

## Land snails in Estonian forests: numbers and species richness

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**Abstract.** A drastic decline in land snail populations has been revealed in the oligotrophic areas of acidified regions of Europe. Since snail shells are an important calcium source for forest passerines, this decline causes severe reductions in forest passerine reproductive rates. In Estonia, about 40% of all woodlands consist of pine forests on poor, naturally acidic soils. It has been shown that birds breeding in such forests suffer calcium deficiency. A research project was carried out to estimate the current situation in Estonian forest land snail populations. This was the first large-scale quantitative investigation of forest snail fauna in the eastern Baltic area. Data about the abundance and species richness of snails are presented by geologically different regions and forest types of Estonia. The effect of industrial forest liming, occurring near some big oil-shale and cement works, was studied. Our data confirm that the number of snails in a substantial portion of Estonian forests is very low, and therefore birds breeding there may be vulnerable to possible increases in acidification. However, atmospheric pollution with calcareous materials in some ecologically problematic industrial regions seems to compensate for calcium deficiency for snail populations.

**Key words:** land snails, species diversity, forest, calcium shortage, pollution.

### INTRODUCTION

A drastic decline in land snail populations was revealed at the end of the 20th century by ecologists in the oligotrophic areas of heavily acidified regions of Europe, such as The Netherlands (Graveland et al., 1994; Graveland, 1996a, b; Graveland & Van der Wal, 1996), southern Sweden (Wärebörn, 1992; Gärdenfors et al., 1995), and Poland (Drozdowski, 1988, 1989). Simultaneously, numerous studies have shown an increase in the proportions of birds laying either abnormally thin-shelled eggs or no eggs at all in recent years (see Graveland & Van der Wal, 1996 for

references), and many authors have suggested that increasing atmospheric pollution may be the cause. Graveland et al. (1994) demonstrated experimentally that defective eggshells in forest passerines may be related to a decline of snail abundance in acidified soils. Molluscs need calcium for their calcareous shells, but continuing acidification and base cation leaching may result in decreased calcium content in litter and the surface soil layer (Wäreborn, 1969, 1970, 1992). Snail shells are claimed to be the main calcium source for eggshell formation in many forest bird species (Schifferli, 1973; Graveland et al., 1994). Therefore birds inhabiting acidified areas where the number of snails has decreased may have difficulties in obtaining sufficient calcium for their eggs.

According to Graveland and his colleagues (Graveland et al., 1994; Graveland & Van der Wal, 1996), birds can compensate for the lack of snail shells by using anthropogenic calcium sources (chicken eggshells, mortar, etc.) in densely populated areas. However, calcium deficiency may cause severe reductions in forest passerine reproductive rates in less densely populated and more natural acidified areas. There is urgent need for determining the extent of calcium deficiency in different areas with variable ecological conditions (Graveland, 1996b; Graveland & Berends, 1997; Graveland & Drent, 1997). Unfortunately, as Wäreborn (1992) pointed out, it is difficult to estimate the real extent of a decline in land snail populations in different regions, since there is a lack of quantitative investigations to be used as background for comparisons.

Industrial acidification is not a very serious problem in Estonia (Frey, 1988; Sepp & Asi, 1994). Instead, in some regions in northern and north-eastern Estonia even a noteworthy base cation deposition occurs due to industrial pollution (Martin et al., 1994). However, a substantial portion of our territory (about 40% of all woodlands) is covered by pine forests on poor, naturally acidic soils (Taimre, 1989), with a low density of human population. A calcium-provision experiment carried out in the populations of two forest passerines – pied flycatcher *Ficedula hypoleuca* and great tit *Parus major* – revealed that birds indeed suffered calcium deficiency in poor pine forests in south-western Estonia (Mänd et al., 1998, 2000a, b; Tilgar et al., 1999; Tilgar, 2002; Mänd & Tilgar, in press).

