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The situation of the freshwater mussel *Unio crassus* (Philipsson, 1788) in north-east Germany and its monitoring in terms of the EC Habitats Directive

Michael L. Zettler [1] & Uwe Jueg [2]

[1] Baltic Sea Research Institute, D-18119 Rostock, Seestrasse 15, Germany
michael.zettler@io-warnemuende.de
[2] D-19288 Ludwigslust, Schweriner Allee 16, Germany
uwejueg@t-online.de

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> Abstract

Since the beginning of the mussel monitoring programme in 1993 *Unio crassus* has been observed in 52 watercourses of Mecklenburg-Vorpommern (north-east Germany). Although this number seems to be high, it has to be stressed that in more than half of the waterways this species became extinct and only empty shells indicated former populations. Eighteen brooks or rivers currently harbour *U. crassus*. The population size varied between hundred and six hundred thousand per river. The populated river length in Mecklenburg-Vorpommern was in most cases less than 10 km. Only three rivers (Nebel, Sude and Warnow) had populated lengths longer than this. Altogether, the length of running waters populated by *U. crassus* in Mecklenburg-Vorpommern was 134 km. About 1.5 million specimens of *U. crassus* inhabit these waters. Due to the consideration of *U. crassus* within the EC Habitats Directive, Mecklenburg-Vorpommern initialised a yearly monitoring scheme starting in 2003. The authors were authorised to perform the monitoring according to previous methods used at the national level. The population dynamics, abundance development and density were shown from different *U. crassus* locations. One of the main factors conjuncted with the decline of *U. crassus* was the increased nitrate-nitrogen content caused by eutrophication. Juveniles were recorded only in watercourses with NO_3-N values around or below 2 mg/l. Furthermore, other causes are stressed. In terms of the EC Habitats Directive a monitoring scheme is needed in Europe so that fast action can be taken to increase protection status to an adequate level.

> Kurzfassung

Die Situation der Bachmuschel *Unio crassus* (Philipsson, 1788) in Nordost-Deutschland und ihr Monitoring im Hinblick auf die europäische FFH-Richtlinie. – Seit Beginn des Großmuschel-Monitorings im Jahre 1993 wurde *Unio crassus* in 52 Fließgewässern von Mecklenburg-Vorpommern (Nordost-Deutschland) nachgewiesen. Obwohl diese Anzahl ziemlich hoch zu sein scheint, muss betont werden, dass in mehr als der Hälfte der Gewässer die Art inzwischen ausgestorben ist und nur noch Leerschalen ein ehemaliges Vorkommen indizieren. In 18 Bächen und Flüsse kommt *U. crassus* aktuell noch vor. Die Populationsgrößen variierten zwischen 100 und 600.000 Individuen pro Gewässer. In den meisten Fällen betrug die besiedelte Gewässerlänge weniger als 10 km. Nur in 3 Flüssen (Nebel, Sude und Warnow) wurden längere Abschnitte von der Bachmuschel bewohnt. Insgesamt waren in Mecklenburg-Vorpommern 134 km Gewässerlänge von über 1,5 Millionen Individuen von *U. crassus* besiedelt. Durch die Berücksichtigung der Bachmuschel in der EU FFH-Richtlinie motiviert, initiierte Mecklenburg-Vorpommern seit 2003 ein jährliches Monitoring. Die Autoren wurden beauftragt, dieses Monitoring in Anwendung national abgestimmter Methoden durchzuführen. In der vorliegenden Studie werden die Populationsdynamik, die Abundanzentwicklung und die Besiedlungsdichte von verschiedenen Standorten aufgezeigt. Als ein vermuteter Hauptfaktor für den Rückgang von *U. crassus* wird der Nitrat-Stickstoffgehalt, verursacht durch Eutrophierung, hervorgehoben. So wurden Juvenilstadien nur in Gewässern mit NO_3-N-Werten < 2 mg/l beobachtet. Andere den Rückgang verursachende Faktoren werden ebenfalls aufgelistet und diskutiert. In Hinblick auf die FFH-Richtline wird ein international abgestimmtes Monitoring-Schema gebraucht, um diese in Europa vom Austerben bedrohte Art schnellstmöglich in adäquate Schutz- und Managementprogramme zu involvieren.

> Key words

Unio crassus, Unionidae, population size, freshwater, Germany, EC Habitats Directive.

