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THE RELEASE OF PHOSPHORUS AND NITROGEN BY LIVING AND DECOMPOSING SNAILS*

ABSTRACT: The excretion of $P\text{-}PO_4$ and $N\text{-}NH_4$ by snails (*Lymnaea (Lymnaea) stagnalis, Lymnaea (Radix) auricularia* and *Planorbarius corneus*) was measured in laboratory experiments. For *L.* (*L.*) *stagnalis* the release of these elements from decomposing animals and their faecal material were also determined. Amounts of nutrients excreted by the snails studied varied greatly in the ranges <1 to 70 μg $P\text{-}PO_4$ and <2 to over 200 μg $N\text{-}NH_4$ per individual. These amounts were very much related to the sizes of snails.

The phosphorus and nitrogen contained in the tissues of *L.* (*L.*) *stagnalis* are released to the water very rapidly due to the rapid decomposition that the bodies of snails undergo.

The release of phosphorus from freshly produced faecal matter is considerable – even greater than the excretion by live snails (expressed per unit weight). However, the limited mass of faeces produced as compared with the body weight of an snail, ensures that this still accounts for only 3% of daily excretion of phosphorus from the body of a live snail.

KEY WORDS: snails, phosphorus and nitrogen release, faeces production, decomposition

1. INTRODUCTION

The aquatic invertebrates have diverse influences on aquatic vegetation. The impact is very complex, however. Beside the direct ones following from the consumption of plant tissues, mining of steams and leaves and other types of mechanical damage (which may basically be defined as negative influences on aquatic plants), there are also indirect impacts which mainly entail the stimulation of plant growth via enrichment of the aquatic environment in nutrients, mainly nitrogen and phosphorus the animals release.

The enrichment of the nutrient pool in water has been the subject of intensive study as far as planktonic crustaceans are concerned (e.g. Lehman 1980, Ejsmont-Karabin 1984, Kairesalo and Seppala 1987, Ejsmont-Karabin and Węgleńska 1989). In contrast, only occasional studies have considered other groups of invertebrates, particularly those inhabiting the inshore zone of water bodies overgrown by macrophytes. Limited data on the release of phosphorus and nitrogen compounds by

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some oligochaetes, bryozoans, molluscs, bottom crustaceans and insects larvae may be mentioned here (Nalepa *et al.* 1983, Sørensen *et al.* 1986, Lauritsen and Mozley 1989, Underwood 1991, Pinowska 1994). These studies point to the variable if sometimes intensive nutrient excretion, suggesting that this way of enrichment of the environment in nutrients may be of great significance. It is not merely excretion that is such a major enriching process. The release of P and N from the faecal matter of invertebrates and through the decomposition of animal tissues after death may be also of some significance.

The aim of this study has thus been to determine in laboratory experiments the amounts of phosphate-phosphorus and ammonium-nitrogen released by gastropods (*Lymnaea (Lymnaea) stagnalis* (L.), *Lymnaea (Radix) auricularia* (L.) and *Planorbarius corneus* (L.). The main object of the study was *L.* (*L.*) *stagnalis*, for which the release of these compounds from faecal matter and the decomposing tissues of dead individuals was also determined.

2. METHODS

Living and dead snails and their faecal matter were exposed in glass vessels of capacities 100 or 250 ml, at a temperature of 18–20°C in laboratory conditions offering well water with low concentrations of the nutrients under analysis. The amounts of phosphorus and nitrogen release were estimated by comparing concentrations in water before and after exposure. Snails were starved for 24 h before experiment. Prior to exposure, snails were rinsed in a sieve using the water that was used in experiments following 24 hours of quarantine in laboratory conditions. Faecal matter used in experiments was collected from the floor of the vessels in which snails were exposed using a pipette, separated out using 50 μm plankton net. In assessing the rates and amounts of nutrients released from the bodies of dead snails, as well as the loss of body mass (difference in mass before exposure and after exposure periods of differing duration), use was made of snails that had previously been frozen at c. –20° C and were then exposed after thawing in darkness for 1, 3, 7 days or 3, 7, and 12 days. The periods of exposure ranged from one to several days in relation to the experiment variant. Phosphate-phosphorus in water was determined by molybdenum blue method according to Golterman (1969) and ammonium-nitrogen by direct nesslerization method according to Standard Methods (1960). Total phosphorus was analysed after wet digestion of dry animal subsample. In the resulting solution TP was determined as SRP in water sample. Total nitrogen was analyzed after wet digestion of animal subsamples according to Kjeldahl procedure. Total N was converted to ammonia-nitrogen determined then after Solørzano(1969).

