



Discovery of the mountain glass snail,
Hessemilimax kotulae (Westerlund, 1883) (Mollusca,
Gastropoda, Vitrinidae), in the High Vosges
Mountains (northeast France) and its conservation

Jean-Michel BICHAIN & Julien RYELANDT

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COUVERTURE / *COVER*:

Sampling sites and specimen of *Hessemlimax kotulae* (Westerlund, 1883) from the High Vosges (northeast France).

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Discovery of the mountain glass snail, *Hessemilimax kotulae* (Westerlund, 1883) (Mollusca, Gastropoda, Vitrinidae), in the High Vosges Mountains (northeast France) and its conservation

Jean-Michel BICHAIN

Musée d'Histoire naturelle et d'Ethnographie de Colmar
11 rue Turenne, F-68000 Colmar (France)
jean-michel.bichain@museumcolmar.org

Julien RYELANDT

Conservatoire botanique national de Franche-Comté – Observatoire régional des Invertébrés
7 rue Voirin, F-25000 Besançon (France)
julien.ryelandt.ori@cbnfc.org

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ABSTRACT

We report here four new localities for the mountain glass snail *Hessemilimax kotulae* (Westerlund, 1883) in the northeast part of France. These new records extend the range of this species considerably within the Vosges Mountains, where it was previously known from only a single site. Specimens were found at the base of or in scree slopes facing mainly north or northeast or along streams in fir or mixed forests, at elevations between 863 and 1145 m. Because *H. kotulae* is difficult to find and identify, we provide the description of habitats where the species has been found and the associated gastropod assemblages as well as morphological and anatomical characters in order to facilitate its identification by non-malacological conservationists. Finally, we revised the species conservation status on the French Red List. We further discuss the conservation of land snails that reach the upper limit of their distribution at the highest elevations of the low mountain ranges in north-eastern France, in the context of global warming.

KEY WORDS

Climate warming,
conservation,
IUCN Red List,
low mountain range,
species range limit,
new records.

RÉSUMÉ

Découverte de la semilimace alpine, Hessemilimax kotulae (Westerlund, 1883) (Mollusca, Gastropoda, Vitrinidae), dans les Hautes-Vosges (nord-est de la France) et sa conservation.

Nous signalons ici quatre nouvelles localités pour la semilimace alpine *Hessemilimax kotulae* (Westerlund, 1883) dans le nord-est de la France. Ces nouvelles mentions étendent considérablement l'aire de répartition de cette espèce dans le massif des Vosges, où elle n'était auparavant connue que d'un seul site. Les spécimens ont été trouvés à la base ou dans des éboulis principalement exposés au nord ou au nord-est, ou le long de petits ruissellements dans des forêts de sapins ou mixtes, à des altitudes comprises entre 863 et 1145 m. Dans la mesure où *H. kotulae* est difficile à trouver et à identifier, nous fournissons dans cet article la description des habitats où l'espèce a été trouvée et des cortèges de gastéropodes associés ainsi que les caractères morphologiques et anatomiques, et ce, afin de faciliter son identification par les gestionnaires des espaces naturels non-malacologues. Enfin, nous avons réévalué le statut de conservation de l'espèce dans la Liste Rouge française. Nous discutons également de la conservation des gastéropodes terrestres qui atteignent la limite supérieure de leur distribution aux plus hautes altitudes des chaînes de basse montagne du nord-est de la France, dans le contexte du réchauffement climatique.

MOTS CLÉS

Réchauffement climatique, conservation, Liste Rouge de l'UICN, chaîne de basses montagnes, extrême limite de répartition, signalisations nouvelles.

INTRODUCTION

The mountain glass snail, *Hessemilimax kotulae* (Westerlund, 1883), is a cold-adapted species with a wide distribution in the Alpine-Carpathian region (Kerney *et al.* 1999; Welter-Schultes 2012). The species occurs from montane to alpine elevations between 600 and 2 770 m a.s.l., essentially in the Carpathians (Czech Republic, Poland, Romania, Slovakia and Ukraine), in the central and eastern Alps (Austria, Germany, Italy, Switzerland) and also in the Sudetes and Black Forest mountains (Soós 1943; Alzona 1971; Klemm 1973; Grossu 1983; Lisický 1991; Turner *et al.* 1998; Nardi *et al.* 2007; Sysoev & Schileyko 2009; Fehér 2010; Egorov 2011; Welter-Schultes 2012; Rüetschi *et al.* 2012; Horsák *et al.* 2013). This species is mainly found in coniferous or deciduous forests at high elevations (Lisický 1991; Müller *et al.* 2009; Fehér 2010; Welter-Schultes 2012), and more rarely on moors and in fens above the timberline or in rocky areas. Populations at lower elevations exist in cold air sinks (Müller *et al.* 2009) and in habitats where cold air emanates from scree slopes (Hässlein 1966; Růžička *et al.* 2012). Moist crevices under rocks or in boulders, as well as moist dead wood, appear to play an important role by providing refuges for the species during periods of drought or frost (Rüetschi *et al.* 2012). What restricts the species to cold climates remains unclear. Hypotheses include the need for constant wet conditions for their eggs and juveniles (Umiński 1975) and putative negative effects related to competition (Falkner 1991).

According to Müller *et al.* (2009), this species should be considered a high mountain species particularly vulnerable to global warming, especially those populations located at the highest elevations of low mountain ranges. This is particularly the case in France, where the species is only documented from a single locality in the southern part of the Vosges (Brugel 2014), a low mountain range located in northeast France. Putative old reports of the species in the Massif Central (Bouillet 1836; Van Bruggen 1957) are either erroneous (Falkner

et al. 2002) or have never been confirmed. These westernmost populations of the species are therefore of considerable conservation significance.

After the fortuitous discovery of *H. kotulae* in the High Vosges in September 2022, a more extensive survey was carried out in habitats considered suitable for the species. This survey led to the discovery of the species in three new isolated localities, all at elevations above 850 m. In the context of climate change, it seems essential to provide a first overview of the regional distribution of this taxon considered a climate-sensitive indicator (Bässler *et al.* 2010) in order to eventually be able better to assess the rate and magnitude of biodiversity change occurring in these mountain ecosystems.

