Freshwater Molluscs (Gastropoda et Bivalvia) in Selected Mountain Lakes of the Hohe Tauern, Austria: A Contribution to the Faunistic Mapping of the Eastern Alps

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Abstract. In the present study, the aquatic mollusc colonization of eight mountain lakes located in the Hohe Tauern (Eastern Alps, Austria) was investigated. From a geographic point of view, three of the investigated lakes can be assigned to the upper montane altitude level, ranging from 1000 to 1400 msm, while the other five lakes belong to the subalpine altitude level (1400 to 2200 msm). Altogether, eight species of freshwater snails and five species of bivalves were collected during the field study. The investigation clearly shows that, besides the diversity of species, also the number of individuals per species declines significantly with increasing sea level. Above 2000 msm, the population density of a single species usually drops below 1 individual per m^2. Seven of the 13 species belong to the Red List of threatened animals in Austria, and some of them are already highly endangered (*Anisus spirorbis*, *A. leucostoma*).

Kurzfassung. Süßwassermollusken (Gastropoda et Bivalvia) in ausgewählten Gebirgsseen der Hohen Tauern, Österreich: Ein Beitrag zur faunistischen Kartierung der Ostalpen. – In der vorliegenden Studie wurde die Besiedlung von acht in den Hohen Tauern (Ostalpen, Österreich) gelegenen Gebirgsseen durch aquatische Mollusken untersucht. Aus geographischer Sicht sind drei der begutachteten Seen der oberen montanen Höhenstufe (1000 bis 1400 msm) zuzuordnen, während die übrigen fünf Seen der subalpinen Höhenstufe (1400 bis 2200 msm) angehören. Insgesamt konnten im Zuge der Feldstudie neun Arten von Süßwasserschnecken und fünf Muschelspezies aufgesammelt werden. Die Studie belegt auf recht klare Weise, dass neben der Artendiversität auch die Anzahl der Individuen pro Art signifikant mit steigender Seehöhe abfällt. Über 2000 msm reduziert sich für gewöhnlich die Populationsdichte einer einzelnen Art auf weniger als 1 Individuum pro m^2. Sieben der 13 Spezies gehören der Roten Liste bedrohter Tiere in Österreich an, wobei einige Vertreter bereits in höherem Maße gefährdet sind (*Anisus spirorbis*, *A. leucostoma*).

Key words. Mountain lake, aquatic snail, mussel, motane zone, subalpine zone, abundance, Red List.

Introduction

During the last decades, freshwater molluscs have been gradually recognized as preferential indicator organisms for the characterization of biotope structures and an evaluation of the water quality in rivers and brooks (FALKNER 1990; PATZNER 1994a). As outlined in numerous publications (see overviews in PATZNER 1995; GLÖER & MEIER-BROOK 2003), many species of this group show a considerable sensitiveness to any changes of their environment, causing the disappearance of a certain population within a rather short period of time and, on the other side, the fast dispersal of another population better adapted to the new environmental conditions. However, in the past many biotopes have been subject to significant disturbances by human activity, leading to a successive reduction of mollusc habitats and, as a consequence, to an enhanced disappearance of gastropod and bivalve populations. As a result of this, more than 50 % of all mollusc species have been included into the Red List of threatened animals in Austria until now (FRANK & REISCHÜTZ 1994). Modern malacological studies primarily serve for the preservation of all endangered species by continuously increasing the knowledge about their local and regional distribution and exploring the major characteristics of the colonized biotopes.

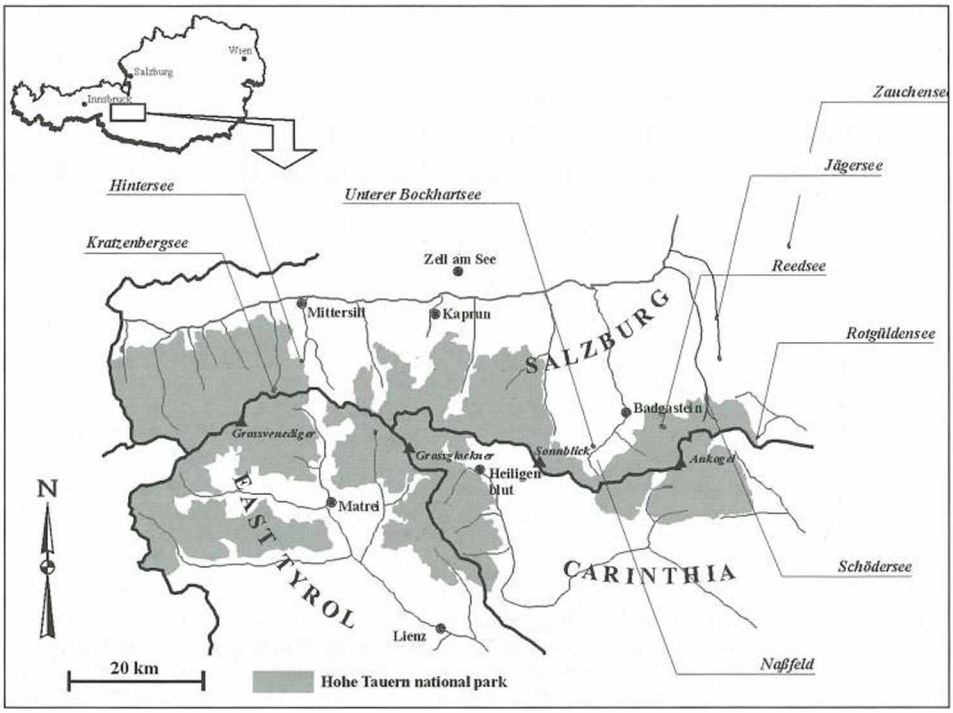

Fig. 1. Geographic map showing the position of the eight investigated mountain lakes. All studied waters are exclusively located in the county of Salzburg, three of them in the Hohe Tauern national park (dark-shaded area).