The fresh weight of snails and faeces was determined to within 1 mg on a balance, following drying of the snails with filter paper. Dry masses were measured to the same level of accuracy after drying to constant weight at 105°C.

The significance of differences of nutrient release between snail species were estimated using ANOVA, with post-hoc Tukey's test.

3. RESULTS

Amounts of nutrients excreted by the studied snails varied greatly – in the ranges <1 to 70 μg $P\text{-}PO_4$ and <2 to over 200 μg $N\text{-}NH_4$ per individual. These amounts were closely related to the sizes of snails, however, whether it was fresh weight with shell that was considered (Fig. 1), or dry body weight (Fig. 2). Comparisons between *Lymnaea* (*Lymnaea*) *stagnalis* and *Lymnaea* (*Radix*) *auricularia* – whose ranges of size variability were similar – revealed linear relationships with size form for *L.* (*L.*) *stagnalis* that contrasts with the exponential one noted for *Planorbarius corneus*. In the latter, excretion was very much more pronounced in larger individuals. All correlation coefficients presented in Figs 1 and 2 were highly significant statistically, at the $P < 0.00001$ level.

The amounts of $P\text{-}PO_4$ and $N\text{-}NH_4$ excreted by animals were compared for individuals using snails >1 and <3.5 cm in shell height (for *L.* (*L.*) *stagnalis* and *L.* (*R.*) *auricularia*) or width (in the case of *P. corneus*) for which both excretion of these elements were simultaneously analysed (Fig. 3). Differences statistically significant at $P < 0.03$ were noted for the amounts of $P\text{-}PO_4$ excreted by individuals of *P. corneus* and *L.*

