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A contribution to the biology and ecology of the threatened species *Anisus vorticulus* (Troschel, 1834) (Gastropoda: Pulmonata: Planorbidae)

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Received on February 28, 2007, accepted on March 6, 2007.
Published online at www.mollusca-journal.de

> Abstract

Our investigation revealed that *Anisus vorticulus* is characterized by interesting ecological and biological features. It is a robust species which tolerates frozen over waters in winter and dry waters in summer. It can build up a large population size within a year like a *r*-selected species, because the species breeds from March to July and even until November in the warm winter of 2006/2007. By this reproduction strategy, a remaining population which survived e.g. weed removal of its habitat, can reach large abundances within a short time again, if the habitat's conditions are the best. But concerning the habitat requirements *A. vorticulus* behaves like a *K*-strategist, because it can only live in sunlit habitats with clear water. It is specialised on periphytic algae which need the sun for their photosynthetic activity and anaerobic conditions are not optimal. Summarising we can say that *A. vorticulus* is a stenotopic *r*-strategist.

> Kurzfassung

Unsere Untersuchungen zur Biologie und Ökologie ergaben, dass *Anisus vorticulus* durch interessante biologische und ökologische Faktoren charakterisiert ist. Sie ist eine robuste Art, die Durchfrieren der Gewässer im Winter und Austrocknung im Sommer verträgt. *A. vorticulus* kann innerhalb eines Jahres hohe Populationsdichten aufbauen wie ein *r*-Stratege, da er sich von März bis Juli und im warmen Winter 2006/2007 sogar bis November vermehrt. Durch diese Vermehrungsstrategie kann eine Restpopulation, die z. B. die Entkrautung ihres Habitats überlebt hat, innerhalb kurzer Zeit wieder hohe Abundanzen erreichen, wenn die Habitatbedingungen optimal sind. Aber bezüglich der Habitatbedingungen verhält sich *A. vorticulus* wie ein *K*-Stratege, da er nur in sonnenexponierten Gewässern mit klarem Wasser dauerhaft leben kann. Er ist spezialisiert auf Aufwuchs, der die Sonne für die Photosynthese benötigt und für den anaerobe Verhältnisse nicht optimal sind. Zusammenfassend können wir sagen, dass *A. vorticulus* ein stenotoper *r*-Stratege ist.

> Key words

Anisus vorticulus, biology, ecology, management, conservation.

Introduction

The recent paper of Terrier & al. (2006) provides a good overview of more than hundred data from the literature concerning the threatened species *Anisus vorticulus* listed in the EU Habitats Directive and concludes that the knowledge of the biology and ecology of this species is very poor.

Our recent investigations of two distinct populations in the marshes of Hamburg (nature reserve Kirchwerder Wiesen), and flood plain of the Rhine near Karlsruhe revealed new information on the biology and ecology of *A. vorticulus*. We interpret these data by means of ecostatistical analyses, compare it to present knowledge, and discuss their relevance for conservation efforts.

Material and methods

In Hamburg the molluscs were collected by Diercking's method (Glöer 2002b). To carry out semiquantitative analyses we collected the molluscs on an area of ca. 1 m^2 every month per year in 2006. So