Consequently, the main objectives of this article are to: 1) provide diagnostic characters that may facilitate unambiguous identification of this species by non-malacologist conservationists; 2) provide a description of the habitats where the species was found and the associated gastropod assemblages; and 3) propose an update of its threat status in the French IUCN Red List. Finally, we discuss the conservation issues regarding land snails that reach their upper distributional limits at the highest elevations of the low mountain ranges of northeast France.

MATERIAL AND METHODS

STUDY AREA AND SAMPLING METHODS

The Vosges is a low elevation mountain range in northeast France (Fig. 1A). With the Palatinate Forest on the German side, to the north, they form a single geomorphological unit of about 8000 km². The Vosges form a southwest to northeast oriented relief and represent the western border of the Upper Rhine Valley, the Black Forest in Germany forming its eastern boundary. The southern and central parts of the massif, also called the High Vosges (Fig. 1A, B), are mainly formed of granite, gneiss and volcanic rocks (Von Eller *et al.* 1970a, b; Flück *et al.* 1991).

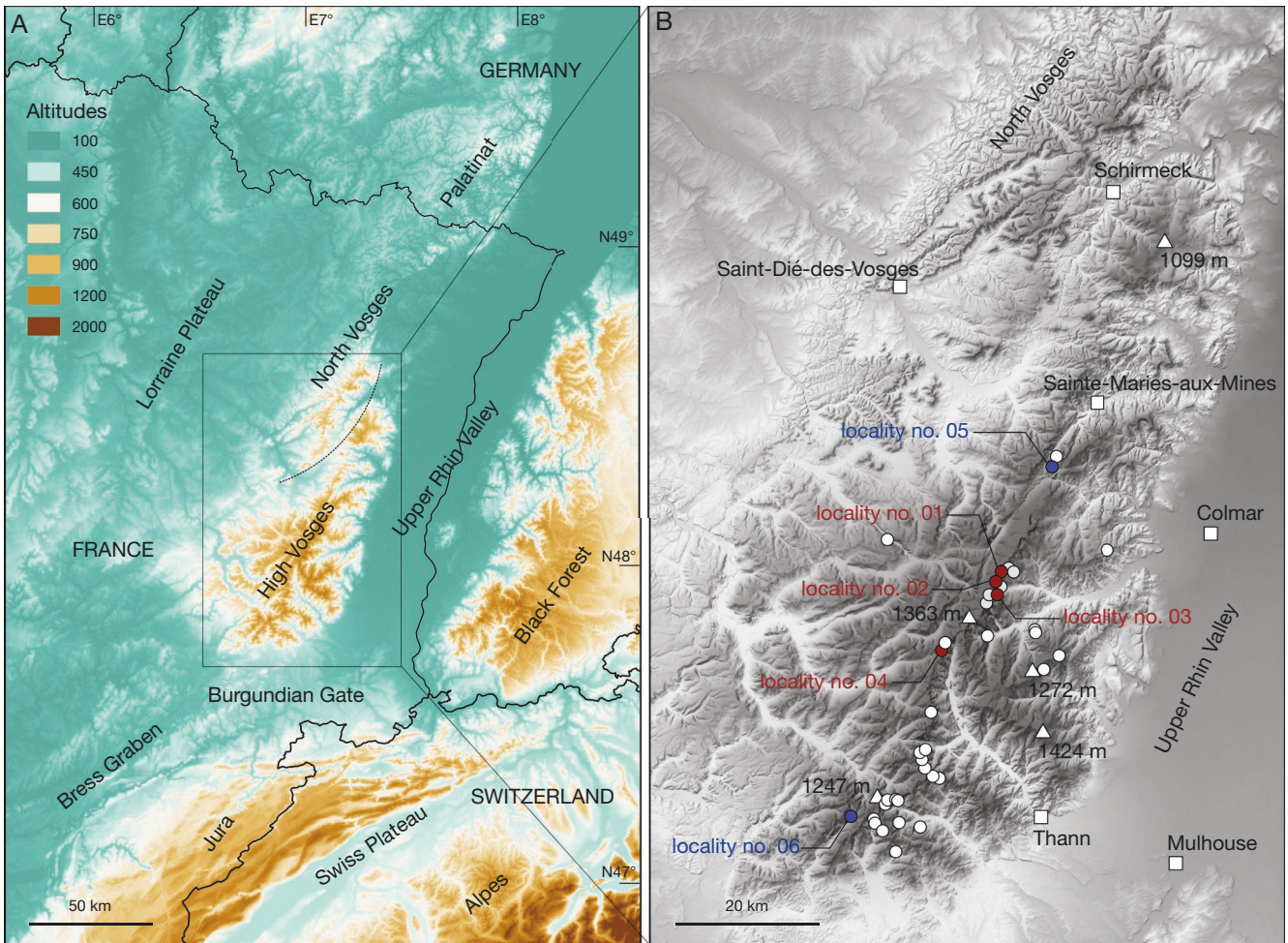


Fig. 1. — Geographical location of the sampling area: **A**, global view; **B**, location of the sampling sites in the high Vosges. Symbols: □, cities; △, main peaks with elevation indicated; ○, sampling sites; ●, new records of *Hessemilimax kotulae* (Westerlund, 1883) (localities no. 01 to no. 04); ●, past records of *Semilimax semilimax* (locality no. 05, Geissert 1996a) and *H. kotulae* (locality no. 06, Brugel 2014). The **dotted line** on **A** indicates the boundary between the sandstone Vosges (north Vosges) and the crystalline Vosges (High Vosges). This line passes approximately between Saint-Dié-des-Vosges and Schirmeck on **B**.