Introduction

The “brook mussel” (in German: Bachmuschel) *Unio crassus*, listed as an endangered species in Germany as well as in most other European countries, is primarily confined to Europe and western Asia**,** from the Iberian Peninsula in the west to the Ponto-Caspian region in the east (NAGEL 1988). The distribution area reaches northwards to Skandinavia and southwards to the Mediterranean watershed. Historically this species was widespread in tributaries of almost all rivers in Germany. The decline of *U. crassus* observed already by ISRAEL (1913) and JAECKEL (1952) has become more rapid in recent years (ENGEL 1990; HOCHWALD 1997; LECHNER 1999). In most other European countries extinction and decreasing population densities have been observed as well. This dramatic change led to consideration of this species within the EC Habitats Directive (e.g. COLLING & SCHRÖDER 2003). Most current explanations for the decline of this mussel focus on man-made degradation of habitats and water quality. Factors affecting *U. crassus* populations include agricultural, industrial as like as domestic pollution and run-off (ENGEL & WÄCHTLER 1992; HOCHWALD 2001; ZETTLER et al. 1995). Dredging and weed cutting also have an impact on mussel populations (ALDRIDGE 2000; ENGEL & WÄCHTLER 1990). However, changes in water and habitat quality do not only affect mussels directly, but also indirectly e.g. by influencing the density and the composition of the ichthyofauna. Before *U. crassus* is able to grow as a mussel in the sediment the larvae (glochidia) must undergo a period of metamorphosis as ectoparasite on specific host fishes. A specialists workshop on the Island of Vilm in 1999 estimated the entire German population size of *Unio crassus* to be approximately 1 million individuals. We conclude that about 90 % of the German population has been lost during the last few decades. Over 90 % of the remaining individuals are thought to occur in the federal state of Mecklenburg-Vorpommern.

Previous studies have documented the state of unionids in stagnant and running waters (see WEBER 2005 for citations). In terms of *Unio crassus* in Mecklenburg-Vorpommern, we have a good picture of distribution (ZETTLER 1999a; ZETTLER & JUEG 2001), morphology and growth (ZETTLER 1997, 2000). However, very little information exists on population dynamics, density and stock of this highly endangered species across its whole distribution range. This study had three major objectives:

- to show the recent distribution and the population size of *U. crassus* in north-east Germany;
- to describe the population dynamics and abundance of *U. crassus* in selected rivers; to understand the causes for successful reproduction and the decline of this species.

Material and methods

The study area is Mecklenburg-Vorpommern, a federal state in the north east of Germany (Fig. 1). With more than 28,000 km of running waters and 720 km² lakes and ponds within a land area of 23,000 km² Mecklenburg-Vorpommern encloses a large proportion of Germany’s freshwater habitats. Since the beginning of the 1990s the authors have measured the occurrence of unionid mussels across all running waters in Mecklenburg-Vorpommern. Due to its rapid decline over the whole study area *Unio crassus* was of particular interest. Each watercourse was surveyed by diving or hand sampling, depending on water depth. In addition, a hand held screen was used for scraping gravel and sieving sandy substrates and a bathiscope was used for watching the mussel sipho openings at the sediment surface (Fig. 2). Due to the consideration of *U. crassus* within the EC Habitats Directive Mecklenburg-Vorpommern started a yearly monitoring programme in 2003. The authors were authorised to perform the monitoring using methodology previously carried out at the national level. The first author was closely involved in the compilation of a catalogue for the assessment of the *U. crassus* population. For further informations see KOBIALKA & COLLING (2006).

Each watercourse in Mecklenburg-Vorpommern depending on its length was divided into sections. Each section was sampled at least once during the last 10 years, usually several times. Rivers where *U. crassus* occurred [1] were included in the monitoring programme. Every year (since 2003) at 10 to 13 stations abundance, population dynamics and reproductive success of *U. crassus* was studied. The monitoring programme has a 6-year cycle, i.e. after 5 years the programme starts again. Only one water body (River Löcknitz with 3 stations) took readings each year. Altogether 23 watercourses with 55 stations were included. At each station two different areas were selected each containing one “brook meter” (BM) – 1 meter running length – which was checked completely for living mussels using the methods described above. All living *U. crassus* were counted, measured and their age (and shell length) was determined. For catching the juveniles it is necessary to sieve the sediment (q. v. RICHARDSON & YOKLEY 1996). To calculate the population size, the mean density (from the two different BMs at each station) was multiplied by the running length of each section. The whole population size of Mecklenburg-Vorpommern was calculated from the sum of all sections along each watercourse.

[1] Only living populations were considered.