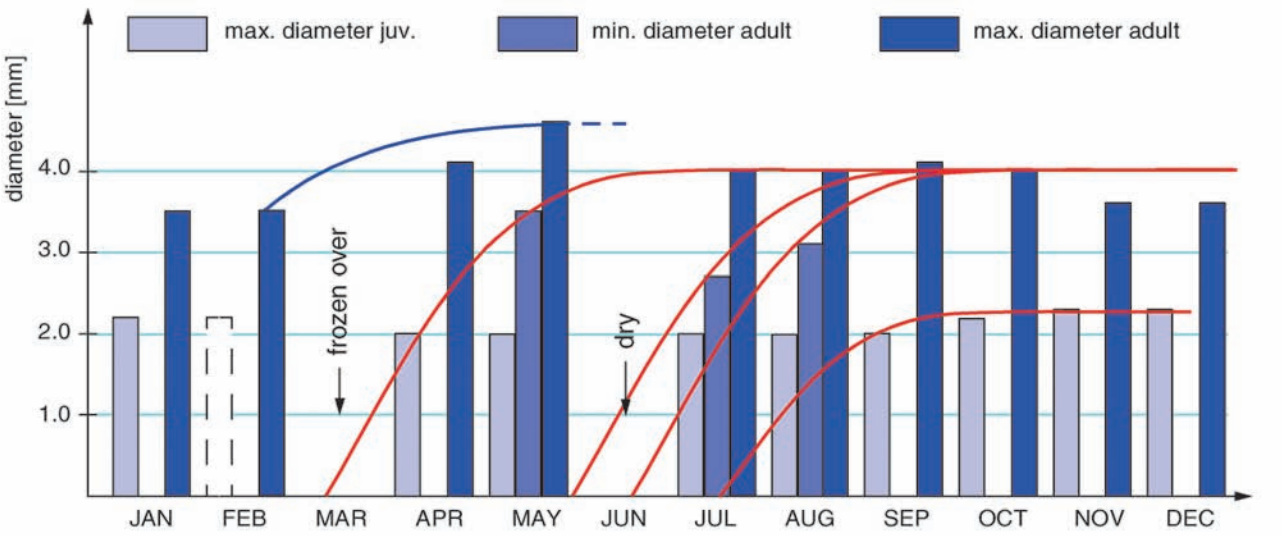

Fig. 1. Frequency of juvenile, young adult and adult specimens of *A. vorticulus* in the course of the year in Hamburg (May 2005 – April 2006). The measured specimens were collected at different sampling sites in the marshes of the river Elbe in Hamburg. **Red graph**: Growth rate of the juveniles and young adults; **blue graph**: Growth rate of the adults in their second year of life. Dotted column: juveniles could not be found.

Fig. 2. The shell of *Anisus vorticulus* (shell width = 3.5 mm). Features for determination see GLÖER 2002a, or GLÖER & MEIER-BROOK 2003.

we could examine, by measuring the shells, periods of reproduction and growth. On the other hand, we obtained a complete overview of the species' inventory of the sampling sites.

In Karlsruhe the shells were collected either from 1/10th m² bottom-samples of the substrate of the banks, taken in autumn of 2005 (GROH & WEITMANN 2005–2006) or from dredgings taken with a Surber-Sampler with a mesh-width of 0.5 mm. Probes were taken from the waterbody, the surface of the sole and from submerged and emerged vegetation of total 1 m² surface. The latter samples have been taken in October 2006 (GROH 2006).

Results and discussion

Regarding the distribution map of *A. vorticulus* of Germany (COLLING & SCHRÖDER 2006) our populations do not live in the main area of distribution which should be the colline region of Schleswig-Holstein and Mecklenburg-Vorpommern. However, we found abundances higher than 300 individuals/m² in Hamburg as well as near Karlsruhe. But at most sampling sites in Hamburg and Karlsruhe we could only find 1–50 ind./m².

MÜLLER & MEIER-BROOK (2004) mentioned high abundances of *Anisus vorticulus* in Brandenburg (Klein Plessower See: > 100 ind., Stübnitzsee: 11–100 ind.). Unfortunately the authors did not collect the specimens quantitatively, so their data are not comparable with ours, as it is with the results of TERRIER & al. (2006).

Biology of *Anisus vorticulus*

To get information about life cycle and longevity of *A. vorticulus* we collected this species every month of the year 2006 in the marshes of Hamburg. Regarding Falkner's laboratory experiments (mentioned in TERRIER et al. 2006, p. 198), copulation was observed between specimens with a shell diameter of at least 2.5 mm. So we could size-seperate the specimens, collected every month, into two groups: juveniles and adults. The adults were divided into small adults (2.5–3.0 mm) and large adults (> 3.0 mm). Analyses of these clusters/month revealed a clear picture of life cycle and longevity (Fig.1).

By the recent investigations we found specimens with a growing shell diameter up to May/June while the first juveniles seem to hatch in March, because the first specimens with a diameter of 2 mm could be found in April (Fig. 1). So we can conclude that *A. vorticulus* has a longevity of 17–18 month. In the first

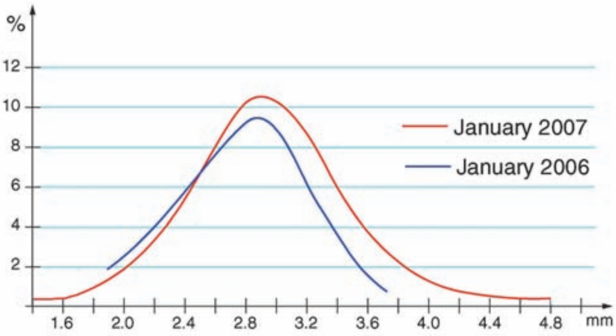

Fig. 3. Distribution of shell diameter [mm] in a population of *Anisus vorticulus* in Hamburg in January 2006 (n = 55) and January 2007 (n = 163).