Concerning the malacological research in Austria and, especially, the county of Salzburg, main scientific activity began in the first half of the 20th century and experienced its bloom time in the 1990s with the start of a project including the county-wide mapping of freshwater molluscs (see overview in PATZNER 1995). For the alpine foreland and the city of Salzburg, numerous data regarding the distribution of aquatic snails and bivalves in rivers and lakes have been collected during the last 10 years (e.g. PATZNER et al. 1992, 1996; PATZNER 1996; PATZNER & ISARCH 1999). In contrast, for the alpine regions of Salzburg only a restricted malacological information on terrestric and aquatic molluscs is available with the relevant research partly dating back to the 1920s (e.g. GASCHOTT 1927; MAHLER 1950; SPERLING 1975). Later malacological studies in selected areas of the Central Alps have been carried out by FRANK (1986, 1992, 1996), concentrating mainly on the distribution of terrestric snails. Although the investigations of FRANK are characterized by great minuteness of detail, they only cover a small part of the inner-alpine region.

The main objective of the present study is the continuation of the investigation started by FRANK and the further accumulation of knowledge concerning the distribution of freshwater snails and mussels in central-alpine waters. To achieve these objectives, mountain lakes and adjacent waters of the inneralpine area in Salzburg have been explored malacologically. Besides the species diversity, also abundances of individual species occurring in the lakes have been evaluated according to a well defined scheme. Additionally to the faunistic investigations, also physico-chemical water parameters have been measured and various biotope characteristics such as shore morphology and vegetation have been recorded.

lake		geogr. pos., altitude	size, depth	vegetation	ground substrate
Jägersee		End of the Kleinarl valley, South of Kleinarl, county of Salzburg 1,105 msm	S: 0.1 km² D: c. 5 m	Mixed forrest with maples, spruces, etc., herb vegetation along the western side	Organic substrate mixed with sand, blocks of silicate rocks
Hintersee		End of the Felber valley, South of Mittersill, county of Salzburg 1,315 msm	S: 0.08 km² D: max. 6 m	Spruces, larchs, herb vegetation, dense submerse vegetation	Organic substrate mixed with sand, blocks of silicate rocks
Zauchensee		End of the Zauchen valley, South of Altenmarkt, county of Salzburg 1,339 msm	S: 0.06 km² D: max. 8 m	Spruces, herb vegetation, partly dense submerse vegetation	Organic substrate mixed with sand and stones
Schödersee		End of the Grossarl valley, South of Grossarl, county of Salzburg 1,450 msm	S: up to 0.10 km² D: max. 2 m	Moor and grass vegetation	Organic substrate, grass
Unterer Bockhartsee/Naßfeld		Above Sportgastein, Gastein valley, county of Salzburg 1,830 msm	S: up to 0.16 km² D: max. 12 m	Sparse vegetation including herbs and bushes, no submerse plants	Silicate blocks of cm to dm size
Rotgüldensee		North of the Grosser Hafner, above Murwinkel, county of Salzburg 1,760 msm	S: up to 0.15 km² D: max. 10 m	Sporadic lining by larchs and pines, no submerse vegetation	Silicate blocks of cm to dm size
Reedsee		Kötschach valley, East of the Graukogel, county of Salzburg 2,070 msm	S: up to 0.06 km² D: max. 6 m	Spruces, larchs and pines	Medium- to coarse-grained inorganic substrate mixed with detritus
Kratzenbergsee		End of the Hollersbach valley, county of Salzburg 2,170 msm	S: up to 0.26 km² D: max. 30 m	Grass vegetation rich of species (e.g. sedges)	Silicate stones and blocks

Fig. 2. General characteristics of the studied mountain lakes including information on the geographic position, altitude, size, water depth, surrounding vegetation, and ground substrate.

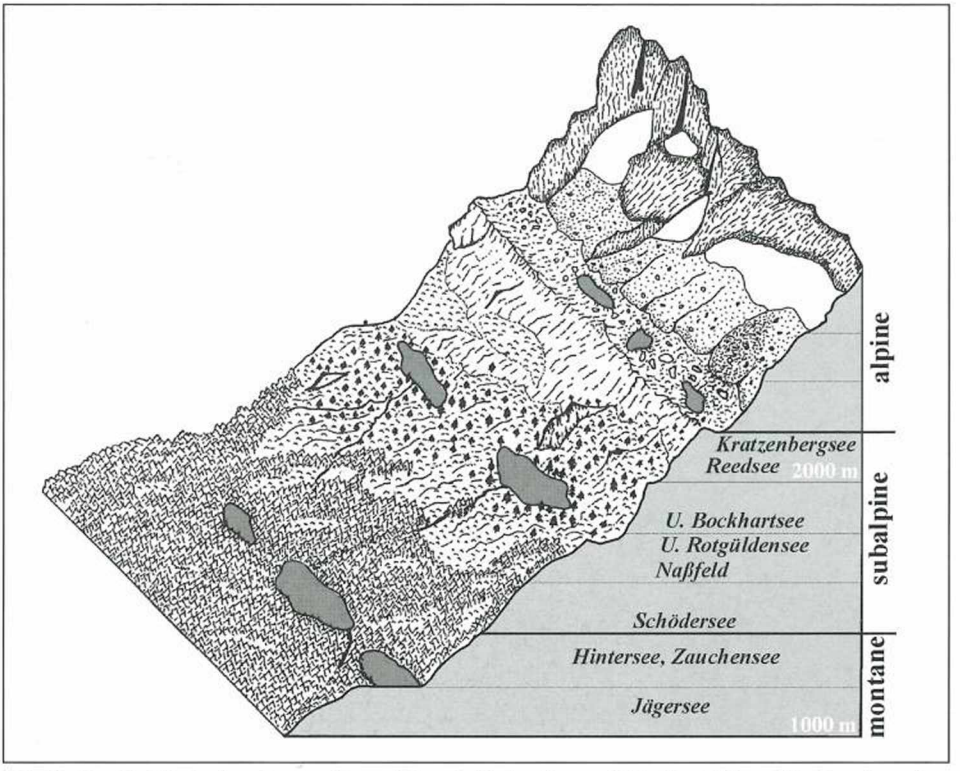

Fig. 3. Sketch illustrating the postion of the studied waters within the alpine altitude categories. While three lakes can be assigned to the upper montane altitude level, five lakes belong to the subalpine altitude category.