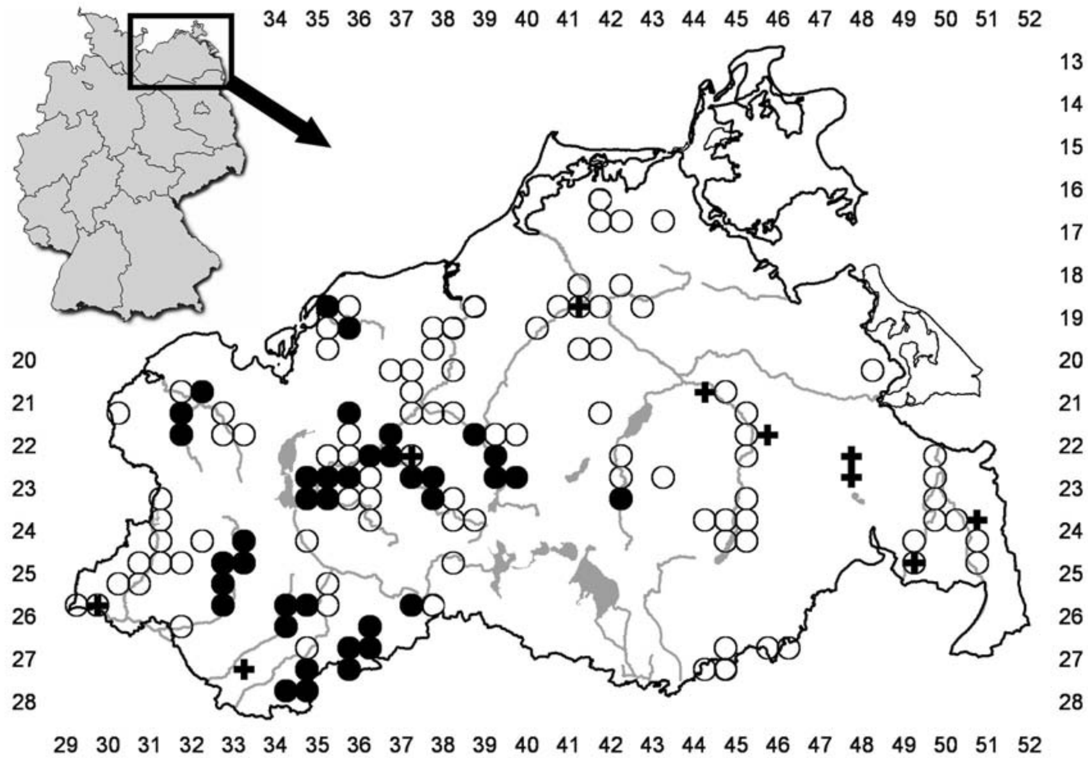

Fig. 1. Distribution of the freshwater mussel *Unio crassus* in north-east Germany (Mecklenburg-Vorpommern). Black dots mark locations with current occurrence, circles indicate extinct populations and crosses refer to subfossil records. The map bases on quarter raster of an ordnance map (1:25,000).

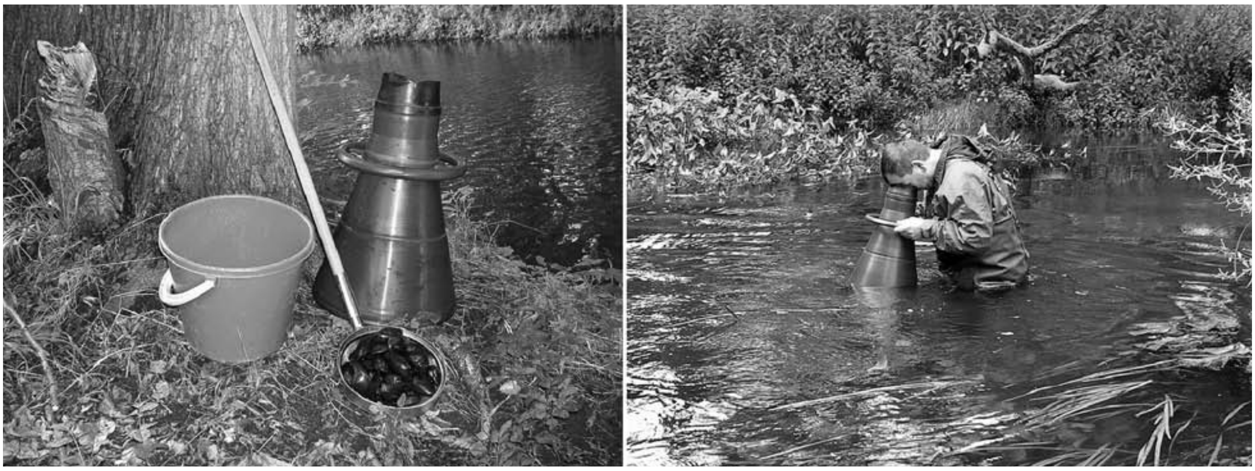

Fig. 2. The equipment for the monitoring of unionid mussels in running waters. On the left hand side a bucket for storage the mussels, a hand held screen for scraping gravel and sieving sandy substrates and a bathiscope for watching the mussel sipho openings at the sediment surface (see right).

This monitoring scheme was used e. g. in the study of Hartenauer (2006). Two differing methods were stressed and should be discussed at this place. First she changed the transect length from one brook meter to an adequate length. Of course, the transect length should adapted to the investigated water system. However, for the calculation of population size (individuals of the whole water body) the averaged density (individuals per brook meter) will needed. In our experience the limits of the density per brook meter given in Kobialka & Colling (2006) are representative for each (small or large) water body whereas the abundance per square will never work. The investigators have to pay attention on the selection of representative subareas. Secondly Hartenauer (2006) argued against the shell length measurement and reduced the individual measurements to the age. The shell length determination is the simplest way to receive an information of the population structure. Of course the shell length parameters per age could vary enormously (Zettler 1997, 2000).

