Molluscs at the Kafa Biosphere Reserve

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Highlights

→ As far as the author is aware, this is the first systematic assessment of terrestrial molluscs in an Ethiopian rainforest, if not the whole of Ethiopia.

→ A total of 32 species of terrestrial molluscs were recorded.

→ Knowledge of the ecology and conservation status of Ethiopian land snails is very poor at present. Further research is required to complete the checklist of land snails in the Kafa BR.

→ None of the recorded species has been assessed by the IUCN Red List.

→ Boginda Forest in the core zone was the most species-rich forest, with 16 recorded snail species.

→ Freshwater molluscan diversity is very poor in the Kafa BR, with only nine species recorded in rivers, streams and ponds.

→ One pea clam (*Pisidium* sp.) was discovered that is most probably new to science. Freshwater gastropods are absent from almost all investigated ponds and streams, despite seemingly good habitat conditions. This could be due to biogeographic factors or chemical water parameters and requires further research.

→ Freshwater mussels (Unionoida) would be a good indicator group for the ecosystem health of streams and rivers.

→ The carnivorous Streptaxidae are a potential indicator group for the ecological integrity of rainforests, although further research is required.

→ Molluscs face an unprecedented rate of extinction, with 83% of East African land snails restricted to the endangered rainforests. Further research and conservation measures to curb deforestation are urgently required if these species are to survive.

→ Future research should focus on identifying forest endemics in the Kafa BR, as these are potentially good indicator species and especially prone to extirpation.

1. Introduction

This assessment of molluscs in the Kafa BR sampled both aquatic and terrestrial habitats.

1.1 Terrestrial molluscs (land snails)

Very few publications exist on the terrestrial snail fauna of Ethiopia. In 1871, the German naturalist Jickeli conducted a survey of land snails in what was then called Abyssinia (Jickeli 1874). Although he described several terrestrial snail species, his research was primarily focused on the marine malacofauna of the Red Sea, and consequently he did not penetrate far into the hinterland of present-day Ethiopia. In 1883, Bourguignat described some species collected during an expedition to northern Ethiopia (Tigray) in 1881. Then, almost 50 years later, the British malacologist Connolly described several species new to science collected from the Ethiopian Rift Valley (Connolly 1928). Most noteworthy in the context of the present biodiversity assessment, however, is a publication by the German malacologist Johannes Thiele, who described land snails collected during an expedition to Ethiopia led by the German naturalist Oscar Neumann from 1899 to 1901 (Thiele 1933). Neumann passed through present-day Kafa Zone on his journey, close to the town of Bonga, and Thiele's account is the first scientific material on molluscs in this area. A detailed description of Neumann's itinerary to southwestern Ethiopia, including many ethnographic details, is given in Neumann (1902).

Apart from Thiele's work, there are very few publications with notes on particular species (e.g. Verdcourt 1956, 1960, 1976, 1980). In general, most knowledge of Ethiopian land snails, including type descriptions, are scattered across dozens of original papers in different languages, which are difficult to access. There is currently no synoptic treatment of Ethiopian land snails. In addition, the study of Ethiopian terrestrial gastropods is seriously hampered by the high number of synonyms for many taxa. This is partly because many early descriptions from the 19th century were based on very few available specimens, sometimes single empty shells.

Apart from Thiele's work, this study is the only work known to the authors covering land snails from the Southern Nations, Nationalities and Peoples' Region (SNNPR) of Ethiopia. However, the study is more systematic because Thiele described material collected opportunistically by Neumann, whose primary research objects were birds.

As far as the author is aware, there are currently no publications dealing with the land snail communities of specific ecosystems in Ethiopia, e.g., montane forests or wetlands. However, a few biogeography and ecology papers have been published in recent years describing land snail faunae in other African lowland and montane forest ecosystems, including some neighbouring countries (Tattersfield & Seddon 1998; Wronski & Hausdorf 2010; Wronski et al. 2014; Tattersfield et al. 2001a, 2006). Wronski et al., for instance, found a maximum of 44 snail species on a 20 x 20 m sampling plot in a montane rain forest in Uganda. The maximum number of snail species found in an entire montane forest in Uganda was 66, in the same study (Wronski & Hausdorf 2010). On Bioko Island (Equatorial Guinea), Wronski et al. (2014) found no significant correlation between altitude and species richness (maximum sampling altitude: 1830 m a.s.l.). However, species richness was positively correlated with leaf litter thickness on Bioko Island. In addition, the degree of endemism generally increased with altitude and annual rainfall in Ugandan rainforests, and decreased with soil acidity (Wronski & Hausdorf 2010; Wronski et al. 2014). In the former study, the authors also showed that more than 50% of all snail species collected in Ugandan rainforests are microgastropods with an adult shell size measuring less than 5 mm (Wronski & Hausdorf 2010).

In another study, Tattersfield et al. found a total of 68 snail species on four transects on Mt. Kenya. Over 64 plots, the number of species per plot (70 x 70 m) ranged from 6.75 to 23 (Tattersfield et al. 2001a). The study on Mt. Kenya also suggests that species richness and abundance decrease with altitude. Annual rainfall was found to be the most important factor (of those assessed) in the variation between the local, terrestrial snail communities on Mt. Kenya.

As several authors have shown, Ethiopian land snail faunae comprise a mixture of Palearctic faunal elements, e.g., representatives of the family Helicidae, and typical Afrotropical taxa, e.g., representatives of the family Achatinidae (Jickeli 1874; Haas 1936; Bacci 1948). In recent years, some significant contributions have been made to increase our understanding of the distribution patterns of land snails in a few selected areas in the African tropics. However, the ecology and lifecycles of African tropical land snails remain largely unknown, especially in comparison to other animal groups.

In any event, land snails are highly dependent on moisture and precipitation, so it is not surprising to find that the species diversity of terrestrial snails is comparatively high in tropical rainforests. Although land snails have developed mechanisms to survive short periods of drought, their diversity and abundance are expected to be highest in habitats that retain moisture even in periods of drought. These conditions can be found in primary forests with a closed canopy, a thick leaf litter layer and abundant decaying deadwood on the forest floor. Secondary forests and tree plantations exhibit significantly lower snail abundance and diversity (Tattersfield et al. 2001b). In general, terrestrial snails tend to be most abundant and diverse on limestone, while acidic soils tend to be less favourable (Sturm et al. 2006).

1.2 Aquatic molluscs (freshwater snails and bivalves)

In contrast, the freshwater molluscan fauna of Ethiopia has been studied quite extensively, with a number of eminent publications and synoptic treatments (e.g., Brown 1965). Itagaki et al. wrote a treatise on the freshwater snails and bivalves of Ethiopia with useful, pictorial determination keys (Itagaki et al. 1975), while Brown provides a complete overview on all African freshwater snails in his milestone work, including their medical importance, ecology and biogeography (Brown 1994). The imbalance in current knowledge between aquatic and terrestrial molluscs is due to the fact that the aquatic group features some genera of medical importance as intermediate hosts of human and livestock parasites, thus rendering the lifecycles and distribution patterns of aquatic snails an attractive research object.