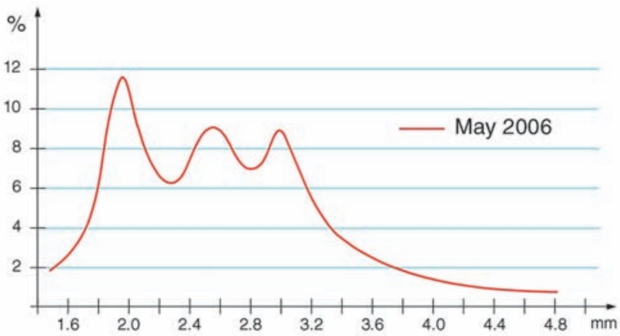

Fig. 4. Distribution of shell diameter [mm] in a population of *Anisus vorticulus* in Hamburg in May 2006 (n = 165).

year they reach at a width of 4 mm within 12 weeks. In the second year they reach their maximal size of 5–5.5 mm in May/June.

The growth rate of the shells (GRF = growth rate factor) from March to June is linearly calculated to be $GRF_{Mar\text{-}Jun}$ = 33 µm/day. This value corresponds to the values given by KILLEEN (1999) from Britain. In July this factor decreases to GRF_{Jul} = 18 µm/day down to $GRF_{Aug\text{-}Dec}$ = 11 µm/day for the adults in the second year. This decline of growth rate is possibly correlated with temperature. In spring the temperatures are similar to those in autumn, nevertheless the growth rate decreases at the end of the year, because it is a selective advantage for the specimens to survive the season of small food supply with smaller shells so they do not suffer a large tissue degrowth in winter (ELEUTHERIADES & LAZARIDOU-DIMITRIADOU 1995).

The highest abundances of adults appear in May/June, while the adults of the former year are still living, and from September, when the newborn are fully grown. So we can conclude that the juveniles, hatched in spring, breed in the same year until June/July. Thus we can say that *A. vorticulus* is iteroparous.

For the first time PIECHOCKI (1975) studied the egg masses of *A. vorticulus* on a population from Poland, according to which the specimens produce egg capsules which contain 4–5 eggs, of which not all are developed. KILLEEN (1999) assumes that there is a high mortality among the juveniles. In most regions, where *A. vorticulus* occurs, it can be found in small abundances (< 20 ind./m^2) up to > 482 ind./m^2. Maybe the reproduction rate correlates with the habitat's quality and if the optimum conditions are not reached, eggs are developed to a lower extent or mortality of the juveniles becomes higher.

Population structure

In winter the population structure measured by the shell diameter follows a Gaussian distribution (Fig. 3). In the warmer winter of 2006/2007 there were some more smaller as well as larger shells than in January of 2006. So it seems to be that breeding time and growth rate are correlated with temperature. In the warm winter of 2006/2007 we found in January specimens with a shell diameter of 1.3 mm, which hatched in November, calculated by the $GRF_{Aug\text{-}Dec}$ mentioned above.

In summer we could not find a Gaussian distribution (Fig. 4) because there occurs a periodically hatching of the juveniles every 12–18 days, calculated by the $GRF_{Mar\text{-}Jun}$ mentioned above.

Dispersal and colonisation

We found *A. vorticulus* in many biotopes of a large area which do not present the optimum conditions. So we do not believe that the species survived in these habitats for many years. Thus we have to assume that passive dispersal, e.g. by birds, is not a problem for this small gastropod. But only if it reaches habitats of optimal conditions by vectors it can build up stable populations. Only with that can we explain the occurrence of small populations of *A. vorticulus* in many distinct biotopes, as mentioned in the literature and found by us, too.

Ecology of *Anisus vorticulus*

For the following analyses of habitat preference we studied 28 populations of *A. vorticulus* with abundances from 1–482 ind./m^2.

Sediment preference. A sediment preference is not visible. The sediment can be sandy, loamy or earthy with portions of organic matter (Tab. 1).