Tab. 1. Population inventory of the freshwater mussel *Unio crassus* in Mecklenburg-Vorpommern. Monitoring watercourses are indicated by an asterisk.

watercourses	specimens	juveniles	last inspection	remarks
Aalbach (Barkow)	0		1996	extinct since decades
Aalbach (Malliner Wasser)	0		1998	extinct since decades
Barthe*	0		2007	extinct recently
Beke	0		1997	extinct since decades
Besendorfer Graben*	16,000	yes	2003	
Bresenitz*	93,250	yes	2006	
Brüeler Bach	0		1996	extinct since decades
Datze	0		1996	extinct since decades
Elbe	0		2005	extinct since decades
Elde	0		2006	extinct since decades
Gehlsbach*	0		2007	extinct recently
Godendorfer Mühlbach	0		1996	extinct since decades
Göwe*	51,000		2004	
Großer Hellbach*	2,000		2004	
Hohensprenzer Mühlbach	0		1996	extinct since decades
Kleiner Hellbach*	1,500		2004	
Kösterbeck*	0		2006	extinct recently
Krüseliner Bach	0		1996	extinct since decades
Landgraben	0		2000	extinct since decades
Lewitzkanal	0		1996	extinct since decades
Libnower Mühlbach	0		1996	extinct since decades
Linde	0		1996	extinct since decades
Löcknitz*	148,300	yes	2006	
Löcknitz-Mühlbach*	34,400	yes	2003	
Lößnitz	0		1996	extinct since decades
Ludwigsluster Kanal*	6,200		2004	
LV 97 (Bandenitzer Bach)*	1,400		2003	
Meynbach*	5,000		2003	
Mildenitz*	0		2007	extinct recently
Moosterbach*	500		2007	near extinction
Motel*	1,000		2002	
Motel (Wittenburger Bach)	0		1996	extinct since decades
Mühlenbach (Kirch Rosin)	0		1996	extinct since decades
Nebel*	618,835	yes	2006	
Ostpeene*	100		2007	near extinction
Peene (Alt Sürkow)	0		1996	extinct since decades
Radebach	0		1996	extinct since decades
Radegast*	86,000	yes	2004	
Randow	0		2001	extinct since decades
Recknitz	0		2003	extinct since decades
Rögnitz	0		1996	extinct since decades
Schaale	0		1993	extinct since decades
Stepenitz	0		1996	extinct since decades
Sude*	132,000		2003	
Teppnitzbach*	54,600	yes	2005	
Thymenfließ*	0		2007	extinct recently
Tollense	0		2004	extinct since decades
Trebel	0		1996	extinct since decades
Uecker	0		1996	extinct since decades
Waidbach	0		1996	extinct since decades
Warbel	0		1996	extinct since decades
Warnow*	287,425	yes	2005	
total	**1,539,510**	**8**		

The shell length data could have an eminent importance in comparison of the same water body between the different monitoring years. Especially for the older specimens the age is often hardly to estimate and vary between the operator significantly. But for the assessment of the population structure only the presence/absence or percentage of the youngest individuals are to be indicated (Kobialka & Colling 2006).

The main abiotic parameters (current, water depth and width, sediment structure, vegetation, shadow) were recorded locally. Chemical values (nitrate nitrogen, phosphate, temperature etc.) were supplied by the Federal Ministry of Environment.

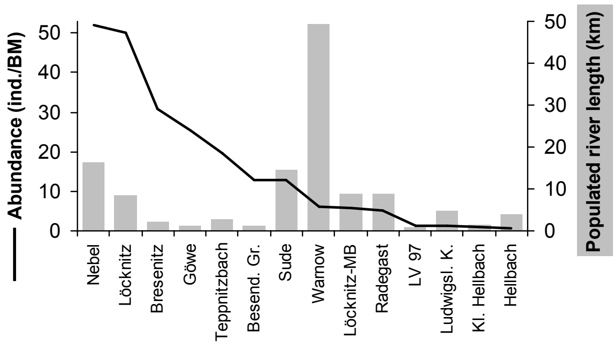

Fig. 3. The abundance (individuals per brook meter) of *Unio crassus* in Mecklenburg-Vorpommern and the populated river lengths in km. Only since 2003 monitored watercourses are included. 8 rivers are not considered, but previous results showed that the length not reached 10 km altogether.

Results

Since the beginning of the mussel monitoring programme in 1993 *U. crassus* has been observed in 52 watercourses [1] in Mecklenburg-Vorpommern (Tab. 1, Fig. 1). Although this number seems to be high, it has to be stressed that in more than half of the sites this species became extinct and only empty shells indicated former populations. Eighteen brooks or rivers currently harbour *U. crassus*. The population size varied between hundred and six hundred thousand. The populated river length in Mecklenburg-Vorpommern is in most cases less than 10 km (Fig. 3). In only three rivers (Nebel, Sude and Warnow) the populated length was greater than this. The total populated running length of waters in Mecklenburg-Vorpommern was 134 km. About 1.5 million individuals of *U. crassus* inhabit these waters (Tab. 1).

Recruitment of juveniles (10–30 mm or 1 to 3 years old) was recorded in only eight watercourses. With about 150,000 individuals the River Löcknitz [2] is one of the best populated water bodies within Germany (Tab. 1 and Fig. 4). A unique long-term study from 1995 to 2006 allowed us to see the development and the population dynamics of *U. crassus* in this selected site. Plots of length-frequencies showed balanced population dynamics only for the first 5 years. Since 2001 a unimodal distribution was visible, with a notable absence of small individuals. Whereas the abundance remained relatively stable and varied between 100 and 180 ind./BM the percentage of juveniles decreased continuously after 2000 (Fig. 4 and 5). During the first 5 years 40 % or more individuals of the population belonged to juvenile cohorts. After 2002 a maximum of only 10 % of individuals was recorded as juveniles.