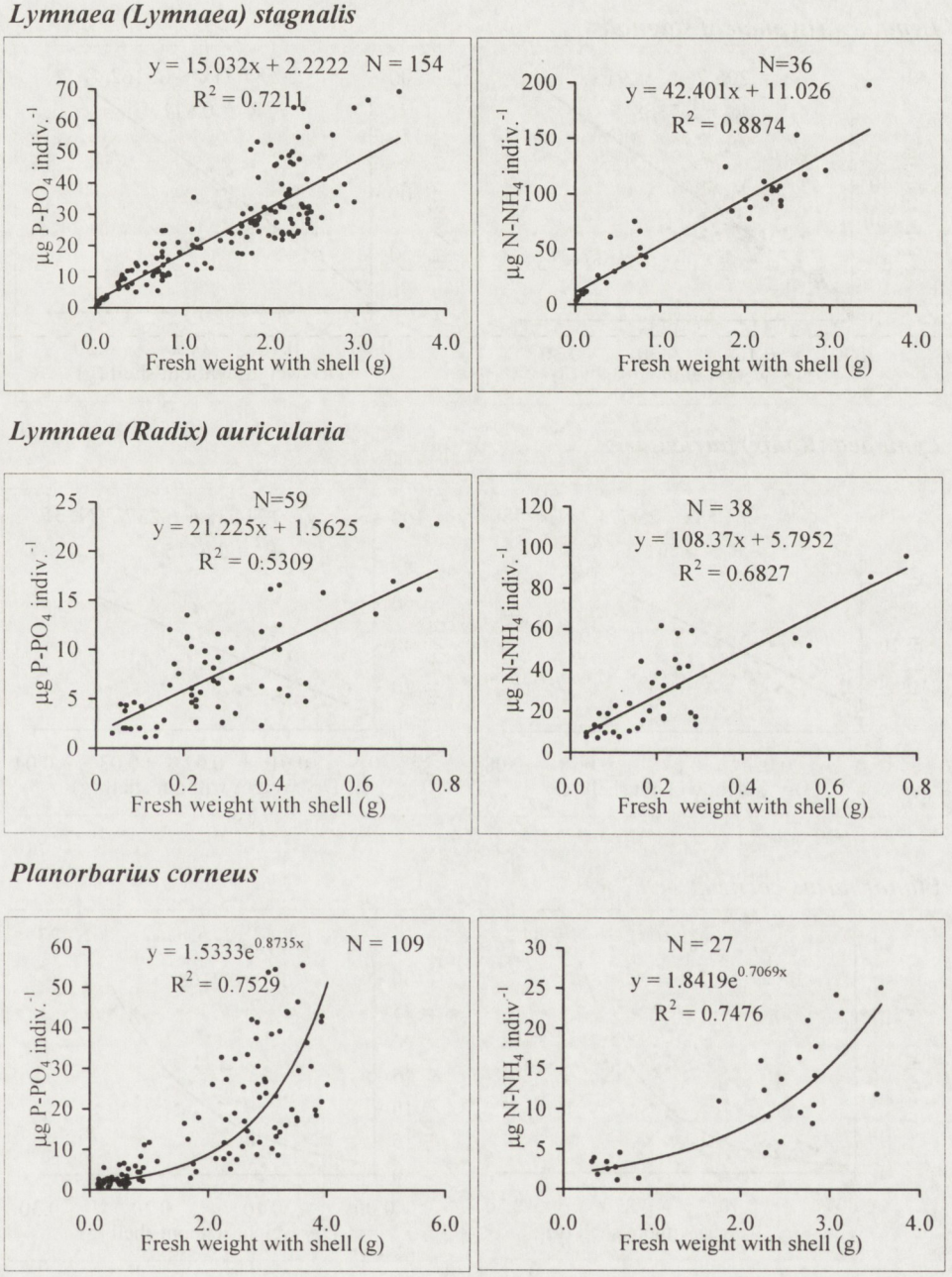

Fig. 1. Relationships between daily excretion of $P\text{-}PO_4$ and $N\text{-}NH_4$ and fresh weight (with shell) of snails

(R.) auricularia – the species characterised by the highest and lowest values, respectively. All three species differed significantly (at $P < 0.008$), as regards the amounts of excreted $N\text{-}NH_4$, with individuals of *L.* (*L.*) *stagnalis* exhibiting the highest values. The ratios of N to P excreted differed markedly between the species, being 3.8 for *L.* (*L.*) *stagnalis*, 3.8 for *L.* (*R.*) *auricularia* and 0.5 for *P. corneus*. A characteristic feature is that *P. corneus* excreted the highest amount of P of any of the three species of snail studied, as well as the smallest amount of N (Fig. 3).

Daily excretion expressed in µg per g body dry weight varied between 139 (*P. corneus*) and 527 (*L.* (*R.*) *auricularia*) in the case of $P\text{-}PO_4$, and between 74 and 2145 in the case of $N\text{-}NH_4$ (Table 1). The excretion of $P\text{-}PO_4$ by *L.* (*R.*) *auricularia* was at a significantly greater intensity ($P = 0.0001$) than in