The High Vosges extend over about 50 km with a maximum elevation of 1424 m. Being the first significant high relief on the path of oceanic perturbations, this mountain range is subject to both oceanic and continental influences, dominated by westerly winds and with average annual temperature and precipitation at the highest elevations of 4°C and 1800–2000 mm respectively (Sell *et al.* 1998; Heuacker *et al.* 2015). The summit ridge is characterised by poaceous and ericaceous moorland (heather, blueberry and cranberry) with the presence of Alpine, Pyrenean or Boreo-Alpine species such as the Alpine pasque flower, *Pulsatilla alpina* (L.) Delarbre, 1800 (Renonculaceae), the Pyrenean angelica, *Epikeros pyrenaicus* (L.) Raf., 1840 (Apiaceae), or the creeping sibbaldia, *Sibbaldia procumbens* L., 1753 (Rosaceae). Depending on local conditions, above 1000–1100 m, forest associations are dominated by almost pure stands of beech (*Fagus sylvatica*). Below, the stands are dominated by mixed mountain forest of fir (*Abies alba*), more or less mixed with beech (Sell *et al.* 1998) and occasionally maple (*Acer pseudoplatanus*). The landscapes of the eastern side of the High

Vosges are marked by glacial cirques with steep walls or large scree slopes occasionally covered with maple, mountain ash (*Sorbus aucuparia*) and elm (*Ulmus glabra*).

Sampling was carried out in this area (Fig. 1B), above 600 m, mainly in cold and wet habitats, preferentially along streams, in moist deciduous or mixed forest and on north-facing scree slopes. We also sampled two other sites, one (station 6 on Fig. 1B) in the Southern Vosges Massif corresponding to the first documented mention of *Hessemilimax kotulae* (Westerlund, 1883) in France by Brugel (2014), and the other (station 5 on Fig. 1B) in the Central Vosges where *Semilimax semilimax* (J. Férussac, 1802) was recorded by Geissert (1996a), the only French locality for this species and which has not been revisited for nearly 30 years.

Vitrid species were specifically searched for by eye and occasionally by the wet sieving method (Horsák 2003) from the end of August to the end of October 2022. In addition, living individuals and empty shells of all gastropod species encountered were also collected. In total, 41 sites were sampled, of which 11 are in the Frankenthal-Misheimle National

Nature Reserve (FM-NNR international ID: 147288). To estimate the completeness of these inventories, the checklist of gastropod species known from above 600 m in this region was consulted (Bichain *et al.* 2021; <https://malacologie.museumcolmar.org/atlas>).

ANATOMY OF THE REPRODUCTIVE SYSTEM

Live collected juveniles and adults of *Hessemilimax kotulae*, as well as ambiguous vitrinid specimens (i.e., for which the specific identification was problematic based on morphological characters alone), were photographed in the laboratory using a camera equipped with a 150 mm macro lens. For anatomical identification and studies, animals were kept in water for about 12 hours and then preserved in 75% ethanol. Bodies were extracted from their shells with round-tip tweezers, avoiding damage to the tissue and shell. All dissections were performed under a stereomicroscope using thin pointed forceps. Reproductive systems were dissected out and photographed using a digital camera mounted on the stereomicroscope. Line drawings were realized by hand from these photographs. The terminology used here to describe the different parts of the reproductive system follows Giusti *et al.* (2011) and the nomenclature of all the taxa cited in this article follows MolluscaBase (www.molluscabase.org, accessed on 2.XI.2022).

ABBREVIATIONS

Institutions and collection

FM-NNR	Frankenthal-Misheimle National Nature Reserve;
MHNEC	Musée d'Histoire naturelle et d'Ethnographie, Colmar;
Coll. JMB	J.-M. Bichain collection, Colmar.

Anatomical description

A	atrium;
AAVS	apical portion of atrial-vaginal stimulator;
AG	albumen gland;
BAVS	basal portion of atrial-vaginal stimulator;
BC	bursa copulatrix;
FHD	first hermaphrodite duct;
OSD	ovispermiduct;
PC	penial complex;
POS	prostatic portion of spermoviduct;
PR	penial retractor;
PS	penial sheath;
UOS	uterine portion of spermoviduct;
VD	vas deferens.

SYSTEMATICS

Class GASTROPODA Cuvier, 1795
 Order STYLOMMATOPHORA A. Schmidt, 1855
 Family VITRINIDAE Fitzinger, 1833
 Genus *Hessemilimax* Schileyko, 1986

Hessemilimax kotulae (Westerlund, 1883)

Vitrina kotulae Westerlund, 1883: 54.

Vitrinopugio kotulae – Hesse 1923: 111.

Semilimax kotulae – Forcart 1944: 666.

Semilimax (Hessemilimax) kotulae – Schileyko 1986: 134.

Hessemilimax kotulae – Giusti *et al.* 2011: 336, accepted name in MolluscaBase (<https://www.molluscabase.org/>, consulted on 21.X.2022).

REMARK

Giusti *et al.* (2011) treated *kotulae* in a mono-specific genus distinct from *Semilimax* Stabile, 1859 on the basis of a few anatomical differences including the presence in *Hessemilimax* of: 1) a long finger-like penile complex; 2) a distinctive terminal portion of the main pilaster; and 3) the absence of a horn-like chitinous structure within the atrial-vaginal stimulator papilla. However, Giusti *et al.* (2011) recognised that some of their analyses indicated that *Hessemilimax* constitutes a monophyletic group with the species of *Semilimax* and that the basal relationships of this clade remain unresolved (see Pfarrer *et al.* [2021] for a critical discussion and alternative results to the approach of the Giusti *et al.* [2011]).

ORIGINAL DESCRIPTION

Testa perdepressa, auriformis, tenuissima, virescente-hyalina, superne sub-lente ruguloso-striata; spira plana, 2/5 longitudinis aequans; anfr. 2, fortissime accrescentibus, ultimus depressissimus; apertura maxima, fere 7/8 testae longitudinis efficiens, anstrorsum latior, margine columellari fortissime exciso usque ad apicem testae, ut infra conspecta spira tota cum vertice bene conspicua, margine superiore parum exciso, margine anteriore rotundato-subtruncato; limbus membranaceus jam ab anfractu penultimo fere ad marginem anteriorem prolongatus, medio latissimus et fere 1/2 baseos occupans. Long. 5-6, lat. 31/2-4, alt. 2mm.