In most of the waterbodies *U. crassus* was not found at all sites. Colonisation occurred particularly in the middle of the running water systems. The abundance varied greatly (Fig. 6). The current environmental conditions of the upper and lower courses of the rivers inhibit the occurrence of *U. crassus*. Formerly the conditions are likely to have been more suitable, as is indicated by the presence of old shells.

One of the main factors conjuncted with the decline of *U. crassus* is the increased nitrate nitrogen content caused by eutrophication (Fig. 7). Juveniles were only recorded in watercourses with NO_3-N values around or below 2 mg/l. Unfortunately these conditions do not exist in all waterbodies. The largest and most balanced population cohorts were harboured by waters with very low NO_3-N contents. Most of the *U. crassus* populations in locations with NO_3-N concentrations clearly above 2 mg/l were extinct or are near extinction. The River Sude seems not to fit this trend but although the population size is very high (see Fig. 5 and 6) no juveniles were observed. Age-class distribution of live mussels collected at four sites showed an excess of older mussels. The average life expectancy of *U. crassus* in the River Sude was 16 years and in 2003 the mean age 10 years.

Discussion

Considering literature from other federal states of Germany (e. g. Bock et al. 2004; Colling & Schröder 2003; Engel 1990; Hochwald 1997; Kobialka & Misere 2005; Lang 2000; Lechner 1999; Petrick

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1 Here both the living and extinct populations were considered.

2 Here only the part of Mecklenburg-Vorpommern was considered. *U. crassus* occurs in the adjacent Brandenburg as well, but only in low numbers (Zettler 1999b).