Besides the medical importance of some freshwater molluscs, much attention has been given to the rich amount of mollusc fossils that have been preserved in the lacustrine deposits of the East African Rift System (EARS) over the past millions of years. Further insight into the origins and evolution of freshwater biota has been gained through the study of fossil molluscs from East African long-lived lakes, including Lake Turkana (e.g., Williamson 1981). In terms of families and species, Afrotropical freshwater molluscan fauna is generally much poorer than the terrestrial equivalent. The majority of freshwater mollusc species are found in long-lived lakes, which are absent from the study area. Riverine molluscan communities exhibit comparatively poor species diversity (Brown 1994). Itagaki et al. identified a total of 29 species of freshwater molluscs during an extensive nationwide survey conducted in Ethiopia between 1969 and 1971. They found 18 species which are widely distributed across East Africa and another eight which could not be determined to the species level (Itagaki et al. 1975). A literature review suggests that Ethiopian freshwater molluscan fauna is neither species-rich nor particularly rich in endemics.

1.3 Expectations of the mollusc assessment

The study area in Kafa BR comprises a huge variety of different habitat types and covers a significant altitudinal gradient, from 1300 to 2700 m a.s.l. Tattersfield et al. found indications that terrestrial snail species numbers peak at elevations between 1000 and 1500 m a.s.l. on Mt. Kenya (Tattersfield et al. 2001a). A similar pattern was expected in the Kafa BR. The most species-rich habitats were expected in primary forests at lower elevations. Primary forests have closed canopies, retaining moisture inside the forest even in periods of drought, and high structural diversity, with dead logs, abundant leaf litter and decaying wood on the forest floor. These features should promote diversity of the invertebrate communities on the forest floor, including terrestrial snails.

Secondary forests or tree plantations have been shown to be less species-rich (Tattersfield et al. 2001b). Likewise, bamboo forests are expected to be less species-rich due to their high elevation and poor forest floor structure, which is mainly composed of bamboo logs. Open wetlands are expected to exhibit a poorer terrestrial snail community than forests, as the soils tend to be acidic wetlands mostly lack important snail microhabitats such as dead logs and leaf litter.

The best time to collect land snails is during the rainy season, immediately after rainfall (Sturm et al. 2006). As the fieldwork was carried out in December 2014, during the dry season, conditions were expected to be poor. Nevertheless, some snails were expected to be dormant or hidden in the ground, under dead logs or in the cracks of the bark of larger trees, especially during periods of extended drought.

Expectations for freshwater molluscs were also rather low, as the riverine molluscan communities in East African montane rainforests tend to be species-poor. The main centres of freshwater molluscan biodiversity are in the larger standing waterbodies of the East African Rift System (EARS), outside the study area. Nevertheless, a number of pulmonate species in the family Planorbidae were expected to occur in the ephemeral ponds in the extended wetlands of the Kafa BR.

2. Materials and Methods

Table 1 provides an overview of the study and sampling sites along with their geographic coordinates. Broader areas representing a single habitat type or forest are termed "study sites" (e.g., Boginda Forest (BO), Gojeb River floodplain forest (GO-riv)) while localities where specific sampling sessions were carried out are termed "sampling sites". Thus a single study site can contain multiple sampling sites. Note that the study sites were subdivided into individual sampling plots.

2.1 Sampling methods

Two different habitat types were sampled: terrestrial habitats, including forests and river floodplains, and freshwater habitats, including rivers, streams and temporal ponds. Different habitat types required different sampling methods.

Terrestrial habitats were sampled semi-quantitatively (see Appendix: sampling methods) following the standard method described in Emberton et al. (1996), Wronski & Hausdorf (2010) and Wronski et al. (2014), with slight modifications. The standard method combines a visual search of a 20 x 20 m sampling plot for four person hours with soil-plus-litter sampling. To sample soil and litter for microgastropods (< 5 mm shell size), 5 l of soil and litter is collected in a bag, sieved, dried and searched. However, soil-plus-litter samples were not collected for the present study after an initial trial, due to time constraints in the field, low yield of microgastropods and the time-consuming process of determining microgastropods to the species level, which would have exceeded the time planned for the overall assessment.

Sampling effort was also reduced to three person hours to account for the low accessibility of some sampling sites and the ensuing time constraints. In doing this, overall comparability among sampling sites was ensured.

Freshwater habitats were qualitatively sampled via a visual search for gastropod shells along the shoreline, attached to floating vegetation, emerging plants, deadwood and leaves as well as on the surfaces of stones and rocks (if present). Separately, sediment was sieved, mainly for bivalves, using a metal sieve (mesh size 1 mm) attached to a telescopic stick. This method is useful for sampling at greater depths or in otherwise inaccessible sections (see Appendix: sampling methods). The low mesh size allows the capture of minute, sediment-dwelling bivalves of the genus *Pisidium*, which seldom exceed 3 mm in shell size. Quantitative sampling of freshwater habitats is labour intensive and requires sophisticated equipment and thorough planning; therefore, it was not considered feasible in the short timeframe available for this assessment.

In addition to live specimens, dead shells were also collected. For terrestrial molluscs, live specimens were drowned in water overnight and preserved in 80% ethanol the next morning. This procedure allows better examination of the soft body parts of the snail than immediate fixation in ethanol. For freshwater molluscs, specimens were directly fixed in ethanol, as this facilitates future DNA analyses. There is a considerable interest in such analyses from the Institute of Animal Ecology and Systematics at the Justus Liebig University Giessen. All specimens were collected in screwcap vessels, separated by sampling site and labelled accordingly. Locality datasheets were filled in for all sampling sites (plots) to capture additional information on vegetation and substrate, etc. Locality sheets for terrestrial habitats were specifically designed for this study. Sampling sites were not chosen at random but selected based on favourable habitat conditions.

2.1.1 Data analysis

In accordance with the national regulations of the Ethiopian Biodiversity Institute (EBI) and the Material Transfer Agreement (MTA), half of the specimens were brought to laboratories at the Institute of Animal Ecology and Systematics at the University of Giessen, Germany, for species identification and digital microscopic imaging, with the primary objective of completing the species list. The other half were handed over to the EBI. Terrestrial specimens were determined based on conchological characteristics, via comparison with images, original descriptions and the determination keys provided in Jickeli 1874, Bourguignat (1883), Pilsbry (1919), Haas (1936), Herbert & Kilburn (2004) and Cossignani (2014).

The presence of determined taxa in East Africa was checked using the revised list of non-marine Mollusca of East Africa (Verdcourt 2006). In addition, an expert on East African land snails, Torsten Wronski from the Hamburg University Zoological Museum, kindly helped determine some difficult specimens based on digital images. Unfortunately, we were unable to access Thiele's 1933 study, which contains several original descriptions of representatives of the genus *Cerastus*, as it is only available in hardcopy at the Frankfurt and Berlin University Libraries.

The single collected aquatic gastropod species was easily determined using the determination key provided in Itagaki (1975). Aquatic bivalves were determined using Mandahl-Barth (1954) and comparative specimens from the African mollusc collections at the University of Giessen. Pea clams of the genus *Pisidium* were determined by Ulrich Bößneck from the University of Giessen.