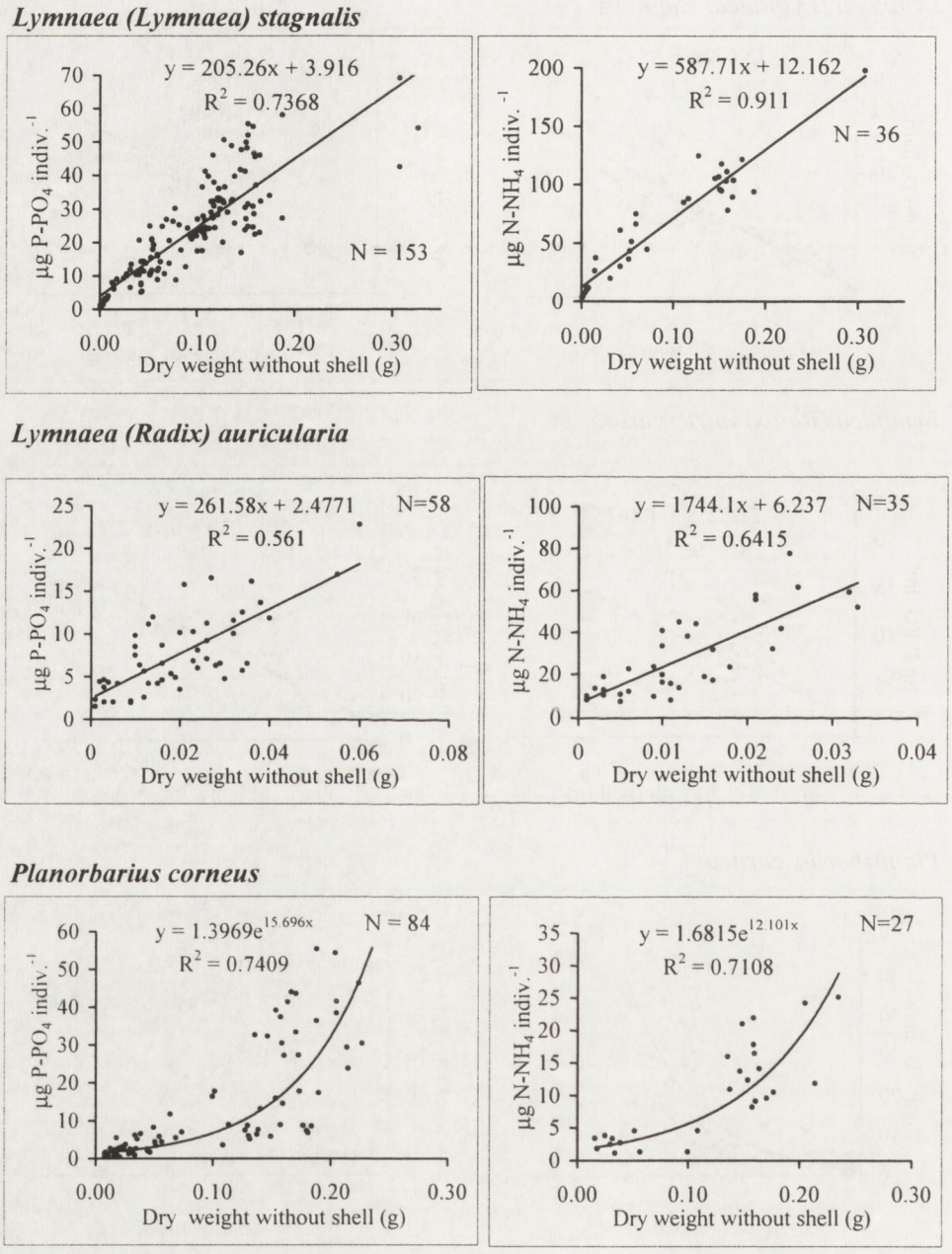

Fig. 2. Relationships between daily excretion of $P\text{-}PO_4$ and $N\text{-}NH_4$ and snail body dry weight (without shell)

the remaining species, though nitrogen excretion differed significantly among all species at $P = 0.0001$. Data for the amounts excreted per 1 g fresh weight vary from 18–55 µg in the case of $P\text{-}PO_4$ and 10–231 µg for $N\text{-}NH_4$ with minimal values for *P. corneus* and maximal for *L. (R.) auricularia*.

The *L.* (*L.*) *stagnalis* body contains 8.2 mg (±SD 0.7) of total phosphorus and 44.1 mg (±SD 5.3) of total nitrogen per 1 g body dry weight. These elements are released quickly to the environment following the animal death, due to a rapid process of decomposition. Just one day after this had begun in the experiment, some 30% of the initial body dry weight had been lost, and the figure had risen

Table 1. Daily excretion (in µg g dry weight^{-1}) of phosphorus and nitrogen for three species of snails

	$P\text{-}PO_4$			$N\text{-}NH_4$		
	Mean	± SD	*N*	Mean	± SD	*N*
Lymnaea (Lymnaea) stagnalis	384.4	110.3	30	987.7	432.4	30
Lymnaea (Radix) auricularia	527.0	235.5	29	2144.7	922.3	29
Planorbarius corneus	138.7	77.3	22	74.4	42.7	22

Calculated for individuals of similar size (>1–<3.5 cm) for which nitrogen and phosphorus were simultaneously analysed.

