Internship Report (March 2013 – June 2013):

Gastropod abundance and species richness in old-growth and reclaimed forests of the Ville Ridge (North Rhine-Westphalia, Germany)

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Abstract

Gastropods are important components of the detritivore food web, as they are able to accelerate and contribute to nutrient and carbon turnover. More specifically, snails and slugs are responsible for the fragmentation of coarse litter and other plant material, increasing the thickness of the upper soil layer and thus offering conditions to improve activity of microorganisms. Still, gastropod abundance and diversity are dependent on a microclimate that fits their needs, the type of forest (incl. canopy cover and nutrient composition of leaves) and soil composition. Six forest areas in the Ville (Bruehl, North Rhine-Westphalia, Germany) belonging to the old forest, the old and the younger recultivation were analyzed in this study regarding gastropod species richness and abundance. It is hypothesized that the reclaimed forests have not yet attained original conditions, lacking for example stenoecious forest species, but that the gastropod assemblages from old reclamations slowly approach that of the old-growth sites. Based on the intermediate disturbance theory and the concept of succession it is assumed that species richness as well as species occurrence in old reclaimed stands would exceed that of youngest restoration stages, and of the old forest sites. This hypothesis was partly confirmed, considering that the new recultivation areas still differ from the old forest sites with respect to gastropod abundance, diversity and habitats (forest, forest associated, disturbed areas). The old recultivation Huttanus-Plantage showed a tendency towards an old forest profile, however the same could not be affirmed for the other surveyed areas (Am Tongraben, Silbersee and Donatussee), which emphasizes the importance of addressing the complexity of biological interactions in an ecosystem context (microclimate, soil, foliage and vegetation characteristics).

Keywords: Terrestrial gastropods, species richness, soil characteristics, soil pH, open cast mining, land reclamation

1. Introduction

Human impact on forest areas usually results from urbanization, fuel extraction, intensive forest management (timber) and agriculture. From an ecosystem approach, deforestation is not only the cut down of trees. It is the destruction of the physical environment of innumerous biota which directly and indirectly depends on the forest environment to survive. Deforestation also changes micro- and mesoclimate along with water and nutrient flows. A lack of trees implies that the annual leaf litter input ceases. This has direct consequences for detritivores. Detritivores play an important role in nutrient cycling, that is, they help to transform organic matter to inorganic compounds, which are then made available to primary producers, e.g. plants (Reece et al. 2011).

As any severe disturbance, deforestation usually has a severe impact on organisms with limited active dispersal capacity (Reece et al. 2011). These organisms cannot evade the disturbance, being usually locally driven to extinction. One disturbance-sensitive group is that of gastropods (Kappes et al. 2009a). Gastropods have to re-colonize re-growing forests from in-situ refuges or by passive dispersal.

One of the most intense disturbances on forest ecosystems is open cast mining. Open cast mining implies not only the removal of trees, but also the removal of topsoil and thus of any possible in-situ refuges Thus, any succession on post-mining land is a primary succession. Restoration or reclamation tries to speed up this succession to reach tolerable conditions.

Often, the restoration of ecosystems implies a primary step related to the recovery of the physical structure, which is then followed by biological recovery (Reece et al. 2011). In the last decades, a new consensus of forest management has risen, which aims at re-stabilizing the ecosystems to their pre-disturbance equilibrium. This new concept of forestry considers the importance of heterogeneous environments, wood debris, litter and longer rotation intervals (Führer 2000, Jabin et al. 2004, Kappes et al. 2006, Taylor et al. 2003).

However, imbalances in an ecosystem caused by disturbance can affect the area for centuries until it eventually recovers. This study aimed at assessing and comparing gastropod assemblages from two old forest and four reclaimed areas situated in the Ville forest between Brühl and Erftstadt (Regierungsbezirk Bergheim). The old forest sites, which were not destroyed by charcoal extraction, are 130 - 190 years old and have been part of a natural forest reserve since 1978. The other areas were restored after lignite mining, with the restoration period dating from the 1920s (two forest sites) and the 1960s (2 forest sites).

1.1 The Ville – a short overview of the studied areas

1.1.1 The Old Forest

Two of the surveyed areas, Naturwaldzelle and Am Schnorrenberg, are parts of the Old forest. The oldest trees here have reached an age of approximately 200 years. The Old Forest Naturwaldzelle was embedded in the project Natura 2000, which is an important component of the European Nature and Biodiversity Policy (LANUV NRW 2013, ec.europa.eu 2013). From its 66 ha, approximately 20 ha are protected since 1978 as “strict nature reserve/wilderness area (Ia)” according to the International Union for Conservation of Nature (IUCN), i. e. forestry activities are strictly forbidden. The remaining 46 ha are categorized as “habitat/species management area (IV)”, in which only sustainable forestry is allowed (iucn.org 2013). Shortly, the development goal hidden behind these conservation areas is to protect the forest, whereby the maintenance and protection of indigenous species is especially strived (LANUV NRW 2013).

The grass species *Milium effusum L.* and the European Beech *Fagus sylvatica* are the natural i. e. indigenous representatives of the Old Forest (LANUV NRW 2013). To date, the Old Forest consists mainly of deciduous trees. It is composed of beech (*Fagus*) and oak (*Quercus*) trees that are between 151 and 201 years old, 46- to 66-year old beech trees, 43- to 49-year old birch (*Betula*) and European hornbeam (*Carpinus betulus*). The soil type of this region varies from clayey to loamy-sandy silt to gritty-loamy sand and is considered to be moderate to nutrient rich (LANUV NRW 2013).

1.1.2 Forest areas restored after lignite mining

Two other areas of study (Am Tongraben and Huttanus-Plantage) correspond to land parcels of the Ville that are relatively close to the Old Forest (distance: approx. 2 km), which were deforested for the exploitation of charcoal between the end of the 19th century and the beginning of the 20th century. The restoration process of these areas began in the 1920s, after the lignite mining activity had been stopped (Kremer 1999, Forschungsstelle Rekultivierung 2011). Firstly, the old recultivation sites were afforested with deciduous trees, such as alder (*Alnus*), poplar *(Populus)* and robinia (*Robinia*) trees. Later, 1928, reforestation based on a diverse, mixed-forest approach began, in which beech and oak trees and various species of shrubs were planted (Kremer 1999, Forschungsstelle Rekultivierung 2011). The new recultivation sites, at the Donatussee and Silbersee, were reforested after 1960. Since 1961, restoration measures are based on scientific theories and include the mixing of hardwood forests under poplar-nurse crop, and techniques to avoid soil compaction (Uwe Schölmerich, Regionalforstamt Rhein-Sieg-Erft, personal communication, June 25, 2012).

The soil type in these areas is composed of a mix of sand, gravel, loam, charcoal and clay. Currently, a considerable part of the Ville is protected as a nature conservation area.