TYPE LOCALITY. — *Hab. Galicia in M. Tatra, 900-2200' s.m., praecipue in regione alpina, sub lapidibus non rara.* English translation: Inhabits Galicia [historical and geographical region extending over what is today south-eastern Poland and western Ukraine] in the Tatra Mountains, 900-2200 m a.s.l., especially in the alpine region, not rare under the stones.

TYPE MATERIAL. — Unknown (Sysoev & Schileyko 2009).

MATERIAL EXAMINED. — **France** (new records) • 2 live adult specimens; Haut-Rhin, Stosswihr, Hirschsteinried; 48°4'12"N, 7°2'7"E; elevation 1050 m; 08.IX.2022; J.-M. Bichain; MHNEC (locality no. 01 on Fig. 1B) • 1 living juvenile specimen; Haut-Rhin, Stosswihr, Hirschsteinried; 48°04'12.8"N, 7°02'07.7"E; elevation 1050 m; 17.IX.2022; J.-M. Bichain; MHNEC (locality no. 01 on Fig. 1B) • 2 live adult specimens; Haut-Rhin, Stosswihr, Schluchtmatt; 48°3'35"N, 7°1'46"E; elevation 880 m; 29.IX.2022; J.-M. Bichain; MHNEC (locality no. 02 on Fig. 1B) • 1 live adult specimen; Haut-Rhin, Stosswihr, Rothried; 48°2'30"N, 7°1'38"E; elevation 895 m; 26.X.2022; J.-M. Bichain, A. Foltzer & L. Retz; MHNEC (locality no. 03 on Fig. 1B) • 3 live adult specimens; Haut-Rhin, Wildenstein, Pourri-Faing; 47°59'30"N, 6°56'45"E; elevation 1145 m; 31.X.2022; J.-M. Bichain & A. Stoffer; coll. JMB (locality no. 04 on Fig. 1B).

HABITATS AND SPECIES DIVERSITY

Among the 41 sampling sites, live individuals of *Hessemilimax kotulae* were found at four, three of which are located within the boundaries of the FM-NNR (Fig. 1B). The locality of



FIG. 2. — Sampling sites and specimens of *Hessemilimax kotulae* (Westerlund, 1883) from the High Vosges: **A**, locality no. 01: small stream in a mixed forest dominated by fir, Hirschsteinried, altitude 1050 m; **B**, locality no. 02: scree slope, Schluchtmatt, elevation 880 m; **C**, locality no. 03: Rothried, foot of avalanche slope, elevation 895 m; **D**, locality no. 04: Pourri-Faing, scree slope covered by beech, elevation 1145 m; **E**, live specimen of *H. kotulae* sampled at locality no. 01 (extended body length: 8.1 mm); **F**, live specimen of *H. kotulae* sampled at locality no. 02 (extended body length: 14.7 mm); **G**, shell of the specimen of *H. kotulae* illustrated in F (shell length: 4.7 mm, shell width: 3.3 mm); **H**, live specimen of *H. kotulae* sampled at locality no. 03 (extended body length: 15.9 mm); **I**, live specimen of *H. kotulae* sampled at locality no. 04 (extended body length: 12.1 mm).

Brugel (2014) (locality no. 06 on Fig. 1B) did not yield any live specimens nor empty shells of *H. kotulae* despite an intensive search for several hours. Also, we did not find *S. semilimax* at the locality indicated by Geissert (1996a) (locality no. 05 on Fig. 1B), although we did collect all other species listed by this author.

Hessemilimax kotulae was first collected (two adults and one juvenile, black mantle) in a small swampy area from a small stream in a mixed forest dominated by fir (locality no. 01 on Figs 1B; 2A, E). The species was also collected (two adults, variegated mantle) at the foot of a scree slope colonized by maple, in particular between moss-covered boulders with underflow (locality no. 02 on Figs 1B; 2B, F) and at the foot of an avalanche slope (1 adult, variegated mantle) among boulders covered by dense vegetation of nettles and *Lunaria* sp. (locality no. 03 on Figs 1B; 2C, H). Finally, the species was observed (three adults, black mantle) in a beech forest, with firs and maples on northeast-facing scree slopes (locality no. 04 on Figs 1B; 2D, I). This last habitat appears to be rather dry, without perennial surface water runoff. However, this scree slope has many small but deep interstitial spaces

that may provide cool and wet refuges for the species. In this habitat, we also found a live specimen of *Mediterranea depressa* (Sterki, 1880), a central European species that is also at the westernmost limit of its distribution in the Vosges (Bichain & Ryelandt 2021). All these localities at which *H. kotulae* were found are at an elevation between 863 m and 1145 m and are no more than 11 km apart from each other.

The 41 sampling sites yielded 47 gastropod species, including 27 species from the four sites where *H. kotulae* occurs, with: *Acanthinula aculeata* (O. F. Müller, 1774), *Aegopinella nitens* (Michaud, 1831), *Aegopinella pura* (Alder, 1830), *Arianta arbustorum* (Linnaeus, 1758), *Clausilia bidentata* (Strøm, 1765), *Cochlicopa lubrica* (O. F. Müller, 1774), *Cochlodina laminata* (Montagu, 1803), *Discus rotundatus* (O. F. Müller, 1774), *Edentiella edentula* (Draparnaud, 1805), *Eucoebresia diaphana* (Draparnaud, 1805), *Euconulus fulvus* (O. F. Müller, 1774), *Helicodonta obvoluta* (O. F. Müller, 1774), *Isognomostoma isognomostomos* (Schröter, 1784), *Lehmannia marginata* (O. F. Müller, 1774), *Limax cinereoniger* Wolf, 1803, *Macrogastra attenuata* (Rossmässler, 1835), *Macrogastra plicatula* (Draparnaud, 1801), *Malacolimax tenellus* (O. F. Müller, 1774), *Mediterranea*

ranea depressa (Sterki, 1880), *Monachoides incarnatus* (O. F. Müller, 1774), *Nesovitrea hammonis* (Ström, 1765), *Oxychilus alliarius* (J. S. Miller, 1822), *Oxychilus cellarius* (O. F. Müller, 1774), *Phenacolimax major* (A. Férussac, 1807), *Trochulus* cf. *sericeus* (Draparnaud, 1801), *Vitreola crystallina* (O. F. Müller, 1774), *Vitrina pellucida* (O. F. Müller, 1774). If we include the localities of Brugel (2014) and Geissert (1996a), with the hypothesis that this author's *Semilimax* corresponds in fact to *S. kotulae*, a total of 41 species could potentially occur in syntopy with *H. kotulae*.