In 1995–96, we carried out a research project to estimate the current state of land snail populations in Estonian forests, in order to be able to adequately measure possible changes in the future. To our knowledge, this was the first large-scale quantitative investigation of forest snail fauna in the eastern Baltic area. Here we present data about the abundance and species richness of land snails in geologically different regions and forest types of Estonia, and also describe the effect of industrial forest liming, which has occurred in some areas.

## MATERIAL AND METHODS

Three most common types of forests all over Estonia were studied: (a) dry boreal pine forests, (b) fresh boreal spruce forests, and (c) fresh boreo-nemoral deciduous/mixed forests. Eight study plots in places without significant atmospheric

pollution were selected in each forest category. Three of them were situated in West Estonian Islands (Silurian limestone bedrock, but pine forests on sand dunes), three in southern Estonia (Devonian sandstone bedrock), and two in north-east Estonia (calcareous moraine plateau and sand dunes). In selecting study plots, we preferred nature reserves or permanent environmental monitoring sites, to ensure their persistence for future re-sampling. The detailed data about the exact location of the study plots and their botanical descriptions are given in the reports of a land snail monitoring project (Veegen, 1995, 1996) deposited in the Centre of Information and Technology of the Estonian Ministry of the Environment. To investigate the effect of industrial liming on snails, one study plot in each forest category was chosen near the oil-shale industry (Ahtme, NE Estonia) and one in pine forest near cement works (Kunda, N Estonia). All these plots are subjected to high atmospheric pollution with calcium-rich dust, especially Kunda pine forest and Ahtme deciduous forest, where the herbs and leaves were covered with a visible whitish coating. In one pine forest plot in S Estonia a liming experiment with oil-shale ash was carried out in 1987. The geographic co-ordinates of all study plots are given in Table 1. More details are given in Kiristaja (2001).

Ten litter samples were collected from each study plot using 25 × 25 cm square quadrats with a distance of 10 m from one another. Five of them were placed tightly against the nearest tree, and snails were collected also from this side of the tree trunk up to 2 m. The samples contained herbs, lichens, mosses, and litter layer plus the top 1–2 cm of the mineral soil. The material was air-dried and carefully hand-sorted in laboratory conditions, using a magnifying glass. The searching time per sample was 0.5–1.5 h, depending on the sample volume. All snails (live individuals and empty shells separately) were counted and identified, following Kerney & Cameron (1996).

All samples were collected in dry weather during a short mid-summer period between 22 July and 8 August in 1995 (pine and deciduous/mixed forests) and 23 July and 5 August in 1996 (spruce forests). Repeated sampling in six plots showed that the abundance of snails in the same places was about 70% higher in 1996 than in 1995. Therefore, the spruce forest data of 1996 were corrected correspondingly.

The frequencies of each snail species were expressed as the number of quadrats with the species per 10 quadrats analysed in the respective group of plots (forest type, region, or site).

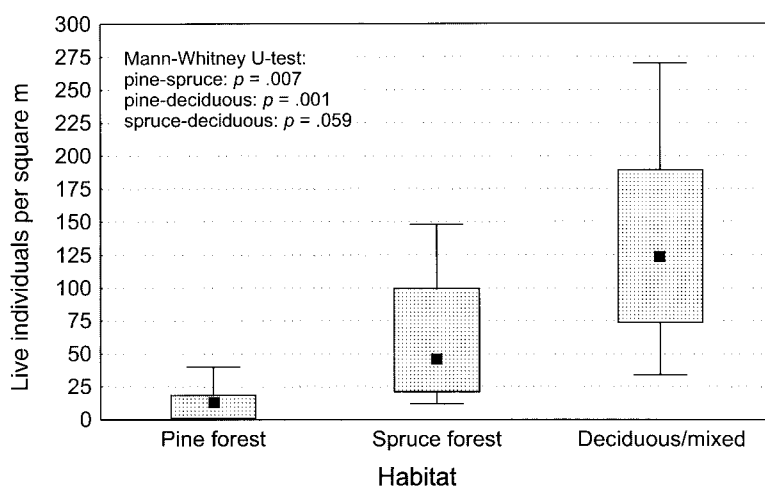
After the snails were extracted from the litter, all ten litter samples from each study plot were carefully mixed. The smaller sub-samples were then taken randomly out from this homogenized material for chemical analyses. Two chemical variables were measured in the laboratory: pH (electrometrically in fresh litter suspended in distilled water) and total calcium content (ashed and extracted with HCl).