Phytal preference. 27.3 % of the populations studied lived in waters without submerged vegetation. After WATSON & ORMEROD (2004, p. 232) the abundance of *A. vorticulus* is directly proportionally correlated

Tab. 1. Sediment preference of *Anisus vorticulus* in Hamburg (n=28).

mud		**earthy to sandy**		**sand**	
soft	solid	peaty	detritus	fluffy	solid
2.7%	23.1%	25.6%	35.8%	2.7%	10.1%
25.8%		**61.4%**		**12.8%**	

Tab. 2. Biotop preference of *Anisus vorticulus* in Hamburg (n=28).

river		**canal**	**brook**	**ditch**		**pond**
not near-natural	near-natural	without tide	near-natural	permanent	temporary	sunlit
3.3%	20.0%	3.3%	3.3%	30.0%	23.3%	6.6%
23.3%		**3.3%**	**3.3%**	**53.3%**		**13.2%**

with the abundance of floating plants but inversely proportionally correlated with the abundance of submerged vegetation. However, we could not find such a correlation between the abundance of *A. vorticulus* and submerged or floating vegetation.

Biotop preference. A preference on a special biotop is not significant (Tab. 2).

The analyses of the ecological data concerning the type of waters revealed that *A. vorticulus* lives in Hamburg in standig to slowly flowing waters or lentic regions of rivers and canals (Tab. 2). In Karlsruhe the main biotopes were pond-like oxbows behind the dams, so only influenced by groundwater level fluctuations and only exceptionally perennial slowly running ditches. In the literature many different types of waters are mentioned as biotops for *A. vorticulus* (refered in TERRIER & al. 2006).

Associated freshwater molluscs

Anisus vorticulus is associated with numerous freshwater gastropods which are predominantly euryoecious (Tab. 3).

The associated species which live in both regions together with *A. vorticulus* are ubiquists or are indifferent concerning the habitat preference, so we cannot reach at a conclusion which habitat is preferred by this associations. *Valvata cristata* reaches the highest abundances in small ponds with rich vegetation which is in contradiction to *Hippeutis complanatus* with its highest abundances in ponds with a muddy sediment and missing submerged vegetation. Analysing the preferred habitats by the associated gastropod fauna as well as the differential analyses between the molluscan communities in Hamburg and Karlsruhe gives no clear result. The associated mollusc fauna seems to be stochastically assembled.

The mean value of the number of species associated with *A. vorticulus* in Hamburg is 15.3, with a minimum of 3 and a maximum of 26 species. The mean value of species density in Hamburg is 13.5 species/habitat with a maximum of 34 species/habitat. In Hamburg, *A. vorticulus* could never be found in association with the stenotopic species *Omphiscola glabra* and *Aplexa hypnorum*. In Karlsruhe, the mean value of associated species is 16.2 species/habitat within a range between 4 and 26 (n = 38). Here it was only rarely (15.8%) found together with the stenotopic species *Aplexa hypnorum*.

A significant co-occurrence with bivalved molluscs could not be detected (Tab. 4), though many Sphaeriidae are good indicators for habitat types (MEIER-BROOK 1975, GLÖER 2006a, ZETTLER & GLÖER 2006).

The results of ecostatistical analyses of habitat preferences and associated molluscs were indifferent and not convincing, in case we used all data available. However, a differential analysis of the habitats in Hamburg and Karlsruhe with the highest abundances revealed a clear picture of habitat preference under the premise that the habitat with the highest abundance provides optimal conditions.

A. vorticulus prefers sunlit waterbodies of low and clear water. The biotopes can be drainage ditches or pond-like oxbows. The water level can fluctuate and a short pessimal time, during the waterbody is dried out or frozen over in winter, can be survived by *A. vorticulus*. In such habitats, we found in Hamburg as well as in Karlsruhe the ninespine stickleback *Pungitius pungitius* (Linnaeus, 1758) and the weatherfish *Misgurnus fossilis* (Linnaeus, 1758). In the preferred habitats of *A. vorticulus* only these piscine species can survive (DIERCKING & WEHRMANN 1991).

The chemical water quality is not a limiting factor if we take the chemical data mentioned by TERRIER & al. (2006, p. 196, Tab. 1) from France into consideration, which give the result of saprobic classification of approximately III. The decisive factor for *A. vorticulus* is a sufficient nutrient level (mesotrophic in a natural way) coincident with clear water. In shallow and clear

Tab. 3. Communities of *A. vorticulus* with freshwater gastropods in habitats in which *A. vorticulus* occurs in abundances > 50 ind./m². Species which are associated with *A. vorticulus* in 2/3 or more of all studied sampling sites (in both regions n=8) in Hamburg as well as in Karlsruhe, are marked in grey. **HH** = Hamburg, **KA** = Karlsruhe.