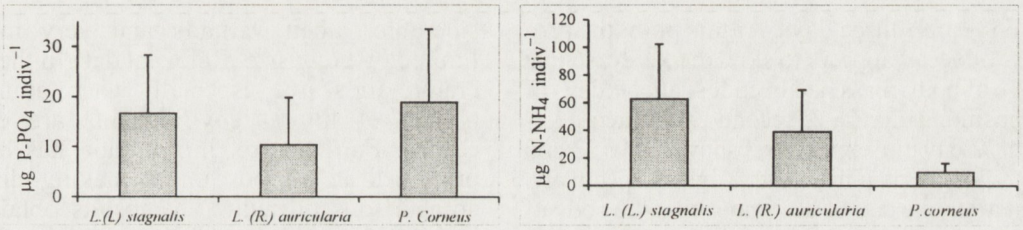

Fig. 3. Daily excretion (mean ±SD) of phosphorus and nitrogen for three species of snails. Individuals of similar size (>1 and <3.5 cm) for which excretion of $P\text{-}PO_4$ and $N\text{-}NH_4$ were simultaneously analysed: *Lymnaea (Lymnaea) stagnalis* and *Lymnaea (Radix) auricularia* N = 30, and for *Planorbarius corneus* – N =24

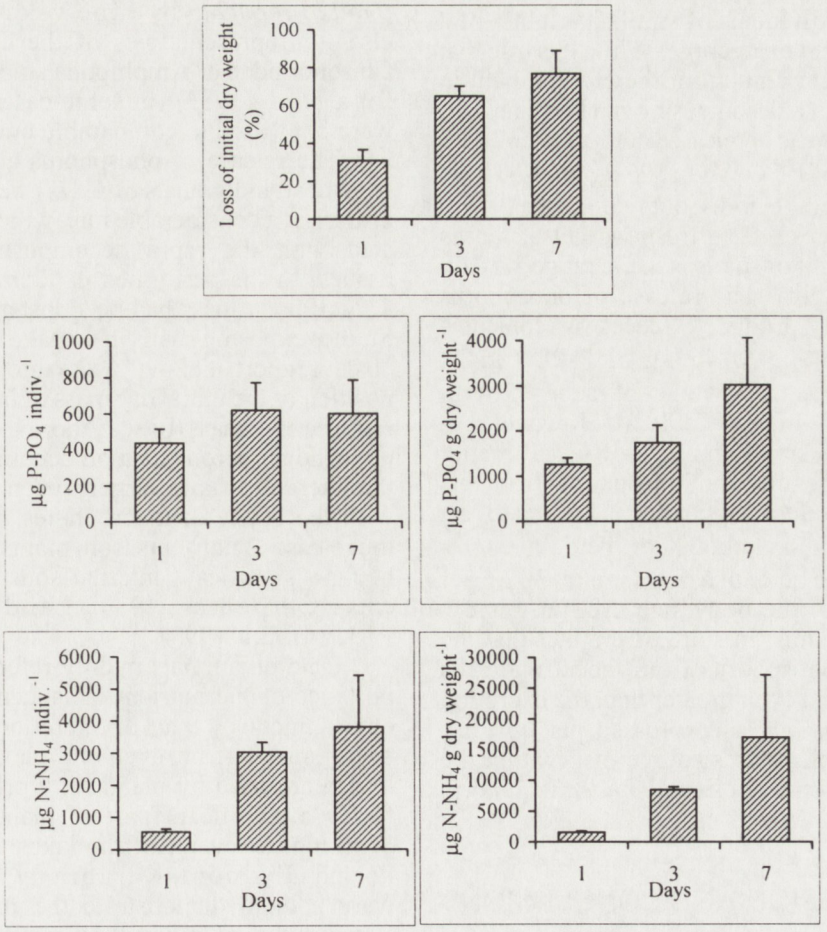

Fig. 4. Loss of dry weight (mean ±SD) of snails and release to the water of $P\text{-}PO_4$ and $N\text{-}NH_4$ (from 1 individual or 1 g of dry weight of a snail) after 1, 3, and 7 days of decomposition of *Lymnaea (Lymnaea) stagnalis*