## RESULTS AND DISCUSSION

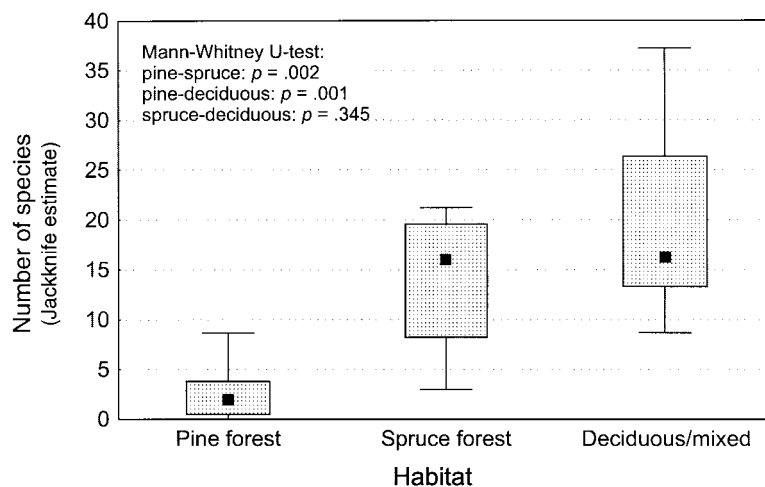
The main numerical results of the study are presented in Table 1. Among forests not subjected to industrial or experimental liming, the density of land snails (both live individuals and empty shells) and species richness and diversity were all significantly (according to the Mann–Whitney U-test) the lowest in the pine forests and the highest

in the deciduous/mixed forests. However, the species richness and diversity in the spruce forests did not differ significantly from those in the deciduous/mixed forests. No significant variance in the evenness of species distribution was found between the studied forest categories. For better illustration of the differences between forest types, abundances of live snails and Jackknife estimates of species richness are given in Figs. 1 and 2.

A significant difference between the habitats studied was also found in the live individuals/empty shells ratio: the proportion of live individuals was significantly



**Fig. 1.** Density of land snails in different forest habitats of Estonia. Median, quartiles, and minimum and maximum are given.



**Fig. 2.** Jackknife estimates of the number of land snail species in different forest habitats of Estonia. Symbols as in Fig. 1.