In cases where species determination was impossible, the morphospecies concept was used, and specimens were assigned provisional names derived from the genus or family plus a single letter, e.g., *Subulinidae* sp. A, *Cerastus* sp. B etc. In general, the nomenclature of Verdcourt (2006) was followed to assign species, genus and family names to collected specimens.

Digital images of selected, small specimens (< 10 mm shell size) were acquired using a Keyence VHX-2000 digital microscope (see Appendix: sampling methods). Larger shells were photographed using a Canon PowerShot G7 digital camera. All vouchers are currently stored in the African mollusc collection at the Institute of Animal Ecology and Systematics at the University of Giessen, Germany.

3. Results and Discussion

As part of a wider biodiversity assessment, nine sampling sites (or 20 x 20 m sampling plots) were sampled systematically for terrestrial molluscs, while seven sampling sites were sampled for aquatic molluscs (Table 1). For aquatic molluscs, some sites revealed no aquatic mollusc presence, despite sampling effort. These are not included in the count.

The data collected on terrestrial snails was supplemented by the results of visits to five sampling sites, from which the author and other colleagues from the biodiversity assessment collected additional specimens in an opportunistic, non-systematic manner. Because of their very different habitats, the following section treats terrestrial and aquatic molluscs separately.

Table 1: Overview of study sites and corresponding sampling sites and plots, with site description and geographic coordinates

Study site	Sampling site	Date of collection	Latitude	North/South	Longitude	East/West	Altitude (m a.s.l.)	Site description
BK	ETH14.002	04.12.14	7.29474	N	36.37632	E	2318	Hani River, on road bridge Bonga Kaka near Boka Forest
	ETH14.003	04.12.14	7.24119	N	36.45184	E	2596	Adiyo River near Boka Forest, river bridge on main road from Bonga to Kaka
	ETH14.004	04.12.14	7.24077	N	36.45202	E	2596	Boka, meadow near bridge over big river on main road from Bonga to Kaka, near Bamboo Forest
	ETH14.018	12.12.14	7.29449	N	36.37394	E	2300	Boka Forest, north of main road Bonga – Kaka
BA	ETH14.005	04.12.14	7.24462	N	36.45872	E	2686	Bamboo Forest on main road from Bonga to Kaka

Study site	Sampling site	Date of collection	Latitude	North/South	Longitude	East/West	Altitude (m a.s.l.)	Site description
AW	ETH14.006	05.12.14	7.09281	N	36.23154	E	1293	Awurada Valley, small creek near Gumi River, primary forest
	ETH14.007	05.12.14	7.09281	N	36.23154	E	1293	Awurada Valley, small creek near Gumi River, primary forest
	ETH14.AWU	05.12.14					1300-1500	Awurada Valley, coffee forest, Participatory Forest Management (PFM) site, no plot but opportunistic collection
AG	ETH14.008	06.12.14	7.36464-7.36409	N	36.22566-36.22580	E	1700	Alemgono Wetlands
SHO	ETH14.009	06.12.14	7.35706	N	36.20436	E	1615	Shoriri Wetlands, river
	ETH14.010	06.12.14	7.36004	N	36.20761	E	1700	Shoriri Wetlands, secondary forest
KO	ETH14.011	07.12.14	7.30744	N	36.12192	E	1800	Wushwush, river on road bridge near Eukalyptus plantation
	ETH14.012	07.12.14	7.30268	N	36.0975	E	2070	Komba Forest core zone, south of main road from Bonga to Misa
	ETH14.013	07.12.14	7.29585	N	36.08855	E	2108	Komba Forest core zone south of main road from Bonga to Misa
GO-riv	ETH14.014	10.12.14	7.55341	N	36.05643	E	1500	Gojeb River floodplain forest, 20 m from river near bridge on main road Bonga – Medabo short before Medabo
	ETH14.015	10.12.14	7.55547	N	36.05721	E	1500	Gojeb River, near bridge over Gojeb River on main road from Bonga to Medabo near Medabo
GO-wet	ETH14.GJE	10.12.14						Gojeb Wetlands, coffee planatation near road bridge over Gojeb River on main road Medabo – Bonga

Study site	Sampling site	Date of collection	Latitude	North/South	Longitude	East/West	Altitude (m a.s.l.)	Site description
BO	ETH14.016	10.12.14	7.50164	N	36.09260	E	2074	Boginda Forest, NABU campsite on main road Konda-Bonga short after Saja village
	ETH14.017	11.12.14	7.50054	N	36.09553	E	2136	Boginda Forest core zone, probably secondary forest
	ETH14.BOG	09.12.14	7.50176	N	36.09124	E	2000	Boginda Forest directly at NABU campsite near Saja village
KDA GH	ETH14.KDA	Dec 2014	7.25416	N	36.25768	E	1783	Small creek and meadow 500 m above KDA Guesthouse, Bonga

3.1 Terrestrial molluscs (land snails)

The 14 sampling sites studied systematically and opportunistically were situated in bamboo forest, montane rainforest and river floodplain forest and covered an altitudinal range from 1293 to 2686 m a.s.l. A total of 32 land snail species were collected. The sampling site with the highest number of species was located in the core zone of Boginda Forest (BO), and yielded 14 species. Boginda Forest was also the most species-rich study site, with 16 species recorded. The second most species-rich study site was Awurada Valley Forest (AW), with 12 species collected. Species richness at study sites with systematic sampling ranged from five in Boka Forest (BK) to 16 in Boginda Forest (Table 2).

The collected land snails could be assigned to nine families. The most species-rich family in this study were the Cerastidae, with eight species, followed by the *Subulinidae* with seven species and the Achatinidae with six species. The species diversity of the carnivorous Streptaxidae was comparatively low, at only three species. In contrast, Wronski and Hausdorf (2010) found the Streptaxidae to be the most species-rich family in Ugandan rainforests. However, the streptaxids have minute shells, and their species determination poses severe difficulties. Close to 200 species in the streptaxid genus *Gulella* have been described from East Africa alone (Verdcourt 2006). Differentiation is partly based on variation in the dentition pattern of the aperture, which is difficult to assess (Herbert & Kilburn 2004). In light of the difficulties of determining streptaxid species, the actual number of species from this family might be greatly underestimated in this study.
The following section presents the results by study site, including observations about the habitat conditions.

3.1.1 Bamboo Forest (BA)

Only one site was sampled in the Bamboo Forest (*Arundinaria alpina*), with a total of six species found. The structural diversity of the forest floor and understorey was low, with bamboo logs making up the bulk of dead matter on the ground. However, the sampling site was chosen to include one larger flowering tree (*Schefflera abyssinica*) with a trunk diameter of > 1.5 m. Many specimens were collected in the interspace of the roots of this tree, greatly contributing to the total species count on this plot. The leaf litter layer was almost devoid of snails. There were a few signs of moderate cutting of bamboo close by. The sampling site was located in the core zone of the Kafa BR.

