Entomologica Austriaca

www.entomologie.org Band 34 Online first

Reconfirmation of the primeval forest relict *Rhysodes sulcatus* (Fabricius, 1787) in Austria: a second national record, accompanied by multiple other EU Habitats Directive listed beetle species, highlighting the conservation potential of extensively managed forests

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Abstract: Reconfirmation of the primeval forest relict *Rhysodes sulcatus* (Fabricius, 1787) in Austria: a second national record, accompanied by multiple other EU Habitats Directive listed beetle species, highlighting the conservation potential of extensively managed forests. *Rhysodes sulcatus* (Fabricius, 1787) is among the rarest saproxylic beetles in Europe and is regarded as a strict primeval forest relict species sensu Eckelt (2017). In Austria, it was previously known only from a single record from Carinthia dating from 1983. Here, the discovery of *R. sulcatus* in Lower Austria is reported, representing the second confirmed national record after more than four decades. The record originates from an extensively managed forest within the Natura 2000 site "Kamp- und Kremstal" (site codes AT1207A00 and AT1207000) and is accompanied by the occurrence of several additional saproxylic beetle species of high conservation concern, including primeval forest relicts and species listed in Annex II or Annexes II and IV of the EU Habitats Directive (e.g. *Lucanus cervus*, *Rosalia alpina*, *Cucujus cinnaberinus*, *Limoniscus violaceus* and *Osmoderma eremita* sensu lato). The co-occurrence of multiple highly specialized and ecologically diverse saproxylic beetles within a managed forest indicates long-term structural habitat continuity and exceptional habitat quality. The findings suggest that a carefully applied, extensive forest management retaining large-diameter deadwood, habitat trees and a spatial network of unmanaged old-growth forest patches can maintain the structural and ecological prerequisites required for the long-term persistence of some of Europe's rarest and most threatened saproxylic beetle species.

Kurzfassung: Wiederbestätigung des Urwaldrelikts *Rhysodes sulcatus* (Fabricius, 1787) in Österreich: Ein zweiter nationaler Nachweis, begleitet von zahlreichen weiteren in der EU-Habitatrichtlinie aufgeführten Käferarten, der das Erhaltungspotenzial extensiv bewirtschafteter Wälder unterstreicht. *Rhysodes sulcatus* (Fabricius, 1787) zählt zu den seltensten xylobionten Käferarten Europas und gilt als strikte Urwaldreliktart sensu Eckelt (2017). In Österreich war die Art bislang lediglich durch einen einzigen Nachweis aus Kärnten aus dem Jahr 1983 bekannt. In der vorliegenden Arbeit wird die Entdeckung von *R. sulcatus* in Niederösterreich dokumentiert und damit der zweite bestätigte Nachweis für Österreich nach mehr als vier Jahrzehnten erbracht. Der Fund erfolgte in einem extensiv bewirtschafteten Waldgebiet innerhalb des Natura-2000-Gebietes „Kamp- und Kremstal" (Gebietsnummern AT1207A00 und AT1207000) und steht im Zusammenhang mit dem gleichzeitigen Vorkommen mehrerer weiterer xylobionter Käferarten von hohem

naturschutzfachlichem Wert. Dazu zählen sowohl Urwaldreliktarten als auch Arten der Anhänge II bzw. II und IV der FFH-Richtlinie (z.B. *Lucanus cervus*, *Rosalia alpina*, *Cucujus cinnaberinus*, *Limoniscus violaceus* und *Osmoderma eremita* sensu lato). Das gemeinsame Auftreten mehrerer hochspezialisierter sowie ökologisch unterschiedlicher xylobionter Käferarten in einem Wirtschaftswald weist auf eine langfristige strukturelle Habitatkontinuität und eine außergewöhnlich hohe Lebensraumqualität hin. Die Ergebnisse deuten darauf hin, dass eine sorgfältig umgesetzte, extensive Waldbewirtschaftung, welche großdimensioniertes Totholz, Habitatbäume und ein räumlich vernetztes System von Altholzinseln erhält, die notwendigen strukturellen und ökologischen Voraussetzungen für den langfristigen Erhalt einiger der seltensten und am stärksten gefährdeten xylobionten Käferarten Europas bereitstellen kann.

Keywords: *Rhysodes sulcatus*, saproxylic coleoptera, Natura 2000, structural habitat continuity, forestry

Citation: Oswald M. 2026. Reconfirmation of the primeval forest relict *Rhysodes sulcatus* (Fabricius, 1787) in Austria: a second national record, accompanied by multiple other EU Habitats Directive listed beetle species, highlighting the conservation potential of extensively managed forests. – Entomologica Austriaca 34: Online first (07 May 2026).

Introduction

Saproxylic beetles constitute a key component of forest biodiversity and play a central role in wood decomposition processes, nutrient cycling and the maintenance of forest ecosystem functioning (Speight 1989, Schmidl & Bussler 2004, Thorn et al. 2020, Graf et al. 2022, Bergmark et al. 2024, Fierro et al. 2024, Henneberg 2025, Muinden & Ochieng 2025). Owing to their often highly specialised habitat requirements, many saproxylic species are particularly sensitive to forest management practices that reduce deadwood availability, structural heterogeneity and the spatial and temporal continuity of suitable habitats (Grove 2002, Paillet et al. 2010, Graf et al. 2022, Staab et al. 2023, Haeler et al. 2024, Hågvar & Ødegaard 2025, Mirea et al. 2024, Mitesser et al. 2025, Rothacher et al. 2025). Consequently, a substantial proportion of the Central European saproxylic beetle fauna is currently threatened, with some species being already, at least regionally, extinct or persisting only in the few remaining forest remnants characterised by long-term ecological continuity and a high degree of naturalness such as *Buprestis splendens* (a thermophile, sun-exposed pine deadwood specialist), *Lacon querceus* (a specialist of large decaying oak trunks) or *Boros schneideri* (a boreal, old-growth conifer bark specialist (Müller et al. 2005, Nieto & Alexander 2010, Horák et al. 2012, Eckelt et al. 2017, Jurc et al. 2022).