The following subchapter provides a brief introduction on the class of the Gastropoda (i. e., snails and slugs), underlining some features of their behavior, nutrition, habitat requirements and dispersal abilities.

1.2 Gastropoda and the environment

Gastropods are considered to be very successful members of the group of terrestrial invertebrates, especially if their presence in habitats of extreme temperature conditions (e. g. deserts and arctic regions) is taken into account.

There are three main life forms of gastropods, namely snails, semi-slugs (whose shells are too small for them to retract) and slugs. All three life forms can be found in European forests (Schaeffer 1991, Lozek 1962, Kappes 2011). Gastropod body sizes range from less than 0.2 cm (mesofauna) up to 20 cm (macrofauna), but most snail species are smaller than 2 cm, that is, members of the macrofauna (Kappes 2011). Besides, gastropod species also differ greatly with respect to longevity, considering that their life spans vary between less or equal to one year in several small or annual species and 19 years. (Barker 2001, Dr. Heike Kappes, researcher in the Terrestrial Zoology department, snail (macro-)ecology at the Netherlands Centre for Biodiversity Naturalis, personal communication, May 22, 2013).

The next paragraphs depict some information on the behavior of these organisms and some conditions that have to be met to allow their survival and persistence in a given environment, allowing them to occupy their realized niche.

Gastropods and their physico-chemical environment

Terrestrial gastropods are generally either moving or resting. Snails and slugs move through adhesive locomotion, which is enabled by the release of mucus. Mucus is composed basically of water (89-98 %) and some macromolecules, such as complex carbohydrates and glycoproteins (Barker 2001). Approximately 65 % of the energy uptake of gastropods are invested in mucus production (Theenhaus & Schaefer 1999).

Considering the great water content in the mucus released by gastropods and the fact that water accounts for approximately 78 to 92 % of their body weight, water is essential for gastropods. Gastropods rely on strategies for avoiding losses of water, e. g. from excessive evaporation on days of low relative humidity. As gastropods move and release mucus, on the one hand they expose themselves to a given risk of drying out. On the other hand, foraging, reproduction and dispersal require locomotion performances. While resting, gastropods have acquired several passive ways to conserve water, e. g. by avoiding temperature extremes and selecting habitats that provide favorable microclimates. Finally, dehydrated terrestrial gastropods face reductions in the rates of their metabolic activities: feeding, circulatory, excretory and digestive functions are compromised and may even stop (Barker 2001).

Barker (2001) described that the major decisions that snails and slugs take and that define their behavior are related to the time and place at which they should be active or inactive, as to how they would achieve appropriate roosting sites and as to what they should do in active periods. Physical factors (inorganic ions, soil texture, etc.) affecting an environment are known to play a decisive role on snails' and slugs' choice concerning their activity or inactivity periods (Barker 2001).

In general, gastropods prefer relatively cool areas that are permanently moist, given they are quite sensitive to soil and weather conditions (Kappes et al. 2006). Thus gastropods are often occurring in suitable microhabitats such as provided by coarse woody debris. Coarse woody debris locally enhances the diversity and density of gastropod populations as it functions as microclimate regulator, providing additional shelter (Kappes 2005, Kappes et al. 2006), but also as additional food sources (Kappes et al. 2012).

Considering the high dependency of gastropods to an appropriate microclimate that fits their needs, the type of forest (incl. canopy cover and nutrient composition of leaves) also plays a role in supporting species diversity and species richness. Previous studies imply that deciduous forests tend to support gastropod populations to a greater extent than do conifers. Main reasons are that conifers tend to acidify the soil, which negatively impacts calcium availability; and that nutrients of conifer leaves are more difficult to be obtained due to their harder texture (Kappes 2011).

The acidity of soil may change from disturbances, including acidic depositions and mining waste (Spiro et al. 2012, Bradshaw 1997, Tiwary 2001). If acidity increases, disequilibrium may cause soil calcium depletion, which in turn affects snail populations due to their high requirements of calcium intake. In this case, slug-form gastropods differ from snails, as the species richness and biomass of the former group only weakly change along the soil pH gradient (Kappes 2006, Kappes et al. 2007). However, effects from low densities of invertebrates with calcium-rich exoskeletons may cascade up the food chain and for example negatively affect bird breeding success (Graveland & van der Wal 1996, Schlender et al. 2007).

Gastropod nutrition and nutrient cycling

Snails and slugs are considered to be generalists, which means that they are able to eat nearly every type of organic matter and absorb its nutrients. Thus, gastropods can eat seeds, fresh and scenescing leaves, wood, fungi, dead animals, soil particles, etc., whereby plant material usually has the largest share in their nutrition (Barker 2001). Desirable constituents in gastropods' nutrition are carbohydrates, cellulose, fatty acids, amino acids, calcium, vitamins (especially vitamins A, B and D), among others (Barker 2001).

Regarding nutrient cycling, gastropods are contributing to the fragmentation of coarse litter and other plant material, increasing the thickness of the upper soil layer and thus offering conditions to improve activity of microorganisms (Mason 1970a, Mason 1970b, Richter 1979). Through mucus and excrements release by snails and slugs, microbial activity is stimulated and may spread more rapidly in the area (Herlitzius & Herlitzius 1977). Furthermore, selective primary consumption by snails and slugs was found to liberate phosphates to the soil (Thompson et al. 1993). Basically, gastropods are able to accelerate and contribute to nutrient and carbon turnover by the detritivore food web (Barker 2001, Thompson et al. 1993, Mason 1970a, Mason 1970b, Jennings & Barkham 1975).

1.3 Recovery of Gastropoda populations in restored forest areas: the Ville

Deforestation increases oscillations in the micro- and mesoclimate of a given forest area (Geiger et al. 2009), which, as mentioned in the previous subchapters, may threaten gastropod species that are susceptible to changes in moisture and temperature. The topsoil removal that proceeds open cast mining then extirpates all remaining soil-living biota and later hampers re-colonization during the reclamation process (Bradshaw 1997, Bradshaw 2000, Kappes et al. 2012).

Against this background, the following study aimed at analyzing and comparing species richness and density of gastropods in the old forest, in the old recultivated forest and in the forest areas that were restored later. It is hypothesized that the reclaimed forests have not yet attained original conditions, that is, they for example lack stenecious forest species, but that the gastropod assemblages from old reclamations slowly approach that of the old-growth sites. Based on the intermediate disturbance theory and the concept of succession it is assumed that species richness as well as species occurrence in old reclaimed stands would exceed that of youngest restoration stages and of the old forest sites.