3.1.2 Boka Forest (BK)

Only one site was sampled in Boka Forest, with a total of five species found, making it the least species-rich plot. The collected specimens consisted mainly of dead shells. A few live specimens were collected under decaying wood and in the interspace of the roots of a larger tree. Only a few large timber trees were present in this forest fragment, and the structural diversity of the forest floor was low, as larger decaying logs were absent. There was only about 50% canopy cover, and there was evidence of bamboo encroachment. This forest patch should be classified as secondary forest, as there was evidence of high human impact, both current and historical. Other patches of this fragmented forest were visited, but habitat conditions for snails were found to be even poorer upon visual inspection.

3.1.3 Komba Forest (KO)

Two sites were sampled in Komba Forest, both located in the core zone of the Kafa BR. The area was very difficult to access. Seven species were found at each sampling site. The combined species list for Komba Forest has ten snail species in total, making the forest an average study site in terms of species-richness. The habitat conditions were very dry, as evidenced by the discovery of several dormant snails which had developed a protective membrane (epiphragm) to endure the drought. There were clear signs of selective tree cutting and understorey clearing on both sites, and only very few timber trees with a diameter of > 2 m were found. Dead logs made up less than 10% of the forest floor cover at both sampling sites.

3.1.4 Awurada Valley Forest (AW)

At Awurada Valley Forest, one sampling site was systematically sampled, while additional snails were collected opportunistically in the forest during the hike, which included PFM sites. The systematic sampling site was very close to the Gummi River in the core zone of the Kafa BR. It was also the site with the lowest altitude (1293 m a.s.l.) and the second most species-rich sampling site of the entire assessment, with nine species in total. Habitat conditions were quite moist, and plenty of dead logs were present, covering about 30% of the forest floor. Canopy cover was about 90%. A comparatively high number of live specimens were found in the interstices of decaying logs and the leaf litter layer. No direct signs of human activity were found near this sampling site, except for a recently abandoned hunter camp.

The sampling site was very difficult to find, and even the local guides lost their way, so we had to cut our way through the dense thicket for about an hour to reach it. The dataset was complemented by snails collected along the way, yielding a total of 12 terrestrial snail species. This made Awurada Valley the second most species-rich forest after Boginda Forest (16 species).

3.1.5 Alemgono Wetlands (AG)

Only one terrestrial snail species (*Limicolaria chefneuxi*) was collected opportunistically in a small secondary forest patch. The Alemgono Wetlands were not sampled further for terrestrial snails. The focus here was on freshwater habitats.

3.1.6 Shoriri Wetlands (SHO)

After collecting aquatic molluscs in the wetlands, only a single site in a nearby secondary forest was sampled for terrestrial molluscs (ETH 14.010). Eight land snail species were collected at this sampling site, an average species-richness compared to the other sites. The forest featured only a few larger timber trees and abundant shrubs up to 4 m high, with wild coffee plants in the understorey. The canopy cover was about 70% and dead log cover was < 5%. Habitat conditions were very dry, and snails were found hidden deeply under decaying wood. There were indications of moderate human impact, as a path runs nearby and the forest seems to be used for harvesting wild coffee.

3.1.7 Gojeb Wetlands (GO-wet)

A single terrestrial snail species was collected opportunistically on a coffee plantation (see also GO-riv). This site was not sampled further for terrestrial molluscs.

3.1.8 Gojeb River floodplain forest (GO-riv)

Only one sampling site was studied in the floodplain forest very close to Gojeb River. Seven terrestrial snail species were found here, an average species-richness compared to the other sites. However, two additional freshwater species (*Radix natalensis* and *Corbicula* sp. A) were found on the forest floor in high numbers, indicating a recent flooding event. Taking this peculiarity into account, the total count of mollusc species in this forest was nine. This floodplain forest is a gallery forest mainly composed of palm trees and a few timber trees. The maximum diameter of trees at the sampling site was 1 m. Canopy cover was only about 40%, and the dead log cover on the forest floor was < 5%. The high number of dead *Corbicula* sp. shells and live *Radix natalensis* specimens indicate that the area is subject to inundation during a significant portion of the year.

3.1.9 Boginda Forest (BO)

Two sampling sites were investigated in Boginda Forest. Both sites were located within the core zone of the Kafa BR. One sampling site (ETH 14.016) yielded a total of 14 terrestrial snail species, making it by far the most species-rich site investigated. The other sampling site (ETH 14.017) yielded seven snail species. The total count was 16 species, making Boginda Forest the most species-rich forest in this study. Most strikingly, a comparatively high number of microgastropods could be collected by hand from the forest floor, contributing to the overall high diversity. None of the other study sites yielded such high numbers of small snails. The site with locality code ETH 14.016, had few large timber trees (up to 1.5 m diameter) in the vicinity. The canopy cover was about 80% and the cover of dead logs on the forest floor was < 5%. Heavy signs of selective logging were found nearby. The other sampling site (ETH14.017) is probably a secondary forest, with strong signs of human activity. The canopy cover was about 70%, while the cover of dead logs on the forest floor was about 10%. However, the largest tree in a 100 m perimeter around the sampling plot was only 0.6 m in trunk diameter. There was evidence of heavy selective logging, probably to clear access to beehives installed on several trees (Fig. 4). There was a particularly large number of army ants here, possibly indicating ecosystem disturbance.

3.1.10 KDA Guesthouse (KDA-GH)

Two terrestrial snail specimens were collected opportunistically on a nearby meadow. One was assigned to a species (*Limicolaria choana*) found at none of the other study sites.

Table 2: Summary of collected mollusc species in each study site

No.	Species	BA	BK	KO	AW	AG	SHO	GO-wet	GO-riv	BO	KDA GH
TERRESTRIAL MOLLUSCS											
Halolimnohelicidae											
1	*Vicariihelix mukulensis* (Pilsbry 1919)	1		1							
Cerastidae											
2	*Cerastus lymnaeiformis* (Haas 1936)		1				1		1	1	
3	*Cerastus* sp. A	1									
4	*Cerastus* sp. B				1						
5	*Cerastus* sp. C									1	
6	*Cerastus* sp. D		1								
7	*Edouardia* sp. A	1									
8	*Edouardia* sp. B						1				
9	*Edouardia* cf. *carinifera* (Melvill & Ponsonby 1897)			1						1	
Subulinidae											
10	*Bocageia germaini* (Pilsbry 1919)	1								1	
11	*Nothapalus paucispira* (Martens 1897)	1		1			1			1	
12	*Homorus antinorii* (Morelet 1872)			1	1		1		1	1	
13	*Subulinidae* sp. A				1						
14	*Subulinidae* sp. B						1				
15	*Subulinidae* sp. C								1		
16	*Subulina muzingeri* (Jickeli 1874)									1	
Maizaniidae											
17	*Maizania elatior* (Martens 1892)			1	1			1		1	
Veronicellidae											
18	*Laevicaulis natalensis* (Simroth 1913)				1		1		1	1	1
Urocyclidae											
19	*Urocyclidae* sp. A (slug)								1		
20	*Trochozonites* sp. A									1	
21	*Trochozonites* sp. B									1	
Vitrinidae											
22	*Vitrinia* sp. A	1	1	1	1				1	1	
23	*Vitrinia* sp. B				1					1	
Streptaxidae											
24	*Afristreptaxis* cf. *aethiopicus* (Thiele 1933)		1	1	1					1	
25	*Gullela* sp. A			1	1		1		1	1	
26	*Gullela* sp. B			1						1	