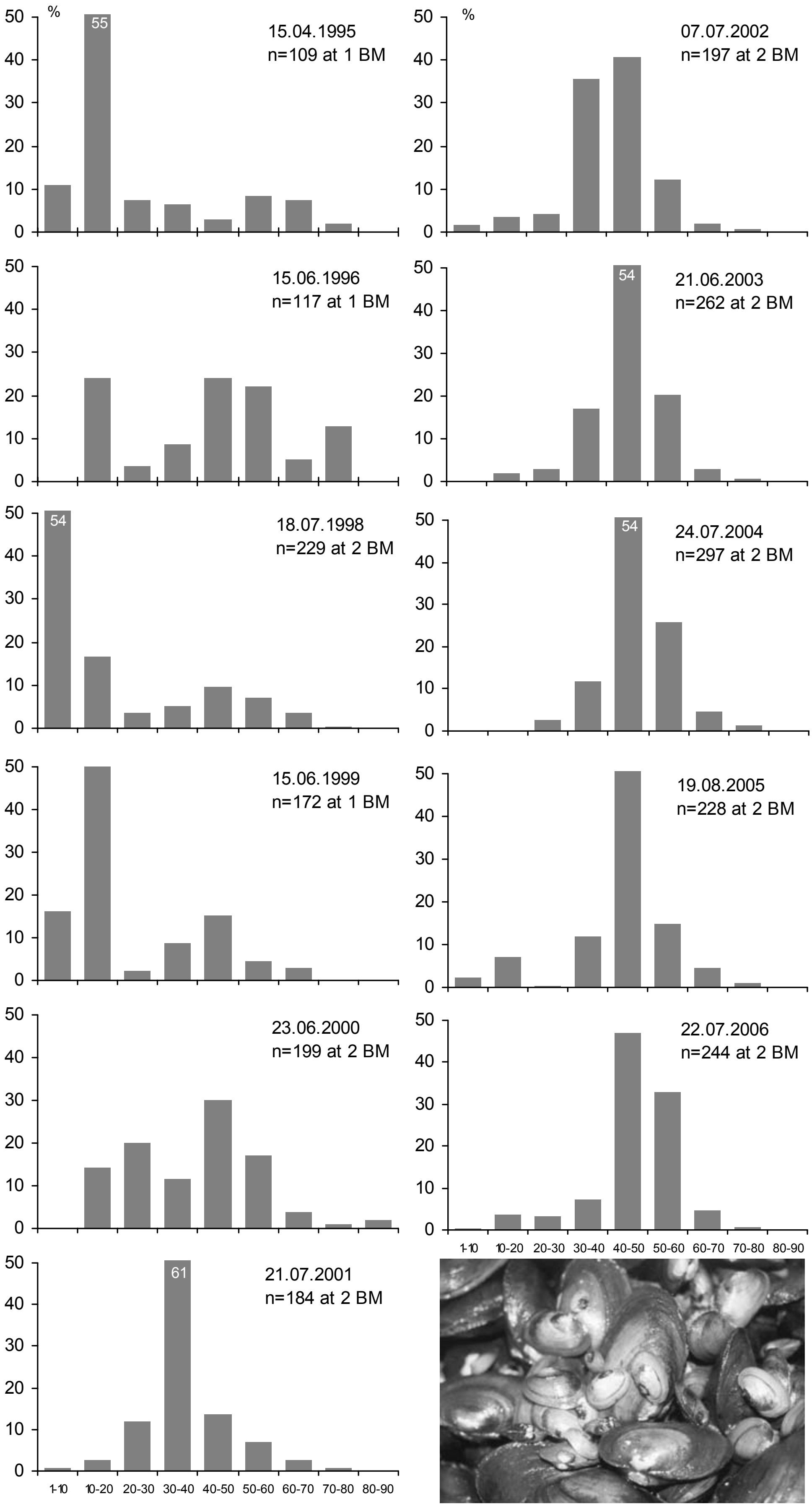

Fig. 4. Population dynamics of *Unio crassus* in the brook Löcknitz near Ziegendorf from 1995 to 2006. The x-axis shows the shell length in mm (clustered into 9 equal sized groups). The percentage of each shell length group is indicated by grey columns. (BM=brook meter). For the correlation between shell length and age of this location see the paper of ZETTLER (1997).

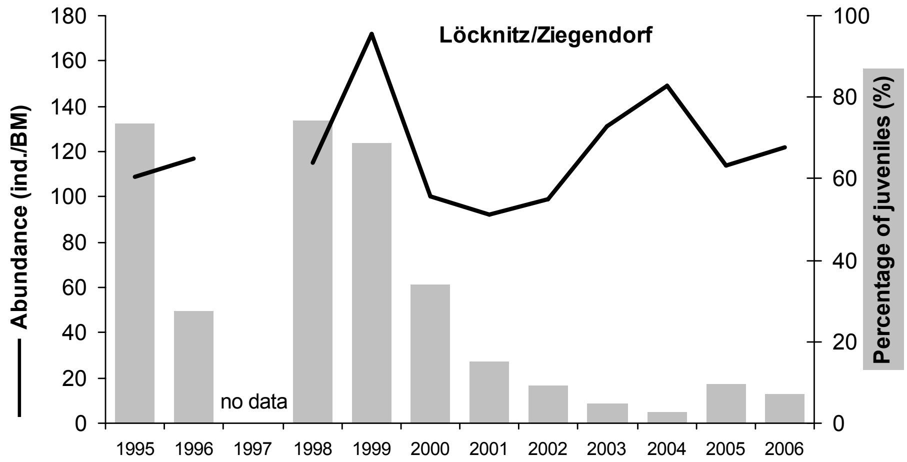

Fig. 5. Development of *Unio crassus* in the brook Löcknitz near Ziegendorf from 1995 to 2006. The abundance (line) is denoted by individual per brook meter (ind./BM). The percentage of juveniles (shell size smaller 30 mm, 1 to 3 years old) is indicated by grey columns.

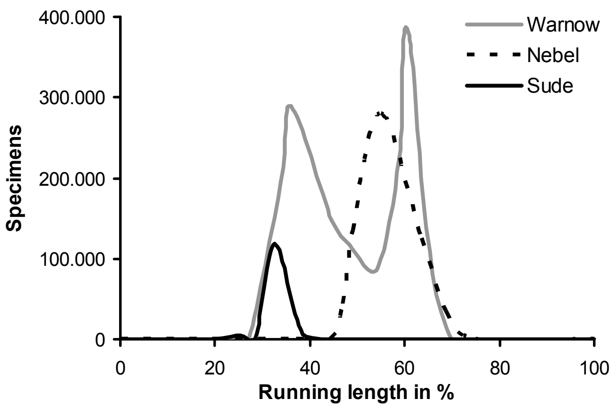

Fig. 6. Population stock of *Unio crassus* in selected rivers of Mecklenburg-Vorpommern in 2006 in relation to the running length of the river. The considered lengths were 135 km for the River Warnow, 67 km for the River Nebel and 79 km for the River Sude.

1997; Schadl 1992; Zettler 1999b; Zettler & Jueg 2001) and the knowledge from the workshop on Vilm in 1999 (see above) it is likely that more than 90 % of the whole German population of *Unio crassus* exists in the waters of Mecklenburg-Vorpommern. It is clear from Table 1 that *U. crassus* has declined significantly in Mecklenburg-Vorpommern in the last decades. More than half of all locations contained extinct populations. However, with about 1.5 million individuals the remaining population size is likely to be the largest in Germany. Four rivers are each identified by more than 100,000 and four by more than 50,000 individuals. Eighteen watercourses are currently inhabited by *U. crassus*.

The population dynamics for *U. crassus* from different locations are highly distinctive. As shown here, the length-frequency plots also differ within one locality between years. The growth of juveniles mirrors the reproductive success only in some years. The longevity of a unionid species will also affect changes in population numbers. Size-frequency distribution suggests that recruitment is irregular between years (Aldridge 1999; Weber 2005). Although freshwater mussel populations are commonly dominated by older cohorts, sampling techniques often contribute to that age (size) bias (Bruenderman & Neves 1993; Richardson & Yokley 1996). Assuming that our sampling effort reflects the correct population demographics the results suggest that even in the largest *U. crassus* population in Germany some years occur without any juveniles being observed. Not only the extent of recruitment but also the place within a watercourse can vary between years. This is probably due to the residence time of glochidia on host fish during infection. The high variability of juvenile occurrence can be explained by differences in the timing and position of dropping of juveniles to the sediment. Otherwise, suitable environmental factors (see below) are needed to maintain the largest and healthiest population. How long a population could compensate this missing recruitment depends on the water specific age range. The maximum ages of *U. crassus* in waters of Mecklenburg-Vorpommern ranged from 15 to 25 years (Zettler 1997). The maximum size and age of unionids will greatly affect the reproductive potential of the animals (Aldridge 1999).