Finally, the regional database (Bichain *et al.* 2021) records 79 species in the High Vosges above 600 m elevation (178 sampling sites with 1215 species occurrences, maximum elevation 1320 m, mean elevation 838 m, median 779 m). The data acquired in this study (41 sampling sites with 414 species occurrences, minimum elevation 573 m, maximum elevation 1221 m, mean elevation 926 m, median 940 m) cover 75% of the taxa recorded in the regional database above 800 m (62 spp.) and all taxa known above 1000 m (49 spp.) except for *Platyla polita* (W. Hartmann, 1840) and *Pupilla alpicola* (Charpentier, 1837).

DIAGNOSTIC CHARACTERS

Across the sampled sites, only nine live individuals of *Hessemilimax kotulae* were observed. According to the criteria given by Umiński (1975), eight specimens were identified as breeding individuals in mature stage II (Umiński 1975: fig. 14, Figs 2F, H, I; 3A) and one as a non-breeding individual in juvenile stage III (Umiński 1975: fig. 12, Figs 2E; 3B). The description of the reproductive system given below corresponds to the final stage of sexual maturity (mature stage II) *sensu* Umiński (1975) and Giusti *et al.* (2011: 336-339, figs 70-73).

Shell morphology and soft body tissue coloration

Shell vitriniform, thin and fragile, transparent, yellow-green, depressed with 1.7 to two whorls; last whorl extremely extended and constituting more than 60% of the overall shell length (Fig. 2G). Protoconch not prominent, smooth without spiral rows of small pits. Very wide aperture with columellar and basal margins bordered by a broad periostracal fringe; umbilicus widely open showing all whorl coils. Shell length of adults: 4-6 mm, shell width of adults: 3-4.5 mm.

Body unable to withdrawn completely into the shell; right mantle lobe long and rather narrow reaching the apex of the shell and covers, especially in juvenile specimens, a large part of the shell when the animal is undisturbed. Body color from black (Fig. 2E, I) to light gray, most often with dark spots giving a variegated pattern (Fig. 2F, H); live adult when extended reaches 15.9 mm (Fig. 2H).

Reproductive system (Fig. 3A, B)

Female distal part characterized by short, wide free oviduct; bursa copulatrix with short duct initially slightly flared. Male distal part with large, finger-shaped penial complex; penial gland covering most of the proximal penial complex; penial sheath enveloping almost the entire distal part of the penial complex. Penial retractor long, inserted apically near the

emergence of the vas deferens. Vas deferens long, crossing penial sheath, running along the surface of the free oviduct and entering its distal part before ovispermiduct. Internal structure of the penial complex consisting in two distinct pilasters (see Giusti *et al.* 2011: fig. 72). Main pilaster ending in a π -shaped papilla; smaller pilaster appearing next to the main pilaster and ending about halfway along its length.

Wide and long atrial-vaginal stimulator inserted on the opposite side of the penial complex. Basal part of the atrial-vaginal stimulator sac-shaped without external glandular coating. Apical part with a slender portion more or less invaginated into the basal part of the atrial-vaginal stimulator while the free sac-like part is covered with a spongy external glandular coating. Internal papilla of stimulator short to long, conical, pointed, open at tip, protruding into basal part of the atrial-vaginal stimulator (see Giusti *et al.* 2011: fig. 73).

REMARK

According to Umiński (1975), the juvenile stage III is achieved when individuals reach a shell diameter of 2.6-3.7 mm and genitalia length of 3.1-4.1 mm. Changes between the juvenile stage III and the mature stage I are mainly quantitative, with the increase in size of the different parts of the reproductive system. However, the emergence of glandular tissue covering the proximal part of the penial complex seems to determine the onset of the mature stage I. Based on these criteria, we assume that the specimen presented in Figures 2E and 3B is probably a juvenile stage III.

MORPHOLOGICAL AND ANATOMICAL DIFFERENCES FROM OTHER SYMPATRIC VITRINID SPECIES

Three other vitrinid species were sampled in sympatry or in syntopy with *H. kotulae*: *Eucobresia diaphana* (Fig. 4A), *Phenacolimax major* (Fig. 4B) and *Vitrina pellucida* (Fig. 4C). Anatomically, *H. kotulae* is easily distinguishable by the presence of an atrial-vaginal stimulator, by its flat and enlarged shell with only two whorls and an umbilicus widely open. In addition, the live animal often has a variegated mantle, an appearance absent in the other species. *Vitrina pellucida* has a much more globular shell with three whorls and a pale body. *Phenacolimax major* has a flatter shell than *V. pellucida* also with three whorls but a darker body. In these two species, the lobe of the mantle does not reach the apex of the shell (Fig. 4B, C) except when the animal is more or less stressed. *Eucobresia diaphana* has a flattened and elongated shell with 2.5 whorls but the last whorl is less developed than in *H. kotulae* and has a much less open umbilicus. The body can be light grey or entirely black but never with a variegated pattern like *H. kotulae*. Also, the lobe covering the apex is spatula-shaped and wider than in *H. kotulae*. However, some specimens in the field, particularly juveniles of *H. kotulae*, may be more difficult to differentiate from *E. diaphana* and require more careful observation or even examination of the genitalia.