No.	Species	BA	BK	KO	AW	AG	SHO	GO-wet	GO-riv	BO	KDA GH
Achatinidae											
27	*Limicolaria* sp. A			1							
28	*Limicolaria martensiana* (Smith 1880)				1						
29	*Archachatina* cf. *ustulata* (Lamarck 1828)				1						
30	*Limicolaria dhericourtiana* (Bourguignat 1885)		1								
31	*Limicolaria chefneuxi* (Bourguignat 1885)				1	1	1				
32	*Limicolaria choana* (Bourguignat 1885)										1
AQUATIC MOLLUSCS											
Lymnaeidae											
33	*Radix natalensis* (Krauss 1848)					1			1		
Sphaeriidae											
34	*Pisidium pirothi* (Jickeli 1881)		1	1	1		1				1
35	*Pisidium viridarium* (Kuiper 1956)					1					
36	*Pisidium casertanum/ethiopicum*		1	1	1						
37	*Pisidium* sp. A (spec. nov.)		1	1							
38	*Sphaerium hartmanni* (Jickeli 1874)		1	1		1					
Corbiculidae											
39	*Corbicula* sp. A								1		
Iridinidae											
40	*Mutela* sp. A								1		
41	*Etheria elliptica* (Lamarck 1807)								1		
TOTAL species count		**6**	**9**	**14**	**14**	**4**	**9**	**1**	**11**	**16**	**3**

As far as the author of this report is aware, this work is the only systematic assessment of terrestrial molluscs in a montane rainforest in Ethiopia, if not the whole of Ethiopia. Thus, it greatly contributes to the knowledge of invertebrate communities in the northernmost extension the Afrotropical rainforest. However, the results did not entirely meet our expectations, as the number of species found is only about 50% of that found in similar forests in Uganda (Wronski & Hausdorf 2010). In the Albertine Rift in Uganda, species richness ranged from 31 to 69 species in individual montane rainforests. However, more than 50% of snail species collected there were microgastropods (< 5 mm shell size), which in the current study were collected opportunistically rather than systematically assessed, due to time constraints in the field and the difficulties associated with their determination.

In another study, Wronski et al. (2014) collected 56 species by hand on 37 plots in rainforests on Bioko Island (Equatorial Guinea). This was a closer approach to that implemented in the current study, but three times more sampling plots were used. In any event, the molluscan fauna of a rainforest cannot be completely assessed with so few plots (Cameron & Pokryszko 2005). More sampling is required to compile a more complete checklist of terrestrial snails in Kafa BR.

It is not known whether the comparatively low number of species reflects the relative geographic isolation of the Ethiopian montane rainforests from the Congo-Basin and the Albertine Rift, where most of the characteristic Afrotropical land snail families and genera have undergone massive adaptive radiation (Pilsbry 1919). The assessment was carried out in the dry season. The general impression is that conditions were very dry and thus unfavourable for snail collection, and we saw no rainfall at all during the entire stay in the area. This impression is supported by the observation that most of the collected specimens were dead shells.

Many land snails, especially the smaller species, depend on decaying wood and abundant leaf litter in which to feed and endure dry periods. In the Awurada Valley forest, where conditions where relatively moist at the time of collection, a high number of live snails was collected in the interstices between massive, decaying logs on the forest floor. We were unable to find sites with a comparable structural diversity in the Boka, Komba and Boginda Forests. The general impression was that anthropogenic influence in the latter sites was comparatively high, as supported by clear signs of selective logging and understorey clearing. These activities can be assumed to have a negative effect on land snail diversity and abundance by reducing the structural diversity of the forest floor and the capacity to retain humidity retention.

A significant part of the African rainforest land snail community is composed of small and minute species (shell size < 5 mm) (Wronski & Hausdorf 2010; Tattersfield et al. 2001b). These land snails have very limited dispersal capability, are adapted to microenvironmental conditions and are thus especially vulnerable to environmental alterations like clear cutting (Tattersfield et al. 2001b). This is supported by the fact that only five snail species were found on the only sampling plot in Boka Forest, the least species-rich plot in the entire assessment. The structural diversity of the forest floor was very poor here compared to the other sites.

There were several specimens which could not be assigned to any species with certainty. The number of species which could not be determined to species level was especially high in the families Cerastidae, Streptaxidae and Subulinidae. Given the current poor knowledge of Ethiopian land snails, further studies should aim at clarifying their systematic status. Researchers should scrutinise original descriptions of same-genus species from East Africa and examine type material found in museum collections in Europe and North America. The possibility that this assessment collected species new to science cannot currently be ruled out. DNA sequence analysis could be a powerful method to shed light on the phylogenetic relationships and biogeographic history of the land and freshwater molluscs of the Kafa BR. It can also be assumed that the total number of collected species in the Kafa BR would greatly increase with higher sampling effort.

3.2 Aquatic molluscs (freshwater snails and bivalves)

The richness of mollusc species in aquatic habitats within the Kafa BR was very poor at the time of collection. However, a seasonal effect can be excluded, as no dead shells were collected in most waterbodies. Altogether, only nine mollusc species were collected at seven different sampling sites. The most species-rich sampling sites were the Gojeb River and Boka and Komba Forests with four species per site. However, variance between individual sampling sites was very low, ranging from one to four species. Several sampling sites showed no mollusc presence at all, despite apparently good habitat conditions and highly experienced collectors. Most striking is the absence of pulmonate snail species from almost all sampling sites. Pulmonates of the genera *Bulinus* and *Biomphalaria*, for instance, are known to tolerate a wide spectrum of different environmental conditions and are almost omnipresent in high numbers in other East African stagnant water bodies, such as temporal ponds and floodplains. A typical representative of the pulmonates, *Radix natalensis*, was found only in temporal ponds in Alemgono Wetlands and – atypically – in the floodplain forest of Gojeb River, apparently enduring the dry season on the forest floor. *R. natalensis*, however, is a wide-spread African snail which is known to act as the intermediate host of the liver fluke *Fasciola gigantica* – a parasite which severely affects livestock. Itagaki et al. (1975) found the human parasite *Schistosoma* prevalent along the Gojeb River. However, the presence of intermediate hosts from the genera *Bulinus* and *Biomphalaria* in the area could not be confirmed in this study, as neither live snails nor dead shells from these genera were found.

