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Monitoring of three protected saproxylic beetles (*Cerambyx cerdo, Osmoderma eremita, Rosalia alpina*) in South Tyrol: Population status and habitat management.

Abstract

In this study we present the results of monitoring several important populations of three protected saproxylic beetles: *Cerambyx cerdo, Osmoderma eremita*, and *Rosalia alpina*. These three species are of special interest since their occurrence denotes the presence of old trees and near natural forests.
Cerambyx cerdo and *Osmoderma eremita* were monitored at one site with species-specific standardised sampling techniques (visual survey transects, pheromone, and bait traps). Capture-mark-recapture techniques were employed. However, the low number of recaptures did not allow for a reliable estimate of population size for these species. Furthermore, additional new occurrences were confirmed, expanding the local known distribution.
Finally, a target monitoring on a newly discovered population of *Rosalia alpina* involved surveys of newly placed beech logs and the surrounding natural habitats. This monitoring resulted in 79 individuals counted with 21 recaptures. Using the individual patterns on the elytra, an open population model for capture–mark–recapture (POPAN analysis) was used to estimate a local population of 171 adult individuals.
This study sums up the methods, results and conclusions of coordinated surveys and monitoring of saproxylic beetles from 2023 to 2025 and underlines the need and potential for long-term monitoring to inform targeted habitat management and conservation.

Keywords: capture-mark-recapture, conservation strategy, habitats directive species, forest entomology

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1. Introduction

Saproxylic biodiversity is of undeniable importance to complete the lifecycle of wood and enable the regeneration of organic matter. Among this biodiversity, beetles represent the most species-rich and numerically dominant group of saproxylic invertebrates and occupy one of the most charismatic positions with some species growing to an impressive size and taking several years to complete their life cycle (Parisi et al. 2018; Roth et al. 2019; Haeler et al. 2021; Graf et al. 2022; Seibold et al. 2023). Some of these beetles are specialists that require a specific set of conditions for sustaining viable populations or microhabitats in which they can habit (Bergmark et al. 2024; Soutinho et al. 2025). Their ecological importance led to the inclusion of certain saproxylic beetles, considered umbrella and/or flagship species, in the European Habitats Directive (European Union 1992).
The Habitat Directive together with the Directive 2009/147/EC (European Union 2009) on the conservation of wild birds aims to protect listed species and habitats within the European Union and provides also the legal framework for the designation of Special Areas of Conservation under the Natura 2000 network. This directive aims to

contribute to the conservation of biodiversity by protecting natural habitats and wild fauna and flora across the territory of the member states. Measures adopted under the directive are designed to maintain or restore natural habitats and species of community interest to a favourable conservation status; member states are therefore required to monitor populations and implement appropriate conservation and management actions (European Union 1992).

In the study region Alto Adige/South Tyrol the species *Cerambyx cerdo*, *Lucanus cervus*, *Osmoderma eremita*, and *Rosalia alpina* are reported to be present (Kahlen 2018; Kranebitter & Figl 2024). Further, *Stephanopachys substriatus* was historically reported in the region and was recently detected at a wood-storage site near Mauls; however, its presence in primary habitats has not been demonstrated despite targeted surveys (Degasperi et al. 2022, unpublished report). Furthermore, there are other saproxylic beetles listed in the Habitats Directive and not recorded so far in South Tyrol, that could potentially occur. These species are *Rhysodes sulcatus,* recorded in Italy, but with only two recent observations (Mazzei et al. 2019); *Limoniscus violaceus* that was observed in Austria, France and Italy, with new records from Sicily (Gouix et al. 2012; Gillett & Blanc 2023); *Cucujus cinnaberinus* also reported in southern Italy and recently in Veneto and Austria (Biscaccianti et al. 2008; Stoch 2016; Bonacci et al. 2022; Vicariotto 2025); and *Phryganophilus ruficollis,* a rare species absent from Italy, but recently found in Austria (Eckelt et al. 2020). South Tyrol, due to the conversion of lowland forests into intensive crops and settlements has limited lowland deciduous forests. As a result, suitable habitats for the saproxylic beetles listed in the European Habitat Directive are mostly restricted to old grown forest and mature trees in urban or agricultural environments (Redolfi De Zan et al. 2023).

To comply with the Directive obligations, a collaborative project was started in 2023 in South Tyrol. This project, called "SpeciesMonitoring" coordinated and financed by the Office of Nature of the Autonomous Province of Bolzano-South Tyrol, in collaboration with Eurac Research, aims to monitor selected species of conservation concern. Within this monitoring program the above mentioned saproxylic beetles were monitored and the present study reports and analyses the first results. Previous surveys (Kahlen & Eckelt 2013; Eckelt et al. 2015; Degasperi et al. 2022) were used as baseline information to design the here presented study.

The monitoring of all species followed established protocols (Campanaro et al. 2017; Maurizi et al. 2017; Redolfi De Zan et al. 2017) and ISPRA guidelines (Stoch & Genovesi 2016). All data were geo-referenced and sent to the Museum of Nature South Tyrol and the office of Nature of the Province of Bolzano/Bozen. Permits for collecting and handling the specimens were requested and obtained from ISPRA (Protocol number: 12841/2023). A summary of study areas, sampling design and effort is provided in Table S1.

