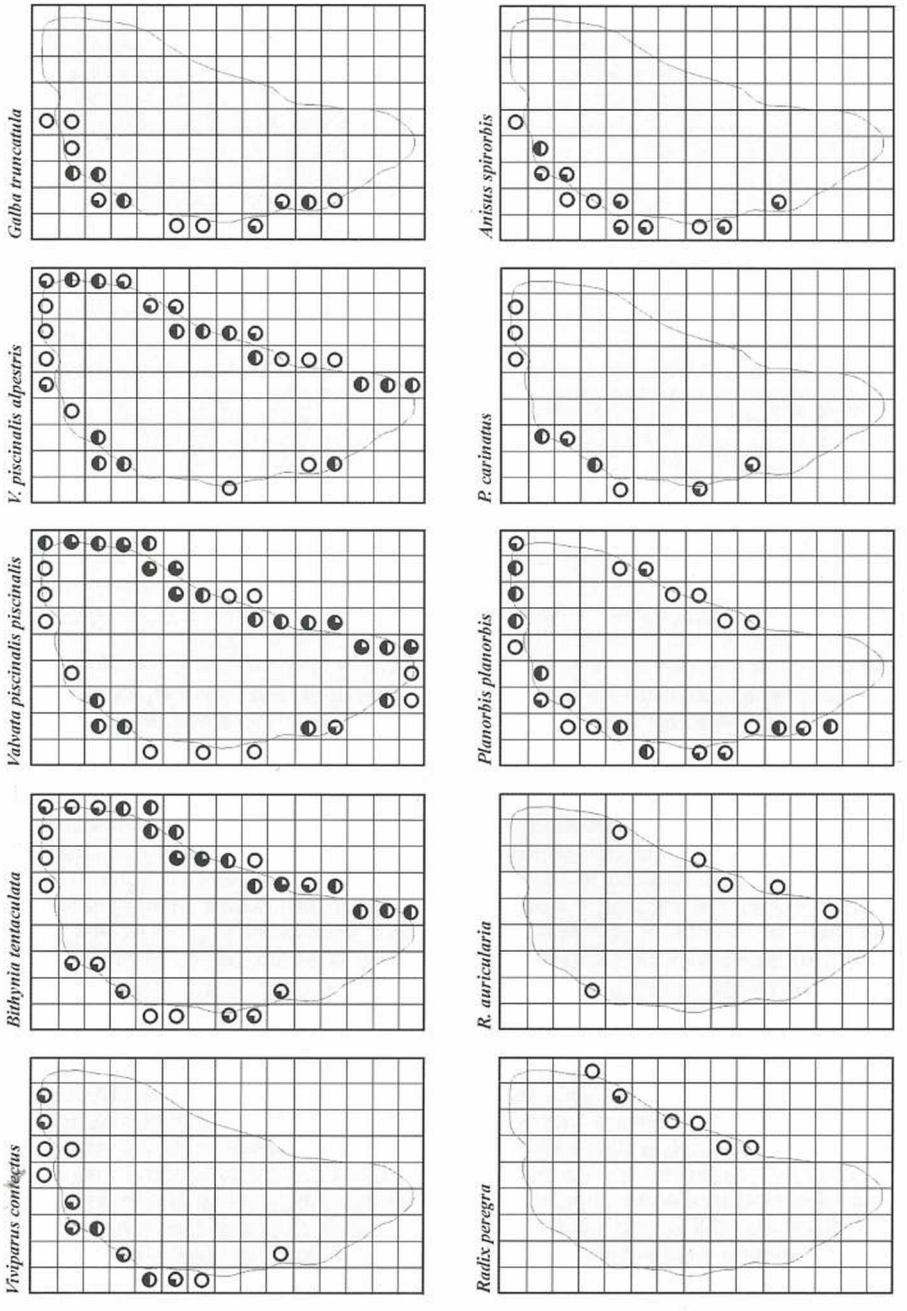
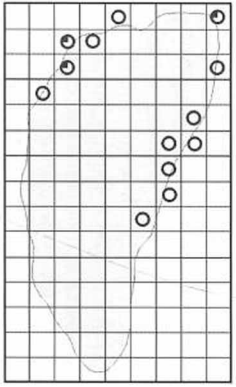
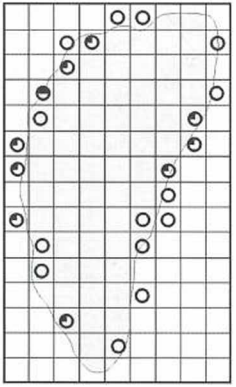


Fig. 2. Distribution patterns of the aquatic gastropods and bivalves collected along the shore of the Höllerersee. To describe the mollusc distribution as precisely as possible, the shore was sampled every 50 m and sample points were plotted into a grid with a grid size of 50×50 m. Occurrence of single species was assigned to 4 classes. Besides living animals, also empty shells were included into the study.