Species name	Presence [%]		Species name	Presence [%]	
	HH	KA		HH	KA
Viviparus contectus	62.5	–	*Lymnaea stagnalis*	87.5	12.5
Bithynia tentaculata	62.5	87.5	*Physa fontinalis*	87.5	12.5
Bithynia leachii	87.5	–	*Planorbarius corneus*	100	–
Bithynia troschelii	37.5	–	*Planorbis planorbis*	87.5	12.5
Marstoniopsis scholtzi	37.5	–	*Planorbis carinatus*	25.0	25.0
Valvata cristata	87.5	100	*Gyraulus albus*	62.5	62.5
Valvata piscinalis	25.0	12.5	*Gyraulus riparius*	12.5	–
Acroloxus lacustris	12.5	87.5	*Gyraulus parvus*	–	12.5
Galba truncatula	–	62.5	*Gyraulus crista*	25.0	12.5
Stagnicola palustris	25.0	50.0	*Anisus vortex*	100	62.5
Stagnicola corvus	75.0	12.5	*Bathyomphalus contortus*	87.5	50.0
Radix auricularia	12.5	–	*Segmentina nitida*	87.5	25.0
Radix balthica	37.5	–	*Hippeutis complanatus*	75.0	87.5

Tab. 4. Communities of *A. vorticulus* with freshwater Bivalvia in habitats in which *A. vorticulus* occurs in abundances > 50 ind./m². **HH** = Hamburg, **KA** = Karlsruhe.

Species name	Presence [%]		Species name	Presence [%]	
	HH	KA		HH	KA
Sphaerium corneum	–	25.0	*Pisidium milium*	12.5	62.5
Sphaerium nucleus	75.0	25.0	*Pisidium casertanum*	25.0	–
Musculium lacustre	25.0	12.5	*Pisidium pseudosphaerium*	–	37.5
Pisidium nitidum	12.5	12.5	*Pisidium obtusale*	12.5	25.0
Pisidium subtruncatum	–	12.5			

water the ground is warming up more rapidly than in turbid water, which results in a diurnal circulation of oxygenous water in summer, and hinders anaerobic conditions in the substrate by means of production of toxic compounds like hydrogen sulphide. Biological inventory of the Lettenlöcher, small ponds in the floodplain of the Rhine, revealed no *A. vorticulus*, where the sediment was anaerobic. After aeration of these ponds *A. vorticulus* could be found in abundances of 60–150 ind./m² (Fuchs 2007).

On the other hand the light in clear water promotes photosynthetic activity of periphytic algae (Aufwuchs), possibly diatoms, the food of *A. vorticulus*. For foraging there is a need of substrate for the Aufwuchs, which can be a thin organic matter, peat, dead tissues of submerged or emerged aquatic plants, or woody litter, as well as aquatic macrophytes. Because *A. vorticulus* prefers sunlit waters, it seems to be specialised on food which needs the sunlight. So we consider that *A. vorticulus* is a food specialist and by this a stenotopic species. Surprisingly, in the same waterbody the banks which are exposed to sunlight bear much higher densities of *A. vorticulus* than similar looking but partly shaded banks at the opposite side of a narrow oxbow (e.g. Oberer Eggensteiner Altrhein: sun-exposed northern bank: 56–181 ind/m², shaded southern bank: 1–28 ind./m²).

After we found these habitat preferences by ecological statistical analysis we searched for such habitats precisely and could find more habitats in Hamburg which are inhabited by *A. vorticulus* in abundances up to 482 ind./m².

Summarising (Tab. 5) we can state that *Anisus vorticulus* in Germany is an ecologically robust species, which tolerates frozen-over waters in winter and dried-out waters in summer. It can build up large population sizes within a year like a *r*-selected species. But concerning the habitat requirements *A. vorticulus* behaves like a *K*-strategist, because it can only survive in sunlit habitats with clear water.

Tab. 5. Summarized data on biology and ecology of *Anisus vorticulus*.