Apart from *R. natalensis*, all other collected freshwater molluscs were bivalves. The pea clam *Pisidium pirothi*, a widespread species with low habitat requirements, was present at most of the sampled freshwater sites. The Gojeb and Gummi Rivers were difficult to access due to dense riparian vegetation, deeply eroded river banks, in the case of the Gojeb River, a rocky bottom. They thus could not be sufficiently sampled. Unfortunately, only fragments of larger bivalves could be collected, even though we strongly expected to find several species of unionid or iridinid bivalves in the larger rivers. However, shells of the freshwater 'oyster' (*Etheria elliptica*) were found on the Gojeb River in April 2015 by Peter Tattersfield from Cardiff National Museum, United Kingdom. This finding is reported here. In addition to the widespread fingernail clam species *Sphaerium hartmanni*, one basket clam species of the genus *Corbicula* (Corbiculidae) was collected in the Gojeb River, which could not be determined to species level. Thus four bivalve families were represented in the freshwaters of the Kafa BR: Sphaeriidae, Corbiculidae, Etheriidae and Iridinidae. Another remarkable finding is the discovery of a species belonging to the genus *Pisidium* that is almost certainly new to science. This species was found in a small stream near to Boka Forest and in a larger stream close to Komba Forest.

At present, no plausible explanation can be given for the relatively poor freshwater molluscan fauna in the Kafa BR. The almost complete absence of snails in apparently suitable habitats with emerging plants, e.g., in the wetlands of Boka Forest, is especially striking. Altitudinal effects can be excluded, as pulmonate snails have been found at up to 3800 m a.s.l. in East Africa (Jackson Pool, Mt. Elgon, author's data). Further investigations are required to elucidate whether chemical water parameters or biogeographic factors play a role in shaping this striking biodiversity pattern.

4. Conclusions and Recommendations for Conservation and Monitoring

4.1 General issues

Molluscs, along with other animal and plant groups, are undergoing an unprecedented period of extinction. In fact, it has been claimed that molluscs are the animal group facing the highest extinction rate of all (Regnier et al. 2009). Especially prone to extirpation are narrow endemics, species with low dispersal capacities and species depending on climax vegetation (Kay 1995). It has been shown that molluscs with long lifespans and low fecundity are particularly threatened.

In East Africa, 83% of terrestrial snail species are believed to be restricted to rainforests. However, rainforests only cover around 2-3% of the surface area in East Africa (Seddon et al. 2005). Against this background, and in light of the high deforestation rate in East Africa and Ethiopia, there are serious concerns for the conservation of molluscs.

Unfortunately, at present very few studies have been published about the distribution patterns and ecology of African tropical land snails, and knowledge about their lifecycles is very limited. In a similar vein, knowledge about the conservation status of snail species found in this assessment is lacking, as proved by the fact that none of the terrestrial snail species collected has been assessed by the IUCN Red List. In light of the scarcity of information available, it is doubtful whether meaningful conservation measures targeting individual snail species or communities can be planned at present. This underlines the importance of further investigating the diversity and ecology of African tropical land snails and the need to design and implement effective conservation measures to ensure their survival. For the time being, however, it can be assumed that threatened snail species can greatly benefit from effective protection of other umbrella or surrogate species (e.g., forest birds) which are characteristic of the same types of macrohabitat.

One pattern that emerged from this study is the fact that sites with high structural diversity of the forest floor support a comparatively higher number of species. This is supported by another study in the Kenyan Kakamega Forest, which found that species-richness is 15-50% lower on tree plantations than in indigenous forest (Tattersfield et al. 2001b). The same authors also noted that some species are exclusively confined to indigenous forest. These species should be a research priority in the Kafa BR, as they will become (regionally) extinct if deforestation in the BR is not effectively halted. Due to the isolated geographic position of the rainforests in the Kafa BR, re-colonisation from other East African rainforests is unlikely.

The current assessment of molluscs has several shortcomings: First, species determination for terrestrial snails was extremely difficult due to the complete lack of determination keys and the synoptic treatment of Ethiopian land snails. Consequently, determination could not be completed for many specimens, especially within the families Cerastidae, Subulinidae and Streptaxidae. However, this is a common difficulty also encountered by other experts (Wronski & Hausdorf 2010). It cannot be ruled out that these families show a higher degree of 'cryptic' species diversity which could not be identified in this study.

Second, total forest assessment was impossible given the short duration of the fieldwork and the high heterogeneity of habitats.

Third, the timing of the fieldwork in the dry season was not ideal for collecting snails.

Finally, knowledge of the conservation status, ecology and lifecycles of Afrotropical land snails is fragmented at present, making developing conservation recommendations and monitoring schemes challenging and vague. Table 3 summarises the information available on the distribution and conservation status of the collected mollusc species.

Nonetheless, the present study represents a first, important contribution to knowledge of molluscs as representatives of the invertebrate forest floor community of the Kafa BR. However, the present assessment must be regarded as far from complete, and extensive research is needed to gain full insight into the species composition of the molluscan communities of Kafa BR.

Even though much more is known about the ecology and lifecycles of East African freshwater snails compared to land snails, too few freshwater mollusc species were collected to allow meaningful, detailed conclusions on habitat management and monitoring. In general, freshwater molluscan diversity was found to be very low in the streams, rivers and ponds of the Kafa BR. Five of the nine species which were found are common and widespread in East Africa, while the systemic positions of another three bivalve species could not be determined with certainty. One of those species exhibited intermediate morphological characteristics of the critically endangered *Pisidium ethiopicum* and the globally distributed *Pisidium casertanum*. In addition, one species belonging to the genus *Pisidium* is almost certainly new to science. Further studies should investigate whether environmental (e.g., water chemistry) and biogeographic factors (e.g., isolation from the Nile drainage) have led to the comparative poverty of the Kafa BR's freshwater molluscan communities. In addition, it should be examined whether molluscicides such as copper sulfate have been employed on a large scale in a putative attempt to eradicate snail-borne diseases such as schistosomiasis.

It has been established that deforestation leads to increased siltation and nutrient loads in adjacent rivers and standing waterbodies. A slightly increased siltation rate and nutrient load, however, can lead to an increase in freshwater molluscan biodiversity. Higher nutrient loads mainly benefit the freshwater snail group Pulmonata, whose representatives depend on aquatic vegetation for feeding and reproduction. However, as several representatives of Pulmonata transmit severe human and livestock diseases, deforestation and higher nutrient loads in freshwaters associated herewith are also likely to promote the incidence of severe snail-borne diseases such as schistosomiasis and tropical fascioliasis. In light of these adverse effects of higher nutrient loads in streams, rivers and ponds associated with reduction in forest cover, conservation measures should generally focus on curbing deforestation and halting erosion.

Freshwater molluscs play a key role in providing ecosystem services and are essential for wetland maintenance, mainly due to their contribution to water quality, nutrient cycling through filter-feeding and algal grazing and as a food source for other animals (Darwall et al. 2011). According to the IUCN pan-African assessment of freshwater molluscs, 22% of freshwater mollusc species in East Africa are threatened, while 38% are data deficient (Darwall et al. 2011). These high proportions of threatened and data-deficient molluscs indicate a clear need for urgent conservation measures to preserve Africa's last pristine wetlands and streams, and for further research into the distribution and conservation status of East African freshwater molluscs, including those of the large rivers and streams of the Kafa BR.