Within the saproxylic beetle fauna, primeval forest relict species sensu Eckelt et al. (2017) represent one of the most conservation-relevant components in Central Europe. These highly specialised taxa are characterised by narrow life-history requirements, with larval development often restricted to specific deadwood substrates, including large-diameter trunks, particular decay stages or distinct microhabitats such as cavities, fungal fruiting bodies or bark interfaces (Grove 2002, Stokland et al. 2012, Seibold et al. 2015). Many species exhibit prolonged larval development times and limited dispersal ability, rendering them highly dependent on the spatial and temporal continuity of suitable

substrates (Siitonen 2001, Ranius & Hedin 2001, Jonsson et al. 2005). In addition, saproxylic beetles encompass a wide range of trophic guilds, including xylophagous, mycetophagous, saprophagous, and predatory species, and thereby form complex interaction networks that drive wood decomposition processes, nutrient cycling, and the formation of secondary microhabitats for other organisms (Grove 2002, Stokland et al. 2012). Their strong association with large and over-mature trees and with dead wood of high quantity and quality reflects the dependence of many species on structurally complex and dynamically developing forest systems that are largely absent from intensively managed stands (Bauhus et al. 2009, Lassauce et al. 2011, Eckelt et al. 2017). Owing to these ecological constraints, many saproxylic beetles are particularly sensitive to even subtle disruptions in habitat continuity, such as the removal of veteran trees or interruptions in deadwood dynamics, which can lead to local extinctions and long-term declines (Siitonen 2001, Seibold et al. 2015). Consequently, the occurrence of primeval forest relict species reflects not only the presence of specific habitat elements, but the persistence of forest development processes over extended temporal scales, making them robust indicators of long-term ecological continuity, structural complexity, and the integrity of forest ecosystems (Schmidl & Bussler 2004, Müller et al. 2005, Eckelt et al. 2017).

Among saproxylic beetles of high conservation concern, species listed in Annex II or Annex II and IV of the EU Habitats Directive are of particular relevance, as their presence is legally binding for the designation and management of Natura 2000 sites. Such species are widely recognised as indicators of structurally rich forests with high amounts of large diameter deadwood, habitat trees and long-term habitat continuity (Schmidl & Bussler 2004, Müller et al. 2005, Bussler 2003, Eckelt et al. 2017). Assemblages comprising several of these species simultaneously are typically restricted to old-growth forests, nature reserves like national parks or long-established forest refugia and are usually highly fragmented or absent in managed forest landscapes (Zehetmair et al. 2015, Aurenhammer et al. 2019, Jacobsen et al. 2020, Jurc et al. 2022, Mirea et al. 2024, Popescu & Gostin 2025).

Within this context, *Rhysodes sulcatus* (Fabricius, 1787) (Coleoptera: Rhysodidae) is of particular interest, as it is among the rarest saproxylic beetles in Europe and is regarded as a strict primeval forest relict species sensu Eckelt et al. (2017). The species is also listed in Annex II of the EU Habitats Directive and the Bern Convention (Kostanjšek et al. 2018). Ecologically, *R. sulcatus* is highly specialised on large-diameter deadwood in advanced stages of decay with high moisture content and occurs on logs of both coniferous and broadleaved trees irrespective of species, although most records are from beech (*Fagus sylvatica*), silver fir (*Abies alba*), and spruce (*Picea abies*) (Kostanjšek et al. 2018). These substrates are typically colonised by slime moulds and wood decaying fungi, which are considered to serve as the primary food resource for both larvae and adults (Speight 1989, Kostanjšek et al. 2018, Bury et al. 2021). Due to its cryptic lifestyle, low dispersal capacity and the extreme rarity of suitable substrates, the species is scarcely detected even in apparently suitable habitats (Kostanjšek et al. 2018).

Across Europe, *R. sulcatus* is known from only a small number of recent records, many of which represent rediscoveries after decades without confirmed observations. Such

cases have been reported from Poland (Bury et al. 2021), Czechia (Mertlik 2011), France (Brustel & Gouix 2011), Bulgaria (Bekchiev et al. 2020), Italy (Di Santo & Biscaccianti 2014) and the western Balkans (Vrezec 2007, Šag et al. 2016) and represent mostly small, isolated relict populations with very few individuals detected.

In Austria, *R. sulcatus* was previously known only from a single historical record from Carinthia dating from 1983 (Schneider 1990). Despite targeted surveys in subsequent decades, including an extensive investigation in 2014, by a team of highly regarded Coleopteran experts, carried out in the framework of a provincial conservation project, the species could not be reconfirmed, despite apparent suitable habitats remaining in southern Austria (Ökoteam 2015).

Against this background, the present study documents the reconfirmation of *R. sulcatus* in Austria after more than four decades and reports the co-occurrence of several beetle species listed in Annex II or Annex II and IV of the EU Habitats Directive as well as primeval forest relict species sensu Eckelt et al. (2017) within the same forest estate. The findings are presented in the context of long-term forest continuity and are discussed in relation to the extensive, low-intensity forest management regime applied in the study area.

Methods

Study site

Field surveys were conducted in the Kamp valley ("Kamptal"), cadastral municipality of St. Leonhard am Hornerwald, Lower Austria, Austria. The study area is situated within the Natura 2000 site "Kamp- und Kremstal" and comprises forest stands belonging to the forest estate "Forstbetrieb Hornerwald – Rudolf Hoyos", covering a total area of 351.05 ha (Fig. 1).

The study area is situated south of the Kamp river and is characterised by a strongly dissected terrain with steep slopes descending towards the river, rocky hilltops, and narrow tributary valleys. Altitude ranges from approximately 350 m (Kamp river) to 608 m a.s.l. (Dürrenberg). This pronounced topographic heterogeneity results in a high diversity of habitat types and forest site conditions at small spatial scale.

As part of a recent habitat mapping, 235.07 ha of the forest estate were assigned to habitat types of the EU Habitats Directive (LACON Landschaftsplanung GmbH 2025). The largest proportion is formed by habitat type 9130 "Asperulo-Fagetum beech forests", covering 149.08 ha. Approximately one sixth of the forest area is occupied by habitat type 9170 "Galio sylvatici-Carpinetum oak-hornbeam forests" (39.78 ha) and habitat type 9180* "Tilio-Acerion ravine and slope forests" (38.70 ha). Only small areas are represented by habitat type 9110 "Luzulo-Fagetum beech forests" on dry, shallow soils (3.81 ha) and habitat type 91E0* "Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*" (2.94 ha). Non-forest habitat types (6190 "Pannonic open grasslands" and 8220 "Siliceous rocky slopes with chasmophytic vegetation") together account for only 0.76 ha (Fig. 2.)