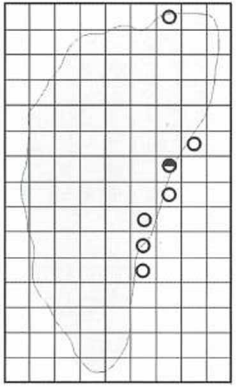
A. leucostoma



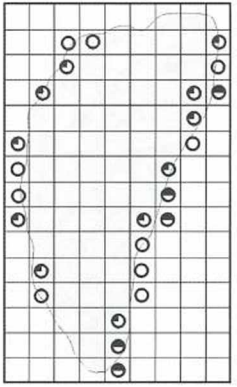
Bathyomphalus contortus

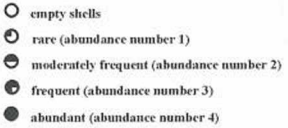


Gyraulus albus

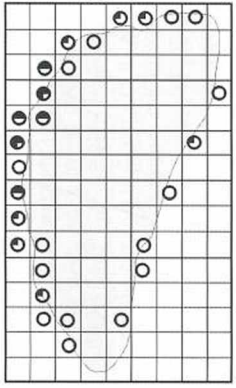


Physella heterostropha

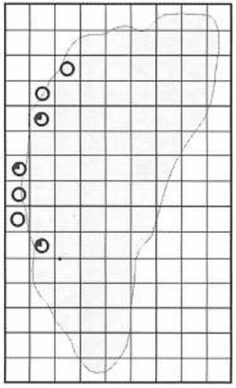




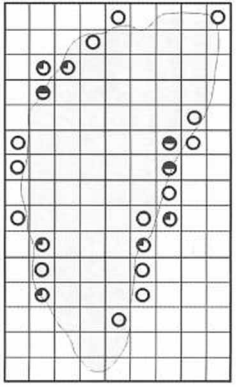
Anodonta cygnea



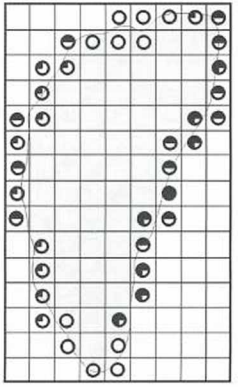
A. anatina



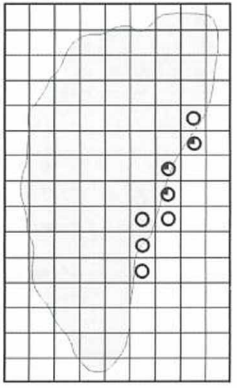
Pisidium subtruncatum



P. casertanum



P. hibernicum



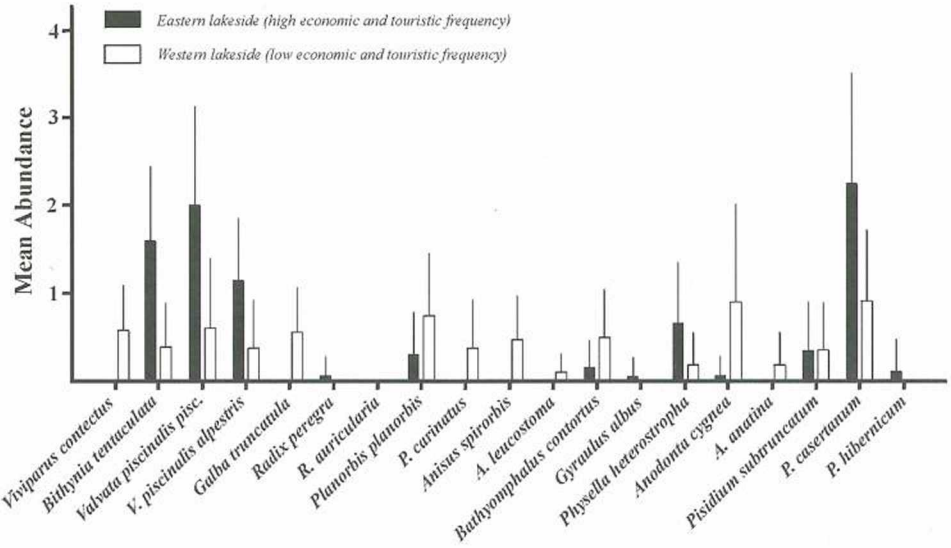


Fig. 3. Mean abundance (±1 standard deviation) of determined mollusc species along the eastern and the western shore. While total number of species is higher at the western shore compared to the eastern shore (15 vs. 12), abundance of single species reaches its maximum at the eastern shore.

Results

Mollusc sampling. As illustrated in Fig. 2, in the Höllerersee 14 species of aquatic gastropods and 5 species of bivalves (2 mussels and 3 pill clams) could be collected. Among the sampled freshwater snails, highest abundance was registered for *Bithynia tentaculata*, *Valvata piscinalis piscinalis*, and *V. piscinalis alpestris*, from which either living animals or empty shells were found all around the lake. A similar frequency was determined for *Pisidium casertanum* which represented the only mollusc species occurring at all sample points.