4.2 Indicator groups and species

4.2.1 Terrestrial habitats

Knowledge of the taxonomic status, conservation status, ecology and lifecycles of terrestrial land snails in Ethiopia is extremely scarce. Nonetheless, terrestrial snails represent an important invertebrate community of the forest floor, with potentially suitable indicator species for ecosystem health. Future research should focus on clarifying the taxonomic status of land snails in the Kafa BR, as well as on the study of their ecology and lifecycles.

Future investigations should specifically target species within the terrestrial gastropod family Streptaxidae. The streptaxids are typical inhabitants of the rainforest floor. As (almost) all representatives of this family are predators of other forest-floor-dwelling snails, they are a higher trophic level and are thus useful surrogates for the entire molluscan community of the rainforest floor. Therefore, the author suggests further investigating the suitability of the streptaxids as an indicator group or individual streptaxid species as indicator species for the ecosystem health of the invertebrate community of the rainforest floor. In a comparison between the land snail communities of primary forest versus tree plantations in Kenya, Tattersfield et al. showed that some snail species are restricted to indigenous forest (Tattersfield et al. 2001b). These species are probably good indicator species for the ecological integrity of primary forests. However, the number of sampling plots in the current study was too low to infer which species are exclusively restricted to primary forest. Therefore, future research should focus on identifying the snail species restricted to primary forest, with the goal of incorporating them into a monitoring scheme.

Table 3: Summary of collected mollusc species and corresponding information on habitat, distribution, conservation status and endemism ('x' indicates 'not applicable')

Voucher ID	Scientific name	Family
ETH14.005V	*Vicariihelix mukulensis* (Pilsbry 1919)	Halolimnohelicidae
ETH14.010C	*Cerastus lymnaeiformis* (Haas 1936)	Cerastidae
ETH14.005C	*Cerastus* sp. A	Cerastidae
ETH14.007C	*Cerastus* sp. B	Cerastidae
ETH14.016C	*Cerastus* sp. C	Cerastidae
ETH14.018C	*Cerastus* sp. D	Cerastidae
ETH14.005E	*Edouardia* sp. A	Cerastidae
ETH14.010E	*Edouardia* sp. B	Cerastidae
ETH14.016E	*Edouardia* cf. *carinifera* (Melvill & Ponsonby 1897)	Cerastidae
ETH14.005B	*Bocageia germaini* (Pilsbry 1919)	Subulinidae
ETH14.005N	*Nothapalus paucispira* (Martens 1897)	Subulinidae
ETH14.AWUH	*Homorus antinorii* (Morelet 1872)	Subulinidae
ETH14.007S	*Subulinidae* sp. A	Subulinidae
ETH14.010S	*Subulinidae* sp. B	Subulinidae
ETH14.014S	*Subulinidae* sp. C	Subulinidae
ETH14.016S	*Subulina muzingeri* (Jickeli 1874)	Subulinidae
ETH14.007M	*Maizania elatior* (Martens 1892)	Maizaniidae
ETH14.016L	*Laevicaulis natalensis* (Simroth 1913)	Veronicellidae
ETH14.014U	*Urocyclidae* sp. A (slug)	Urocyclidae
ETH14.017TA	*Trochozonites* sp. A	Urocyclidae
ETH14.017TB	*Trochozonites* sp. B	Urocyclidae
ETH14.005V	*Vitrinia* sp. A	Vitrinidae
ETH14.016V	*Vitrinia* sp. B	Vitrinidae
ETH14.016H	*Afristreptaxis* cf. *aethiopicus* (Thiele 1933)	Streptaxidae
ETH14.007G	*Gullela* sp. A	Streptaxidae
ETH14.017G	*Gullela* sp. B	Streptaxidae
ETH14.013L	*Limicolaria* sp. A	Achatinidae

Habitat/ forest type	Study sites	Distribution	IUCN Threat Status	CITES Appendix	Endemism
Bamboo forest, montane forest	BA, KO	East African montane forest	not assessed	x	x
Montane forest, river floodplain forest	BK, SHO, GO-riv, BO	East Africa	not assessed	x	x
Bamboo forest	BA	unknown	x	x	unknown
Mid - altitude forest	AW	unknown	x	x	unknown
Mid - altitude forest	BO	unknown	x	x	unknown
Mid - altitude forest with bamboo encroachment	BK	unknown	x	x	unknown
Bamboo forest	BA	unknown	x	x	unknown
Mid - altitude secondary forest	SHO	unknown	x	x	unknown
Mid - altitude forest	KO, BO	South East Africa	not assessed	x	x
Bamboo forest, montane forest	BA, BO	Uganda, Ruwenzor	not assessed	x	x
Bamboo forest, montane forest	BA, KO, SHO, BO	East Africa	not assessed	x	x
Montane forest, river floodplain forest	KO, AW, SHO, GO-riv, BO	Ethiopia	not assessed	x	Ethiopia
Mid - altitude forest	AW	unknown	x	x	unknown
Secondary mid - altitude forest	SHO	unknown	x	x	unknown
River floodplain forest	GO-riv	unknown	x	x	unknown
Montane forest	BO	Ethiopia	not assessed	x	Ethiopia
Montane forest, coffee plantation	KO, AW, GO-wet, BO	East Africa	not assessed	x	x
Montane forest, anthropogenic landscape	AW, SHO, GO-riv, KDA GH	Eastern and Southern Africa	not assessed	x	x
Floodplain forests	GO-riv	unknown	x	x	unknown
Montane forest	BO	unknown	x	x	unknown
Montane forest	BO	unknown	x	x	unknown
Bamboo forest, montane forest, floodplain forest	BA, BK, KO, AW, GO-riv, BO	unknown	x	x	unknown
Montane forest	AW, BO	unknown	x	x	unknown
Montane forest	BK, KO, AW, BO	Ethiopia	x	x	possibly Ethiopia
Montane forest, river floodplain forest	KO, AW, SHO, GO-riv, BO	unknown	x	x	unknown
Montane forest	BO, KO	unknown	x	x	unknown
Montane forest	KO	unknown	x	x	unknown

Voucher ID	Scientific name	Family
ETH14.AWUL	*Limicolaria martensiana* (Smith 1880)	Achatinidae
ETH14.AWUA	*Archachatina* cf. *ustulata* (Lamarck 1828)	Achatinidae
ETH14.018L	*Limicolaria dhericourtiana* (Bourguignat 1885)	Achatinidae
ETH14.AWUL1	*Limicolaria chefneuxi* (Bourguignat 1885)	Achatinidae
ETH14.KDAL	*Limicolaria choana* (Bourguignat 1885)	Achatinidae
ETH14.008R	*Radix natalensis* (Krauss 1848)	Lymnaeidae
ETH14.003Pp	*Pisidium pirothi* (Jickeli 1881)	Sphaeriidae
ETH14.008Pv	*Pisidium viridarium* (Kuiper 1956)	Sphaeriidae
ETH14.003PA	*Pisidium* sp. A (spec.nov.)	Sphaeriidae
ETH14.003Pc	*Pisidium casertanum/ethiopicum*	Sphaeriidae
ETH14.008S	*Sphaerium hartmanni* (Jickeli 1874)	Sphaeriidae
ETH14.015S	*Corbicula* sp. A	Corbiculidae
ETH14.015M	*Mutela* sp. A	Iridinidae
ETH15.GJE	*Etheria elliptica* (Lamarck 1807)	Etheriidae

For the time being, species from other animal groups where we have extensive knowledge of their habitat requirements (e.g., birds) should be used as surrogate species to design meaningful conservation measures and habitat-specific monitoring schemes.