Description of the investigated mountain lakes

All mountain lakes explored by this study are located in the Central Alps of the county of Salzburg. As illustrated in the map on Fig. 1, three lakes are situated within the Hohe Tauern national park and thus are subject to an enhanced protection. General characteristics of the investigated waters are summarized in Fig. 2. Besides significant differences in size and depth, the mountain lakes are characterized by rather high variations in their surrounding vegetation and the occurrence of submersed plants. As an important detail, two storage lakes with periodically fluctuating water lines (Unterer Bockhartsee, Rotgüldensee) have been included into the study.

As shown in Fig. 3, the studied lakes and associated waters are located on different alpine altitude levels. While the Jägersee, the Hintersee, and the Zauchensee belong to the upper montane altitude category, ranging from 1000 msm to 1400 msm, the remaining lakes (Schödersee, Unterer Bockhartsee/Naßfeld, Unterer Rotgüldensee, Kratzenbergsee, Reedsee) are assigned to the subalpine altitude level, which ranges from 1400 msm to 2200 msm. The most highly located lake is the Kratzenbergsee (2170 msm) which nearly reaches the alpine altitude level. As a general trend, increasing altitude position within the Central Alps is marked by a respective decline of the mean temperature, increased amounts of rainfall per year, and a dramatic drop of the vegetation diversity.

Material and Methods

The malacological investigations were carried out between June and October 1999 as well as between June and August 2000 (Tab. 1). Sampling of molluscs and determination of physico-

Tab. 1. General data of the sample points selected during the field study. Estimation of shading was based on the assumption of vertical light. Abbreviations: JS – Jägersee, ZS – Zauchensee, HS – Hintersee, KS – Kratzenbergsee, UBS – Unterer Bockhartsee, NF – Naßfeld, RGS – Rotgüldensee, RS – Reedsee, SS – Schödersee.

Sample point	Date of sampling	Geogr. X-position	Geogr. Y-position	Shading (%)	Shore morphology	Shore vegetation, submerse plants (overview)
JS1	22.06.99	233.250	449.800	10	flat, overgrown	grasses, diverse humidity indicators
JS2	22.06.99	233.070	449.750	60	flat, overgrown	grasses, sword flags, diverse herbs
JS3	22.06.99	232.820	449.720	50	steep, stony	grasses, diverse herbs, bushes
JS4	22.06.99	233.110	449.980	60	steep, stony	alder, maple, hazel-bushes, grasses
ZS1	25.06.99	228.600	449.400	40	flat, stony	grasses, bushes
ZS2	25.06.99	228.310	448.900	50	flat, stony	grasses, bushes
ZS3	25.06.99	227.750	448.700	55	flat, stony	grasses, bushes
HS1	23.07.99	228.500	385.180	40	flat, overgrown	hazel-bushes, alder, grasses, horse-tails
HS2	23.07.99	228.370	385.120	20	steep, stony	grasses, diverse herbs
HS3	23.07.99	228.450	384.700	10	flat, overgrown	alder, grasses, *Caltha palustris*
HS4	23.07.99	228.600	385.050	10	steep, overgrown	grasses, *Caltha palustris*, bushes
KS1	30.07.99	225.400	380.750	10	flat, stony	wool grass, sedges
KS2	30.07.99	225.300	380.850	20	flat, overgrown	sedges
KS3	30.07.99	224.720	380.700	20	flat, overgrown	no vegetation
KS4	30.07.99	225.300	380.500	20	flat, overgrown	no vegetation
UBS1	02.08.99	214.780	429.150	0	flat, stony	alder bushes, grasses, herbs (e.g. *Tussilago farfara*)
UBS2	02.08.99	215.000	428.070	0	steep, stony	alder bushes, diverse grasses
UBS3	02.08.99	215.100	429.350	0	steep, stony	diverse grasses, herbs
NF1	02.08.99	213.400	429.270	10	----------------	diverse grasses, horse-tails
NF2	02.08.99	213.380	429.230	10	----------------	diverse grasses, horse-tails, bushes
NF3	02.08.99	212.900	428.950	5	----------------	diverse grasses, horse-tails
NF4	02.08.99	212.200	429.070	10	----------------	diverse grasses
RGS1	15.08.99	217.650	439.390	10	flat, overgrown	grasses, larchs, cembra pines
RGS2	15.08.99	217.500	439.500	0	flat, stony	grasses, larchs, cembra pines
RGS3	15.08.99	217.700	439.600	0	flat, stony	grasses
RS1	20.08.00	217.850	456.290	60	flat, overgrown	grasses, larchs, cembra pines, spruces, bushes
RS2	20.08.00	217.780	455.900	80	flat, overgrown	larchs, cembra pines
RS3	20.08.00	217.400	455.550	50	flat, overgrown	spruces, larchs, cembra pines
SS1	02.08.00	219.300	449.070	60	flat, overgrown	bushes, grasses, sedges
SS2	02.08.00	219.280	449.030	40	flat, overgrown	bushes, grasses, sedges
SS3	02.08.00	219.210	449.000	50	flat, overgrown	bushes, herbs, sedges
SS4	02.08.00	219.250	449.110	40	flat, overgrown	grasses, sedges