Detailed results of the distribution of single species along the shore are summarized in Fig. 2. Except for *P. casertanum*, most collected gastropods and bivalves show very specific distribution patterns with a preference to either the eastern and southern part or the western and northern part of the studied lake. Colonization of only a specific lake site could be observed for *Viviparus contectus*, *Galba truncatula*, and *Anisus spirorbis*, whose occurrence is presently limited to the northern and western part of the Höllerersee, while *Radix peregra* and *Gyraulus albus* were only found at the eastern part until now. Within the group of freshwater bivalves, *Anodonta anatina* colonizes only few habitats at the western shore, whereas *P. hibernicum* exclusively occurs at the eastern shore (Fig. 2). Summarizing the results of mollusc mapping, the western side of the lake is characterized by higher species diversity (15 species) than the eastern side (12 species). In contrast, total abundance of gastropods and bivalves is remarkably enhanced on the eastern side, where some species presently occur with very high frequency (Fig. 3).

Biotope description. A summary of the biotope studies can be seen in Fig. 4. Concerning the ground substrate of the Höllerersee, differences between the single lakeshores could be worked out very clearly. While at the Eastern shore a predominance of muddy and mixed substrate with a maximum depth of about 50 cm can be observed, the remaining parts are mainly characterized by stony ground mixed with plant and wood fragments. In the swimming-baths at the northern and southern end of the lake (Fig. 1), natural ground has been covered by medium- to coarse-grained gravel. Bank vegetation (incl. macrophytes) is very sumptuous on the eastern and western shore (Fig. 4), whereas especially in the area of the