Evidence for local extinctions caused by industrial pollution in Mecklenburg-Vorpommern is anecdotal. It is said, probably correctly, that both silting and deoxygenation are harmful to the mussels and some rivers that were suitable for *U. crassus* in the past are undoubtedly now unsuitable with a much altered fauna (e.g. River Elbe, Elde, Peene, Trebel). However, in the River Elbe the run-off of polluted water from upper industrial regions is likely to have caused extinctions. In southern Germany there is some evidence that pol-

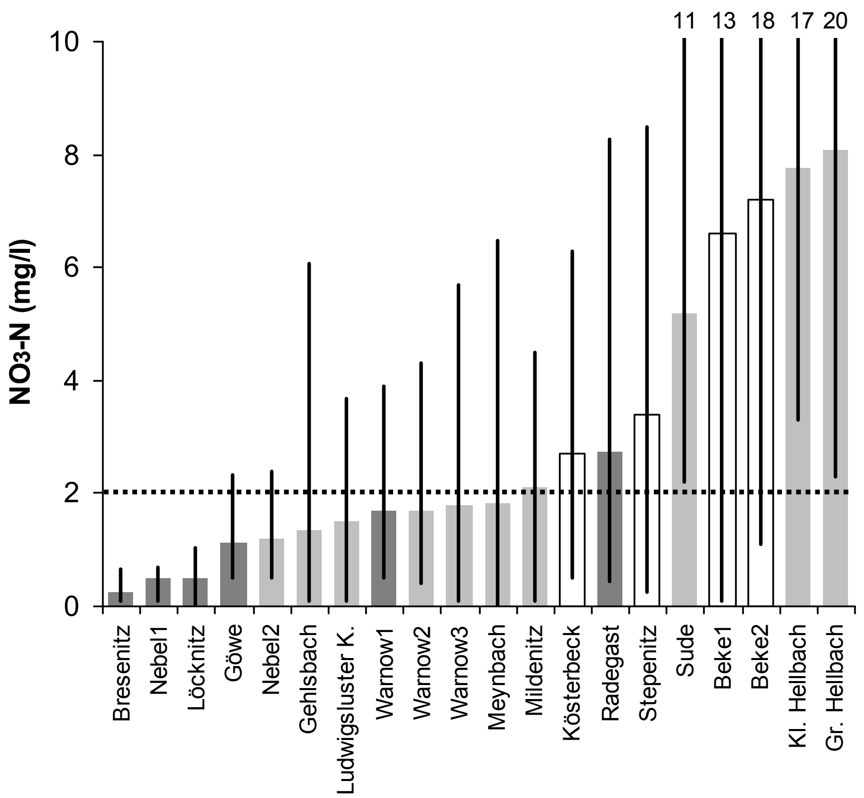

Fig. 7. Typical nitrate nitrogen concentrations in rivers currently or formerly populated by *Unio crassus* in Mecklenburg-Vorpommern exemplary shown for 1993 (dark grey=population with juveniles, grey=populations without juveniles, white=extinct populations). The mean values are shown as columns, whereas the minimum and maximum deviations are indicated by lines (monthly measurements). The dotted line marks the threshold of 2 mg/l of nitrate-N. It has to be stressed that the stations of mussel sampling and nitrate measurements were not identical everytime.

lution has had a serious effect. It is thought that phosphate from sewage has encouraged algal growth to the level that it fills the substrate interstices and smothers the small mussels e.g. juveniles of the freshwater pearl mussel (BAUER 1988). Otherwise, eutrophication caused by agricultural drainage seems to be one of the major causes of the decline of *U. crassus* in Germany (ENGEL 1990; HOCHWALD 1997; KÖHLER 2006; ZETTLER et al. 1995; ZETTLER 1996). Mortality of juveniles is directly or indirectly related to the nitrate nitrogen concentration which is well below 2 mg/l in unpolluted rivers throughout the whole year and between years (Fig. 8a). In these rivers successful growth of juveniles could be observed. Moderately polluted rivers have nitrogen values between 2 and 10 mg/l (Fig. 8b). In these water bodies no or only very limited recruitment was recorded. In more heavily polluted rivers with nitrogen values up to 20 mg/l the populations of *U. crassus* became extinct already or nearly extinct. Whereas the adults could produce glochidia in a comparable way to unpolluted populations no juveniles grew into adults. Current toxicity data of nitrates does not indicate any mechanism by which these observations can be explained as a consequence of direct toxic effects of nitrate on *U. crassus* (KÖHLER 2006).

