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EFFECTIVE GROWTH CESSATION IN ADULT *UNIO CRASSUS* PHILIPSSON, 1788 (BIVALVIA: UNIONIDAE) FROM GERMANY

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ABSTRACT: Information on the growth and age of the endangered freshwater mussel *Unio crassus* Philipsson, 1788 is crucial to correctly assess the conservation status of a particular population. This long-term study of individually marked specimens from four populations from central and southwest Germany revealed that zero growth and shrinkage of adult mussels from the upper 50% of their population's length range were common phenomena. Therefore, overall shell length measurements or counting of growth lines on the shells of live adult mussels may grossly underestimate their age and should be regarded as unsuitable for determining the actual age structure of a population.

KEY WORDS: growth cessation, age determination, long-term study, *Unio crassus*, Unionidae

INTRODUCTION

Unio crassus Philipsson, 1788, the thick shelled river mussel, is an endangered species of European freshwaters that urgently needs protection measures. To detect anomalies in reproduction and over-aging of a population, basic information on the longevity of the mussels and their age structure is required. Commonly, the determination of age in live mussels is based either on length frequency classes or on the number of external rings on the shell surface that are assumed to represent annual growth demarcations. However, the reliability of these methods has been disputed for several years (HAUKIOJA & HAKALA 1978, DAY 1984, BAILEY & GREEN 1988, see also reviews: NEVES & MOYER 1988, HAAG & COMMENS-CARSON 2008). Furthermore, field observations on the growth of individual freshwater mussels are rare. Here we provide evidence from a long-term study that growth patterns in *U. crassus* include zero growth and shrinkage.

MATERIAL AND METHODS

Length measurements of individually marked specimens over periods of time were repeated for two main populations of *U. crassus* in Hessia, Germany. The populations represented two subspecies, *U. c. crassus*: Orke population from a millstream parallel to the Orke River in the Weser River catchment area (51°08'N, 8°52'E), and *U. c. riparius* C. Pfeiffer, 1821: Seenbach population from a brook in the Lahn River sub-catchment of the River Rhine catchment area (50°34'N, 9°03'E). In addition, we re-measured three mussels from two streams in the Upper Rhine Valley, Baden-Württemberg, Germany: Holchenbach (48°38'N, 7°57'E) and Kammbach (48°37'N, 7°57'E) (Fig. 1). All the populations were reproducing, although presumably on a low level. Length was defined as the maximum distance between anterior and

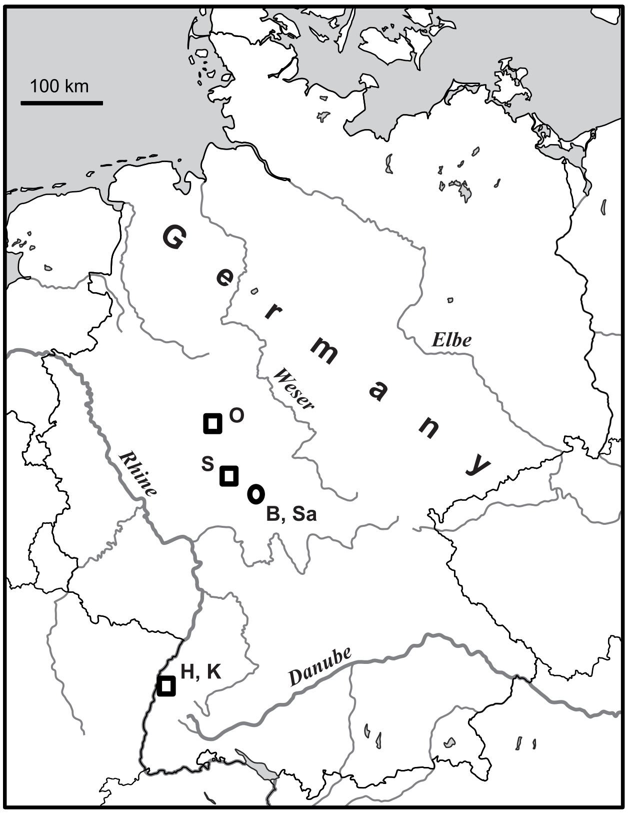

Fig. 1. Population localities: O – Orke, S – Seenbach, H – Holchenbach, K – Kammbach; B – Bracht, and Sa – Salz, data from Nagel (1991), see: Table 2

posterior shell margins. Results of the first re-capture are given in Table 1.

The mussels were numbered and tagged using glue and queen bee marking platelets (Orke only) or a white marker in 1997, 2010–2012 (Orke), in 1996 and 1999 (Seenbach), in 2000 (Kammbach) and in 2009 (Holchenbach). All the mussels were from the upper 50% of their population's length range (Orke: ca. 105 mm, Seenbach: ca. 80 mm, Holchenbach and Kammbach: ca. 70 mm). Measurements were taken with a Vernier calliper. We calculated that the margin of error due to repeated measurements was 0.5 mm. Measurements were conducted by experienced researchers in the following areas: Orke – C. Dümpelmann (all measurements); Seenbach – A. Schwarzer (1st measurement), K.-O. Nagel (2nd measurement); Kammbach – L. Rupp (1st measurement), M. Pfeiffer (2nd measurement); Holchenbach – M. Pfeiffer (1st measurement), K.-O. Nagel (2nd measurement).