chemical water parameters took place at three to four points around the lake. Selection of these sample points mainly depended upon the density of the local shore vegetation and submersed plants, offering suitable micro-habitats for the aquatic snails and mussels. The nomenclature of the sample localities, their geographic position as well as necessary descriptions of the shore morphology and vegetation are summarized in Tab. 1.
Methods for the sampling of freshwater molluscs in rivers and lakes are described in details in the literature (e.g. PATZNER 1994b; GLÖER & MEIER-BROOK 2003) and, therefore, are only outlined very briefly in the present contribution. Main tools for the field work were a hand sieve (grid size: 0.5 mm), a sieve with telescope handle for sampling of deeper waters and accessories for separation and storage of the animals (e.g. feather tweezers, tightly lockable glass phials). Malacological mapping mainly included the inspection of the water line and its vegetation. Additionally, wood fragments and leaves washed ashore as well as stones were checked for their colonization by molluscs. Finally, a sample of the ground substrate was taken at each site and subsequently explored in the laboratory. This step should guarantee the recording of small shells and larval stages. For a complete description of the sample points, the respective form offered by the Biologische Unterwasser-Forschungsgruppe of the University of Salzburg (BUFUS) was used. Determination of single species was carried out according to the keys published by GLÖER & MEIER-BROOK (2003), JANUS (1973), and TURNER et al. (1998). Abundance of the animals was quantified as follows: 1 – rare (< 1 individual per m^2), 2 – moderately frequent (1 – 10 individuals per m^2), 3 – frequent (10 – 100 individuals per m^2), 4 – abundant (> 100 individuals per m^2).
Physico-chemical water analysis included the measurement of the following environmental factors:

Temperature (°C)
pH
Electric conductivity ($\mu S\ cm^{-1}$)
Oxygen saturation (%)
Total water hardness (°dH)
Nitrate content ($mg\ NO_3^-\ L^{-1}$)
BSB_5 ($mg\ L^{-1}$)

Temperature, pH, electric conductivity and O_2 saturation were usually measured with portable instruments. The content of nitrate was determined with specific test sticks (Stelzner GmbH, measuring range: 0 to 500 $mg\ NO_3^-\ L^{-1}$). For measuring the remaining physico-chemical factors, a water sample was evacuated in a 0.5 L bottle with tightly lockable screw cap and stored in an opaque box at a constant temperature of 20°C. The BSB_5 was analyzed with a WTW Oxi-196 electrode, whereas the total hardness of the water was determined by chelatometric titration (e.g. JANDER & JAHR 1989).

Results

Species diversity and abundance of molluscs in the studied lakes. During the malacological investigations of the mountain lakes decribed above, eight gastropod and five bivalve species could be collected (Fig. 4). The results of the faunistic mapping are summarized in Tab. 2.
In the **Jägersee**, mollusc colonization is significantly uneven. Highest species diversity was reported for the western shore of the lake (JS2), where the density of macrophytes reached a maximum. In the respective micro-habitats, *Anisus leucostoma*, *Radix labiata* and *Galba truncatula* showed high abundances, while *Acrolxus lacustris*, *A. spirorbis*, *Bathyomphalus contortus* and *Planorbis planorbis* occurred with lower frequencies (Tab. 2) on stones, plant stalks and in the detritic ground substrate. Within the group of the bivalves, a significant predominance of the pill clams was registered (*Pisidium casertanum*, *P. obtusale*, *P. nitidum*, *P. subtruncatum*), whereas *Musculium lacustre* was limited to few individuals per m^2 at the time of investigation (Tab. 2). Contrary to the western shore, the number of mollusc species along the northern, southern, and eastern shore was subject to a remarkable decrease because of the sparse submersed vegetation and the predominance of inorganic ground substrate.