Finally, all these species, except *H. kotulae* (Fig. 4D), present spiral rows of small pits on the apex (Fig. 4E, F, G), clearly visible under high magnification of about $\times 40-80$.

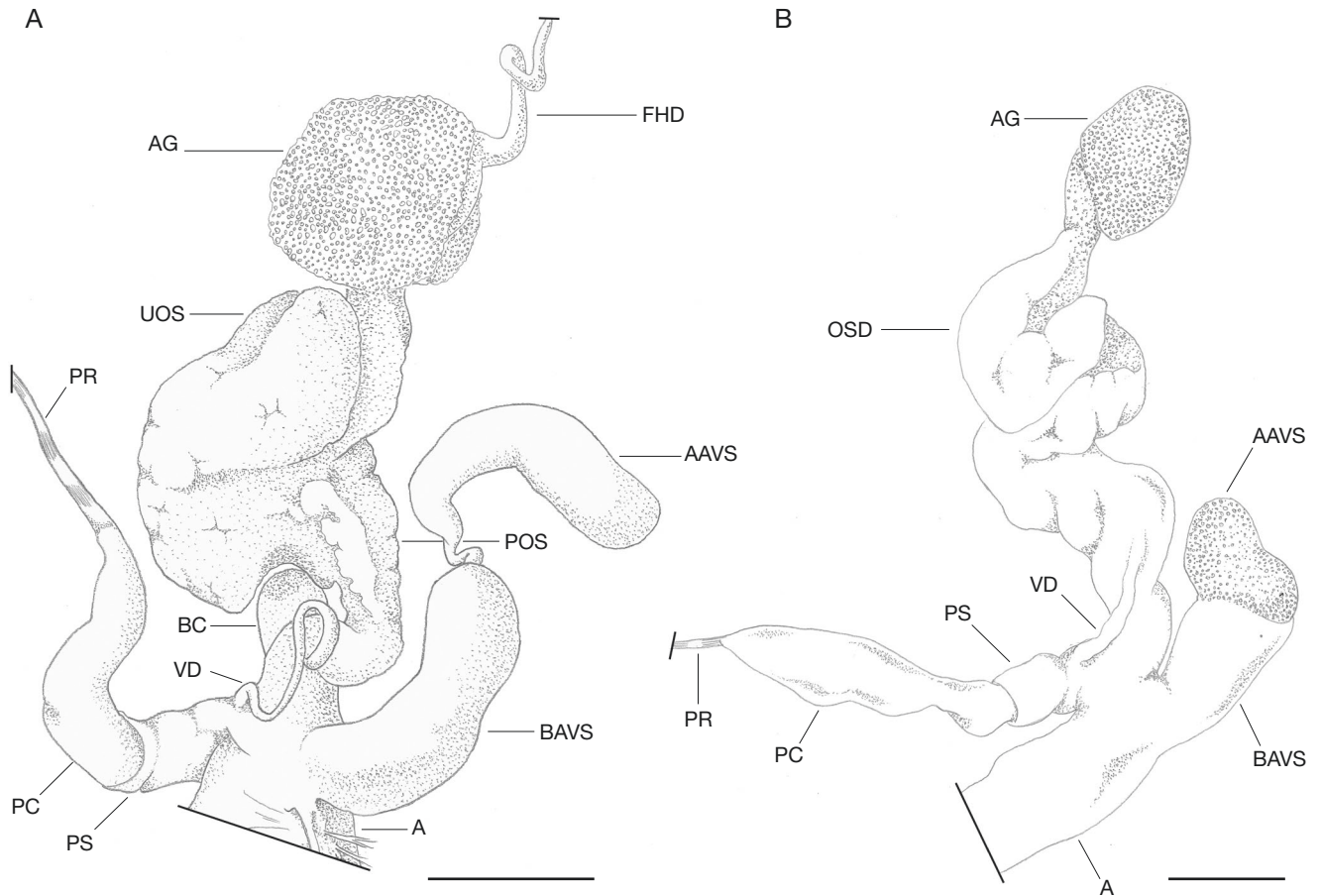


FIG. 3. — Reproductive system of two specimens of *Hessemilimax kotulae* (Westerlund, 1883) from the High Vosges: **A**, mature stage II (animal figured in Fig. 2F); **B**, juvenile stage III (animal figured in Fig. 2E). **Solid lines** indicate the parts cut during dissection. Abbreviations: see Material and methods. Scale bars: A, 1 mm; B, 0.5 mm.

PROPOSAL FOR NATIONAL AND REGIONAL IUCN STATUS

The mountain glass snail is currently listed in the French IUCN Red List (IUCN comité français, OFB & MNHN 2021) as Near Threatened [NT nr B1a]. However, we argue that the putative effects of global warming on this species (Müller *et al.* 2009; Bässler *et al.* 2010) allow application of option b (continuing decline) of criterion B (geographic range), which implies an estimated, inferred, or projected continuing decline in the: 1) extent of occurrence; 2) area of occupancy; 3) area, extent, and/or quality of habitat; 4) number of sites or subpopulations; and 5) number of mature individuals (IUCN 2022). Indeed, based on two climate warming scenarios (+1.8°C vs +4.0°C), the statistical models used by Müller *et al.* (2009) and Bässler *et al.* (2010) predict a considerable risk of extinction for *H. kotulae* within the Bavarian Forest National Park, a low mountain range in southeast Germany (elevations < 1430 m). Their results suggest that an increase in mean annual temperature of +1.8°C will lead to a decrease in the probability of occurrence of *H. kotulae* by about 70% at elevations of 1400 m and that the +4.0°C scenario would probably lead to regional extinction. Consequently, Bässler *et al.* (2010) speculated that the mountain glass snail is a species highly vulnerable to climate change throughout its geographic range, with a high risk of global extinction.