2. Methods

2.1 Surveyed area

Samples of six different areas were taken from the Ville Forest (Bruehl, North Rhine-Westphalia, Germany). Two areas belong to the category Old Forest: Altwald Ville Naturwaldzelle (1) and the old forest area Am Schnorrenberg (2), located northern of the Schlunkweg. Two forest areas from the old recultivation were studied (Huttanus-Plantage (3) and am Tongraben (4)), whereby they have started being restored in the 1920s. Additionally, two areas of the new recultivated forest were surveyed, namely the southern area of the Silbersee (5) and the northern area of the Donatussee (6), where the oldest trees are about 50 years old (Table 1, Figure 1).

Table 1. Surveyed forest parcels and their corresponding geographic coordinates

Surveyed area	Geographic coordinate
1. Naturwaldzelle	50.79221°N 6.84670°E
2. Am Schnorrenberg	50.80824°N 6.87683°E
3. Huttanus-Plantage	50.80290°N 6.86378°E
4. Am Tongraben	50.79845°N 6.85992°E
5. Silbersee	50.79460°N 6.85133°E
6. Donatussee	50.80767°N 6.84970°E

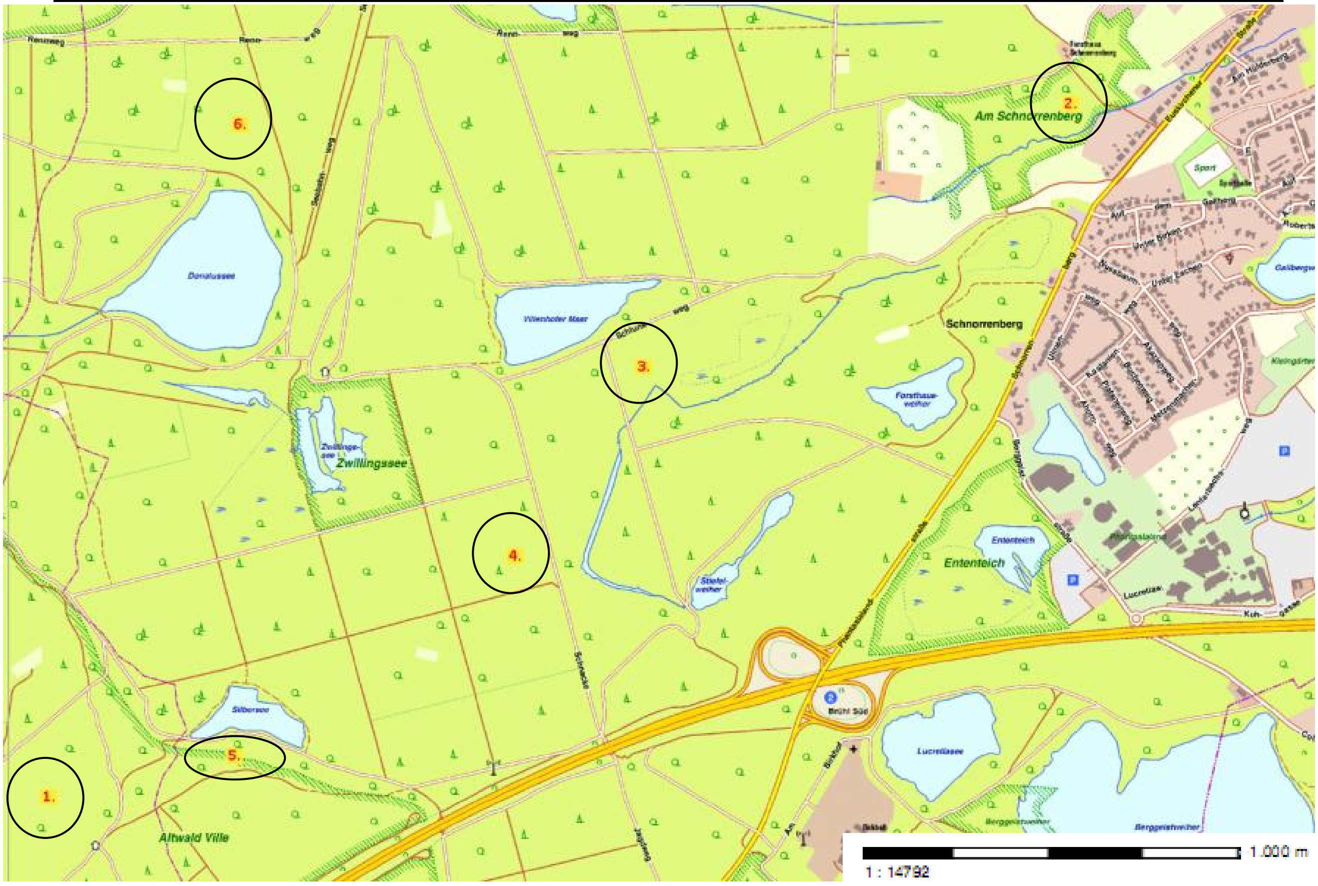

Figure 1. Sampling sites (Altwald, Old and New Recultivated Forests).**1**: Naturwaldzelle, Old Forest Ville. **2**: Am Schnorrenberg, Old Forest. **3**: Huttanus-Plantage, Old Recultivation. **4**: Am Tongraben, Old Recultivation. **5**: Silbersee, New Recultivation, **6**: Donatussee, New Recultivation. (Map data © TIM Online, Karten NRW)

2.2 Experimental design

The present study was conducted between March and April 2013. A total of six forest areas were surveyed in this study (see subchapter 2.1). From each of these areas, eight leaf litter samples corresponding to 1/8 m² and soil samples from below these litter samples were collected. The leaf litter was searched for large slugs and snails in the field, which were photographically documented and released. Then the leaf litter samples were put in plastic bags for further processing in the laboratory. Besides the eight samples, each of the six areas was surveyed randomly for snails and slugs for half an hour (30 person-minutes). Sampling was restricted to local temperatures above 4°C, given the soil was not frozen.

In the laboratory, leaf litter was carefully searched for slugs and snails. Leaf litter samples were dried for 30 minutes to 1 hour at 60 °C in the compartment drier, sieved to 2mm and finally analyzed under stereo microscopes (Stemi 2000-CS, Zeiss, United States) for small snails and slugs. Severely degraded or broken shells were disregarded as their species could not be determined.

Sampling data (temperature, humidity, vegetation type, local characteristics and soil pH) and the corresponding Gastropoda species were documented for further analysis.