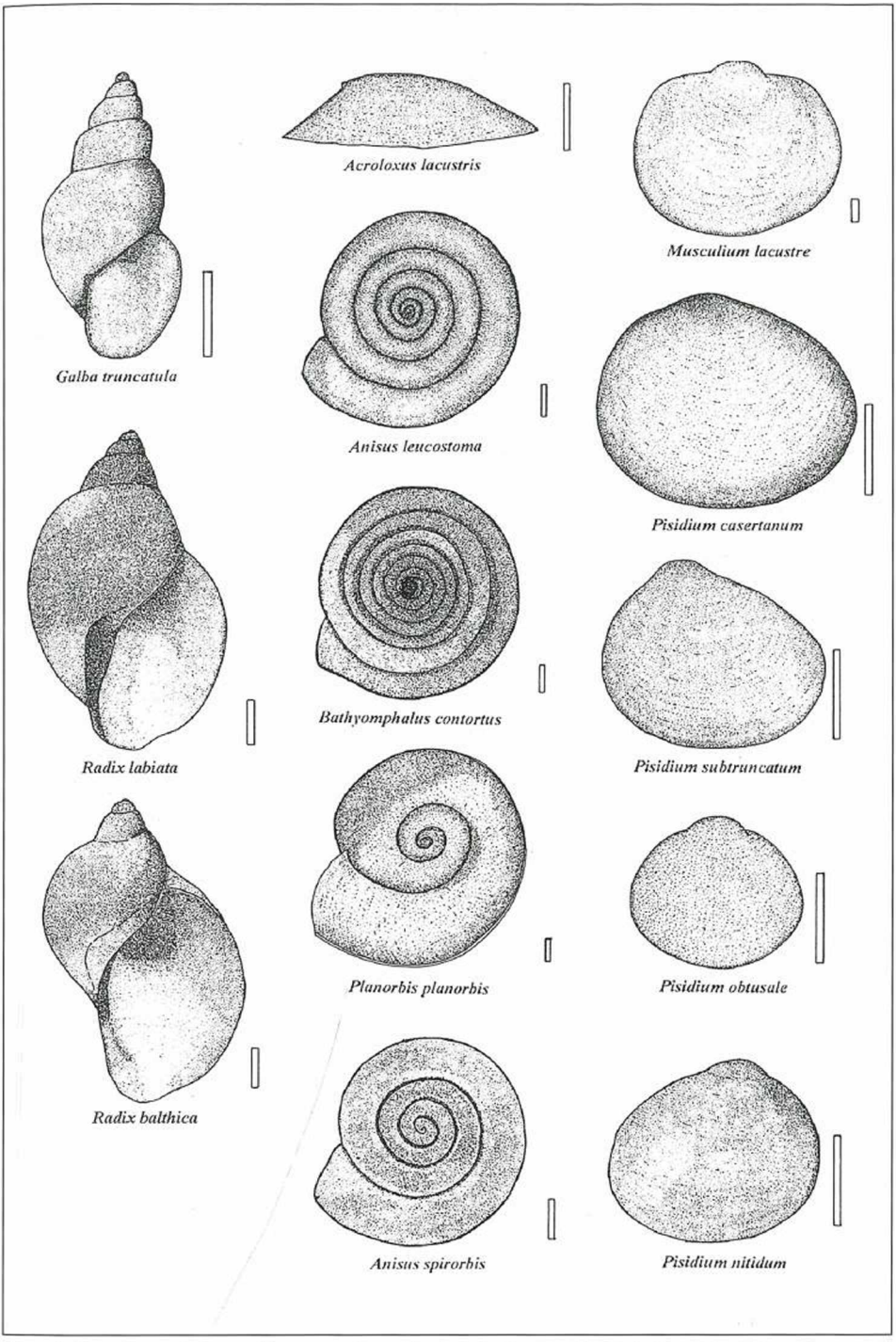

Fig. 4. Drawings of the mollusc species collected during the field study. Altogether, three mud snails, four planorbids (illustrations show the bottom view), one cup snail, and five mussels could be determined. Bars represent 1 mm, respectively.

Tab. 2. Results of the malacological mapping and abundance analysis. Abundance categories 1 to 4 are described in detail in the methods section. — – no occurrence of any aquatic molluscs. The last line of the table illustrates the position of the species within the Red List of threatened animals in Austria (county of Salzburg) (FRANK & REISCHÜTZ 1994). Endangerment categories: n.e. – not endangered, 1 – threatened by extinction, 2 – highly endangered, 3 – endangered, 4 – potentially endangered.

Sample points / Species		*Radix labiata*	*Radix balthica*	*Galba truncatula*	*Anisus spirorbis*	*Anisus leucostoma*	*Bathyomphalus contortus*	*Planorbis planorbis*	*Acroloxus lacustris*	*Musculium lacustre*	*Pisidium casertanum*	*Pisidium subtruncatum*	*Pisidium obtusale*	*Pisidium nitidum*
Jägersee	JS1	2	—	—	—	—	—	—	—	—	—	—	—	—
	JS2	3	—	2	3	3	3	3	2	2	2	2	3	2
	JS3	2	—	2	—	—	2	—	—	—	2	2	—	2
	JS4	2	—	—	—	3	—	—	—	—	3	—	—	—
Zauchensee	ZS1	2	2	2	—	—	—	—	1	—	2	—	1	—
	ZS2	2	3	2	—	—	—	—	2	—	3	2	2	—
	ZS3	2	2	—	—	—	—	—	—	—	2	—	—	—
Hintersee	HS1	1	2	—	—	—	—	—	—	—	1	1	—	—
	HS2	2	2	—	—	—	—	—	—	—	2	1	—	—
	HS3	—	1	—	—	—	—	—	—	—	—	—	—	—
	HS4	—	—	—	—	—	—	—	—	—	—	—	—	—
Kratzenbergsee	KS1	—	—	1	—	—	—	—	—	—	1	—	—	—
	KS2	—	—	2	—	—	—	—	—	—	1	—	—	—
	KS3	—	—	—	—	—	—	—	—	—	—	—	—	—
	KS4	—	—	—	—	—	—	—	—	—	—	—	—	—
Unterer Bockhartsee	UBS1													
	UBS2													
	UBS3													
Naßfeld	NF1	1	3	2	—	—	—	—	—	—	2	—	1	—
	NF2	2	2	1	—	—	—	—	—	—	3	—	2	—
	NF3	—	3	—	—	—	—	—	—	—	3	—	1	—
	NF4	—	2	1	—	—	—	—	—	—	1	—	1	—
Rotgüldensee	RGS1													
	RGS2													
	RGS3													
Reedsee	RS1	—	1	1	—	—	—	—	—	—	1	1	—	—
	RS2	—	2	1	—	—	—	—	—	—	—	—	—	—
	RS3	—	—	2	—	—	—	—	—	—	2	—	—	—
Schödersee	SS1	2	1	—	—	2	1	—	—	—	2	1	—	—
	SS2	3	2	—	—	2	1	—	—	—	2	2	—	—
	SS3	3	1	—	—	—	2	—	—	—	3	—	—	—
	SS4	2	2	—	—	—	2	—	—	—	3	1	—	—
Red List (Salzburg)		n.e.	n.e.	n.e.	2	2	3	4	3	3	n.e.	n.e.	n.e.	3