Table 1. Initial length measurement and change in length of *Unio crassus*: δa – years between measurements; origin: O – Orke, S – Seenbach, H – Holchenbach, K – Kammbach; L – length at first measurement (mm); δL – change in length; significant differences (> 0.5) highlighted grey

δa	Origin		Length at first measurement and change in length											
1	**O**	L	62.2	68.7	69.4	70.3	73.0	73.9	75.5	75.9	76.2	77.2	77.8	79.1
		δL	0.2	0.8	–0.6	0.1	0.0	–0.6	1.7	–0.2	0.2	–1.9	0.0	–0.5
		L	80.1	84.0	85.7	86.6	87.0	88.7						
		δL	–0.5	–0.6	–0.3	–0.2	–0.4	–1.1						
2	**O**	L	53.1	65.8	67.4	71.3	71.8	79.4	80.0	81.1	81.2	87.6	87.7	90.2
		δL	0.7	–0.8	3.0	0.3	–0.4	–0.1	–0.1	0.7	4.9	–0.1	–0.2	0.7
3	**O**	L	72.2	84.0	**S**	63.3								
		δL	0.5	–0.4		–1.1								
4	**O**	L	74.3											
		δL	–1.1											
6	**H**	L	49.0	56.0										
		δL	4.0	0.9										
8	**S**	L	56.9	**K**	42.5									
		δL	0.8		9.5									
9	**S**	L	54.9	57.0										
		δL	0.9	1.7										
12	**S**	L	47.5											
		δL	2.1											
13	**S**	L	58.0											
		δL	0.7											
14	**O**	L	79.6	83.8	87.4									
		δL	–5.1	0.8	–0.3									
16	**S**	L	54.8	55.1	56.8									
		δL	4.4	2.0	1.8									

RESULTS

A total of 46 individually marked mussels was re-captured in four streams. The time lag between the two measurements was 1 to 14 years (Orke), 3 to 16 years (Seenbach), 8 years (Kammbach), and 6 years (Holchenbach). The second length measurements showed an increase in length, as well as growth cessation and even shrinkage of shells (Table 1). The maximum values (rounded off) for increase were: Orke 5 mm, Seenbach and Holchenbach 4 mm, and for decrease (= negative growth, shrinkage): Orke 5 mm and Seenbach 1 mm (Table 2). The mean/maximum growth per year was: Orke 0.002/2.5 mm, Seenbach 0.05/0.3 mm and Holchenbach 0.4/0.7 mm and the maximum shrinkage per year was: Orke –1.9 mm and Seenbach –0.4 mm. The corresponding values for the single specimen from Kammbach were: increase 9.5 mm, mean growth per year 1.2 mm. The mean growth was calculated on significant differences only (> 0.5 mm), therefore 20 values from Orke were excluded. These latter values can be regarded as zero growth.

Table 2. Initial range of shell length and subsequent change in *Unio crassus*: δa – years between measurements; n – number of specimens; range L – range of shell lengths at first measurement; Δ – mean change in length; range δ – range of changes in length

δa	n	range L	Δ	range δ
Orke				
1	18	62.2-88.7	–0.2	–1.9-1.7
2	12	53.1-90.2	0.7	–0.8-4.9
3	2	72.2–84.0	0.1	–0.4-0.5
4	1	74.3		–1.1
14	3	79.6-87.4	–1.5	–5.1-0.8
Seenbach				
3	1	63.3		–1.1
8	1	56.9		0.8
9	2	54.9-57.0	1.3	0.9-1.7
12	1	47.5		2.1
13	1	58.0		0.7
16	3	54.8-56.8	2.7	1.8-4.4
Holchenbach				
6	2	49.0-56.0	2.5	0.9-4.0
Kammbach				
8	1	42.5		9.5
Bracht*				
1	73	58.1-83.0	0.4	–1.4-1.4
Salz*				
1	16	48.8-75.0	0.3	–0.2-0.9
1.75	7	52.9-74.4	0.6	–0.6-4.2

* Data from NAGEL (1991: 206, 207). Salz partly recalculated from original measurements. Geographic coordinates: Bracht – 50°19'N, 9°17'E, Salz – 50°24'N, 9°22'E; populations are now extinct.

DISCUSSION

One common feature observed in the investigated adult specimens of *U. crassus* (all of which were from the upper 50% of the population's length range) was the inconspicuous length increments occurring over a period of years, up to 16, as well as cases of zero growth and shrinkage in two populations. The mean changes in length per year were mainly close to zero.

The phenomenon of growth cessation was previously mentioned by DOWNING & DOWNING (1993) and ANTHONY et al. (2001: 1352) for North American unionid mussels. Still earlier, NAGEL (1991: 206, 207; see also summary data in Table 2 for comparison) reported an overall growth cessation in two populations of *U. crassus* based on measurements repeated after one year on 73 and 16 mussels, respectively. These animals also belonged to the upper 50% of the population's length range.