Currently, *H. kotulae* is formally documented from France only in the Vosges Mountains; its presence in the Massif Central is speculative and based on old data (Bouillet 1836; Van Bruggen 1957; Falkner *et al.* 2002: note 225). Recent field surveys (Sylvain Vrignaud, personal communication), especially in historical localities, have not confirmed its occurrence in the Massif Central. Therefore, for the national and regional IUCN assessment, we rely only on recent data (Brugel 2014 and this work). To minimize the effects of under-sampling, the maximum area of occurrence (EOO, B1 criterion) is estimated at a maximum of 3000 km² (< 20 000 km²), i.e., the total area of the central and southern Vosges mountains (Heuacker *et al.* 2015), including the High Vosges; the maximum area of occupancy (AOO, B2 criterion) is estimated at a maximum of about 883 km² (< 2000 km²), i.e., the total area above 800 m within the EOO. Strict application of the IUCN criteria (IUCN 2022) based on the number of recently-documented localities where the species occurs (i.e., five), as well as the high degree of fragmentation of suitable habitats (i.e., option a) would lead, with application of option b (see above), to the category Vulnerable [VU B1ab(i, ii, iii, iv, v) + 2ab(i, ii, iii, iv, v)] at the national scale.

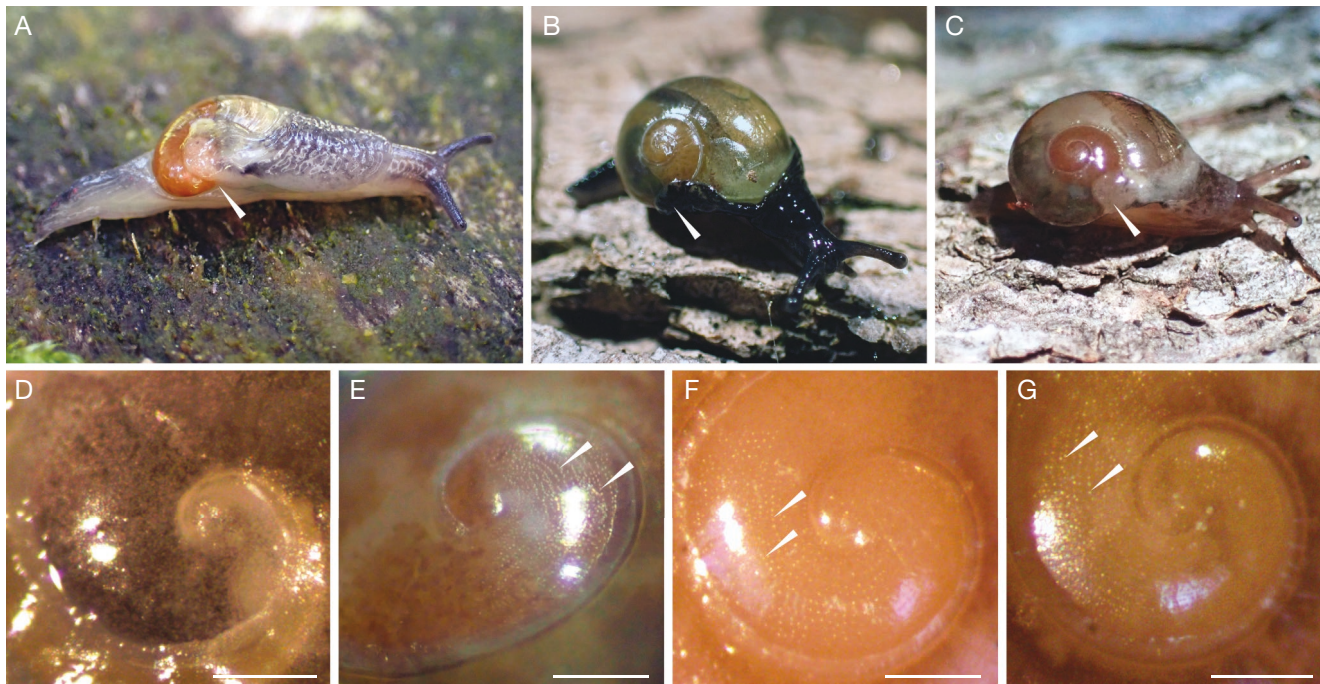


FIG. 4. — Vitrinid species occurring in syntopy with *Hessemilimax kotulae* (Westerlund, 1883) in the High Vosges and apex of the shells: **A**, *Euobresia diaphana* (Draparnaud, 1805) (extended body length: 14.6 mm), specimen sampled at locality no. 01; **B**, *Phenacolimax major* (A. Férussac, 1807) (extended body length: 9.6 mm), specimen sampled at locality no. 04; **C**, *Vitrina pellucida* (O. F. Müller, 1774) (extended body length: 9.3 mm), specimen sampled at locality no. 03; **D**, apex of the shell of *H. kotulae* (animal figured in Fig. 2I); **E**, apex of the shell of *E. diaphana* with spiral rows of small pits (animal figured in Fig. 4A); **F**, apex of the shell of *P. major* with spiral rows of small pits (animal figured in Fig. 4B); **G**, apex of the shell of *V. pellucida* with spiral rows of small pits (animal figured in Fig. 4C). Scale bar: 500 µm. In **A** to **C**, the **white arrows** indicate the folding of the mantle onto the shell. In **E**, **F** and **G** the **arrows** indicate the spirals of small pits.

DISCUSSION

We report here new records of *Hessemilimax kotulae* in various montane habitats in northeast France, in the High Vosges massif. In France, this species was until now formally documented by only a single occurrence in the extreme south of this mountain range (Brugel 2014). Our preliminary results, based on 41 sampling sites, indicate that the species occurs in the Vosges at elevations above 800 m, at the foot of or within scree slopes facing mainly north or northeast, or along streams in fir or mixed forests. These habitats correspond to cold places, more or less humid, but always with interstitial or subterranean environments (Bichain & Ryelandt 2021) that can function as refuges during periods of drought or extreme cold (Růžička *et al.* 2012; Rüetschi *et al.* 2012). Despite a significant sampling effort, a small number of live specimens (i.e., nine) were sampled at four localities, with a maximum of three individuals per locality. These localities, although not distant from each other, are separated by more or less dense and continuous dry forest habitats, or by areas of bare cliffs.