The conservation status of the mapped forest habitat types follows the Natura 2000 conservation status categories (A, B, C) and is based on the habitat mapping conducted

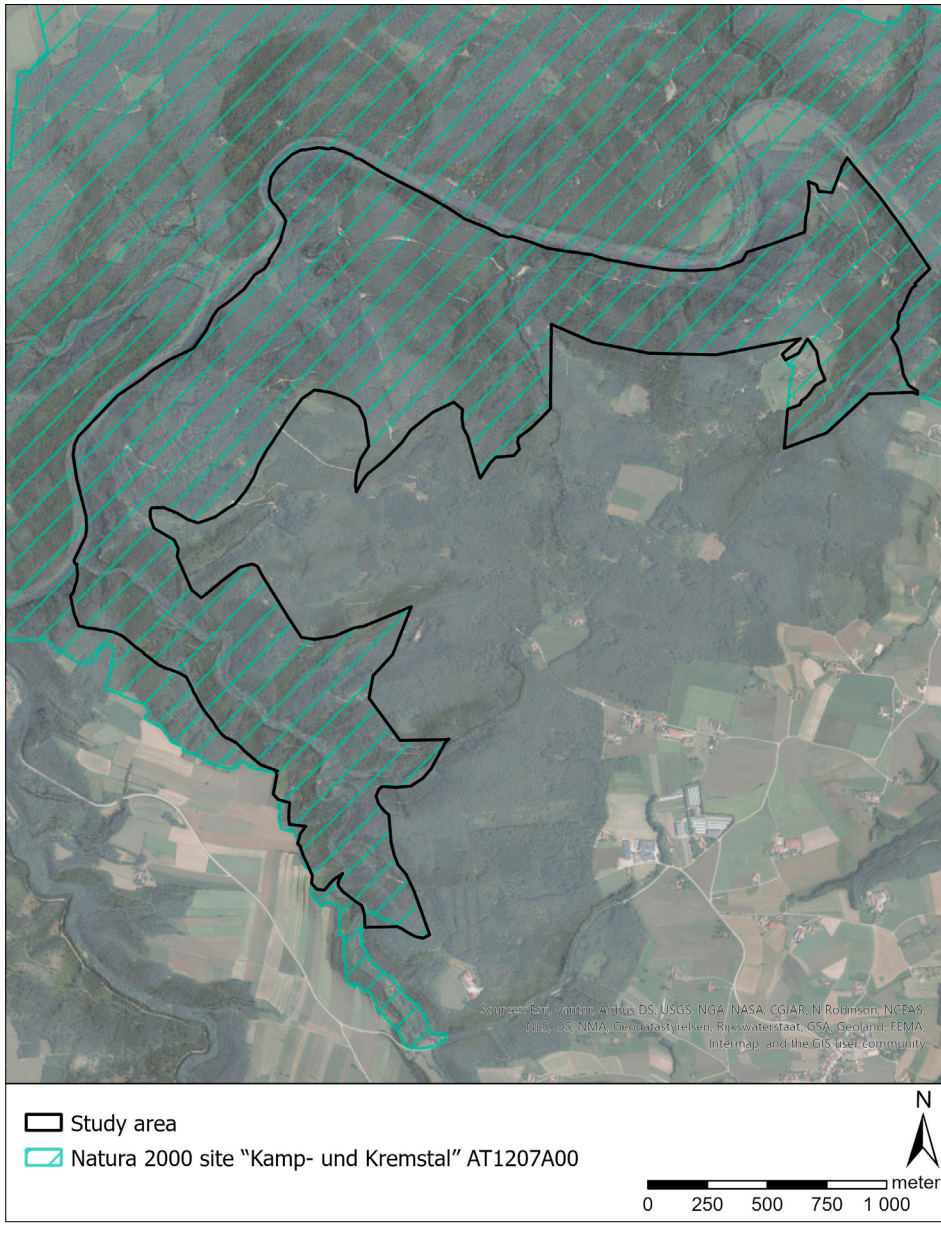

Fig. 1: Location of the study area within the Natura 2000 site "Kamp- und Kremstal" in Lower Austria. The black outline indicates the forest estate managed by the "Forstbetrieb Hornerwald – Rudolf Hoyos" within the blue, hatched areas representing the Natura 2000 site.

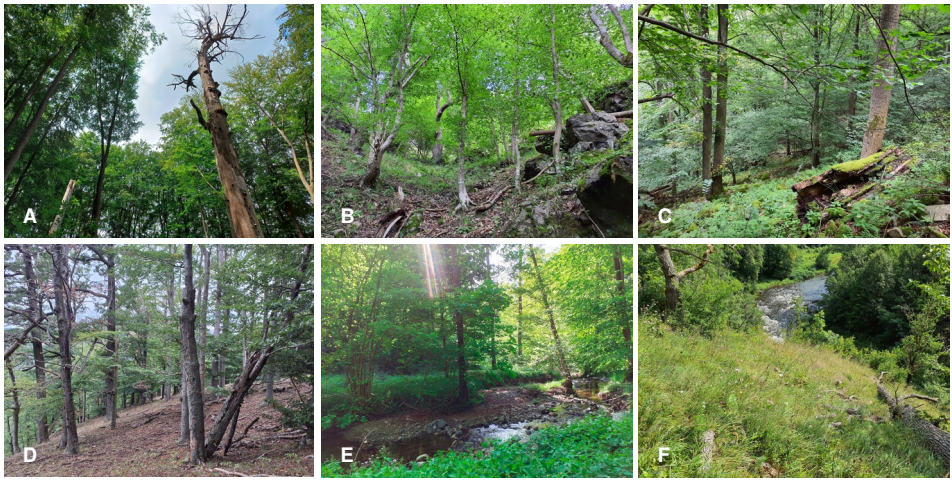

Fig. 2: Representative habitat types within the study area. **A:** 9130 "Asperulo-Fagetum beech forests", with old trees and standing deadwood. **B:** 9170 "Galio sylvatici-Carpinetum oak–hornbeam forest" on rocky slopes. **C:** 9180* "Tilio-Acerion ravine and slope forest", often accompanied by high amounts of deadwood. **D:** 9110 "Luzulo-Fagetum beech forest" on dry, shallow soils. **E:** 91E0* "Alluvial forest with *Alnus glutinosa* and Fraxinus excelsior" along a stream. **F:** Non-forest habitat type 6190 "Pannonic open grasslands". © Mario Oswald.