2. Osmoderma eremita

2.1 Introduction

Osmoderma eremita (Scopoli, 1763) (Figure 1) develops as larvae for two to three years in decaying wood within hollows of old deciduous trees across a wide range of host species. The species has a wide distribution range, being present in central and western Europe and in parts of northern and eastern Europe. Adults emerge from July to September and can live for about one month (Ranius et al. 2005). This species is strongly associated with cavity-rich trees. Suitable habitat trees should preferably be large, sun-exposed and maintain optimal humidity (Dubois 2009; Sabatelli et al. 2023), ideally developing a sparse canopy (Maurizi et al. 2017). Due to the loss of this habitat, *O. eremita* is now mainly found in surrogate habitats maintained by humans, although less stable over time (Ranius & Nilsson 1997; Vignon 2008; Carpaneto et al. 2010; Maurizi et al. 2017). For instance, in France, the species occurs mainly in traditional orchards and hedgerows in agricultural environments, where pruning encourages cavity formation (Vignon 2008; Valladares et al. 2015). In Austria, it is also strongly associated with traditional orchards, particularly old apple trees (Friess et al. 2020).

Fig. 1: *Osmoderma eremita* photographed at the monitoring site Castelfeder (Photo: Elia Guariento)

In South Tyrol, the species is also present in anthropized environments such as peri-urban parks, chestnut groves, and wooded pastures, and its presence has been detected on trees of the genus *Quercus*, *Salix*, and *Castanea*. Historically, the species was distributed in in the main valleys of the province such as the Isarco Valley/Eisacktal, Venosta Valley/Vinschgau and Adige Valley/Etschtal (Kahlen 2018). However, its distribution range has undergone significant contraction and fragmentation. Currently, two populations are known, one in the lower Adige Valley at the N2000 site of Castelfeder, and another in the Vinschgau Valley in the area of Laces/Latsch. In the Isarco Valley around Bressanone/Brixen, individuals were found during safety-related chestnut tree removals, but no broader presence was confirmed (Kahlen & Eckelt 2013; Eckelt et al. 2015;Kahlen 2018, unpublished). However, later findings in 2020 by Georg von Mörl and Thomas Messner (pers. comm.) of larvae and adult remains in nearby chestnut groves suggested a possible extant population in the area.
Prior to this study, the work on this species was to verify the presence of the species in known historical sites and the monitoring based on population metrics (such as the number of adults and/or larvae observed) and habitat assessment using environmental variables (Kahlen & Eckelt 2013; Eckelt et al. 2015, unpublished reports).

2.2 Methods

The species was studied at two sites with different objectives: estimation of the population size at Castelfeder and verification of the actual species presence in the Bressanone/Brixen area.
The Natura 2000 site of Castelfeder (IT3110035, 46.320462, 11.309068) is located on two municipalities of Ora/Auer and Montagna/Montan at 218–382 m a.s.l. and covers an area of 108 ha. This historically significant site, known for its ancient defensive wall, is characterized by dry grassland with mixed oak woods, mainly of the protected habitat 91H0 Pannonian woods with *Quercus pubescens* (Provincia autonoma di Bolzano-Alto Adige 2026) and is managed by extensive grazing. The ideal conditions for saproxylic larvae are gathered in this site, which contains sunny and open areas with isolated old oak trees with dead branches and cavities. Considering the importance of this site for the conservation of saproxylic protected species, a more intensive monitoring design was implemented here, including a higher number of traps and repeated control sessions with the aim of estimating population size.

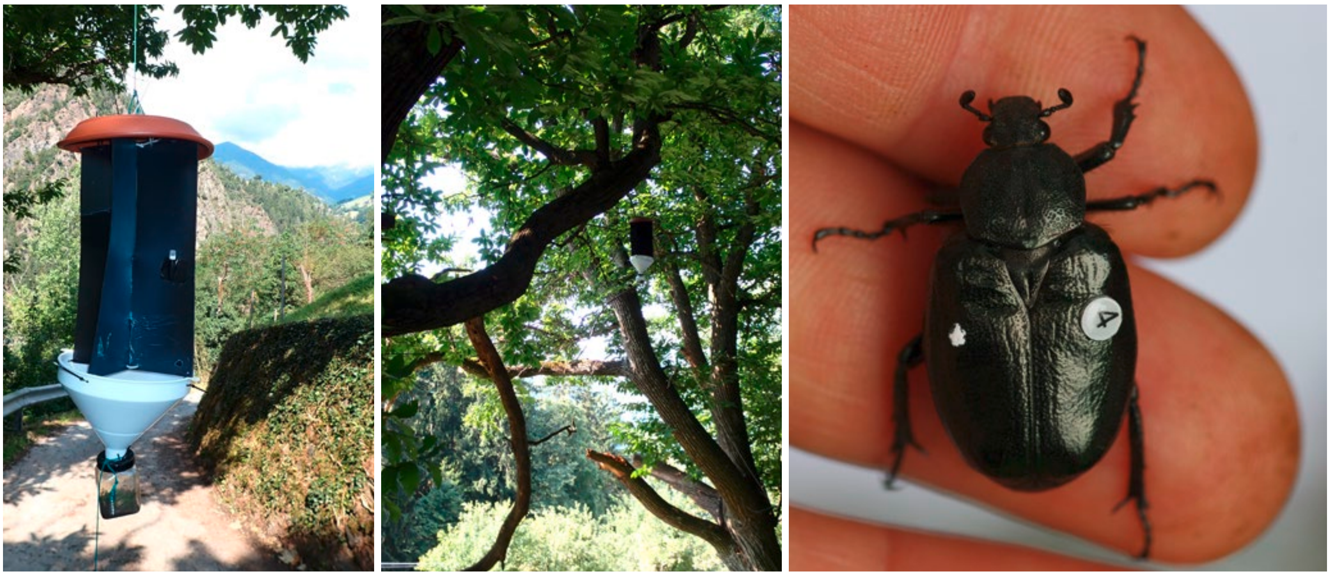

Fig. 2: Left and Center: *Osmoderma eremita* pheromone traps and in a chestnut grove near Bressanone/Brixen.
Right: *Osmoderma eremita* individually marked during the monitoring survey at Castelfeder. (Photo: A. Marsy and E. Guariento)