4.2.2 Rivers and streams

Bivalves from the superfamily Unionoida (families Unionidae and Iridinidae) are potentially good indicators of ecosystem health in rivers and streams. The Unionoida are large freshwater mussels with are easily distinguishable from the Sphaeriidae and Corbiculidae by their much larger shell size (up to 150 mm). Adult Unionoida are benthic filter feeders with very low mobility, like all bivalves, and thus sensitive to siltation. Although very few facts have been established about the lifecycles of African tropical Unionoida, it can be assumed that they use the same intriguing dispersal strategy as their European relatives. Their larvae (Glochidia) are released into the water column and parasitise the gills or fins of certain fish species. The fish disperse the larvae and release them after a couple of months. The larvae then sink to the bottom of the water body before finally developing into adult, filter feeding bivalves. The complexity of the lifecycle of the Unionoida, combined with their low individual mobility, makes them susceptible to deterioration of physical and chemical water parameters and a simultaneous decline in their host fish population.

Habitat/ forest type	Study sites	Distribution	IUCN Threat Status	CITES Appendix	Endemism
River floodplain forest	AW	East Africa	not assessed	x	x
River floodplain forest	AW	Southern Africa	not assessed	x	x
Mid - altitude forest with bamboo encroachment	BK	Ethiopia	not assessed		Ethiopia
Mid - altitude forest, wetlands	AW, AG, SHO	Ethiopia	not assessed		Ethiopia
Anthropogenic landscape	KDA GH	Ethiopia-Sudan	x	x	Ethiopia-Sudan
Temporal ponds	AG	Pan-African	LC	x	x
Temporal ponds, streams, rivers	BK, AW, SHO, KO	Pan-African	LC	x	x
Temporal ponds	AG	global	not assessed	x	x
Streams, rivers	BK, KO	unknown	not assessed	x	unknown
Streams, rivers	BK, KO	only known from type locality	CR	x	Ethiopian Highlands
Temporal ponds, streams, Rivers	BK, KO, AG	Pan-African	LC	x	x
Rivers	GO-riv	unknown	x	x	unknown
Rivers	GO-riv	unknown	x	x	unknown
Rivers	GO-riv	Pan-African	LC	x	x

In Europe and North Africa, the decline and extinction of unionid bivalve populations is strongly correlated with anthropogenic alteration of the hydromorphology and chemical characteristics of rivers and streams. Hence, the author proposes the Ethiopian representatives of the Unionoida as good indicators of ecosystem health of running waters and larger standing waterbodies. They should be incorporated into a future monitoring scheme as a high spatial resolution component, in order to monitor the conservation status of the rivers and streams of the Kafa BR.

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6. Appendix

6.1 Photos

6.1.1 Mollusc species

Figure 1: *Afristreptaxis* cf. *aethiopicus* (BK) (photo: Thies Geertz)

Figure 2: *Bocageia germaini* (BK) (photo: Thies Geertz)

Figure 3: *Cerastus* sp. D (BK) (photo: Thies Geertz)

Figure 4: *Corbicula* sp. A (GO-riv) (photo: Thies Geertz)

Figure 5: *Edouardia* cf. *carinifera* (BO) (photo: Thies Geertz)

Figure 6: *Gullela* sp. A (GO-riv) (photo: Thies Geertz)

Figure 7: *Gullela* sp. B (KO) (photo: Thies Geertz)

Figure 8: *Homorus antinorii* (AW) (photo: Thies Geertz)

Figure 9: *Laevicaulis natalensis* (SHO) (photo: Thies Geertz)

Figure 10: *Limicolaria chefneuxi* (AG) (photo: Thies Geertz)

Figure 11: *Limicolaria* sp. A (KO) (photo: Thies Geertz)

Figure 12: *Maizania elatior* (GO-wet) (photo: Thies Geertz)

Figure 13: *Nothalapus paucispira* (BO) (photo: Thies Geertz)

Figure 14: *Pisidium pirothi* (BK) (photo: Thies Geertz)

Figure 15: *Radix natalensis* (AG) (photo: Thies Geertz)

Figure 16: *Sphaerium hartmanni* (BK) (photo: Thies Geertz)

Figure 17: *Subulina muzingeri* (BO) (photo: Thies Geertz)

Figure 18: *Subulinidae* sp. A (AW) (photo: Thies Geertz)

Figure 19: *Subulinidae* sp. A (AW) (photo: Thies Geertz)

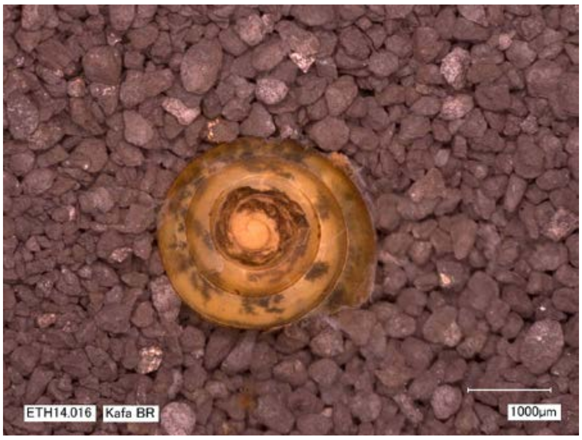

Figure 20: *Trochozonites* sp. A (BO) (photo: Thies Geertz)

Figure 21: *Trochozonites* sp. B (BO) (photo: Thies Geertz)

Figure 22: *Urocyclidae* sp. A (GO-riv) (photo: Thies Geertz)

Figure 23: *Vicariihelix mukulensis* (KO) (photo: Thies Geertz)

Figure 24: *Vitrinia* sp. A (GO-riv) (photo: Thies Geertz)

Figure 25: *Vitrinia* sp. A (KO) (photo: Thies Geertz)

Figure 26: *Vitrinia* sp. B (AW) (photo: Thies Geertz)

Figure 27: *Vitrinia* sp. B (BO) (photo: Thies Geertz)

6.1.2 Sampling methods

Figure 28: Sampling land snails near to Gojeb River (GO-riv) (photo: Thies Geertz)

Figure 29: Sampling aquatic molluscs (GO-riv) (photo: Thies Geertz)

Figure 30: Keyence VHX-2000 digital microscope (photo: Thies Geertz)

Figure 31: Evidence of selective logging in BO (Boginda Forest) (photo: Thies Geertz)

Figure 32: Access to the banks of the Gojeb River (GO-riv) was very difficult during the survey period (photo: Thies Geertz)

Figure 33: An apparently good habitat for snail fauna in the Boka Forest, but with extremely poor species richness (BK) (photo: Thies Geertz)