2.3 Species determination and ecological classification

Species were determined based on the following classification books i. e. means:

- Bogon K. 1990. Landschnecken – Biologie, Ökologie, Biotopschutz. Natur Verlag, Augsburg.
- Cameron RAD. 2003. Land snails in the British Isles. Field Studies Council (FSC), Shropshire.
- Fechter R & Falkner G. 1990. Weichtiere-Europäische Meeres- und Binnenmollusken. Steinbachs Naturführer, Mosaik-Verlag, München.
- Kerney MP, Cameron RAD & Jungbluth JH. 1983. Die Landschnecken Nord- und Mitteleuropas. Ein Bestimmungsbuch für Biologen und Naturfreunde. P. Parey, Hamburg, Berlin.
- Brohmer P, Schaefer M, Hermann A. 2006. Brohmer, Fauna von Deutschland: ein Bestimmungsbuch unserer heimischen Tierwelt. Quelle & Meyer, Wiebelsheim.

The ecological classification of gastropods was done based on Kappes et al. (2009a), in which species are distinguished into three different groups: (1) species that are not necessarily dependent on a forest environment to exist, being able to colonize and survive in disturbed habitats ("D"-species); (2) forest associated species ("FA"-species), that is, besides forests, such species are commonly found in open areas such as herb patches; (3) forest species ("F"-species) (Kappes et al. 2009a). Considering that the southern Ville is on a borderline area (Eifel to lowlands) between the Continental and Atlantic Biogeographic zones of Europe, the ecological classification was only tentatively.

2.4 Soil pH

A protocol for measuring soil pH was provided by the working group for terrestrial ecology (AG Bonkowski) from the University of Cologne. PH determination was done by adding water (and 0.1M potassium chloride (KCl) in parallel measurements) to soil in a proportion of 2.5:1.

From each soil sample, 5 g of air dried soil, which was previously sieved to 2 mm, were put into a 25 mL glass container. 12.5 mL distilled water (and 12.5 mL 0.1M potassium chloride in parallel measurements) were added to the container and well mixed with the soil. The solutions were allowed to stand for one hour, whereby they were stirred up twice. Subsequently, the acidity of the soil samples was measured using the pH-meter "pH 320 Set" (WTW, Germany).

2.5 Statistical analysis

The computer program GraphPad Prism for Windows, version 6.01, GraphPad software (California, USA) was used to calculate the significance ($P<0.005$) of the acquired data through one-way ANOVA followed by the Tukey's Multiple Comparison post hoc test.

3. Results

A total of 458 snails and slugs from to 22 species were found in the six sites. Furthermore, two regionally rare species and morphotypes were encountered in this study - the species *Helicodiscus (Hebetodiscus) singleyanus* (Figure 2d) was found in the old recultivation Huttanus-Plantage and in the old forest Am Schnorrenberg. A slug from the species *Arion rufus* from the old recultivation Tongraben had a white stripe above the foot - this coloration is known from some parts of the North Rhine-Westphalian Eifel.

Ecological groups

Of the 22 species, 59 percent are not dependent on a forest environment to exist, being able to colonize and survive in disturbed habitats (“D”-species, e. g. *Carychium tridentatum, Cepaea hortensis, Phenacolimax major*). 18 percent of the species are regionally considered to be forest associated (“FA”-species, e. g. *Discus rotundatus, Monachoides incarnatus, Aegopinella pura*). The remaining 23 percent are regionally considered as forest species (“F”-species, e. g. *Cochlodina laminata, Acanthinula aculeata, Arion silvaticus*). Some of the above mentioned gastropods are presented in Figure 2.

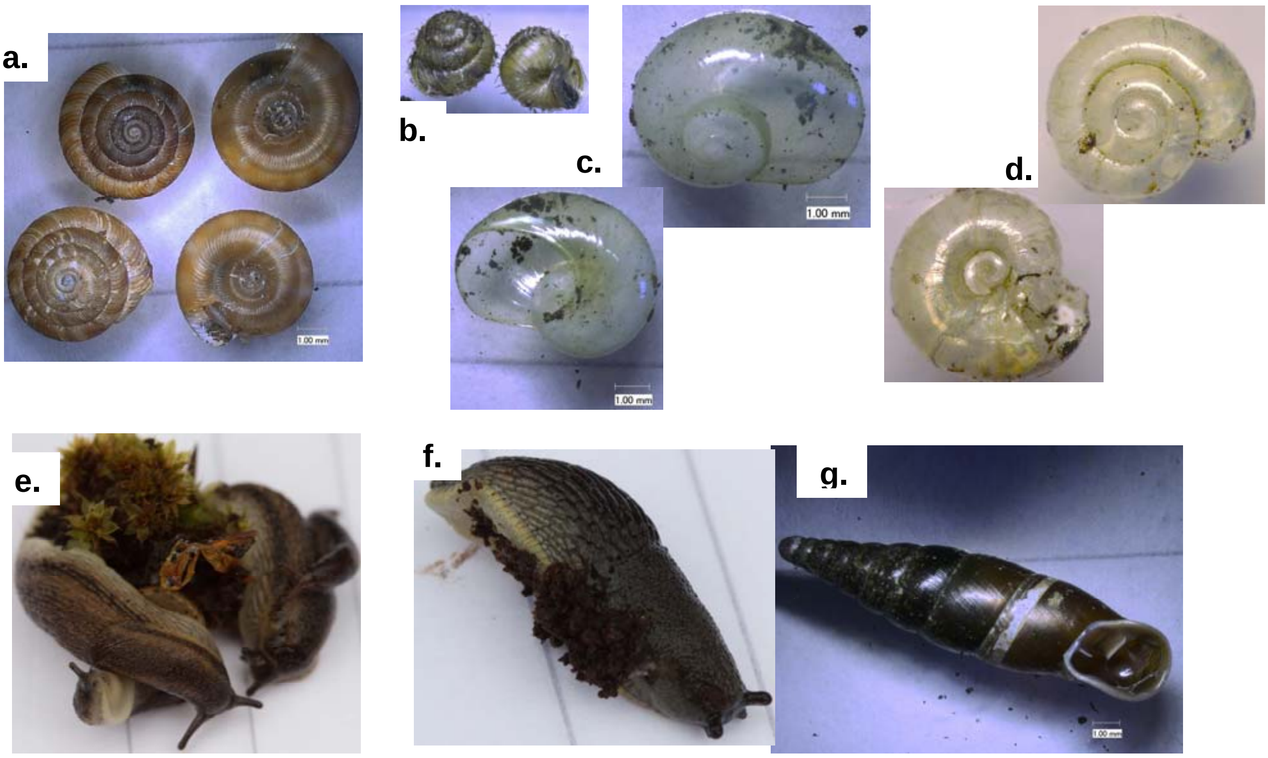

Figure 2. Snails and slugs. a) *Discus rotundatus*. b) *Acanthinula aculeata*. c) *Phenacolimax major*. d) *Helicodiscus (Hebetodiscus) singleyanus.* e) *Arion silvaticus*. f) *Arion rufus* (with white line above foot). g) *Cochlodina laminata*. (Source: a-d and e: Larissa Schultze; e-f: Zuzana Magurová)

As shown in Table 2, 61 snails of 4 different species could be found in the forest area near the Silbersee, which belongs to the new recultivation. Of the four different species, 25 percent were forest species, 25 percent were forest associated species and 50 percent were species able to survive in disturbed habitats. Near the Donatussee, the second new recultivated area, a total of 38 gastropods could be found, which however belonged to ten different species. 30 percent of the ten species were forest species, 30 percent were forest associated species and the remaining 40 percent were species associated to disturbed habitats.