Table 2. Daily production of faeces and release of phosphorus from the faecal matter of *Lymnaea (Lymnaea) stagnalis*

	Release of $P\text{-}PO_4$ µg g^{-1}		Production of faecal matter by 1 indiv.	Release of $P\text{-}PO_4$ from faeces produced by 1 indiv.	
	fresh weight	dry weight	g fresh weight	µg	% in snail excretion
Mean	46	514	0.02	0.9	3.0
±SD	21	21	0.01	0.5	

to 65% after three days. At this point the process of decay appears to slow markedly, so that 77% of body mass had been lost after 7 days of exposition (Fig. 4). A second experiment (3, 7 and 12 days of exposition) showed 59, 72 and 76% losses of initial dry weight respectively. Just after one day of decomposition the body of a snail was shown to have released 435 µg P-PO4 on average, and 541 µg of $N\text{-}NH_4$ per 1 individual. This represents respectively 14 (phosphorus) or 7 times the amount (nitrogen) excreted daily by live *Lymnaea* compared for individuals of similar weight – of 2 g fresh weight on average. While it is true that the rate of enrichment of the environment in N and P from a decomposing snail declines, the average amounts of released nutrient after 7 days are 599 µg of $P\text{-}PO_4$ and 3806 µg of $N\text{-}NH_4$.

An average individual of *L. (L.) stagnalis* produces 0.02 g fresh weight of faeces (where weight of snails is in the range 1.5–2.0 g fresh weight). The release of phosphorus from freshly-produced faeces is considerable, amounting to 46 µg of P-PO4 in 24 hours from 1 g fresh weight of faeces (514 µg from 1 g dry mass) (Table 2). However, because of the small amounts of faecal matter produced, the release of phosphorus from this source per individual per day is limited to just 0.9 µg $P\text{-}PO_4$ or only 3% of the daily excretion from the body of a live snail (c. 30 µg per individual of the body size used in this experiment). Thus, in spite of the fact that the release of phosphorus from faecal matter is intensive, and even greater than the excretion by live *Lymnaea* as expressed per unit dry mass, the role of this source of P within the total excretion from live *Lymnaea* is minor.

4. DISCUSSION AND CONCLUSIONS

The results point to the release of phosphorus and nitrogen by live snails being considerable, albeit variable and very much limited by body size. Relevant data in the literature are scarce, especially where animals typical of littoral environments are concerned. Furthermore, information has been presented in various units, making direct comparisons difficult. The results obtained here for the excretion by live animals of the studied species of phosphate-phosphorus and ammonium-nitrogen do not depart greatly from those given for *Planorbis planorbis* by Underwood (1991), and for *Lymnaea (Galba) turricula* by Pinowska (1994), or else for representatives of the Tubificidae, Chironomidae or Amphipoda studied by Nalepa *et al.* (1983) (in some cases own data were converted to comparable units).

The release of phosphorus and nitrogen from dead individuals of *L. (L.) stagnalis* progresses at a considerable rate, which is associated with the rapid decomposition of its tissues. In the performed experiments, some 70% of body mass had been lost after 7 days. Studies exposing snails in the lake littoral over 10 days report of 82–90% loss through decomposition of the initial dry mass of bodies of several species of snails (Pieczyńska *et al.* 1984).

The numerous data on decomposition in the literature have largely been concerned with the decay of macrophytes, pointing to the release of nutrients from plants after death being a significant internal source of nutrients (Carpenter 1980, Landers 1982, Pieczyńska 1993).