The **Hintersee** showed rich vegetation lining its shore, partly a fine ground substrate, and dense colonization by submersed plants. Despite these features representing preferential frame conditions for aquatic molluscs, the lake was characterized by only a sparse occurrence of freshwater snails and mussels. Along the eastern and southern shore (HS1, HS2; Tab. 2), *G. truncatula* and *R. labiata* could be mainly found on the stalks of horse-tails and diverse grasses. In the substrate, *P. casertanum* and *P. subtruncatum* occurred with low frequency (Tab. 2). In a flooded meadow south of the Hintersee, *R. labiata* occurred with enhanced abundance.
For the **Zauchensee**, a wider spectrum of mollusc species (in comparison with the Hintersee) could be reported. Around the lake, four species of aquatic gastropods (*G. truncatula, R. labiata, R. balthica, A. lacustris*) and three species of pill clams (*P. casertanum, P. subtruncatum, P. obtusale*) were registered during the field study. Highest species diversity and abundances were detected at the southern end of the lake (ZS2), where a small moor lines the water (Tab. 2).
The **Schödersee** is periodically drained and therefore shows some characteristics typical for upland moors. Similarly to the Jägersee, this mountain lake was characterized by rather high diversity of mollusc species. Besides moderate abundances of *R. labiata*, *A. leucostoma* and *P. casertanum*, *B. contortus*, *P. subtruncatum*, and *R. balthica* occurred with partly very low frequencies (Tab. 2). Most of the observed species were collected in the fine substrate, in detritus or on the submersed vegetation itself. Differences between the lakesides concerning mollusc colonization were not as significant as in the other lakes described above.
In the **Unterer Bockhartsee**, no evidence for a previous or current colonization by freshwater gastropods or bivalves was detected. In the **Naßfeld** situated about 300 metres below the Bockhartsee, a completely different situation with high abundances of some freshwater mollusc species could be observed. In numerous small ponds with rich vegetation and muddy substrate, *R. balthica*, *R. labiata*, *G. truncatula*, *P. casertanum* and *P. obtusale* could be picked up from stalks or separated from the sediment. Similar results were obtained at each of the four sample points (NF1-4; Tab. 2).
Similarly to the Unterer Bockhartsee, the **Rotgüldensee** in the district of Lungau was not colonized by any aquatic molluscs at the time of investigation. The lack of empty shells also excluded a colonization of the lake at an earlier time.
Concerning the **Reedsee** in the upper Kötschach valley, results of the malacological investigations provided only a restricted number of mollusc species occurring in very low frequencies, respectively. At the three sample points (RS1-3), *R. balthica*, *G. truncatula* and *P. casertanum* were collected from the substrate surface or were separated from the sediment. Additionally to the living animals, shell fragments of *P. subtruncatum* were determined.
Due to its more or less isolated position, the **Kratzenbergsee** was colonized by only two mollusc species at the moment (*G. truncatula*, *P. casertanum*; Tab. 2), which were exclusively concentrated along the northern lakeside (KS1, KS2) lined with dense wool grass vegetation. In the remaining areas without comparable vegetation and with the predominance of coarse-grained mineral substrate, no gastropods and bivalves could be collected.

Physico-chemical water analysis. Results of the water analyses carried out at the sample sites are summarized in Tab. 3. Except for the nitrate concentration, all data listed in the table are mean values (n = 3). Concerning the temperature, pH, electric conductivity, O_2 saturation, and BSB_5, errors of measurement were usually up to 5%. For the chelatometric determination of the water hardness, a maximum error of 2% could be estimated.
Depending on the exposition and shading by the adjacent vegetation, the water temperature ranged from 7.9° (Kratzenbergsee) to 14.5° (Unterer Bockhartsee) at the date of study. Minimum temperatures were mainly recorded at the inlets of brooks. The pH usually varied between slightly acidic and alcalic values (pH 6 – 8; Tab. 3). At sample sites without any occurrence of submersed plants or vegetation lining the shore, more or less neutral pH values were measured (e.g. Unterer Bockhartsee, Rotgüldensee). Concerning the electric conductivity, results of measurement could be commonly classified as rather low, ranging from 58 to 158 $\mu S\ cm^{-1}$ (Tab. 3). These values are typical for waters posited in the central-alpine

Tab. 3. Results of the physico-chemical water analysis.

Sample point	Water colour	Temperature (°C)	pH-value	El. conductivity (µS cm^{-1})	Oxygen saturation (%)	BSB_5 (mg L^{-1})	Nitrate (mg L^{-1})	Hardness (°dH)
JS1	clear	8.9	7.84	112	92	2.6	0 – 10	2.3
JS2	slightly cloudy	9.4	7.76	130	95	1.8	0 – 10	2.5
JS3	cloudy	9.2	7.54	106	93	1.9	0 – 10	2.6
JS4	cloudy	8.2	7.32	102	92	2.2	0 – 10	2.8
ZS1	clear	8.5	6.89	95	96	2.4	0 – 10	1.8
ZS2	clear	8.3	7.02	87	95	0.6	0 – 10	1.9
ZS3	clear	8.6	6.54	83	97	0.8	0 – 10	2.4
HS1	clear	10.2	6.32	98	96	1.6	0 – 10	2.6
HS2	slightly cloudy	10.8	6.56	76	90	1.8	0 – 10	2.8
HS3	clear	9.7	6.73	82	95	2.3	0 – 10	2.7
HS4	clear	10.0	6.23	84	93	1.9	0 – 10	2.9
KS1	clear	7.9	6.65	56	94	0.8	0 – 10	3.3
KS2	clear	8.2	6.43	58	97	0.3	0 – 10	3.6
KS3	clear	8.0	6.54	74	96	0.5	0 – 10	3.5
KS4	clear	8.2	6.87	79	98	1.7	0 – 10	3.7
UBS1	clear	14.1	6.65	105	94	1.2	0 – 10	3.8
UBS2	clear	14.3	7.04	116	96	1.8	0 – 10	2.5
UBS3	clear	14.4	7.02	115	96	2.6	0 – 10	2.6
NF1	cloudy	15.1	5.95	125	97	2.4	0 – 10	2.9
NF2	slightly cloudy	14.5	6.43	142	84	2.9	0 – 10	1.8
NF3	slightly cloudy	14.4	6.28	156	84	2.0	0 – 10	1.9
NF4	slightly cloudy	14.2	6.78	158	86	1.2	0 – 10	1.8
RGS1	clear	12.0	6.66	102	93	1.1	0 – 10	2.9
RGS2	clear	11.6	6.91	106	95	2.0	0 – 10	2.7
RGS3	clear	11.6	6.93	109	94	1.4	0 – 10	2.7
RS1	clear	8.2	7.06	58	92	1.8	0 – 10	2.5
RS2	clear	8.4	7.56	72	92	1.1	0 – 10	2.8
RS3	clear	8.7	7.68	76	94	0.9	0 – 10	2.3
SS1	clear	9.7	6.02	83	93	0.8	0 – 10	1.0
SS2	clear	9.9	6.16	87	95	2.5	0 – 10	1.4
SS3	clear	10.0	6.33	69	91	2.8	0 – 10	4.5
SS4	clear	9.8	6.21	65	93	2.7	0 – 10	1.3