The possibility of zero growth or shrinkage of full-grown mussels suggests that age estimates based on length frequency data or counting of growth lines may be misleading and are seriously biased toward older ages. Typical estimates of longevity for *U. crassus* from counting winter rings of live animals are around 15 to 26 years (TUDORANCEA & GRUIA 1968: 386, ZETTLER 1997: 230, HOCHWALD 2001: 128), but may be as low as 9 years (DOUDA 2007: 61, tab. 1). Using different methods on empty shells (banding on thin sections) BJÖRK (1962: 101) and TIMM & MUTVEI (1993, after HOCHWALD 2001) arrived at much higher values, ca. 50 and up to 90 years, respectively, for specimens from North European populations. NAGEL (1991: 211) counted up to 40 years (growth rings on the inner surface of the ligament proper) for mussels from central Germany. NEVES & MOYER (1988: 184/5, see also NAGEL 1991: 211, ZETTLER 1997: 215, and HAAG & COMMENS-CARSON 2008: 507) concluded that counts of external growth lines consistently underestimated age in slow growing species and older specimens.

Length data alone are inadequate to assess the status of an individual as young (= from recent recruitment events) or advanced. There is a large degree of plasticity in growth, for example individuals measuring 40 mm may be between 2 and 14 years

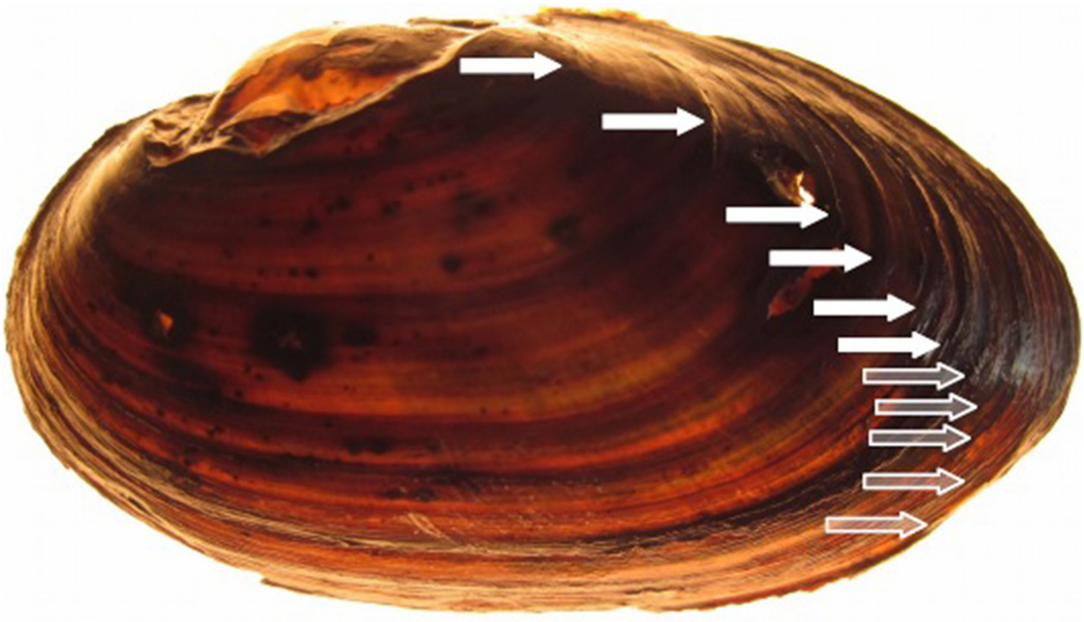

Fig. 2. Backlit left valve of *Unio crassus*, no. 1247, from Seenbach brook. The live mussel was measured on 16.10.1999 to be 54.9 mm long, and its age was estimated to be 12 years. The fresh shell was collected on 5.9.2008, and measured 54.9 mm. Solid white arrows – distinctive growth interruptions (= winter rings), transparent arrows – less distinctive growth interruptions, uppermost solid arrow presumably corresponds to a ring from the second year.

old (Falkner 1986: annex, graph 1; Zettler 1997: 221, fig. 8), depending on whether they are fast or slow growing. The (initial) growth rate expressed as the von Bertalanffy growth constant (K) may vary by at least a factor of 6 (Hochwald 2001: 128; see also Haag & Rypel 2011: 239, 240).

Falkner (1986: 24), Nagel (1991: 208) and Sárkány-Kiss (1997: 206–207) recognised two phases of growth in *U. crassus*: growth at a young age, which probably continues until sexual maturity, and growth at an older age. The early winter rings, when not eroded, are typically well spaced and different in colour and therefore allow for a reliable age estimate. In later years the appearance of differently coloured bands or proliferations of the periostracum as a result of growth interruptions are much more difficult to interpret as characters of ageing. Field experience indicates that counting up to the 8th ring is quite reliable and reproducible (see Fig. 2). However, there are uncertainties concerning the first one or two rings in cases of severe erosion of the umbonal region. Beyond this limit an age estimate based on visible growth interruptions (winter rings) on the shell of live *U. crassus* is less reliable in view of the possibility of zero growth or shrinkage, and its use would be inappropriate to establish the actual age structure of a population.

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