**Table 1.** Numbers and species richness of land snails in Estonian forests in 1995–96

Forest type	District	Study site	Co-ordinates	Litter chemistry		Ind. m <sup>-2</sup>		% live inds	Species richness <sup>a</sup>			
				Ca%	pH	Live	Total		N	Jack	Sh-W	Evn
Pine	W-Estonian Archipelago	Nõmba	58°55' 22°47'	0.18	4.2	19	27	70	3	4.8	0.67	0.42
		Torgu	57°59' 22°05'	0.08	4.2	40	48	83	6	8.7	1.57	0.61
		Viidumäe	58°18' 22°05'	0.04	4.0	8	10	82	2	2.0	0.92	0.92
	NE Estonia	Kauksi	59°00' 27°16'	0.20	4.0	18	19	97	1	1.0	0.00	–
		Koljaku	59°33' 26°02'	0.41	4.2	18	32	57	2	2.9	0.34	0.34
		Ahtme***	59°17' 27°33'	1.56	6.5	174	272	64	13	17.5	2.75	0.74
Kunda***	59°29' 26°29'	?	?	502	2701	19	23	28.6	2.69	0.60	0.60	
S Estonia	Kiidjärve	58°06' 27°00'	?	?	0	0	–	0	0	–	–	
	Mõniste	57°34' 26°28'	0.25	4.0	2	2	100	1	1.9	0.00	–	
	Pikasilla	58°03' 26°07'	0.26	4.1	0	0	–	0	0	–	–	
	PikasillaEx***	58°03' 26°07'	0.30	4.0	131	230	57	3	3.0	1.47	0.93	
	Putkaste	58°48' 22°35'	2.57	6.0	51	93	55	14	21.2	2.73	0.72	
	Sõrve	58°02' 22°09'	1.76	5.1	148	213	69	17	20.6	3.60	0.88	
Spruce	W-Estonian Archipelago	Viidumäe	58°18' 22°05'	0.61	4.7	118	147	80	14	18.5	2.93	0.77
		Lahe	59°36' 25°59'	0.87	4.1	81	106	76	12	14.7	2.77	0.77
		Saarejärve	58°39' 26°45'	0.57	4.6	12	18	67	3	3.0	1.52	0.96
	NE Estonia	Ahtme***	59°16' 27°29'	3.29	6.3	146	374	39	18	19.8	3.36	0.80
		Kolepi	57°46' 27°02'	0.33	4.7	41	93	44	12	17.4	2.87	0.80
		Pikasilla	58°02' 26°07'	0.15	4.2	23	37	62	7	9.7	2.09	0.74
Nigula	58°03' 24°44'	0.42	4.0	19	29	66	5	6.8	1.63	0.70		

**Table 1** continued

Forest type	District	Study site	Co-ordinates	Litter chemistry		Ind. m <sup>-2</sup>		% live inds	Species richness <sup>a</sup>			
				Ca%	pH	Live	Total		N	Jack	Sh-W	Evn
W-Estonian Archipelago		Tubala	58°57' 22°46'	0.88	6.1	270	427	63	30	37.2	4.05	0.83
		Sõrve	58°01' 22°10'	0.75	7.2	246	389	63	23	25.7	4.08	0.90
		Viidumäe	58°18' 22°04'	0.22	5.6	104	146	71	19	27.1	3.53	0.83
Deciduous/ mixed	NE Estonia	Lahe	59°36' 25°59'	0.51	5.7	43	102	42	12	16.5	3.01	0.84
		Sõrumäe	59°08' 27°21'	0.32	4.8	133	230	58	10	11.8	2.54	0.76
		Kose***	59°19' 27°29'	5.36	7.5	1422	4565	31	24	27.6	3.46	0.75
S Estonia		Kuutsi	57°36' 26°35'	1.20	4.9	34	69	50	6	8.7	1.74	0.67
		Pikasilla	58°04' 26°06'	0.97	6.7	125	237	53	12	16.0	3.04	0.85
		Nigula	58°01' 24°40'	?	?	123	219	56	13	14.8	3.05	0.82

<sup>a</sup> N, number of species registered; Jack, Jackknife estimate of species richness; Sh-W, Shannon–Wiener index of heterogeneity; Evn, evenness (calculated on the basis of Shannon–Wiener index). Indices were calculated according to Krebs (1999). Study plots marked by triple asterisks (\*\*\*) were subjected to significant liming due to industrial pollution or liming experiment (PikasillaEx). Data of spruce forests from 1996 have been corrected (see text for explanation). ?, data missing.

higher in the pine forests than in other habitats (Table 1; Mann–Whitney U-test; pine and spruce forests:  $p = 0.033$ ; pine and deciduous/mixed forests:  $p = 0.014$ ). This difference can most probably be explained by the higher corrosion rate of empty shells in more acidic environments of pine forests together with relatively higher predation by, e.g., birds and land snails. This finding is particularly important in the context of studies aimed at estimating the amount of available calcium for birds. It is not enough to present data about live individuals alone, since both live and empty shells serve as calcium sources for birds, but there is no simple relationship between these two shell categories.