area with silicate geology. Except for the small ponds of the Naßfeld, the O_2 saturation always exceeded the 90%-level and reached its highest values at sample sites adjacent to inflowing brooks (Tab. 3). The related BSB_5 could be evaluated as very low for all investigated waters (0.3 to 2.9 mg L^{-1}), indicating only a slightly developed activity of microorganisms in the

lakes. The oligotrophic conditions were additionally indicated by the contents of nitrate, ranging from 0 to 10 mg L^{-1} (Tab. 3). A correlation with the electric conductivity could be worked out for the total water hardness, which varied between 1.3 and 4.5°dH and thus indicated more or less negligible contents of Ca and Mg.

Discussion

Ecology and possible strategies for mollusc dispersal. As demonstrated in the present study, mountain lakes of the montane and subalpine altitude level are usually characterized by a rather limited spectrum of freshwater molluscs. During the investigations, a total number of eight gastropod and five bivalve species could be recorded. Within the group of aquatic snails, *G. truncatula* and *R. labiata* were collected most frequently (Tab. 2). At least one of the two species occurred in all those lakes characterized by any colonization of aquatic molluscs. According to GLÖER & MEIER-BROOK (2003), *G. truncatula* is classified as a widely distributed species, which especially colonizes the shores of larger lakes and is more or less independent of the calcium carbonate concentration in the water. TURNER et al. (1998) describe this gastropod species as an ubiquist, which has already reached upper-alpine (– 2800 msm) waters in the Switzerland. A very similar distribution is reported for *R. labiata*, which, at the moment, is found at a maximum altitude of 2700 msm. The third detected species of Lymnaeidae is *R. balthica*, collected in Schödersee and on the Naßfeld. This species prefers small ponds rich of macrophytes (JAECKEL 1953; GLÖER & MEIER-BROOK 2003; STURM 1999), but is also found in fast flowing brooks and rivers (PATZNER 1996). According to TURNER et al. (1998), *R. balthica* has already reached altitudes up to 2500 msm in the Switzerland.

All four recorded species of Planorbidae preferred lakes of the montane altitude level. According to previous publications (e.g. GLÖER & MEIER-BROOK 2003; STURM 1998), *A. leucostoma*, *A. spirobis*, *B. contortus*, and *P. planorbis* mainly colonize small ponds with thick vegetation or bays of rivers and brooks and can reach high population densities. For *A. leucostoma*, TURNER et al. (1998) describe a distribution up to 2250 msm in the Swiss Alps, whereas the other species have been found at maximum altitudes of about 1500 msm until now. According to this contribution, the occurrence of *A. lacustris* is limited to a maximum altitude of 1300 msm and is, additionally, characterized by low frequencies. The gastropod is mainly found on stalks and leaves of plants, but can also colonize the surface of stones covered with layers of algae.

Within the bivalves, only species belonging to the family Sphaeriidae were recorded during the malacological field work. A rather homogeneous distribution throughout the colonized lakes was shown for *P. casertanum* and, with some exceptions, also for *P. subtruncatum*. Both pill clams are widely distributed in Middle Europe, being extremely tolerant to any changes of environmental conditions (temperature, pH, content of $CaCO_3$), and, in many cases, characterized by high abundances (e.g. KUIPER 1974; MEIER-BROOK 1975; FALKNER 1990; GLÖER & MEIER-BROOK 2003). Preferential habitats range from lakes and small ponds to traces of ruminants filled with rain water. For the Switzerland, TURNER et al. (1998) describe an occurrence of *P. casertanum* up to 2750 msm (Rifflsee at Zermatt), whereas *P. subtruncatum* is limited to a maximum altitude of 2000 msm until now. Concerning *P. obtusale* and *P. nitidum*, ecologic requirements outlined in the literature are contrary to those determined for *P. casertanum* (MEIER-BROOK 1975; GLÖER & MEIER-BROOK 2003). The occurrence of *M. lacustre* is strictly limited to the lowermost posited lake explored in this study (Jägersee). In the Switzerland, the maximum altitude reached by this species is 1350 msm at the moment (TURNER et al. 1998). Regarding its ecology, *M. lacustre* mainly prefers shallow ponds and slowly flowing rivers, thereby often acting as a pioneer species that colonizes a habitat before its competitors (e.g. STURM 1999).