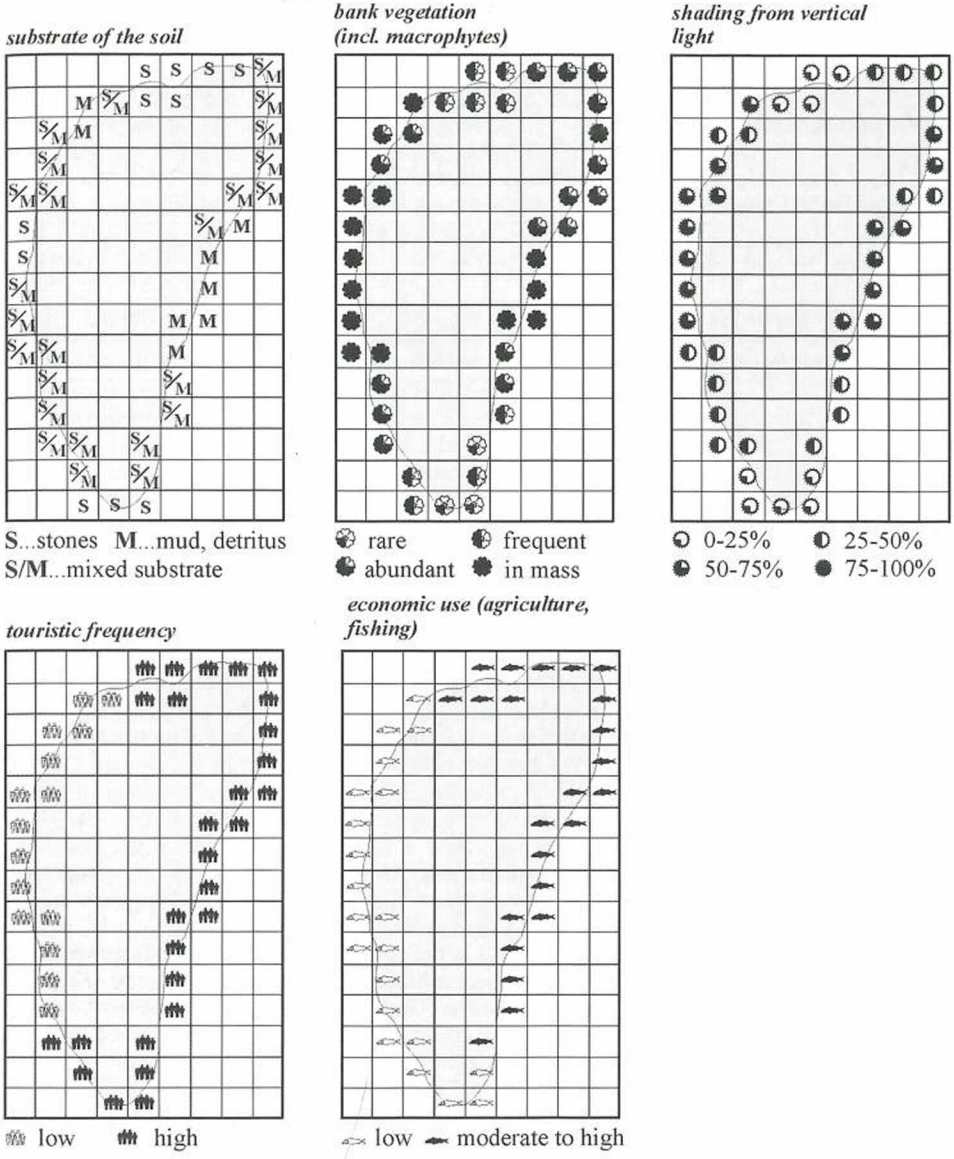


Fig. 4. Analysis and quantification of natural factors (ground substrate, shading, vegetation) and anthropogenic parameters (tourism, economic use) at the sample points.

southern swimming-bath, vegetation has been mainly reduced to some trees and bushes. At the studied sample points, the percentage of shading directly correlates with the diversity and abundance of the lining vegetation, reaching its maxima again at the eastern and western shore.

Regarding the amount of daily visitors and camping tourists, the Höllerersee can be subdivided into two parts (Fig. 3). Along the northern, eastern, and southern shore, touristic activity is high during summer with most visitors being concentrated in the swimming-baths. A main part of the eastern shore consists of private properties (about 500 m^2) with

Tab. 1. Physico-chemical parameters (mean values ± standard deviations) along the eastern and western shore (date of analysis: 15th July 2001, sunny weather).

	Eastern shore	Western shore
Temperature (°C)	24.85 ± 0.21	24.90 ± 0.85
pH	6.20 ± 0.42	6.30 ± 0.69
El. conductivity (µS cm $^{-1}$)	98.50 ± 27.6	93.50 ± 31.8
Oxygen content (mg L^{-1})	4.80 ± 0.69	6.00 ± 0.42
Total hardness (°dH)	2.75 ± 0.21	2.70 ± 0.45
Carbonate hardness (°dH)	2.55 ± 0.36	2.40 ± 0.24
Nitrate content (mg L^{-1})	< 10.0	< 5.0

fluctuating amount of guests. In contrast, the western shore is characterized by low touristic activity with daily visitors only concentrated at certain places, where access to the lake has been made possible. A similar tendency can be recognized for the economic use of the Höllerersee (Fig. 3). Therefore, more extensive fishing is chiefly limited to the northern and eastern side of the lake. At the same sites, herb plants on the bordering land are cut two times a year, whereas the soil is fertilized only once a year.