Regarding the old recultivated forests, 97 and 59 gastropods could be found in the Huttanus-Plantage and in the Tongraben respectively. In the Huttanus-Plantage, 13 different species were determined, 30.76 percent of which were forest species, 23.07 were forest associated and 46.15 percent of which are species rather resistant to disturbance.

The old recultivated area at the Tongraben presented 11 species: 27.3 percent were forest species, 18.18 percent were forest associated species and the remaining 54.54 percent corresponded to gastropod species that are rather independent from a forest environment.

Finally, in the Naturwaldzelle and Am Schnorrenberg, both surveyed areas belonging to the old forest, 96 and 107 gastropods were found respectively. 7 species were found in the Naturwaldzelle, 42.85 percent of which were forest species. Besides, 28.57 percent were forest related and the remaining 28.57 percent were “D”-species.

14 species were determined in the surveyed old forest area Am Schnorrenberg, of which 35.71 percent were forest related, 21.42 percent were forest species, and the remaining 42.85 percent corresponded to species that are known to be successful in dealing with disturbance.

Abundance and species richness in the sites

Regarding the relationship of gastropod abundance in the different treatments (old forest, old recultivation, new recultivation), which were represented by the six forest sites studied, a linear regression was done by adding up the surveyed area [m²] and number of gastropods of the respective eight samples per forest site progressively (Table 3, Figure 3 (left)). The R^2 values of the linear regressions of the Naturwaldzelle, Am Schnorrenberg, Huttanus-Plantage, Am Tongraben, Silbersee and Donatussee were 0.92, 0.99, 0.95, 0.96, 0.93 and 0.94 respectively.

Furthermore, a one-way ANOVA followed by the Tukey's Multiple Comparison post hoc test was done to examine whether the forest sites differed significantly from each other with respect to gastropod abundance. There was only a statistically significant difference between gastropod abundance Am Schnorrenberg and at the Donatussee ($N=8$, $p<0.05$, Figure 3). Generally, the forest sites Am Schnorrenberg, the Naturwaldzelle and Huttanus-Plantage tended to differ from the sites Am Tongraben, at the Silbersee and Donatussee. However no further significant differences between these areas were found regarding gastropod abundance (Figure 3 (right)).

Table 2. Occurrence of species (n) in the surveyed areas. (F)=Forest species, (FA)=forest associated species, (D)= species resistant to disturbance. Data correspond to the amount of gastropods found in the eight parallels and during random search.

		New Recultivation		**Old Recultivation**		**Old Forest**		
	Species	Silbersee	Donatussee	Huttanus-Plantage	Am Tongraben	Naturwaldzelle	Am Schnorrenberg	**Total**
(F)	*Acanthinula aculeata*	4	1	29	15	7	4	60
(D)	*Aegopinella nitidula*						23	23
(FA)	*Aegopinella pura*		2			5	17	24
(D)	*Alinda biplicata*						3	3
(D)	*Arion intermedius*			2				2
(D)	*Arion lusitanicus*			1	3			4
(F)	*Arion rufus*		1	1	2	2	1	7
(F)	*Arion silvaticus*		1	2	4	13		20
(D)	*Boettgerilla pallens*				1			1
(D)	*Carychium tridentatum*	9			1	12	5	27
(D)	*Cepaea hortensis*			1			9	10
(D)	*Cepaea nemoralis*		5					5
(FA)	*Clausilia bidentata*						1	1
(F)	*Cochlodina laminata*			2			9	11
(FA)	*Discus rotundatus*	20	8	17	6	27	1	79
(FA)	*Helicodiscus (Hebetodiscus) singleyanus*			1			1	2
(D)	*Helix pomatia*		2					2
(D)	*Limax maximus*			1	1			2
(FA)	*Monachoides incarnatus*		2	2	2		13	19
(D)	*Oxychilus cellarius*						5	5
(D)	*Phenacolimax major*		5	10	3		15	33
(D)	*Punctum pygmaeum*	28	11	28	21	30		118
	Total	**61**	**38**	**97**	**59**	**96**	**107**	**458**

Table 3. Accumulated gastropod abundance [n] in the different forest sites referring to a given area size [m²] (see Figure 3).

Fläche (m²)	Naturwaldzelle [n]	Am Schnorren-berg[n]	Huttanus-Plantage [n]	Am Tongraben [n]	Silbersee [n]	Donatussee [n]
0,125	9	17	16	2	2	5
0,25	13	29	23	10	13	10
0,375	16	36	26	22	26	13
0,5	55	52	35	27	36	19
0,625	57	55	43	37	48	23
0,75	62	64	50	40	50	26
0,875	72	71	58	42	52	27
1	81	86	80	48	57	27

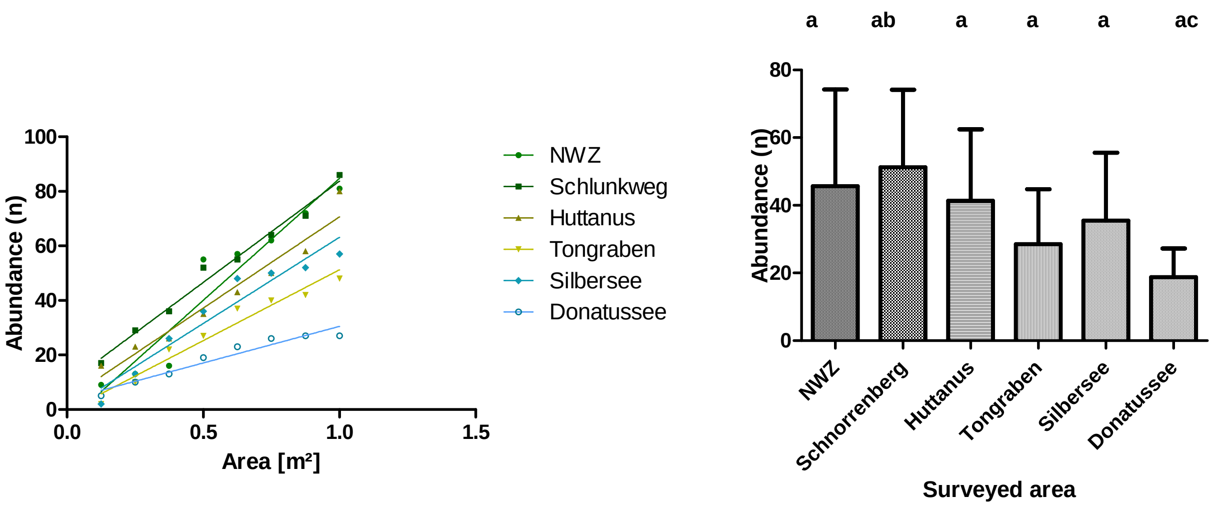

Figure 3. (left) Linear regression of cumulative gastropod abundance in the surveyed forest parcels referring to a given area size [m²]. **(right)** Gastropod abundance in the surveyed forest parcels. A statistically significant difference was found only between Am Schnorrenberg and the Donatussee.