Data on animals mainly refer to the importance of the nutrient enhancement of the environment by way of excretion from live organisms. The nitrogen and phosphorus released are used by plants, and probably this fulfils a significant part of plants demand. Working in several of the lakes of northern Poland, Ejsmont-Karabin *et al.* (1993), were able to demonstrate the fundamental significance of nutrient excretion by zooplankton as a source of P, and to a lesser extent of N, where the production of bacterio-

and phytoplankton were concerned. Lauritsen and Mozley (1989) in turn showed major excretion of NH_4 and PO_4 by the bivalve *Corbicula fluminea*, which was able to meet more than 30% of the phytoplankton needs for these elements (in the Chowan River, USA).

A number of studies have suggested that the release of nutrients by snails and other invertebrates may increase the growth of macrophytes (Brönmark and Vermaat 1998). Working with water chemically conditioned by *Planorbis planorbis,* Underwood (1991) found that *Ceratophyllum* grown in the presence of snails but protected from grazing by a barrier allowing the free movement of water grew longer, had more healthy leaf nodes and more growing tips than control plants. In experiments run in a similar way, Janek (unpublished material) noted an increase in the biomass of *Rhizoclonium* sp. and *Elodea canadensis*, as a result of the enrichment of water by *L.* (*L.*) *stagnalis*. Pieczyńska and Rybak (unpublished material) grew *Ceratophyllum demersum* and *E. canadensis* in aquaria containing small individuals of *Bithynia tentaculata* and *P. planorbis* not harming the plants, finding higher concentrations of $P\text{-}PO_4$ and $N\text{-}NH_4$ and more intensive plant growth than in control aquaria (lacking animals).

While the literature has mainly drawn attention to excretion-mediated nutrient enrichment of the environment, this work has pointed to the significance, not only of the release of N and P from live animals, but also of that from faecal matter and from decomposing dead individuals. It needs to be emphasised that these processes differ in both their intensity and dynamics. Excretion by live snail (which plays the greatest role in the enrichment of the environment) joins the release of nutrients from their faecal matter (of much more minor importance) during all its life (up to 5 years in the case of the species studied). Here we are dealing with a steady enrichment of the environment. In contrast, the period of the decomposition of dead snails is one of a much more intensive influx of nutrients, albeit one of short duration, since the breakdown of the bodies of snails proceeds rapidly.

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5. SUMMARY

The present work has evaluated the excretion of $P\text{-}PO_4$ and $N\text{-}NH_4$ by snails (*Lymnaea* (*Lymnaea*) *stagnalis*, *Lymnaea* (*Radix*) *auricularia* and *Planorbarius corneus*) with the main object of study being *Lymnaea* (*L.*) *stagnalis* – for which releases from faecal matter and the decomposing tissue of dead individuals were also determined.

Amounts of nuntrients excreted by the snails varied greatly (Figs 1–3, Table 1). Single individuals were found to excrete between <1 to 70 μg of $P\text{-}PO_4$ per day, and <2 to over 200 μg of $N\text{-}NH_4$. The variability in the rate of release was marked, but amounts were generally greater in line with greater body masses of snails. The release of phosphorus from freshly produced faecal matter is considerable – even greater than the excretion by live snails (expressed per unit weight). However, the limited mass of faeces produced as compared with the body weight of an snail, ensures that this still accounts for only 3% of daily excretion of phosphorus from the body of a live snail (Table 2).

The release of compounds of nitrogen and phosphorus from decomposing snails proceeds rapidly, due to the rapid decomposition that the bodies of snails undergo. After 7 days of decomposition over 70% of initial body dry weight had been lost, and this corresponds with released of 599 μg $P\text{-}PO_4$ and 3806 μg of $N\text{-}NH_4$ (Fig. 4).

While the literature has mainly drawn attention to excretion-mediated nutrient enrichment of the environment, this work has pointed to the significance, not only of release from live animals, but also of that of nitrogen and phosphorus from faecal matter and in the course from decomposing dead individuals. It needs to be emphasised that these processes differ in both their intensity and dynamics. Excretion by live snails (which plays the greatest role in the enrichment of the environment) joins the release of nutrients from their faecal matter (of much more minor importance) during all its life (up to 5 years in the case of the species studied). Here we are dealing with a steady enrichment of the environment. In contrast, the period of the decomposition of dead snails is one of a much more intensive influx of nutrients, albeit one of short duration, since the breakdown of the bodies of snails proceeds rapidly.

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