by LACON Landschaftsplanung GmbH (2025), applying criteria adapted from the Austrian habitat assessment framework for these habitat types (Ellmauer 2004). Overall, the conservation status of the mapped forest habitat types is predominantly high. Of the 235.07 ha of forest habitat types, 48.21 % (113.02 ha) are assessed as being in excellent conservation status (A), while 41.49 % (97.26 ha) are in good condition (B). Only 10.29 % (24.13 ha) are classified as having a moderate to poor conservation status falling into category C (LACON Landschaftsplanung GmbH 2025).

This favourable condition is attributed to the long-established, extensive forest management regime by the forest estate. In the context of this study, extensive forest management refers to a low-intensity, close-to-nature silvicultural approach that combines active forest use with long-term structural continuity. It is characterised by natural regeneration, selective harvesting in small-scale units (< 0,5 ha) instead of large clear-cuts, retention of overstory trees, long rotation periods, the systematic retention of large-diameter standing and lying deadwood as well as the designation and promotion of habitat trees, and the deliberate integration of several unmanaged old-growth forest patches ("Altholzinseln"). This management approach does not imply the absence of forest use, but rather a silvicultural system continuously adapted to site-specific conditions and ecological feedback over extended time periods.

Sampling design and methods

The primary focus of the survey was on (saproxylic) beetle species listed in Annex II or Annexes II and IV of the EU FaunaFlora-Habitat (FFH) Directive

(Rat der Europäischen Union 1992, 2013) occurring in the study area. Additional beetle species were recorded opportunistically to allow a broader ecological interpretation of the habitat quality and conservation relevance of the study area.

Field surveys were conducted between July 2024 and May 2025 on a total of 15 survey days, covering different seasonal aspects relevant to the targeted beetle species (Tab. 1). Rather than evenly distributing survey effort across the entire forest estate, the study area was first screened for clustered structural key elements and areas known to be essential for saproxylic beetles. These included concentrations of old, large-dimensioned habitat trees, substantial dead wood and microhabitats like tree cavities characterized by stable moisture and advanced stages of wood decay. Based on the initial results, detailed surveys focused in particular on two central study areas that have already been designated by the forestry administration as unmanaged "Altholzinseln". In addition, several individual trees and deadwood structures were also investigated throughout the study area. Exact locations and coordinates are not disclosed to protect sensitive saproxylic species. Habitat characteristics and sampling design are, however, described in sufficient detail to ensure reproducibility.

Tab. 1: Overview of field survey periods, primary target beetle species and applied sampling methods.

Date	Weather conditions	Primary target species	Sampling method
03 July 2024	Sunny to partly cloudy, max. 21 °C, light breeze	*Lucanus cervus, Rosalia alpina, Osmoderma eremita* s. l., *Cerambyx cerdo*	Habitat tree localization and inspection, diurnal beetle survey
15–18 July 2024	Sunny, max. 31 °C, light wind	*L. cervus*, *R. alpina*, *O. eremita* s. l., *L. violaceus*, *C. cerdo*	Habitat tree localization and inspection, diurnal and nocturnal beetle surveys
26 September 2024	Cloudy, max. 19 °C, light breeze	*L. violaceus*, *C. cinnaberinus*	Habitat tree localization and inspection, diurnal beetle/larvae surveys
27 September 2024	Cloudy with drizzle, max. 18 °C, light breeze	*L. violaceus*, *C. cinnaberinus*	Installation of non-invasive bait cups
24–27 October 2024	Sunny to partly cloudy, max. 16 °C, light wind	*L. violaceus*, *C. cinnaberinus*	Inspection and emptying of non-invasive bait cups
02 April 2025	Cloudy, 14 °C, moderate wind	*O. eremita* s. l., *L. violaceus*, *C. cinnaberinus*	Habitat tree localization and inspection, installation of non-invasive bait cups
17 April 2025	Sunny to partly cloudy, max. 24 °C, light wind	*O. eremita* s. l., *L. violaceus*, *C. cinnaberinus*	Inspection and emptying of non-invasive bait cups, diurnal beetle surveys
12–14 May 2025	Sunny to partly cloudy, max. 22 °C, light wind	*O. eremita* s. l., *L. violaceus*, *C. cinnaberinus*	Installation of non-invasive bait cups, diurnal and nocturnal beetle surveys
28 May 2025	Sunny to partly cloudy, max. 19 °C, light breeze	*O. eremita* s. l., *L. violaceus*, *C. cinnaberinus*	Inspection and emptying of non-invasive bait cups, diurnal beetle surveys

Surveys were carried out, where possible, under favourable weather conditions (warm, above 20 °C, low wind speeds, sunny) both during the day and in the evening. Not only adult beetle individuals were observed and recorded, but also larvae, elytra, frass, emergence holes and other indicators of current or past colonisation. In addition, freshly harvested logs temporarily stored along forest roads were examined for approaching or active beetles.

For the targeted investigation of deadwood structures, established and as non-invasive as possible methods were used, such as lifting loose bark, carefully opening only small sections of the decayed wood structures including carefully separating individual wood layers with a stainless-steel spatula. Dead remains, such as elytra or frass, were identified in the field if possible or otherwise collected and retained for later taxonomic identification. Live individuals and larvae were not collected, with the exception of one adult individual of *R. sulcatus*.

Accessible and reachable wood mould cavities were specifically examined for the presence of larvae and adult beetles, with particular emphasis on the hermit beetle *Osmoderma eremita* sensu lato. For this purpose, the wood mould material was carefully removed by hand, examined in a tray (50 × 35 cm) for larvae, pupae, frass and remains, and subsequently returned layer by layer to the respective tree cavity.