Distribution	European to south-western Sibirian
Longevity	17–18 months
Reproduction	iteroparous; breeding time: March–July/August or longer depending upon temperature; specimens hatched in March breed in July/August of the same year, periodically every 12–18 days
Hibernation/Estivation	tolerates frozen over waters in winter and dried out waters in summer
Food	epiphytic algae (Aufwuchs) which need sunlit waters with substrate of thin organic matter, dead tissues of submerged or emerged aquatic plants, or woody litter, as well as aquatic macrophytes; food specialist
Water quality	clear water, mesotrophic in a natural way
Habitat	sunlit waterbodies of shallow and clear water, the biotopes can be drainage ditches, floodplains or oxbows
Population structure	The highest abundances of adults appear in May/June, while the adults of the former year are still living, and from September, when the newborn are fully grown.
Association	stochastic

Tab. 6. Criteria for evaluation of preservation state of the population of *A. vorticulus*.

Condition of Population	**A** (excellent)	**B** (good)	**C** (middling to bad)
Population density	> 50 ind./m^2	10 - 50 ind./m^2	< 10 ind./m^2
Population structure	> 50 % ind. < 2.7 mm	25–50 % ind. < 2.7 mm	< 25 % ind. < 2.7 mm
Habitat quality	**A** (excellent)	**B** (good)	**C** (middling to bad)
Habitat	Sunlit shallow stagnant or very slow running waterbodies with fluctuating waterlevel, mostly perennial, only temporarily outdrying drainage ditches; partly covered with submerse and emerse vegetation; natural banks.	Dammed watercourses exposed to sunlight; drainage ditches covered with submerse and emerse vegetation; mostly natural banks.	Partly shaded channels with slow current or dammed, submerse vegetation only near to the banks; artificial banks.
Consistency of Sediment	Loamy or earthy sediment with a thin layer of organic matter (detritus, peat, dead tissues of submerged or emerged aquatic plants or woody litter); aerobic.	Loamy or earthy sediment with a layer of dead tissues of submerged or emerged aquatic plants, aerobic.	Sediment with a layer rich in dead tissues of submerged or emerged aquatic plants or woody litter; prevailing anaerobic.
Water quality	clear water, saprobic classification II, II-III	clear water, saprobic classification II-III	turbid water, saprobic classification III
Impairments	**A** (none to low)	**B** (middling to bad)	**C** (intense)
Site management	Weed cut carried out carefully fenced in to hinder that cattles can destroy the border of the water.	Weed cut periodically (one time per annum) not carried out carefully. Not fenced in to hinder that cattles can destroy the border of the water.	quite often (more than one time per annum) weed cut. Not fenced in to hinder that cattles can destroy the border of the water.

Conservational evaluation and protection

If the conditions that prevailed in a habitat were optimal, we found in each case more than 50 ind./m². At sampling sites with less than 50 down to 10 ind./m² the species could exist and a change for the better by habitat management could help the species to build up a more stable population. Less than 10 ind./m² were mostly found at samp-ling sites which were not characteristic for *A. vorticulus*.

Habitat management

Weed removal does not seem to influence the population size of *A. vorticulus* but has to be carried out carefully. In some managed waters in the marshes of the Elbe in Hamburg, where the vegetation is regularly cut every year, we found the species in high abundances. Also the massive removal of water vegetation and of the up to 1 m thick anaerobe mud from an oxbow of the Rhine river led to no significant decrease in the population of *A. vorticulus* nearby the banks after 1 year (Oberer Eggensteiner Altrhein).

As *A. vorticulus* cannot be removed quantitatively, the remaining specimens can build up a new population in a short time because they breed over a long time span in the year.

To protect the habitats of *Anisus vorticulus*, the bankside vegetation which shades the water should be cut out. Areas in agricultural use should be fenced in to avoid that cattle can destroy the bank of the water. The prevention of pollution with toxic chemicals or fertilizers should be a matter of course.

The summarised data for conservational evaluation and protection of *A. voticulus* as a result of our investigations in Germany are given in Tab. 6.

Acknowledgements

We like to express our thanks to Reinhard Diercking for collecting the molluscs in Hamburg, to Dr. Ira Richling, and Gerhard Weitmann for their assistance in collecting in Karlsruhe. Parts of our investigations resulted from the EU-LIFE-project “Lebendige Rheinauen bei Karlsruhe” as well as from an expert’s opinion concerning the evaluation of *A. vorticulus* in a Natura 2000 habitat in Hamburg.

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