The ANOVA showed that average species richness in Am Schnorrenberg was statistically significant different from that of Donatussee (N=8, p<0.001), of Silbersee (N=8, p<0.01), of Tongraben (N=8, p<0.01), of Huttanus-Plantage (N=8, p<0.05) and of the Naturwaldzelle (N=8, p<0.05). Species richness did not differ between Donatussee, Silbersee, Tongraben, Huttanus-Plantage and Naturwaldzelle (p>0.05, Figure 4 (right)).

Species-area curves of the sites display a beginning saturation (Figure 4 (left)), with the exception of the curve related to Huttanus-Plantage, which continues to rise. Furthermore, the old recultivation Huttanus-Plantage seems to resemble the old forest Am Schnorrenberg the most, as 13 species could be found in the earlier and 14 species were found in the later, and many species overlap between the two sites.

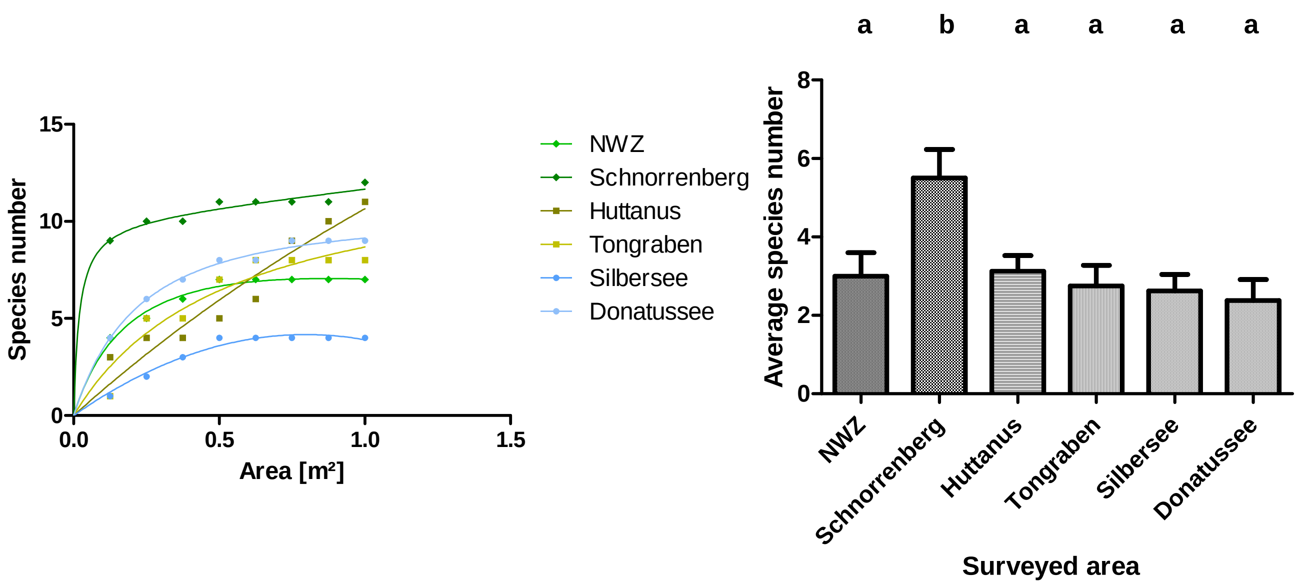

Figure 4. (left) Cumulative species richness in the surveyed forest parcels based on the cumulative area [m²] of the eight parallels analyzed on each site. **(right)** Species richness in the six surveyed forest parcels according to the eight parallel samples. A statistically significant difference was found between the old forest am Schnorrenberg and the Naturwaldzelle; the Donatussee; the Silbersee; the Huttanus-Plantage; and Am Tongraben.

Measurements of soil pH

The soil samples collected in the new recultivated forest at the Donatussee, the old recultivated area at the Tongraben and the old forest Am Schnorrenberg showed the highest average pH values, i. e. 6.52, 6.18 and 6.05 respectively. The lowest average pH values were measured in the soil samples from the old recultivated area at the Huttanus-Plantage (5.98), in the new recultivated forest at the Silbersee (pH= 5.84) and at the old forest Ville Naturwaldzelle (pH= 5.61). Detailed results from each of the eight soil samples from each forest site are presented in Table 4.

The one-way ANOVA showed that the relatively high pH values in the new recultivation at Donatussee are statistic significantly different from the lower pH values at the Silbersee (N=8, $p<0.001$), in the Huttanus-Plantage (N=8, $p<0.001$), in the Naturwaldzelle (N=8, $p<0.001$) and Am Schnorrenberg (N=8, $p<0.01$). Besides, the low pH values in the old forest Naturwaldzelle showed to be significantly different from the old forest Am Schnorrenberg (N=8, $p<0.01$), from the old recultivation am Tongraben (N=8, $p<0.001$) and from the Huttanus-Plantage (N=8, $p<0.05$).

Table 4. Soil pH measurements from the six surveyed forest sites; mean pH was calculated as the average from the pH values of the eight replicates.

	New recultivation area		**Old recultivation area**		**Old Forest**	
	Silbersee	**Donatussee**	**Huttanus-Plantage**	**Am Tongraben**	**Naturwaldzelle**	**Am Schnorrenberg**
mean pH	5.84	6.52	5.98	6.18	5.61	6.05
Samples pH						
1	5.78	6.87	5.92	6.36	5.76	5.8
2	5.92	6.61	5.75	5.63	5.33	6.28
3	5.52	6.35	6.09	6.37	5.43	6.08
4	6.12	6.34	6.12	6.25	6.29	6.04
5	5.95	6.64	5.98	6.45	5.75	5.61
6	5.75	6.43	6.02	5.9	5.57	6.2
7	5.78	6.31	5.8	6.12	5.47	6.27
8	5.86	6.59	6.17	6.35	5.31	6.1

4. Discussion

The hypothesis that many non-specialists species occur in new reclaimed forest sites was supported by the recent study. However, the results did not reveal a clear trend towards higher species richness in any of the three forest age classes. Generally, the low species number (n = 4) at Silbersee is in accordance with the expectations that the new restored areas would exhibit a lower species richness compared to other sites. The area presumably lacks conditions that gastropods depend on, as e. g. the woody debris is composed of relatively thin branches and young stems, and the leaf litter layer does not present clearly differing stages of decomposition. Also, the area was situated on a slope, and leaf litter is instable on slopes. Stable suitable conditions and spatio-temporal connectivity are prerequisites for sample-based gastropod species richness, that is, alpha diversity (Kappes et al. 2009c).