In addition to the under-sampling issue already discussed by Bichain & Ryelandt (2021), the difficulties of access to these isolated, rare, and scattered habitats of the montane region, as well as the low population density, probably explain why the species has not been documented until now in the High Vosges. Moreover, the Vosges are mainly formed of granitic rocks, a substrate not favourable to the long-term conserva-

tion of empty shells (Říhová *et al.* 2018), and, in particular, thin and fragile shells like those of vitrinids (Welter-Schultes 2012; Horsák *et al.* 2013). Adults and particularly juveniles of *H. kotulae* can also be confused, without careful examination of the shell or anatomy, with *Euobresia diaphana*, a common species at these elevations with often tens of individuals per square metre. Indeed, *Euobresia diaphana* exhibits large variation in mantle color ranging from light gray to deep black or more or less variegated, the latter two patterns being frequent in *H. kotulae*.

Therefore, low population density, highly specific habitat needs, quasi-absence of empty shells and misidentification make the species difficult to detect in the field. As an illustration, despite an intensive field search at Brugel's (2014) locality, the species was not found by us, while nearly 30 specimens of *Euobresia diaphana* were observed. Therefore, the question arises whether the pseudo-absence of *H. kotulae* at this locality is related to a very low population density or to its possible local extinction.

Our results also challenge the single occurrence of *Semilimax semilimax* in the Vosges by Geissert (1996a), which would be the only French locality for this species (Falkner *et al.* 2002). *Semilimax semilimax* is also present in the Black Forest (Baden-Württemberg, Germany). However, Geissert (1996a) did not preserve the specimen, collected near the Col des Bagenelles at an elevation of about 900 m (locality no. 05 on Figure 1B), nor give any illustration, description or diagnostic characters that he used to identify it. Since *H. kotulae* can have a com-

pletely black body color, it can therefore be confused at first sight with *S. semilimax*. Our own searches in this locality have so far failed to find either of these two species.

The populations of *H. kotulae* in the High Vosges represent the currently known westernmost populations of the species global range. Although the species occurs in the Swiss Valais (Turner *et al.* 1998; Falkner *et al.* 2002; Rüetschi *et al.* 2012), also a granitic area, this does not necessarily suggest that *H. kotulae* could also be present in the Alps and Jura on the French side of the border. Indeed, these two geographical regions are mainly limestone areas with completely different humidity regime and microclimate.

France therefore has a strong conservation responsibility for this species, which is also highly sensitive to climate change (Müller *et al.* 2009; Bässler *et al.* 2010). Although *H. kotulae* is currently classified as Near Threatened in the French Red List of non-marine molluscs, our application of IUCN criteria leads to the Vulnerable category. This seems more consistent with its categorisation in Germany (Jungbluth & Knorre 2011) and Switzerland (Rüetschi *et al.* 2012).

The good news is that *H. kotulae* is found in protected natural areas in the Vosges. This excludes habitat destruction due to land-use development, e.g. for recreational activities or mountain agriculture. The bad news is the difficulty for local authorities or managers of natural areas to counteract the effects of global warming. Indeed, the most optimistic scenarios predict a warming of +1.5°C to +1.8°C (scenarios SSP1-1.9 & SSP1-2.6) before mid-century (IPCC 2022), which would lead to a significant decline of *H. kotulae* throughout its range (Müller *et al.* 2009; Bässler *et al.* 2010) and its probable extinction in all low European mountain ranges under the most pessimistic scenario of +4°C (scenario SSP5-8.5).

The effects of global warming have a particular impact on species restricted to the highest elevations on the lower mountains (Parmesan 2006; Müller *et al.* 2009; Pearce & Paustian 2013; Sperle & Bruelheide 2021), primarily because: 1) the low maximum elevation limits opportunities for upward range movement to escape temperature increases; and 2) as available surface area decreases with elevation, any upward movement leads to a reduction and fragmentation of habitats, and thus a diminution of population size. Terrestrial gastropods are likely to react strongly to global warming (see for an overview Nicolai & Ansart 2017). Land snails have low dispersal ability and specific (micro-) habitat requirements mainly driven by climate and soil nature. Specifically, their low dispersal ability limits their opportunities to reach favorable habitats at higher elevations or in more northern areas. In addition, at higher elevations on lower mountains, the composition and richness of mollusc communities are also suspected to be altered by new arrivals, which could affect mountain specialist species through predation, competition, and the effects of parasites or disease vectors (Pearce & Paustian 2013).

Two other species, *Pupilla alpicola* (Charpentier, 1837) (Geissert 1963; Geissert 1996b) and *Discus ruderatus* (W. Hartmann, 1821) (Bichain *et al.* 2021), occur exclusively in the upper parts of the Vosges mountains, suggesting that their populations may also decline if global warming reduces their

ranges upwards. The WGI (Worldwide Governance Indicators) has estimated that the increase in global surface temperature is +1.09°C since 1850. Thus, it is very likely that global warming is already affecting populations of *H. kotulae* and other cold-adapted species. However, the lack of background data does not allow for an assessment of the current impact on these mollusc populations and communities. Future monitoring is therefore needed to better identify trends for this component of biodiversity, which is considered highly sensitive to global warming but also to other anthropogenic pressures that affect ecosystems (Cowie *et al.* 2017). Modeling approaches could provide a framework for predicting/identifying putative species extinction (Keith *et al.* 2008; Graham *et al.* 2011) or priority areas for conservation (see for example Moradi *et al.* 2019) in order to consider population translocations, also called assisted migration, to areas that would remain favorable at low or high elevations. This debate, regarding a highly interventionist conservation approach, deserves to be open up for molluscs, a taxonomic group for which translocation experiments/studies are poorly developed (Langridge *et al.* 2021).

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