The monitoring was conducted using custom-built Black Cross Window Trap (BCWT) by assembling two plastic panels (50 × 30 cm, 3 mm thick) arranged in a cross, topped with an inverted plant saucer (30 cm) to form a roof and provide protection from rain. Below, a 30 cm funnel led to a 500 mL plastic container with drainage holes and filled with foam to maintain humidity and prevent beetle mortality. A 1.5 mL Eppendorf tube was attached in the centre of the cross, containing cotton and 1.2 mL of γ-decalactone pheromone (Sigma-Aldrich, W236004) as described by Maurizi et al. 2017 (Figure 2).
At Castelfeder, the monitoring was carried out from 5 July to 4 August 2023. Ten traps were placed at approximately 2 m above ground near suitable cavity trees and spaced by at least 100 m between traps. Traps were checked 2–3 times per week, for a total of 12 control rounds. Captured individuals were sexed and marked (Figure 2).
In the Bressanone/Brixen area where previous signs of the species' presence had been recorded by Georg von Mörl, the possible existence of a population was assumed. Therefore, traditional extensively managed chestnut groves were investigated, and additional potentially suitable sites within a 10 km radius were identified. These sites are characterised by old trees with large cavities, providing suitable microhabitats for *Osmoderma eremita*. (Figure 3).
To detect the species' presence, the same pheromone traps were used, installed at approximately 10 m height due to the position of suitable cavities in the chestnut trees. Five traps were placed across nine suitable sites, remaining active for at least 15 days at each location. The survey was conducted from 26 June to 12 August 2024. Once the species' presence was confirmed, traps were relocated. The traps remained active throughout the period of survey and were checked every 2–3 days. In 2025, from 23 June to 8 August, five additional chestnut sites between Bressanone/Brixen and Chiusa/Klausen were surveyed using the same approach (for more details on the study sites see Table S1 and Figure 3).

2.3 Results

In the capture-mark-recapture study performed at the site in Castelfeder, six individuals were marked, including three males and three females, without recapture. The presence of a population has therefore been confirmed at the site, but this limited number of captures and the absence of recaptures prevented the estimation of population density.
In the study performed in the Bressanone/Brixen area, we recorded the first *Osmoderma eremita* individual (female) in Varna/Vahrn on 7 July 2024 in a private family chestnut grove, managed extensively and composed of very old chestnut trees. Other

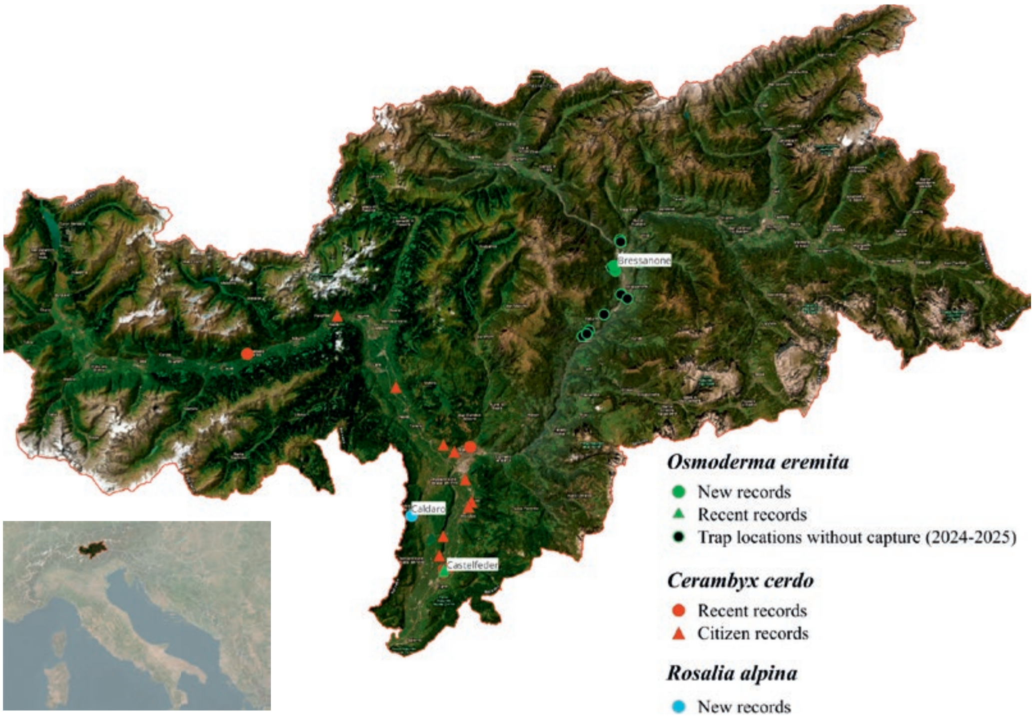

Fig. 3: Study areas and distribution of records for saproxylic beetles investigated in this study in South Tyrol. The study areas described more in detail in this study are marked with the name of the areas. Each species record (2023-2025) has its own colour, *Cerambyx cerdo* records are in red, *Osmoderma eremita* in green and *Rosalia alpina* in blu.

individuals, one male on 22 July and 5 individuals (2 females, 3 males) on 28 July, were captured in another site in Varna/Vahrn, along a wooded path in the immediate vicinity of an old chestnut tree classified as a monumental tree.

No records of *Osmoderma eremita* were obtained from the other seven sites investigated in 2024 and no individuals were captured in the traps installed on 5 suitable sites in July 2025 (Figure 3).