Current evidence suggests that *O. eremita* sensu lato represents a complex of several closely related European taxa. Based on molecular and morphological data, at least four forms (*O. eremita* sensu stricto, *Osmoderma barnabita*, *Osmoderma cristinae* and *Osmoderma lassallei*) are distinguished and treated as species by various authors (Audisio et al. 2007, 2009, Maurizi et al. 2017). In eastern Austria, populations are assigned to the taxon *O. barnabita* Motschulsky, 1845, a classification supported by male genital morphology (Straka 2017). However, as taxonomic delimitation and nomenclature are still under discussion, Austrian conservation practice continues to apply the name *O. eremita* s. l. (Friess et al. 2020, Straka 2021), which is also followed here.

For the targeted survey of the violet click beetle (*Limoniscus violaceus*), non-invasive bait cups were used (after Straka 2015). These consisted of perforated plastic flower pots (diameter 9 or 12 cm) filled with dry cat food as an attractant and wood mould from the sampled cavity. The containers were placed in suitable tree cavities, buried, and checked after approximately two weeks. The larvae can leave the cups independently at any time, thereby avoiding an invasive impact on the population.

The first sampling using bait cups was carried out from 27 September to 27 October 2024 with three traps in tree cavities and decaying tree stumps (2 × sessile oak, 1 × European beech) considered potentially suitable habitat for the target species within the study area. The second sampling took place from 2 to 17 April 2025 with 14 traps (12 × European beech, 1 × sessile oak, 1 × small-leaved lime). The third and final sampling was conducted from 14 to 28 May 2025 with nine traps (3 × European beech, 6 × sessile oak).

In order to ensure monitoring that was as non-invasive as possible, classical invasive killing traps such as flight-interception traps, Malaise traps, pheromone traps or other attractant traps were deliberately avoided. Although these methods can capture a broad

or specific spectrum of species with relatively little effort, they have the disadvantage of inevitably causing the death of individuals and disturbing populations. Given the confirmed presence of rare, endangered and strictly protected species, this aspect was given the highest priority.

Conservation assessment and ecological classification

As no up-to-date national Red List for beetles is currently available for Austria, conservation status was assessed using the Red List of the Czech Republic (Hejda et al. 2017). Species were further classified as indicator species or primeval forest relict species following Schmidl & Bussler (2004), Müller et al. (2005) and Eckelt et al. (2017).

Primeval forest relict species Eckelt et al. (2017) are defined as highly specialised saproxylic beetles with strict requirements regarding deadwood quantity, quality and continuity, as well as stable microclimatic conditions. Species assigned to category 1 are confined to old-growth forests and forest remnants that have continuously retained primeval habitat features, such as large and old living trees, high volumes of large-diameter deadwood and a wide range of decomposition stages. Having largely disappeared from managed forests across Europe, these taxa are regarded as strict primeval forest relict species sensu stricto, reflecting an exceptional dependence on uninterrupted habitat continuity. Species classified as category 2 also meet the criteria of primeval forest relict species but may occur in production forests where their specific habitat requirements are met. Unlike category 1 species, category 2 primeval forest relict species sensu lato are therefore not restricted to natural forest remnants but may persist in extensively managed forests where their specific habitat features are maintained over time (Eckelt et al. 2017).

Results

During the field surveys, all five saproxylic beetle species previously reported from the study area (Straka 2022) and listed in Annex II or Annexes II and IV of the Habitats Directive were confirmed:

- *Lucanus cervus* (Linnaeus, 1758) (Lucanidae), Annex II
- *Rosalia alpina* (Linnaeus, 1758) (Cerambycidae), Annexes II & IV
- *Cucujus cinnaberinus* (Scopoli, 1763) (Cucujidae), Annexes II & IV
- *Limoniscus violaceus* (Müller, 1821) (Elateridae), Annex II
- *Osmoderma eremita* s. l. (Scopoli, 1763) (Scarabaeidae), Annexes II & IV

In addition, one further saproxylic beetle species listed in Annex II of the Habitats Directive was recorded:

- *Rhysodes sulcatus* (Fabricius, 1787) (Rhysodidae), Annex II

Beyond the Annex II species, 16 additional saproxylic beetle species were recorded as incidental findings during the surveys. In total, 22 beetle species were documented within the study area (Tab. 2, Fig. 3).

Fig. 3: Selected beetle species of conservation concern recorded in the study area. **A:** *Lucanus cervus* (imago), **B:** *Rosalia alpina* (imago), **C:** *Cucujus cinnaberinus* (larva), **D:** *Limoniscus violaceus* (larva), **E:** *Osmoderma eremita* s. l. (larva), **F:** *Gnorimus variabilis* (imago), **G:** *Prostomis mandibularis* (imagines), **H:** *Prostomis mandibularis* (larva). © Mario Oswald.

Tab. 2: Recorded beetle species, substrate and host tree within the study area, their conservation status, indicator value, classification as primeval forest relict species and listing in the EU Habitats Directive. In the absence of up-to-date national or federal Red Lists for Austria, conservation status is assessed according to the Red List of the Czech Republic (Hejda et al. 2017). CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened. Indicator species and forest-ecologically particularly relevant species sensu Schmidl & Bussler (2004) are marked with "!". Primeval forest relict species sensu Eckelt et al. (2017): species of category 1 (1) are currently restricted to very few remnants of natural forests, whereas species of category 2 (2) fulfil the same criteria but may also occur in managed forests if their specific habitat requirements are met. Habitats Directive species (Annex): species listed in Annex II and/or Annex IV. Species listed under the Habitats Directive and/or classified as primeval forest relict species sensu Eckelt et al. (2017) are highlighted in green.