In contrast the old forest Am Schnorrenberg (n=14 species) and the old recultivation Huttanus-Plantage (n=13 species) had the highest total species richness. The old recultivation stand Huttanus-Plantage appears to be the site that resembles the old forest am Schnorrenberg the most regarding soil pH and species richness. This assumption is supported by the species-area-curve, which suggests that the species number in the Huttanus-Plantage was not completely surveyed, that is, that there might be other members of the gastropod community in this forest area that were not found in this study. This is supported by the fact that the rate of increase in species richness (the slope) in a community diminishes with increasing area, in other words, the collection effort reaches a saturation level when approximating a site-specific area (Scheiner 2003).

A high gastropod species richness can have several causes: (1) local dispersal, for example: immigration (neutral theory of community assembly, Hubbell 2005), (2) intermediate habitat stability and moderate habitat filtering processes (in the sense of the intermediate disturbance hypothesis, Townsend et al. 2009), (3) more microhabitats, that is, many different resources (Shmida & Wilson 1985, Tews et al. 2004), and/or (4) a higher calcium availability, i.e. higher soil pH (direct physiological constraints, e.g. Kappes et al. 2007).

(1) There probably are dispersal events between two adjacent sites, namely Am Schnorrenberg and Huttanus-Plantage, as species composition of the two sites show some overlap.

(2) Intermediate habitat stability, especially recurring disturbances, need to be reconsidered for the old-growth forest Am Schnorrenberg. This site is close to the city of Brühl, and to some houses/huts with gardens. This site and the Huttanus-Plantage are separated by grasslands (microclimatic disturbance). The forest edge can affect forest species composition for more than 250m from the actual forest border (Kappes et al. 2009a), and land use of a radius of 1km from forest sites was found to explain snail species composition (Kappes et al. 2011). The assumption that disturbances mediated species richness in Am Schnorrenberg is supported by 43% of the species being highly disturbance tolerant or even disturbance-dependent. In contrast, the old-growth site Naturwaldzelle Altwald Ville that is located in the heart of the forest area only had 30% disturbance-related species.

(3) Forest gastropods are dependent on a specific microhabitat to survive and reproduce, a microhabitat that offers enough shelter, sufficient humidity and food sources. In forests, these conditions are achieved mainly through the leaf litter layer and its characteristics and the amount of coarse wood debris (Kappes et al. 2006, Kappes et al. 2012). The old forest sites were expected to exhibit the largest amount of coarse wood debris and suitable microhabitats, as they are natural forest reserves where either non or only sustainable forestry activities are allowed. Thus, the deadwood-containing old forest areas were more likely to present higher numbers of species (Kappes et al. 2009b) and expected to harbour the highest numbers of specialist species (e.g. Kappes 2006). However, the results of this study revealed that there was no consistent pattern. Concerning the specialist species, the assignment to ecological groups was only tentatively because the southern Ville is located on the border between two major European biogeographical regions. Here, 'tentatively' implies that more species are less dependent of forests in the continental biogeographical region (Kappes, unpubl.).

However, the assignments provided some suggestion on the processes that govern gastropod community assembly. When comparing the ratio of forest (F) and forest associated (FA) to disturbed habitats (D) species, the old forest Naturwaldzelle presented the highest ratio of forest and forest associated species to “D-“species, which corresponds to 2.4. All other sites had ratios at and below 1.5: old-growth forest Am Schnorrenberg = 1.3, old recultivation Huttanus-Plantage = 1.1, old recultivation Am Tongraben = 0.83, new recultivation Silbersee = 1 and new recultivation Donatussee = 1.5. It thus can be concluded that the strongest habitat filtering against non-forest specialists occurs in the Naturwaldzelle. This again is in line with the assumptions of disturbance-related relaxed selection pressure on, or increased dispersal of, non-forest species in the old-growth forest Am Schnorrenberg (see above).

(4) A low soil pH is known to have a negative effect on the population of some snail species (Ondina et al. 2004, Kappes et al. 2007). However, the soil pH consistently was >5.3 and thus is relatively high in all sampled sites. Differences in species richness cannot be easily attributed to this environmental factor.

Indeed, there are some diverging statements among ecologists regarding the relation between vegetation, soil and litter characteristics and gastropod distribution (Bishop 1977, Evans 1972, Ondina et al. 2004). Soil characteristics, especially pH, cation levels, texture and calcium content, are considered to have a direct impact on the occurrence of gastropods even though the litter and vegetation characteristics should not be overlooked (Ondina et al. 2004). Due to the complexity of the interactions of the above mentioned factors and the fact that the range of tolerance of a species may vary according to the environmental conditions such as climate; it would not be reasonable to draw a final conclusion on the relationship between the relatively low species number in the Naturwaldzelle and its soil properties. Measurements of calcium, aluminium and magnesium content and litter pH were not taken in this study.

Although there is no consistent pattern on species richness and soil pH across all six sites, soil pH might have had a subtle influence on the total species richness of the gastropods. Within each of the three reclamation age pairs, the sites with the higher average soil pH always had the higher total species richness.

Comments on selected species

With the exception of *Helicodiscus (Hebetodiscus) singleyanus*, all species identified within this study were species that are commonly widespread in North Rhine-Westphalia and not classified as endangered (Kobialka et al. 2009). *Helicodiscus (Hebetodiscus) singleyanus* is considered as data deficient. It is a species indigenous to Northern America, which has also been found in the Czech Republic, Poland, Slovakia and the United Kingdom (Anderson 2005, Horsák et al. 2009a, Horsák et al. 2009b). In this study this species could also be found in the Huttanus-Plantage and Am Schnorrenberg.

Another species that seems worth to be monitored in the Ville forests is *Arion lusitanicus.* This species is able to succeed in open, disturbed habitats (Grimm 2001) and has been increasingly found in forest habitats (Kappes et al. 2009a). When exposed to unfavourable conditions, *A. lusitanicus* is known to have a higher survival probability than its related species *Arion rufus*, a species indigenous to Central and Western Europe (Grimm 2001). In large-scale forest areas however, *Arion rufus* seemingly has an advantage over *A. lusitanicus* (Kappes 2006, Kappes et al. 2009a.). In the present study, *Arion lusitanicus* was found in both the old restored areas (Huttanus-Plantage and Am Tongraben). This occurrence could be explained based on the location of these sites, which are situated next to a walkway frequented by forest visitors, often with dogs, so that it is possible that *Arion lusitanicus* has been introduced by chance, disposal of organic waste from the gardens or similar disturbances.