Comparison of different geological regions showed that species richness is significantly higher in West Estonian Islands than in the mainland (Table 1). Also the abundance of live snails tended to be higher in the archipelago than in the mainland, although the difference was not very significant (Mann–Whitney U-test,  $p = 0.077$ ). The relatively high diversity of the snail fauna in the forests of West Estonian Islands is most probably related to an influence of Silurian limestone prevailing in this area. Indeed, many authors have demonstrated a clear dependence of snail abundance on soil pH, Ca concentration, base cation concentration, and base saturation (Valovirta, 1968; Wäreborn, 1982; Gärdenfors, 1992).

An alphabetic list of 60 registered snail species together with their estimated frequencies by different regions, forest types, and artificially limed sites is given in Table 2. The frequency of *Nesovitrea hammonis* exceeded that of most other species approximately 5–10 times. The contrast between *N. hammonis* and other species is particularly high in dry pine forests. Altogether eight snail species were registered there, with *N. hammonis* exceeding about 10–30 times the frequency of the rest of the species (Chi-square = 17.6,  $df = 1$ ,  $p < 0.000$ ). This is not surprising since laboratory experiments have shown that *N. hammonis* tolerate comparatively lower pH values and calcium levels than other common snail species (Wäreborn, 1970). However, no regional differences in the frequency of this most common forest snail were detected. *Nesovitrea petronella* and *Aegopinella pura* were the next most frequent species, inhabiting the spruce stands and the deciduous forests equally well, but, unlike *N. hammonis*, were not found in the pine forests (Table 2). No significant differences in the species composition were found between the spruce and deciduous forests, but in all pine forests the frequency of most species except *N. hammonis* was negligible.

Data from the forests subjected to significant industrial or experimental liming reveal unusually high values of snail abundance and species richness (Tables 1 and 2). This result is not surprising because of the already mentioned causal relationships between soil chemistry and snails. An artificial liming of a beech forest in southern Sweden increased the density of snails 4–40 times, depending on species and lime dose (Gärdenfors, 1992). Consequently, deposition of airborne calcium-rich materials in certain industrial regions of northern and north-eastern Estonia seems to have a clearly positive effect on local land snail populations. The data from the most polluted deciduous forest near the oil-shale industry at Ahtme (Kose forest in Table 1 = Ahtme decid f in Table 2) and a pine forest near Kunda cement works show the highest values of snail density, many times exceeding the registered densities in the richest “clean” forests in Estonia (Table 1). However, it is noteworthy that the

**Table 2.** Frequencies<sup>a</sup> of snail species in Estonian forests. The last five artificially limed forests were excluded when calculating frequencies of a certain region or forest type. See other details below the table

Species	Total frequency	Geological region <sup>b</sup>			Forest type <sup>c</sup>			Limed forests <sup>d</sup>				
		West islands	NNE	South Estonia	Pine	Spruce	Decid	Limed pine f	Ahtme pine f	Ahtme spruce f	Ahtme decid f	Kunda pine f
<i>Acanthinula aculeata</i>	0.75	1.89	-	0.11	-	1.38	0.88	-	-	4	-	-
<i>Acicula polita</i>	0.08	-	-	0.22	-	-	0.25	-	-	-	-	-
<i>Aegopinella pura</i>	1.83	3.11	0.17	1.67	-	2.75	2.75	-	3	10	1	-
<i>Ariantia arbusorum</i>	0.67	1.78	-	-	-	1.00	1.00	-	-	-	-	-
<i>Arion circumscriptus</i>	0.21	0.44	-	0.11	+	0.13	0.50	-	-	-	-	-
<i>Arion fasciatus</i>	0.17	0.44	-	-	-	-	0.50	-	-	-	-	-
<i>Arion subfuscus</i>	0.38	0.56	0.50	0.11	0.38	0.38	0.38	-	-	-	-	-
<i>Bithynia tentaculata</i> *	+	-	-	+	-	-	+	-	-	-	-	-
<i>Bradybaena fruticum</i>	0.67	0.67	0.50	0.78	-	-	2.00	-	+	-	10	2
<i>Bulgarica cana</i>	+	-	-	-	-	-	-	-	-	5	-	-
<i>Carychium minimum</i>	0.63	1.11	0.17	0.44	-	-	1.88	-	-	-	-	-
<i>Carychium tridentatum</i>	0.25	0.22	0.17	0.33	-	0.13	0.63	-	1	9	-	-
<i>Cepaea hortensis</i>	0.38	1.00	-	-	-	0.25	0.88	-	-	1	5	-
<i>Clausilia bidentata</i>	1.42	3.78	-	-	-	2.50	1.75	-	-	-	-	-
<i>Clausilia dubia</i>	0.04	-	-	0.11	-	-	0.13	-	-	-	3	-
<i>Clausilia pumila</i>	+	-	-	+	-	-	+	-	-	-	-	-
<i>Cochlodina laminata</i>	0.92	2.00	-	0.44	-	0.75	2.00	-	4	8	-	-
<i>Cochlicopa lubrica</i>	0.96	0.78	1.00	1.11	-	0.50	2.38	-	3	10	2	-
<i>Cochlicopa lubricella</i>	1.21	2.22	-	1.00	-	0.75	2.88	-	1	10	3	-
<i>Cochlicopa nitens</i>	0.21	0.11	0.67	-	-	-	0.63	-	-	-	-	-
<i>Cochlodina orthostoma</i>	+	-	-	-	-	-	-	-	-	-	6	-