Scientific name	Recorded substrate and host tree	RL Czech Republic (Hejda et al. 2017)	Indicator species (Schmidl & Bussler 2004)	Primeval forest relict species (Eckelt et al. 2017)	Annex
Ampedus nigerrimus (Herbst, 1784)	Tree cavities with wood mould of *Quercus petraea* and *Fagus sylvatica*	EN	!	-	-
Anoplotrupes stercorosus (Scriba, 1791)	On the ground, various forest types	-	-	-	-
Cerambyx scopolii Fuessly, 1775	Dry, standing deadwood of *F. sylvatica*	-	-	-	-
Cucujus cinnaberinus (Scopoli, 1763)	Under bark of lying dead *Tilia* sp.	VU	!	-	II, IV
Denticollis rubens (Piller & Mitterpacher, 1783)	Large-diameter lying deadwood of *F. sylvatica*	VU	!	-	-
Dorcus parallelipipedus (Linnaeus, 1758)	Large-diameter lying deadwood of *F. sylvatica*	-	-	-	-
Endomychus coccineus (Linnaeus, 1758)	Lying deadwood of *F. sylvatica*	VU	-	-	-
Gnorimus nobilis (Linnaeus, 1758)	Tree cavities with wood mould of *Q. petraea*	VU	!	-	-
Gnorimus variabilis (Linnaeus, 1758)	Tree cavities with wood mould in *Q. petraea* and *Q. robur*, rarely *F. sylvatica*	VU	!	2	-
Ischnodes sanguinicollis (Panzer, 1793)	Tree cavities with ground contact and wood mould in *Q. petraea* and *F. sylvatica*	CR	!	2	-
Limoniscus violaceus (Müller, 1821)	Tree cavities and large decaying stumps of *F. sylvatica* with abundant moist wood mould	CR	!	1	II

Scientific name	Recorded substrate and host tree	RL Czech Republic (Hejda et al. 2017)	Indicator species (Schmidl & Bussler 2004)	Primeval forest relict species (Eckelt et al. 2017)	Annex
Lucanus cervus Linnaeus, 1758	On the ground in open *Q. petraea* stands	VU	-	-	II
Notiophilus rufipes Curtis, 1829	On the ground in open *Q. petraea* stands	-	-	-	-
Osmoderma barnabita Motschulsky, 1845 / *O. eremita* s. l. (Scopoli, 1763)	Tree cavities with abundant wood mould in *Q. petraea* and *Q. robur*	VU / -	!	2	II, IV
Prionus coriarius (Linnaeus, 1758)	On the trunk of *F. sylvatica*	-	-	-	-
Prostomis mandibularis (Fabricius, 1801)	Moist, decayed lying trunk of *Picea abies*	EN	!	2	
Pyrochroa coccinea (Linnaeus, 1761)	Under bark and on trunks of *Fraxinus excelsior*	-	-	-	-
Rhysodes sulcatus (Fabricius, 1787)	Moist, large-diameter lying trunk of *F. sylvatica*	CR	(not listed)	1	II
Rosalia alpina (Linnaeus, 1758)	Dry, standing or logged deadwood of *F. sylvatica*	EN	!	2	II, IV
Schizotus pectinicornis (Linnaeus, 1758)	Under bark of *Tilia* sp. and *F. excelsior*	-	-	-	-
Stenomax aeneus (Scopoli, 1763)	Standing and lying deadwood of *F. sylvatica*	-	-	-	-
Uloma culinaris (Linnaeus, 1758)	Moist, large-diameter lying trunk of *F. sylvatica*	NT	!	-	-
Total number of species	22				

Record of *R. sulcatus*

A single adult specimen of *R. sulcatus* (Fig. 4A) was detected on 14 May, 2025 during an opportunistic inspection of coarse woody debris conducted in the course of the Habitats directive listed beetle surveys. The specimen was found within a lying trunk of European beech (*Fagus sylvatica*) with a diameter of approximately 80 cm (Fig. 4B, Fig. 4C).

The trunk represented a retained deadwood element within an economically managed forest stand, dominated by European beech (*Fagus sylvatica*) and belonging to forestry age class 4 (intermediate-aged stand, 60–80-year-old trees). The deadwood element was in a fully shaded position on a small hilltop and consisted of strongly decomposed wood

Fig. 4: A: Live imago of *Rhysodes sulcatus* (Fabricius, 1787) photographed at the site of discovery on 14 May 2025. **B:** Side view of the decaying, fallen beech trunk (*Fagus sylvatica*, approx. 80 cm diameter) in which *Rhysodes. sulcatus* was recorded. **C:** Lying trunk of European beech (*Fagus sylvatica*, approx. 80 cm diameter) in which *Rhysodes sulcatus* was recorded. The trunk represents a retained deadwood element within an economically managed, intermediate-aged forest stand (forestry age class 4: 60–80-year-old trees) and shows advanced decay with moist, white-rotted wood. © Mario Oswald.

in an advanced stage of decay. The wood was permanently moist, showed pronounced fibrous disintegration and was affected by white rot. The beetle was located between already highly decayed wood layers and was exposed by carefully separating the wood using a stainless-steel spatula. The specimen was collected for taxonomic confirmation and deposited in the collection of the technical consultancy LACON ("LACON Landschaftsplanung GmbH - Ingenieurbüro für Landschaftsplanung – Consulting") in Vienna.

No further individuals of *R. sulcatus* were detected during a targeted follow-up inspection of the same deadwood substrate on 28 May, 2025.

Two additional saproxylic beetle species were recorded along *R. sulcatus* from the same deadwood structure: *Denticollis rubens* (Piller & Mitterpacher, 1783) and *Uloma culinaris* (Linnaeus, 1758).

Conservation status

- Due to the lack of an up-to-date national Red List for beetles in Austria, the conservation status of the recorded species was assessed based on the Red List of the Czech Republic (Hejda et al. 2017). According to this reference, the following four threat categories apply to the species recorded in the study area:
- one species classified as Near Threatened (NT),
- seven species classified as Vulnerable (VU),
- three species classified as Endangered (EN),
- three species classified as Critically Endangered (CR).

Primeval forest relict species and indicator species

Based on the definition proposed by Eckelt et al. (2017), seven of the recorded beetle species qualify as primeval forest relict species.

Among these, two species belong to the most demanding **category 1 (sensu stricto):**

- *Limoniscus violaceus* (Müller, 1821) (Elateridae)
- *Rhysodes sulcatus* (Fabricius, 1787) (Rhysodidae)

Five further species recorded in the study area are assigned to **category 2 (sensu lato):**

- *Gnorimus variabilis* (Linnaeus, 1758) (Scarabaeidae)
- *Ischnodes sanguinicollis* (Panzer, 1793) (Elateridae)
- *Osmoderma eremita* s. l. (Scopoli, 1763) (Scarabaeidae)
- *Prostomis mandibularis* (Fabricius, 1801) (Prostomidae)
- *Rosalia alpina* (Linnaeus, 1758) (Cerambycidae)

In addition, 11 of the recorded species fulfil the criteria of indicator species sensu Schmidl & Bussler (2004) and are considered of particular relevance for forest ecosystems due to their narrow ecological requirements and sensitivity to structural changes.