Other species of conservation interest observed during these surveys with the BCWT traps were *Prionychus ater* and *Gnorimus variabilis,* both categorised as near threatened (NT) in Italy (Audisio et al. 2014). Furthermore, in Castelfeder, six specimens of *Elater ferrugineus,* listed as "Near Threatened" (NT) in Europe (Aleksandrowicz et al. 2018) and Vulnerable (VU) in Italy (Audisio et al. 2014), were also found in the traps.

2.4 Discussion

In our survey at Castelfeder (40 ha monitoring area), six individuals were detected over five weeks with no recapture, precluding robust population estimates. However, such low numbers align with results from comparable studies. While in Northern Europe, *Osmoderma eremita* can occur in large populations with high densities (ranging from 2.8 to 14.2 individuals per tree and cavity occupancy rates ranging between 33 % and 70 %) (Ranius 2000; Lindman et al. 2020), the situation differs considerably in central and southern Europe. For example, in France, emergence rates per tree range from 0 to 9 individuals per year (Vignon 2015) and in Piedmont relatively few individuals were recorded, with 11 and 14 beetles captured across three locations (Perone et al. 2024), comparable to our findings. In Abruzzo, 15 individuals were detected across four out of ten monitored sites using pheromone traps, with populations confined to scattered habitat patches (Giangregorio et al. 2015). By contrast, studies in Lazio reveal a broader range of densities, from very few detections of only 2 individuals (Lenzi et al. 2022) to much higher occupancies and captures up to 35 individuals (Chiari et al. 2013; Sabatelli et al. 2023). Population size may also depend on host-tree characteristics: Castelfeder is dominated by *Quercus petraea*, a medium-sized oak that likely provides smaller cavities than the larger *Q. robur* woodlands typical of northern Europe, which may contribute to the lower densities observed (Ranius et al. 2009).

The flight activity is correlated with daily temperature and varies significantly between years, limiting the effectiveness of pheromone-based monitoring (Larsson & Svensson 2011). Considering the weather of summer 2023, with relatively warm average temperatures (25.1 °C) but frequent rainfall and thunderstorms, it is possible that it might have influenced negatively the outcome of this monitoring. For this reason, such surveys should be repeated at regular intervals to ensure reliable trend assessments (Stoch 2016) recommends repeating the monitoring at least every three years within the six-year reporting cycle of Article 17 of the Habitats Directive.
It is nevertheless conceivable that the relatively low number of individuals captured at this site reflects the small size of the local population. However, given that the environmental conditions at Castelfeder appear to be optimal for the species and that its presence has been confirmed over several years, the population could be considered stable and its current conservation status favourable. Nonetheless, the apparently limited population size, combined with the site's isolation and restricted (or apparent absence of) metapopulation dynamics with the surrounding landscape, may increase its vulnerability to stochastic events, especially considering the species' limited dispersal capacity. Radio-tracking in France has documented a maximum flight distance of 700 m in the wild and of 1454 m in the laboratory (Dubois & Vignon 2008; Dubois 2009). Similarly, Chiari (2011) reported dispersal up to 1504 m in Italy and 39 % of individuals moving beyond 250 m. It is also to consider that not all individuals disperse, which further complicates detection (Chiari 2011), meaning that a substantial proportion of the population may remain undetected during monitoring. Taken together, these findings suggest that the Castelfeder population may function as a relatively isolated unit, whose long-term persistence depends largely on the maintenance of suitable habitat continuity within and around the site.
For *Osmoderma eremita*, cavities should ideally be large, exposed to sunlight while retaining adequate humidity (Dubois 2009; Sabatelli et al. 2023). Oaks take longer to develop such cavities (70–120 years if pruned) but provide more durable microhabitats than faster-growing species (Dubois 2009). In Castelfeder, the site is already protected and managed, with specific recommendations for saproxylic beetles proposed by Degasperi (2018, unpublished report) and integrated in the plan for the management of forest and pasture assets in the municipality of Montagna (Degasperi 2018, unpublished report). These practices should be continued and ensure that existing inhabited trees are conserved to the end of their life cycle, and that young trees are preserved and allowed to mature, to maintain both spatial and temporal continuity of suitable trees.
In addition to *O. eremita*, another noteworthy saproxylic species was recorded during the survey. The presence of *Elater ferrugineus,* a predator of *O. eremita* larvae, able to recognise the pheromone emitted by the adult (Svensson et al. 2004), likely explains its attraction to our traps. Although it can also predate other saproxylic larvae, its presence is still of special note due to their rarity. It is considered a valuable indicator of biodiversity-hotspots, often associated with high densities of rare saproxylic beetles (Andersson et al. 2014).

While results were modest, long-term monitoring is essential to assess population trends and a follow-up sampling is strongly suggested to confirm the results here presented. Future monitoring efforts could also consider measuring body weight, as it may reflect resource availability in cavities (Vignon 2015). At present, isolation seems to be the main threat, and future genetic studies could help assess the population's viability and persistence (Melosik et al. 2018).
At one site of record near Bressanone/Brixen, five individuals were captured in a single trap, suggesting a locally high density of individuals, probably linked to a single old tree. This chestnut tree, classified as a natural monument, already benefit from legal protection, with all interventions requiring authorization from the Office of Nature. At the second site, a single individual was recorded. This may reflect that the traditional chestnut grove management has supported population persistence over time. Incentive payments for landscape care and maintenance are already being used by the Province of Bolzano for the preservation of this type of environments (Provincia autonoma di

Bolzano Alto Adige 2025). In addition, some particularly valuable chestnut trees have been placed under protection as natural monuments and are listed among the Italian monumental trees in the national register managed by the Ministry of Agriculture, Food Sovereignty and Forestry (MASAF). The discovery of *O. eremita* in chestnut groves suggests a potentially broader distribution of the species on a local scale, with many suitable habitats remaining yet unexplored also within the agricultural areas.