As documented in the results section, the two storage lakes included into the malacological study (Unterer Bockhartsee, Rotgüldensee) are lacking any freshwater mollusc fauna. Besides several other parameters, the most reasonable cause for this phenomenon are periodic fluctuations of the water level typical for such lakes. Due to significant altitude variations of the water line, the shore is only lined by very sparse vegetation, which cannot

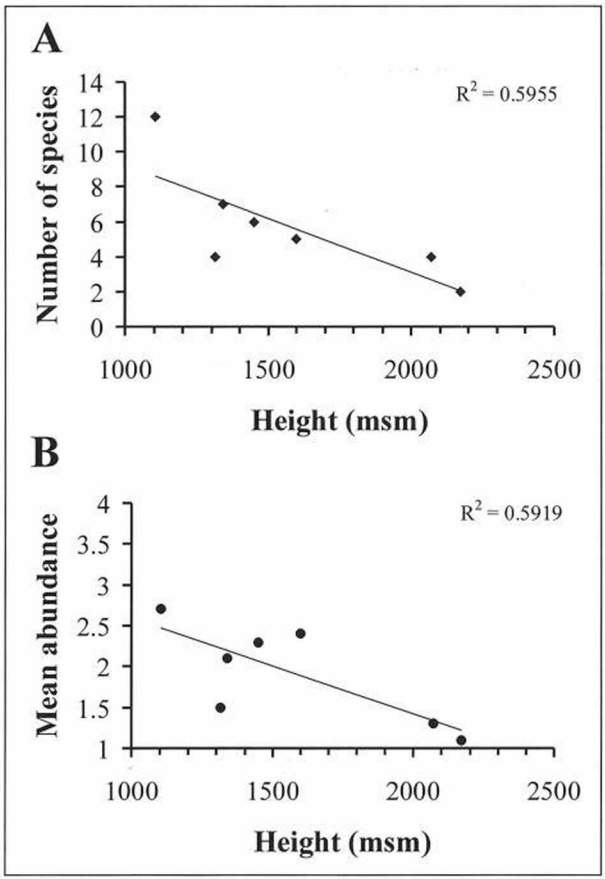

Fig. 5. Dependence of species diversity (A) and mean abundance (B) on the altitude of the investigated lakes. It has to be noted that the two storage lakes (Unterer Bockhartsee, Rotgüldensee) have not been included into the regression analyses. All other lakes are posited at the end of S-N-trending valleys and, therefore, seem to be appropriate for this comparison.

provide enough micro-habitats for molluscs. Additionally, the ground of both lakes is mainly composed of medium- to coarse-grained mineral substrate and therefore does not provide optimum conditions for gastropods and bivalves. As documented in previous studies (e.g. KUIPER 1974), storage lakes offer a possibility for the colonization by molluscs only in very specific cases. Considering the described aspects, the recently decided stop of any additional water power use in the Hohe Tauern has to be evaluated as very positive.

The mode of mollusc dispersal within inner-alpine regions is not fully clarified until now. In general, the transport of larvae or juveniles can be carried out by fishes, if the studied lake is connected with the water system via one or more brooks. As another possibility, the dispersal by birds and mammals should be also taken into account (e.g. PATZNER 1996; STURM 2000). However, the relatively high mollusc species diversity in the Jägersee should be partly caused by the dense population of ducks, colonizing the lake during the summer season and importing snails and mussels from adjacent waters. Within the group of mammals, mainly ruminants seem to be responsible for the dispersal of molluscs, which is, for instance, suggested by the occurrence of pill clams in cow traces (STURM 2000). As demonstrated by several mud snails, mollusc dispersal is carried out not only by passive transport, but also by active movement. *G. truncatula* can leave the water for a longer time and thus acts rather

autonomously concerning the occupation of new habitats. It has to be noted that the colonization of a lake or river by aquatic molluscs does not follow any specific strategy, but, depending on the biotope, takes place more or less randomly (GLÖER & MEIER-BROOK 2003).

Dependence of the species diversity and abundance on the sea level. As already pointed out in the results section, the number of mollusc species as well as their abundance are subject to a significant decrease with increase of altitude of the studied lakes. While in the lowermost located Jägersee, 12 species of freshwater snails and mussels could be collected during the field investigations, in the uppermost posited Kratzenbergsee, this number was reduced to 2. As illustrated in Fig. 5A, a linear relationship between sea level and species diversity could be worked out which largely corresponds with the respective results for the Swiss Alps documented by TURNER et al. (1998). According to the above mentioned authors, at 2000 msm a total number of 15 species can be observed, whereas at 3000 msm molluscs were absent. Regarding the mollusc abundance, a similar trend as for the species number can be obtained (Fig. 5B). While in lakes of the montane altitude level, mean abundance ranges from 1 to 100 individuals per m^2, in most habitats of the alpine altitude category, much less than 1 individual per m^2 is counted. It is a well known fact that water bodies at high altitudes are mainly reserved for generalistic species with very low demands to their environment (some pill clams and mud snails), whereas the montane lakes are additionally colonized by specialists (e.g. planorbids), depending upon higher contents of submersed vegetation and nutrients (GLÖER & MEIER-BROOK 2003).

Endangerment of the collected species. As summarized in Tab. 2, seven of the 13 mollusc species observed in the mountain lakes included in this study are assigned to the endangerment categories 2 to 4 of the Red List (FRANK & REISCHÜTZ 1994). Above all, the two planorbids *A. leucostoma* and *A. spirorbis* have to be evaluated as highly endangered (category 2). Both gastropods could be only found in lakes with sumptuous submersed vegetation (Jägersee, Schödersee). Contrary to these species, all molluscs occurring in the uppermost lakes (e.g. *G. truncatula, P. casertanum*) can be classified as not endangered (n.e.) at the moment and are often very abundant in waters of the alpine foreland. According to the presented results, the recent endangerment classification of the described species should be maintained. Meaningful corrections of this system are only justified after a significant increase of our knowledge concerning the mollusc colonization of alpine waters.

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