Pollution may act indirectly. If pollutants make a river unsuitable for host fishes of the mussel then larvae cannot metamorphose into juveniles and the mussel will eventually disappear (YOUNG & WILLIAMS 1983). As *U. crassus* is more selective in the choice of its host fish than other German unionids (BEDNACZUK 1986; HOCHWALD 1997; MAASS 1987) it is likely that, at least in some localities, environmental changes affecting host fish ecology may be more destructive than direct effects of pollution on *U. crassus* (ENGEL & WÄCHTLER 1989). In some cases, periodic dredging of the river bed or weed cutting have removed mussel habitats (ALDRIDGE 2000; ENGEL & WÄCHTLER 1990; personal observation). The impact may be direct (removal or damage of mussels) or indirect (loss of suitable substrates and fish habitats). Construction of dams and canals hinder the migration of potential host fish and impact water flow and sedimentation, thus altering the substrate. Recently, the overuse of waterways by canoeing and rubber boats of tourists at low water levels may impact the freshwater mussels dramatically. Personal observations suggest this leads also to damage and burial of mussels and drastic increases in turbidity (which causes stress followed by closing of the valves). The increased rebuilding of roads (including

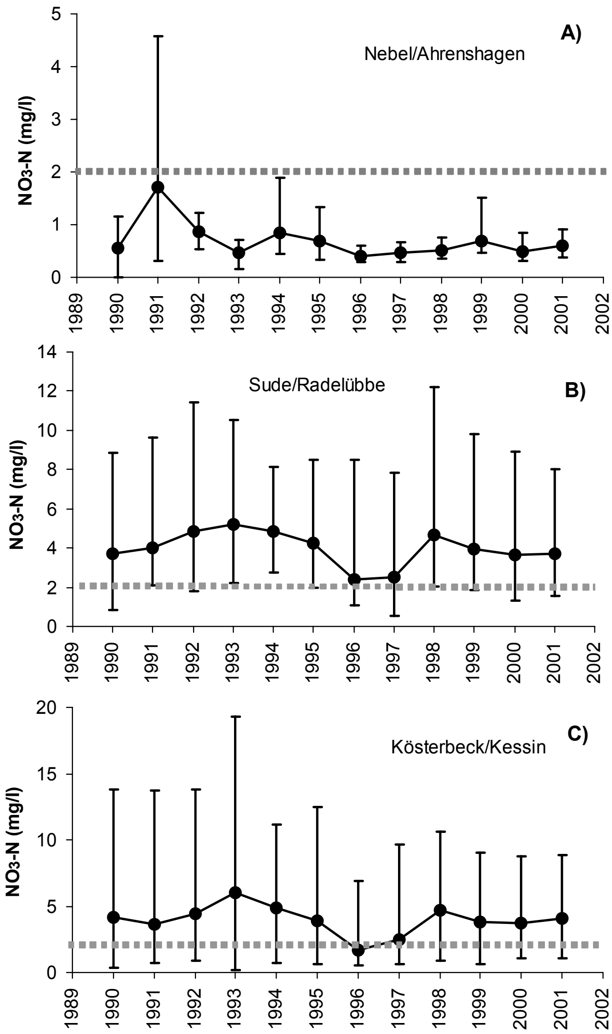

Fig. 8. Mean annual nitrate nitrogen concentrations (with maximum and minimum) in rivers populated by *Unio crassus* at low (A), medium (B) and high (C) NO_3–N. In the last river (Kösterbeck) *U. crassus* was extinct during recent years. The dotted line indicates the threshold of $N0_3$-N of 2 mg/l for an unhindered reproduction success.

bridges) has also apparently affected *U. crassus* populations in recent years. In Mecklenburg-Vorpommern the interaction of pollution of rivers, water constructions (e. g. bridge building), river maintenance and loss of host fishes (in quality and quantity) has caused the extinction of *U. crassus* in some locations and lead to a decrease in the total population. For the EC Habitats Directive to successfully be implemented, first a clear scientific explanation is needed for the narrow range of nitrate concentrations above which impaired reproduction and juvenile growth of *U. crassus* can be observed. Second, additional nitrate discharge into waters (and their drainage) containing *U. crassus* has to be avoided. And third, all technical interventions should be accompanied by scientific expertise to protect the last German populations of the "brook mussel" *Unio crassus*. Irrespective of these points the following conservation measures are proposed: (1) Long-term storage of data on the type (autochthonous) and quantity of host fish populations, (2) introduction of fish artificially infected with glochidia, (3) accumulation of adult mussels to increase their population density and thus the probability of fertilisation occurring and (4) the identification, reduction and elimination of man-made nitrate sources, respectively of the with NO_3-N conjuncted factors causing the harms to *Unio crassus*.

In terms of the EC Habitats Directive a careful monitoring programme will be needed in Europe so that rapid action can be taken to increase protection to an adequate level. The present results suggest we need to register not only the presence of *U. crassus*, but also the age (size) structure of its population and their abundance in monitoring programmes. Age structure and quantitative assessments allow predictions of future stability and development and therefore are sensitive indicators for the situation of this species not only in German waters.

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