3. *Cerambyx cerdo*

3.1 Introduction

Cerambyx cerdo Linnaeus, 1758 (Figure 4) occurs throughout southern and central Europe and develops mainly on old living *Quercus* spp.. In southern Europe it can also colonise other broad-leaved trees such as *Salix* spp., *Ulmus* spp., *Castanea sativa*, and *Ilex* spp. (Casula 2017). Adults are active from May to August, with a peak in June to early July, depending on local climatic conditions (Redolfi De Zan et al. 2017). It has been recorded at altitudes up to 1200 m a.s.l., though it is generally encountered below 1000 m (Chittaro et al. 2023). Like *Osmoderma eremita*, strongly associated with veteran trees in semi open woodland, *C. cerdo* is also found in urban and agricultural areas such as tree-lined avenues, parks, and isolated veteran trees or in hedgerows (Mannu et al. 2021; Santarcangelo et al. 2023). *C. cerdo* requires old, but still living trees, with an average diameter of around 50 cm in southern Europe, and sun-exposed trunk (Albert et al. 2013; Redolfi De Zan et al. 2017b), although exceptions can occur (Chittaro et al. 2023). In South Tyrol, the species seems to colonize mainly species of the genus *Quercus*. The species appears to be present in the flat and submontane areas, mainly in the lower Adige valley/Etschtal and on the sunny slopes of the Venosta/Vinschgau valley. However, the species was not recorded in the Isarco valley/Eisaktal, not even considering historical data (Kahlen 2018).

Fig. 4: *Cerambyx cerdo* copula discovered during the monitoring at Castelfeder. (Photo: Audrey Marsy)

3.2 Methods

Surveys were conducted in the Venosta/Vinschgau valley at Castelbello/Kastelbell, where previous records were reported by Kahlen & Eckelt (2013, unpublished report), to confirm the presence of a local population. Two field visits were carried out during the favourable activity period in 2024 (6 and 17 June), followed by two additional surveys in 2025 (29 May and 11 June), including one nocturnal session using a light trap. The light trap was used as previous reports indicated that the species had occasionally been detected during moth surveys.

Furthermore, with the aim of estimating the population size, a monitoring was conducted in the Natura 2000 site of Castelfeder biotope, previously described in the *Osmoderma eremita* section.

At Castelfeder, the monitoring was carried out from 26 May to 6 July 2023. Traps baited with a wine–sugar mixture were assembled following Redolfi De Zan et al. (2017). We assembled two 500 mL plastic containers using plastic cable ties, the lower lid and the bottom of the upper box were pierced with a hole of around 3–4 cm. A metal mesh was placed between them to allow odour dispersion while preventing insects from falling into the attracting liquid. This attractant, prepared one week before deployment, was a mix of white wine, red wine and sugar, and was not changed during the study period (Figure 5).

These traps were activated each Monday and checked daily until Thursday, then deactivated for the weekend by closing the top lid. In total, 20 control rounds were conducted. Ten traps were installed 2–3 m high on suitable 'station' trees (with *C. cerdo* exit holes). In contrast to the above-mentioned protocols (Redolfi De Zan et al. 2017), no traps were set above 10 m, due to the small average height of the trees (mean 10.4 m, SD = 2.32 m) and frequent presence of dead or broken branches. The traps were set at least 100 m from each other and monitored between 9:30 and 18:00.

This approach was also combined with the Visual Encounter Survey (VES) from the 5th of June, along a 1766 m transect between the traps with the same frequency as the trap monitoring. Individuals encountered were captured by hand or by net. Predation remains were also surveyed along this transect. All captured beetles were sexed and marked with numbered stickers on the elytra and with felt-tip pen on the pronotum (Figure 5).

In 2024, spontaneous reports of *Cerambyx cerdo* were received from private citizens. Following this, in 2025, an online call for observations was published on the official website of the Autonomous Province of Bolzano–South Tyrol to encourage further reporting. Submitted records were accompanied by photographs and were validated prior to inclusion in the dataset.

Fig. 5: Left: *Cerambyx cerdo* traps filled with wine and sugar. Center and right: *Cerambyx cerdo* individually marked during the monitoring survey at Castelfeder. (Photo: E. Guariento and A. Marsy)

3.3 Results

In the capture-mark-recapture study carried out at the Castelfeder sites, a total of 24 individuals were marked, including 20 males and four females. Only three were caught by the traps, while the remaining individuals were detected through the VES method. A single individual was recaptured the following day at the same location. Additional 10 individuals were sighted, but not captured, either prior to the monitoring period or at inaccessible heights in the trees. Figure 6 summarises sightings and captures, illustrating the species' phenology at the site. The first detection occurred on 15 May and the last on 31 July, with peak activity observed in June. Nine dead individuals, likely predated, were also found, but as they may have been discovered days or weeks after death they were excluded from the phenological analyses. In total, 34 alive individuals were seen at the Castelfeder site during the entire period (Figure 6).
Despite targeted survey visits at the site in Castelbello/Kastelbell, only a single *Cerambyx cerdo* female was detected, observed during the nocturnal survey using head-lamp searches rather than attracted to the moth light trap. A few trees with emergence holes were also recorded, although these could not be reliably attributed to *C. cerdo* and may also originate from *C. welensii* occurring also locally.
Following a public call for observations, we obtained 4 citizen-submitted records in 2024 and 7 in 2025, all validated by experts and included in the map. The additional citizen-submitted records were recorded in the municipalities of Parcines/ Partschins, Gargazzone/ Gargazon, Bolzano/Bozen, Laives/ Leifers and Vadena/ Pfatten, forming a scattered pattern between Ora/ Auer and Merano/Meran (Figure 3).