Discussion

The results of the present study demonstrate the outstanding conservation value of the investigated forest area in the Kamp valley ("Kamptal"), particularly regarding nationally rare and highly specialised saproxylic beetles. Although the surveys were temporally and methodologically restricted and deliberately focused on species listed in the EU Habitats Directive, an exceptionally high proportion of threatened, strictly protected and indicator species was recorded. The co-occurrence of the listed species *R. alpina*, *O. eremita* s. l., *L. cervus*, *C. cinnaberinus*, *L. violaceus* and *R. sulcatus* already constitutes an exceptional assemblage that can only be sustained in highly diverse forest sites characterised by long term structural continuity, advanced deadwood development and stable microclimatic conditions (Müller et al. 2005, Eckelt et al. 2017, Bussler 2003, Aurenhammer et al. 2019). Given that the present survey was not designed to comprehensively assess overall

beetle diversity, but rather focused on species listed in the EU Habitats Directive, the results represent only a fraction of the site's full saproxylic biodiversity community (Fig. 5).

The finding of *R. sulcatus* represents the second published record of *R. sulcatus* for Austria, more than four decades after the first and previously only national record from Carinthia in 1983 (Schneider, 1990). This follows a pattern repeatedly observed across Europe, where the species was considered extinct or missing for decades at national or regional scales before being rediscovered at single or very few sites (Brustel & Gouix 2011, Bekchiev et al. 2020, Bury et al. 2021, Mazzei et al. 2019). The habitat conditions at the study site closely match those described throughout the species' European range. Numerous studies emphasise the strict association of *R. sulcatus* with large-diameter deadwood in advanced stages of decay, characterised by high moisture content, slime mould and fungal colonisation and stable microclimatic conditions (Burakowski 1975, Kostanjšek et al. 2018, Bury et al. 2021, Konvička & Čížek 2015). The specimen documented here was found in a massive, heavily decomposed beech trunk with pronounced white rot and permanently moist, fibrous wood structure, fully corresponding to the habitat preferences identified by Kostanjšek et al. (2018), who demonstrated a strong preference for lying deadwood exceeding 60 cm in diameter. Similar substrate characteristics have been reported from Poland, Bulgaria, Italy, France and the Czech Republic (Brustel & Gouix 2011, Bekchiev et al. 2020, Mazzei et al. 2019, Bury et al. 2021), indicating a high degree of ecological consistency across the species' fragmented range. The extreme rarity of *R. sulcatus*, combined with its cryptic and predominantly nocturnal lifestyle, suggests that populations may persist in areas undetected provided that suitable microhabitats remain continuously available (Bekchiev et al. 2020; Bury et al. 2021). Given the species' very limited dispersal capacity (Mazzei et al. 2019) and pronounced dependence on habitat continuity (Kostanjšek et al. 2018, Bury et al. 2021), the present record is best interpreted as evidence of long-term local persistence that has remained undetected so far, rather than recent colonisation, thereby underlining the conservation significance of the study area.

The co-occurrence of *R. sulcatus* with other specialised saproxylic beetles, particularly *L. violaceus*, further strengthens the interpretation of the Kamp valley as a functional refugium for primeval forest relict species. Assemblages comprising multiple primeval forest relict species are widely regarded as reliable indicators of long-term habitat continuity and quality as well as historically uninterrupted forest cover (Müller et al. 2005, Schmidl & Bussler 2004, Eckelt et al. 2017). The comparatively high proportion of primeval forest relict species relative to the total number of recorded beetles supports earlier assessments of the area's exceptional conservation value (Straka 2022) and places the Kamp valley among a small number of studied near-natural, old-growth forest refugia in Central Europe that have maintained long-term ecological continuity and a diverse, highly specialised saproxylic community (Bussler 2003; Aurenhammer et al. 2019; Popescu & Gostin 2025).

Particularly noteworthy is the fact that the most demanding primeval forest relict species recorded, *R. sulcatus* and *L. violaceus* (category 1 sensu Eckelt et al. 2017), were not confined to unmanaged, deadwood-rich old-growth forest patches ("Altholzinseln"),