Table 2 continued

Species	Total frequency	Geological region <sup>b</sup>				Forest type <sup>c</sup>			Limed forests <sup>d</sup>					
		West islands		NNE	South Estonia	Pine	Spruce	Decid	Limed pine f	Ahtme pine f	Ahtme spruce f	Ahtme decid f	Kunda pine f	
		0.33	0.22	1.00	0.22	0.13	0.50	0.63	-	-	-	-	1	
<i>Columella aspera</i>	0.13	0.33	-	-	0.38	-	-	-	-	-	-	-	-	1
<i>Columella edentula</i>	0.42	0.22	1.00	0.22	0.13	0.50	0.63	-	-	5	1	-	-	-
<i>Deroceras agreste</i>	0.04	0.11	-	-	0.13	-	+	-	-	-	-	-	-	-
<i>Deroceras laeve</i>	0.04	-	-	0.11	-	0.13	-	-	-	-	-	-	-	-
<i>Discus rotundatus</i>	0.54	1.44	-	-	-	1.00	0.63	-	-	-	-	-	-	-
<i>Discus ruderatus</i>	1.04	1.33	1.17	0.67	-	2.38	0.75	4	3	6	10	1	1	
<i>Ena obscura</i>	0.42	1.11	-	-	-	-	1.25	-	-	-	-	-	-	-
<i>Euconulus alderi</i>	0.96	2.56	-	-	+	2.25	0.63	-	-	-	-	-	-	-
<i>Euconulus fubus</i>	0.92	0.22	2.50	0.56	+	1.50	1.25	2	+	8	9	5	5	
<i>Euomphalia strigella</i>	0.50	1.22	-	0.11	-	0.13	1.38	-	-	-	-	-	-	-
<i>Galba truncatula*</i>	0.04	-	0.17	-	-	-	0.13	-	-	-	-	-	-	-
<i>Helix pomatia</i>	0.08	0.22	-	-	-	-	0.25	-	-	-	-	-	-	-
<i>Macrogastera plicatula</i>	+	-	-	-	-	-	-	-	-	4	3	-	-	-
<i>Macrogastera ventricosa</i>	0.04	0.11	-	-	-	-	0.13	-	-	-	2	-	-	-
<i>Nesovitrea hammonis</i>	5.42	6.11	6.00	4.33	3.13	7.75	5.38	3	9	10	10	5	5	
<i>Nesovitrea petronella</i>	2.92	1.89	3.33	3.67	-	4.38	4.38	-	1	9	9	4	4	
<i>Oxychilus alliaris</i>	0.38	1.00	-	-	0.13	-	1.00	-	-	-	-	-	-	-
<i>Oxyloma pfeifferi</i>	+	-	-	+	-	-	+	-	-	-	-	-	-	-
<i>Perforatella bidentata</i>	0.67	0.22	1.33	0.67	-	-	2.00	-	-	1	10	-	-	-
<i>Perforatella rubiginosa</i>	0.42	1.11	-	-	-	-	1.25	-	-	-	-	-	-	-
<i>Punctum pygmaeum</i>	1.67	1.56	1.83	1.67	-	2.38	2.63	-	5	5	10	5	5	
<i>Pupilla muscorum</i>	+	-	-	-	-	-	-	-	-	-	-	-	-	5
<i>Succinea oblonga</i>	0.29	0.44	-	0.33	-	0.38	0.50	-	3	-	-	-	-	5