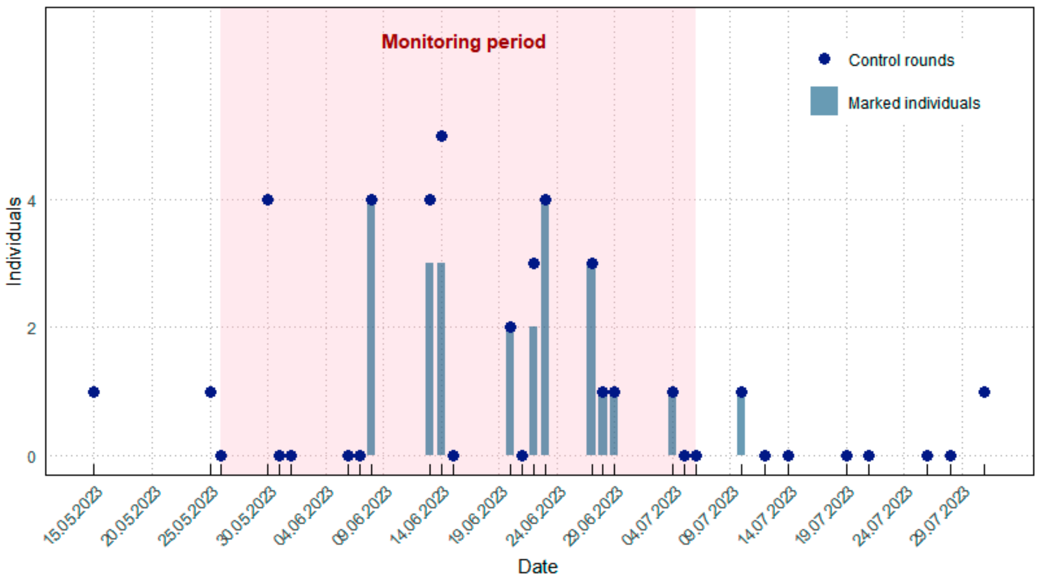

Fig. 6: Monitoring Results (VES and Traps) of *Cerambyx cerdo* at Castelfeder site in 2023. The shaded area marks the time of active trapping, while control round started earlier and ended after this period.

3.4 Discussion

The surveys and data collected confirmed the presence of only one large established population in the Province of Bolzano/South Tyrol at Natura 2000 Site Castelfeder and probably a smaller population in the Castelbello/Kastelbell area. Scattered records between Ora/Auer and Merano/Meran suggest isolated occurrences worth to be investigated closer in the future.
At Castelfeder, trap efficiency was low, with only three individuals captured. The low trap placement (below 10 m) may have influenced negatively the catches. Previous studies have shown a reduced efficacy for the lower height traps due to a higher canopy-level activity (Redolfi De Zan et al. 2017). However, the site at Castelfeder lacks a dense canopy and individuals were frequently observed at the base of trees (21 individuals captured by hand).

This low capture efficiency has also been reported in other studies. Similar results were observed in different regions of Italy and Spain, despite the use of multiple traps, capture success appears highly variable, ranging from zero to hundreds of individuals per trap depending on site and sampling conditions (Redolfi De Zan et al. 2017; Torres-Vila et al. 2022; Sabatelli et al. 2023). Consequently, population estimates often show broad confidence intervals due to limited recaptures (Santarcangelo et al. 2024).
The near absence of recaptures prevented the estimation of population size. Also, the open and non-forest habitat of Castelfeder may allow greater individual mobility, contributing to the lack of recaptures. This is supported by recent radio-tracking studies showing daily movements up to 1,498 m (Drag & Cizek 2018), while Franzen et al. (2025) similarly documented movements exceeding 800 m in a landscape rich in veteran oaks.
For *Cerambyx cerdo*, Castelfeder represents a good-quality habitat. As for *Osmoderma eremita*, it is essential to maintain veteran oaks and secure a spatial and temporal continuum in the availability of suitable trees.
In our case, the combination of different methods proved effective, producing more records (43 individuals observed and 24 marked). Since visual encounter surveys (VES) provided the highest detection success, future monitoring could focus primarily on this method, complemented by searches for predation remains. Bait traps could be reduced and deployed strategically in areas with the highest observation records, thereby optimizing survey efficiency.
The management recommendations mentioned for *Osmoderma eremita* are equally relevant for *Cerambyx cerdo*. In addition, particular attention should be given to conserving habitat trees outside protected areas, since the species has a broader distribution and some records originate from non-protected landscapes and areas even bordering the cities of Bolzano and Merano.
The site at Castelbello presents a potentially suitable habitat, with old oaks present, although fewer and more isolated than at Castelfeder. The detection of only a single female of *Cerambyx cerdo*, despite multiple targeted surveys, suggests that the local population may be small. Nevertheless, the species is clearly present in the area, as supported also by older records. Being already under protection, this site should continue to be considered a potential occurrence point in regional conservation planning.