Water analyses. Results of physico-chemical water analysis are listed in Tab. 1. At the eastern and western side of the lake, measurements were carried out at 10 sites, respectively (see methods section). Concerning the listed data, significant differences between the eastern and western side are only noticeable for the oxygen content, being lower at the more extensively used sites. The remaining parameters show a good correspondence.

Discussion

As shown by a comprehensive malacological study, the mollusc population of the Höllerersee includes 14 species of freshwater gastropods and 5 species of bivalves. This result mainly confirms the findings of a previous investigation of the Höllerersee carried out by STURM (2000b). The only species additionally found in the recent population is *Radix auricularia*, showing a wide dispersal within the alpine foreland (PATZNER 1995) and preferring lakes and ponds with high contents of submerse vegetation (GLÖER & MEIER-BROOK 1998). As a special feature of the investigation, most species found in the lake are characterized by local distribution patterns with a preferential colonization of either the northern and, above all, the western or the eastern part of the lake (Fig. 2). One of the most evident limitations of colonized habitats can be reported for *V. contectus*, occurring only in the northwestern part of the lake. A very endemic occurrence can be further observed for *R. peregra* and *P. hibernicum*, whose habitats are limited to certain sections of the eastern shore, as well as *A. anatina*, living exclusively along the western shore. Similar to this bipartition of the Höllerersee regarding the colonization with freshwater molluscs, also the biotope characteristics vary significantly between the eastern and western lakeside (Fig. 4). While natural factors (except the ground substrate) do not show considerable differences between the two sites, influence by man due to touristic and economic use of the lake and its adjacent environment is strongly enhanced on the eastern shore. As a consequence of a (limited) agricultural cultivation in the East, water chemistry additionally is marked by a slightly increased content of NO_3^- and decreased concentration of O_2, being typical features of eutrophic waters. Considering all parameters necessary for a precise biotope evaluation, we conclude that the western side of the lake has probably preserved its natural appearance to a wide extent, whereas the eastern side has been subject to remarkable anthropogenic disturbances.

As outlined by numerous authors (e.g. ÖKLAND 1983, BRÖNMARK 1985, COSTIL & CLEMENT 1996, PATZNER & ISARCH 1999), the colonization of a water system by aquatic molluscs is controlled by a complex network of biotic and abiotic parameters. However, the diversity of macrophytes has been described as one of the essential factors for the dispersal of freshwater gastropods, because sumptuous vegetation guarantees the formation of numerous microhabitats offering ideal conditions for many mollusc species. Concerning the submerse vegetation, plant morphology and fine structure additionally influence species diversity to a certain extent. COSTIL & CLEMENT (1996) could show that mainly eutrophic environments may represent favourable habitats for gastropods and bivalves, since they provide sufficient amounts of nutrients. The fact that in the Höllerersee highest species diversity and abundance of molluscs is observed at sample points with the respective occurrence of macrophytes supports the hypotheses mentioned above. While species diversity is, however, higher along the western shore than the eastern shore (15 vs 12 species; Fig. 3), abundance of single ubiquitous species shows a somewhat contrary behaviour (see e.g. *B. tentaculata*, *Valvata* sp. or *P. casertanum*; Fig. 2). It is hypothesised that the discrepancies in species diversity are probably caused by human activities, leading to a locally noticeable disturbance of the habitat structures. Molluscs being resistant to such influences, which are, for instance, expressed by rapid changes of the water chemistry, impairment of the macrophyte population, and increased sedimentation of the ground substrate, quickly spread along the shore and become the dominant species after a short period of time. In contrast, more sensitive species are driven back to habitats which are not affected by enhanced human disturbances. Besides *V. contectus* and members of the Planorbidae, this specific behaviour is highly evident for the two mussel species of the Höllerersee. PATZNER & MÜLLER (1996) have described possible factors responsible for the decline of naiad mussels, including natural influences such as diseases, parasites, predators as well as influences by man like water pollution, sedimentation, competition with imported species, and use of bivalves as bait. In the Höllerersee, the large extinction of mussels along the eastern lakeside could be mainly explained by multiple whirling up and sedimentation of the ground substrate due to the bathing activity of tourists and the use of animals for fishing. Activity of predators like muskrats is higher along the western shore and thus regulates an overpopulation by naiads. The investigated lake has been appeared to be a further example for the high variability of mollusc distribution patterns within a water system and has confirmed the irrefutable hypothesis that diversity of species depends on numerous factors.

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