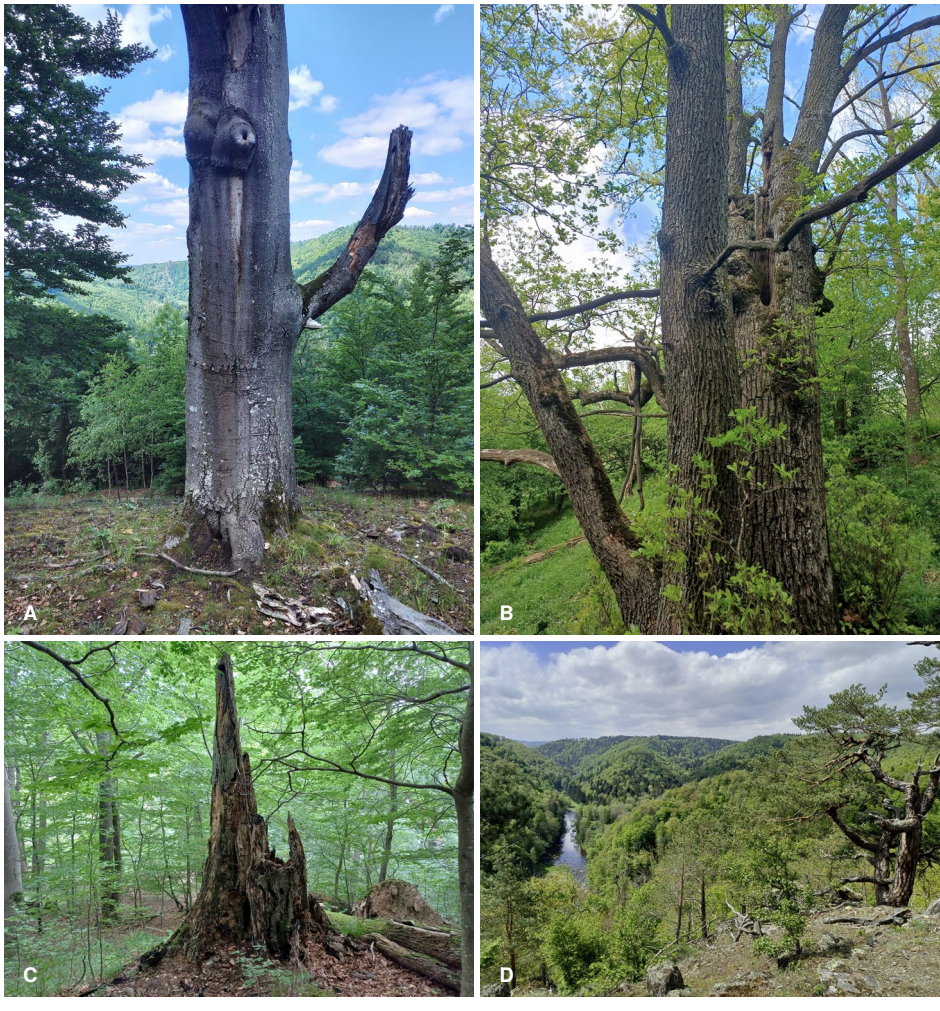

Fig. 5: Representative habitats relevant for the recorded saproxylic beetles, including, **A:** standing large-diameter deadwood, **B:** old habitat trees with large cavities, **C:** large decaying stumps, and **D:** all embedded in a heterogeneous, diversely and extensively managed forest landscape with spatially distributed old-growth patches in the Kamp valley ("Kamptal"). © Mario Oswald.

but were instead detected in retained deadwood elements within economically managed forest stands (forestry age class 4 = 60- to 80-year-old trees). According to the conceptual framework proposed by Eckelt et al. (2017), species of this category are typically restricted to relict old-growth or natural forest remnants. However, similar observations have been reported from other regions, where other strict primeval forest species occurred in managed forests under specific conditions, namely where large-dimension deadwood, habitat trees and unmanaged refugial patches were maintained over long time periods (Aurenhammer et al. 2019, Jurc et al. 2022, Isaia et al. 2022). These observations do not contradict the concept of primeval forest relict species sensu Eckelt et al. (2017)

but rather indicate that their persistence may depend on long-term management legacies maintaining critical structural elements beyond strictly unmanaged forest remnants. Consequently, while such species are highly sensitive to intensive forestry, they may persist in extensively managed forests that retain key habitat structures, with their persistence being further promoted by the presence of spatially networked refugia. In this context, the present results are fully consistent with the conservation recommendations of Kostanjšek et al. (2018), who identified the long-term retention of large fallen logs as a key prerequisite for sustaining populations of *R. sulcatus*.

In the studied area of the Kamp valley, the persistence of this assemblage appears closely linked to the long-established, close-to-nature forest management regime of the "Forstbetrieb Hornerwald – Rudolf Hoyos", characterised by natural regeneration, retention of large standing and lying deadwood, designation of habitat trees and the preservation of several unmanaged old-growth forest patches, acting as such long-time refugia, scattered across the estate. The importance of such management legacies has been emphasised repeatedly in recent forest ecology and conservation studies, which highlight deadwood continuity and a balanced mixture of habitat patch distribution as particularly effective strategies for the conservation of saproxylic beetle communities (Thorn et al. 2020, Jurc et al. 2022, Isaia et al. 2022, Smolis et al. 2023, Lachat et al. 2025, Smolis et al. 2026).

The findings underscore the necessity of maintaining and further developing biodiversity-oriented forest management practices, especially but not solely within Natura 2000 sites, as viable populations of specialised saproxylic beetles depend on the long-term continuity of structurally complex forest conditions rather than isolated, singular deadwood elements (Eckelt et al. 2017, Seibold et al. 2021). Priority measures should therefore include the systematic identification and permanent retention of habitat trees, given their fundamental role as both substrate and providers of tree-related microhabitats, which together represent essential resources for saproxylic biodiversity (Larrieu et al. 2018, Paillet et al. 2022). This should be complemented by the long-term retention of already available and future large-diameter standing and fallen deadwood across a broad range of tree species, sizes and decay stages, as both deadwood quantity and diversity are essential to support the full spectrum of trophic guilds of saproxylic insects and their associated ecosystem processes such as decomposition and nutrient cycling (Grove 2002, Lassauce et al. 2011, Stokland et al. 2012, Asbeck et al. 2021, Seibold et al. 2021). The expansion and spatial networking of unmanaged or extensively managed forest patches are equally critical, as many species show limited dispersal and strong dependence on habitat continuity at the landscape scale (Ranius & Hedin 2001, Jonsson et al. 2005, Müller et al. 2022). Such measures are essential to sustain viable populations of highly specialised saproxylic beetles and to preserve the functional integrity of forest ecosystems shaped by long-term deadwood dynamics (Eckelt et al. 2017, Thorn et al. 2020, Smolis et al. 2026). Conversely, structural simplification through intensive forest management reduces habitat availability and is consistently linked to declines in saproxylic beetle diversity and increased extinction risk (Seibold et al. 2015).

The studied part of the Kamp valley thus represents a compelling example of how conservation-oriented forest management, facilitated by the "Forstbetrieb Hornerwald – Rudolf

Hoyos", can successfully reconcile timber production with the preservation of Europe's most demanding saproxylic beetle species. The rediscovery of *R. sulcatus* under these conditions highlights the potential of such extensively managed forests to function as refugia for primeval forest relict species and should be recognised as an integral component of future forest conservation strategies in Austria and Central Europe.

Acknowledgement

I thank the "Forstbetrieb Hornerwald – Rudolf Hoyos", especially Rudolf Hoyos and Christian Prock, for granting access permission for field surveys. The study was conducted within the professional framework of ACON Landschaftsplanung GmbH and draws on background information from the LACON project report (2025). I am grateful to colleagues and friends, in particular Sebastian Ploner, Elisabeth Glatzhofer and Samuel Messner for taxonomic confirmation, practical support and valuable discussion.

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