4. *Rosalia alpina*

Fig. 7: *Rosalia alpina* female of the newly confirmed population in the forest near Caldaro/Kaltern, spotted on the log pile of *Fagus sylvatica.* (Photo: Audrey Marsy)

4.1 Introduction

Rosalia alpina (Linnaeus, 1758) (Figure 7) is native to central and southern Europe, ranging from Spain to the Caucasus and from Poland to southern Italy (Cizek et al. 2009; Duelli & Wermelinger 2010). It primarily inhabits open to semi-open deciduous forests with low canopy cover, relying on sun-exposed dead or moribund trees. The main host tree is the European beech (*Fagus sylvatica*), but it can also use other deciduous species from the Aceraceae, Betulaceae, Fagaceae, Oleaceae, Tiliaceae, and Ulmaceae families (Cizek et al. 2009; Russo et al. 2011; Bosso et al. 2013a). The species has been reported at elevations of 500–1900 m a.s.l. (Russo et al. 2011). Their life cycle spans two to four years, depending on climatic conditions and wood quality (Campanaro et al. 2017). The larval stage develops within deadwood. Adults are active from May to August, with a flight peak occurring between mid-July and mid-August, depending on altitude (Duelli & Wermelinger 2010; Drag et al. 2011a). In South Tyrol, *R. alpina* was once relatively widespread (Gredler 1866; 1873), and the last confirmed sighting dating from 1932. Despite multiple targeted surveys (Kahlen & Eckelt 2013; Eckelt et al. 2015, unpublished reports), no further records were found, and the species was considered locally extinct (Kahlen 2018). However, on 23 July 2021, a single female was discovered in a beech-mixed forest near Caldaro/Kaltern by Dominik Figl (Kranebitter & Figl 2024). On 8 July 2024, a targeted survey by the authors revealed eight individuals, confirming the species' presence and prompting a more in-depth investigation, the results of which are documented in this article.

4.2 Methods

The monitoring of *Rosalia alpina* was conducted in a deciduous (beech) forest near Caldaro/Kaltern where the species was rediscovered (Kranebitter & Figl 2024). The area, within the forests of the Mendola ridge, is managed by the Caldaro forestry station, with a strong focus on biodiversity conservation.

Monitoring of *Rosalia alpina* was carried out at least once a week between 13 June and 13 August 2025. Nine survey stations were prepared and installed by the forestry service within a 2 km radius of the records of the explorative survey of 2024. Each station consisted of a pile of freshly cut European beech logs (approximately 10 logs per station; min. diameter 20 cm and length 1 m of logs, height of pile ~1 m), following the monitoring methods described in Campanaro et al. (2017). In addition, a ~3,000 m^2 natural habitat patch, primarily composed of old beech stumps and fallen beeches, was also regularly surveyed visually (Figure 8).

For each survey day, weather conditions (temperature, sunshine, wind) and time of survey were recorded. Beech logs, tree trunks, and stumps were examined for adult beetles. To minimize disturbance, beetles were photographed in situ without handling. Photographs from Eurac Research surveys were supplemented by images submitted by private citizens encountered on the field, resulting in many additional pictures and a total of 18 survey days.

Individuals of *Rosalia alpina* beetles were identified using the I3S Contour software, which enables photographic recognition based on characteristic elytra markings (Rossi de Gasperis et al. 2016). For each individual, the outlines of the black spots were traced: on the left elytron in a clockwise direction, and on the right elytron counterclockwise,

Fig. 8: Habitat of *Rosalia alpina*: fallen beech trunk and stump (Photo: Audrey Marsy), a female *R. alpina* on a log and monitoring of log piles, attractive pile of beech wood prepared for this monitoring (Photo: Eurac Research, Andrea De Giovanni).

Fig. 9: Four different individuals of *Rosalia alpina* photographed during the monitoring and showing clear different individual patterns (Photo: Audrey Marsy).

starting from the outside of the upper left black marking. Each new capture was compared to the reference database containing previously identified individuals. The software automatically calculated similarity scores, and final identification was confirmed through visual inspection by the authors to determine whether the individual was already recorded or represented a new observation (Figure 9).

The POPAN open-population model, a robust parameterization of the Jolly–Seber model (Jolly 1965), was used to account for recruitment, mortality, and emigration during the survey period. The model estimates survival (phi), capture probability (p), entry probability (pent), and superpopulation size (N). Models were implemented in R (v. 4.5.0) using the RMark package. Candidate models included covariates such as time of day, sun exposure, and temperature (p ~ time + sun + temp), while alternative structures for phi and pent were tested. Time intervals between capture occasions were irregular and specified explicitly. Competing models were ranked using Akaike's Information Criterion corrected for small sample sizes (AICc) (Drag et al. 2011b; Tikkamäki & Komonen 2011; Chiari S. et al. 2014; Quinby et al. 2020).

4.3 Results

Throughout the study period (13 June to 13 August 2025), a total of 79 individuals of *Rosalia alpina* were identified. Twenty-one of which were captured on at least two separate occasions, resulting in an overall recapture rate of 26.5 %. The oldest observed individual, a male, was still alive 21 days after its initial capture and was recaptured five times. On at least 13 occasions, *R. alpina* was found on the provided wood piles. Individuals were found about 500 m from the area discovered in 2024.

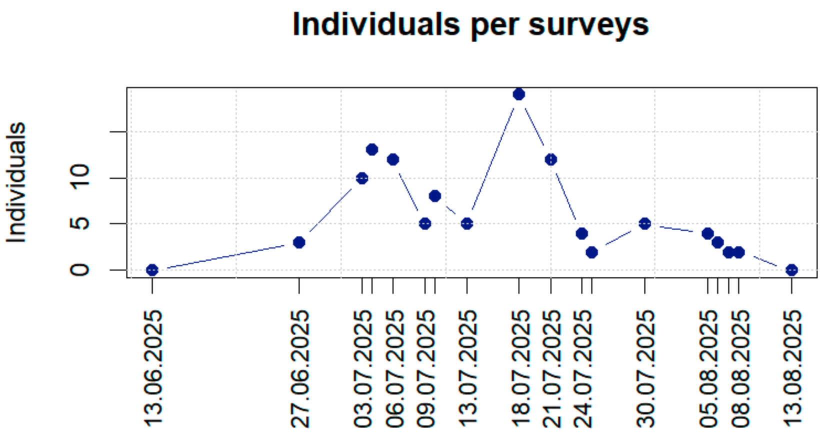

Fig. 10. The abundance of recorded individuals of *Rosalia alpina* showing the overall phenological curve based on monitoring data collected in the Caldaro/Kaltern study area (Mendola woodland), South Tyrol, in 2025.