Because the old-growth site Naturwaldzelle is part of the large sized old-growth forests in the southern Ville, the stenecious forest slug *Limax cinereoniger* was expected (Kappes et al. 2009a). However, the species was not found. This probably was because the slug retreats during unfavourable conditions. The present study was conducted between March and April 2013, with March being on average 3.3°C colder than in the past fifty years. Very often temperatures went below 0°C, which certainly had an effect on gastropod activity.

Conclusion

Based on the acquired data, it can be concluded that the old and new recultivation areas still differ from the old forest sites with respect to gastropod abundance, diversity and habitats (forest, forest associated, disturbed areas). The old recultivation Huttanus-Plantage shows a tendency towards an old forest profile, however the same cannot be affirmed for the other surveyed areas (Am Tongraben, Silbersee and Donatussee), which could be related to disturbance factors and to the fact that, specially the newly restored forest parcels, are still too young to provide clearly favourable microhabitats to stenecious forest gastropods.

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Annex 1

Table 1. Species richness (n) and occurence (n) at Naturwaldzelle, Old Forest

Sampling number	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**Lose**	**Total**
pH	5,76	5,33	5,43	6,29	5,75	5,57	5,47	5,31		
Species										
Acanthinula aculeata	2		1	3			1			7
Aegopinella pura			2	2				1		5
Arion rufus		1							1	2
Arion silvaticus	3	2		1				1	6	13
Carychium tridentatum				12						12
Discus rotundatus	2			4		5	4	5	7	27
Punctum pygmaeum	2	1		17	2		5	2	1	30
Total	**9**	**4**	**3**	**39**	**2**	**5**	**10**	**9**	**15**	**96**
Species number	**4**	**3**	**2**	**6**	**1**	**1**	**3**	**4**	**4**	

Table 2. Species richness (n) and occurence (n) Am Schnorrenberg, Old Forest

Sampling number	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**Lose 1**	**Lose 2**	**Total**
pH	5,8	6,28	6,08	6,04	5,61	6,2	6,27	6,1			
Species											
Acanthinula aculeata	2	1		1							4
Aegopinella nitidula	2	6	2	2	1	1	4	2	2	1	23
Aegopinella pura	4	2		4	1	1	1	4			17
Alinda biplicata	1	1				1					3
Arion rufus								1			1
Carychium tridentatum				2		1	2				5
Cepaea hortensis	2			1				2	1	3	9
Clausilia bidentata										1	1
Cochlodina laminata		1	1			1		4	1	1	9
Discus rotundatus									1		1
Helicodiscus (Hebetodiscus) singleyanus	1										1
Monachoides incarnatus	1	1			1	1			4	5	13
Oxychilus cellarius	3		1						1		5
Phenacolimax major	1		3	6		3		2			15
Total	**17**	**12**	**7**	**16**	**3**	**9**	**7**	**15**	**10**	**11**	**107**
Species number	**9**	**6**	**4**	**6**	**3**	**7**	**3**	**6**	**6**	**5**	

Table 3. Species richness (n) and occurence (n) at Huttanus-Plantage, Old Recultivation										
Sampling number	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**Lose**	**Total**
pH	5,92	5,75	6,09	6,12	5,98	6,02	5,8	6,17		
Species										
Acanthinula aculeata	2	2	3	5	6	4	2	5		29
Arion intermedius	2									2
Arion lusitanicus						1				1
Arion rufus									1	1
Arion silvaticus						1			1	2
Cepaea hortensis					1					1
Cochlodina laminata								1	1	2
Discus rotundatus							2	8	7	17
Helicodiscus (Hebetodiscus) singleyanus				1						1
Limax maximus						1				1
Monachoides incarnatus									2	2
Phenacolimax major		2						3	5	10
Punctum pygmaeum	12	3		3	1		4	5		28
Total	**16**	**7**	**3**	**9**	**8**	**7**	**8**	**22**	**17**	**97**
Species number	**3**	**3**	**1**	**3**	**3**	**4**	**3**	**5**	**6**	

Table 4. Species richness (n) and occurence (n) Am Tongraben, Old Recultivation											
Sampling number	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**Lose 1**	**Lose 2**	**Total**
pH	6,36	5,63	6,37	6,25	6,45	5,9	6,12	6,35			
Species											
Acanthinula aculeata		1	10	1	2	1					15
Arion lusitanicus				1	1					1	3
Arion rufus		1				1					2
Arion silvaticus									1	3	4
Boettgerilla pallens		1									1
Carychium tridentatum				1							1
Discus rotundatus		1	2					2	1		6
Limax maximus										1	1
Monachoides incarnatus					1					1	2
Phenacolimax major									3		3
Punctum pygmaeum	2	4		2	6	1	2	4			21
Total	**2**	**8**	**12**	**5**	**10**	**3**	**2**	**6**	**5**	**6**	**59**
Species number	**1**	**5**	**2**	**4**	**4**	**3**	**1**	**2**	**3**	**4**	

Table 5. Species richness (n) and occurence (n) at Silbersee, New Recultivation

Sampling number	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**Lose**	**Total**
pH	5,78	5,92	5,52	6,12	5,95	5,75	5,78	5,86		
Species										
Acanthinula aculeata				1	2			1		4
Carychium tridentatum		4		1	2	1		1		9
Discus rotundatus			11	1	1	1	1	1	4	20
Punctum pygmaeum	2	7	2	7	7		1	2		28
Total	**2**	**11**	**13**	**10**	**12**	**2**	**2**	**5**	**4**	**61**
Species number	**1**	**2**	**2**	**4**	**4**	**2**	**2**	**4**	**1**	

Table 6. Species richness (n) and occurence (n) at Donatussee, New Recultivation

Sampling number	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**Lose 1**	**Lose 2**	**Total**
pH	6,87	6,61	6,35	6,34	6,64	6,43	6,31	6,59			
Species											
Acanthinula aculueata		1									1
Aegopinella pura			1		1						2
Arion rufus				1							1
Arion silvaticus						1					1
Cepea nemoralis		1							1	3	5
Discus rotundatus	1		2	1					2	2	8
Helix pomatia	1								1		2
Monachodies incarnatus										2	2
Phenacolimax major	2	1		2							5
Punctum pygmaeum	1	2		2	3	2	1				11
Total	**5**	**5**	**3**	**6**	**4**	**3**	**1**	**0**	**4**	**7**	**38**
Species number	**4**	**4**	**2**	**4**	**2**	**2**	**1**	**0**	**3**	**3**	