Table 2 continued

Species	Total frequency	Geological region <sup>b</sup>			Forest type <sup>c</sup>			Limed forests <sup>d</sup>				
		West islands	NNE	South Estonia	Pine	Spruce	Decid	Limed pine f	Ahtme pine f	Ahtme spruce f	Ahtme decid f	Kunda pine f
<i>Succinea putris</i>	0.29	0.44	-	0.33	-	-	0.88	-	-	-	-	-
<i>Trichia hispida</i>	0.79	1.89	+	0.22	-	0.38	2.00	-	-	-	10	3
<i>Vallonia costata</i>	0.88	2.00	-	0.33	-	0.75	1.88	-	5	5	10	5
<i>Vallonia pulchella</i>	0.42	0.44	-	0.67	-	-	1.25	-	1	-	-	4
<i>Vertigo alpestris</i>	+	+	+	-	+	-	-	-	-	-	-	1
<i>Vertigo angustior</i>	0.08	-	-	0.22	-	-	0.25	-	-	-	-	1
<i>Vertigo genesii</i>	+	+	-	-	+	-	-	-	-	-	-	-
<i>Vertigo modesta</i>	+	-	-	-	-	-	-	-	1	-	-	-
<i>Vertigo pusilla</i>	0.38	0.78	0.17	0.11	-	0.88	0.25	-	-	-	-	2
<i>Vertigo pygmaea</i>	0.04	-	0.17	-	-	0.13	-	-	-	3	-	1
<i>Vertigo rommbyensis</i>	0.04	+	0.17	-	+	0.13	-	2	5	-	-	-
<i>Vertigo substriata</i>	0.42	+	1.17	0.33	+	0.75	0.50	-	3	4	-	1
<i>Vitrea crystallina</i>	0.92	2.00	-	0.44	+	0.75	2.00	-	-	8	10	-
<i>Vitrina pellucida</i>	0.83	1.44	0.50	0.44	0.13	0.25	2.13	-	1	-	10	5
<i>Zonitoides nitidus</i>	0.17	0.11	0.17	0.22	-	0.13	0.38	-	-	-	-	2
<i>Zoogenetes harpa</i>	0.17	0.44	-	-	0.38	0.13	-	-	-	-	-	-

<sup>a</sup> Number of quadrats with the species per 10 studied quadrats.

<sup>b</sup> West Islands, Saaremaa and Hiiumaa islands; NNE, north and northeast Estonia.

<sup>c</sup> Pine, dry boreal pine forests; Spruce, fresh boreal spruce forests; Decid, fresh boreo-nemoral deciduous/mixed forests.

<sup>d</sup> Limed pine f, artificially limed (in 1987) pine forest in S Estonia; Ahtme pine f, pine forest in the vicinity of Ahtme oil-shale industry, NE Estonia; Ahtme spruce f, spruce forest in the same area; Ahtme decid f, deciduous forest in the same area; Kunda pine f, pine forest in the vicinity of Kunda cement works, N Estonia.

\* Aquatic snail species (found in wet places in forest).

+ Species was not found in main samples, but was registered during additional sampling.

species richness in these plots did not exceed the value in the richest unpolluted study plot in the western archipelago, Tubala deciduous forest (Hiiumaa Island). A related finding was that despite the high density of snails in Pikasilla pine forest, where an experimental liming had been carried out in 1987 (PikasillaEx in Table 1 = Limed pine f in Table 2), the number of species was still very low there. Thus an increase in snail species richness due to artificial liming seems to be a comparatively time-consuming process, depending on the original richness of the surrounding natural biotopes, while the number of individuals (and consequently the available calcium source for forest birds) increases quite rapidly. In another study, the formation of the land snail fauna was investigated in an afforested oil-shale mining area in NE Estonia (Mänd et al., 2001). It was found that the number of species increased only three times, while the density of individuals increased more than ten times 13–23 years after planting young trees. Thus, artificial liming of naturally nutrient-poor forests does not help much to enrich the species composition of land snail community, but can sufficiently improve calcium availability for birds breeding in those forests.

Comparing our results with those of a study carried out in The Netherlands (Graveland et al., 1994; Graveland & Van der Wal, 1996; Mänd et al., 2000b), one can see that the density and species richness of snails in pine forests of NE Estonia and the West-Estonian Archipelago is close to that in the oligotrophic forests of The Netherlands in 1970, before a drastic decline. In extensive oligotrophic pine forests on S Estonian sandstone bedrock, the number of snails is extremely low and comparable to that of poor forests in The Netherlands in the 1990s, when laying abnormalities of forest birds were already common. These data indicate that calcium deficiency may well be among ecological factors limiting the reproductive performance of passerines in naturally nutrient-poor forests in the eastern Baltic area. A long-term calcium-providing experiment, carried out in SW Estonia (Mänd et al., 1998, 2000a, b; Tilgar et al., 1999; Tilgar, 2002; Mänd & Tilgar, 2002), supports this conclusion.

The number of snails in Estonian boreal spruce forests and boreo-nemoral deciduous/mixed forests seems to be high enough to provide birds with the necessary calcium during laying time. However, birds breeding in dry boreal pine forests, which constitute about 40% of all Estonian woodlands, may be vulnerable to possible increases in acidification. It may sound a little paradoxical, but industrial pollution with airborne calcareous materials in some ecologically problematic industrial regions seems to be able to compensate for natural calcium deficiency as well as to buffer possible negative trends.

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## **Maismaateod Eesti metsades: arvukus ja liigirikkus**

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Euroopa antropogeenselt hapestunud piirkondade oligotroofsetes elupaikades on täheldatud maismaatigude asurkondade drastilist allakäiku. Kuna teokojad kujutavad endast tähtsat kaltsiumiallikat metsalindudele, siis põhjustab tigude vähenemine tõsiseid tagajärgi ka metsavärvuliste sigimisedukusele. Umbes 40% Eesti metsadest on männikud, mis kasvavad vaestel, looduslikult happelistel muldadel. Varasemates töödes on näidatud, et sellistes metsades pesitsevad linnud kannatavad samuti spetsiifilise kaltsiumivaeguse all. Eesti metsade maismaatigude populatsioonide praeguse olukorra hindamiseks korraldatud uurimisprojekt on ühtlasi esimene suuremastaabiline kvantitatiivne metsatigude fauna uuring Baltikumis. Andmed tigude arvukuse ja liigirikkuse kohta koguti erinevate geoloogiliste regioonide ja metsatüüpide kaupa. Uuriti ka põlevkivitööstuste ja tsemenditehase poolt põhjustatud atmosfäärse aluselise metsasaaste mõju tigudele. Tulemused näitavad, et tigude arvukus suures osas Eesti metsades on väga madal, mistõttu seal pesitsevad linnud võivad keskkonna hapestumise korral olla ohustatud. Samas just mõnedes ökoloogiliselt problemaatilistes piirkondades esinev keskkonna saastamine kaltsiumirikka heitmega kompenseerib sealsetes elupaikades esinevat kaltsiumidefitsiiti ja paistab seega mõjuvat tigude asurkonnale soodsalt.