The best-supported POPAN model included time of day, temperature and sunlight as covariates affecting capture probability (p ~ time + temp + sun), while survival probability (phi) and superpopulation size (N) were held constant across sampling occasions (~1). Entry probability (pent) was modeled as a function of the empirically derived proportion of newly observed individuals per occasion (pent ~ empirical_pent), representing a proxy for hatching rate. This model had the lowest AICc value (312.13) and a model weight of 0.95, indicating strong support relative to competing models.
The estimated superpopulation size (N) was 171.2 individuals (95 % CI: 52–164, log-scale mean ± SE: 4.52 ± 0.29). Based on the observed extent of occurrence of 12 ha, this corresponds to a density of 14,27 individuals per hectare. Apparent survival was constant across the monitoring period (phi = 0.82). Capture probability varied across times and weather, with highest detection around midday (11:00) and a positive, but non-significant effect of sunlight and temperature. Entry probability peaked at two timepoints, consistent with two main hatching waves observed during the field season (Figure 10).

4.4 Discussion

In the case of *Rosalia alpina* the methods used for monitoring proved effective in monitoring the population. The use of combined methods such as visual analysis of areas where the species has been confirmed (VES) and the creation of special wood piles to increase the probability of observing individuals and begin to understand the current distribution area of the species has made it possible to collect sufficient data to estimate the size of the population.
Our study shows that the use of the I3S Contour software for individual identification of *Rosalia alpina* is feasible and produces reliable results under optimal conditions, consistent with earlier applications (Rossi de Gasperis et al. 2016) avoiding so any handling and marking of the individual animals. However, we noticed that the reliability of automated matches is highly influenced by photo angle and resolution, necessitating manual verification.
For population analysis, the POPAN model provided stable estimates despite limited sample sizes, though its parameters remain sensitive to influences such as weather and predation. These dependencies introduce variability that may challenge the robustness of the model under dynamic environmental conditions, requiring cautious interpretation.
The estimated density in our study area (~14,27 individuals/ha, with a 26.5 % recapture rate) is intermediate compared to previous reports. Higher densities were reported in the Czech Republic (42–84 individuals/ha) with recapture rates between 26 and 33 % (Drag et al. 2011b). By contrast, much lower values were recorded by Holzinger et al. (2014) in the Austrian Alps (0.005–0.01 individuals/ha), and in Romania by Minodora et al. (2018) with ~ 0.3 individuals/ha. Italian populations also show strong regional variation, ranging from a few dozen individuals in the Casentinesi forests to several hundred in Abruzzo (Campanaro et al. 2017). These results highlight pronounced geographic variability in density, shaped by local habitat conditions and management.
Our data on adult longevity (up to 21 days) align with previous findings. The individuals we observed showed very limited movements, with the recaptured specimen found within a radius of less than 100 m, whereas literature data indicate a maximum dispersal of 1,628 m with occasional movement estimated up to 3 km (Drag et al. 2011b), underscoring the vulnerability of the species to habitat fragmentation and the importance of maintaining deadwood resources at landscape scales. Considering that the mean dispersal capacity of this species is estimated around 100 m for most individuals and considering that a non-negligible proportion may disperse up to 500 m (Drag et al. 2011b), we estimated the potential inhabited area by identifying suitable forest habitats within a 500 m buffer around the recorded observations. Buffers from multiple observation points were merged, and only beech-dominated forest patches were retained, while non-forested areas were excluded. Based on this habitat-filtered approach, the potentially occupied area is estimated at approximately 150 ha. This estimate should be regarded as indicative, as actual occupancy depends on habitat

availability and connectivity: Here we propose to consider this area additionally to the area of actual occurrence, to optimize the conservation of this special single population occurring in South Tyrol.

Our study confirms that *Rosalia alpina* prefers open-canopy beech forests with abundant sunlit deadwood. Indeed, habitat closure and intensive forestry reduce suitable oviposition sites (Russo et al. 2011; Lachat et al. 2013), while timber stacks may act as ecological traps (Adamski et al. 2018). To minimize such risks, harvested firewood should be removed or stored in shaded areas before emergence, or supplemented with sun-exposed logs placed separately as safe oviposition sites. During logging, selected old trees, high stumps and lower-quality trunks should be retained (Duelli et al. 2010). Conservation strategies should further aim to maintain old-growth structures and at least 20 m^3/ha of deadwood in sunlit positions to support large saproxylic beetles (Gossner et al. 2013).

Although our study area supports a relatively robust population, *Rosalia alpina* remains vulnerable at local scales since it is so far the only known population. Current protected areas in Europe do not fully encompass its distribution (Bosso et al. 2013b). As an umbrella species, its conservation may benefit other taxa reliant on old-growth deciduous trees (Russo et al. 2015). Priorities should therefore include securing this local population, enhancing habitat connectivity, enabling expansion into suitable areas, and establishing long-term monitoring. The species is listed in Annexes II and IV of the Habitats Directive (European Union 1992) and is therefore strictly protected, and its habitat must be preserved and maintained, and appropriate measures must be put in place for its management and conservation. It is also important to define the extent and location of potentially suitable habitats and to encourage and monitor the possible colonisation of the species of new forest patches.

5. Conclusions

The three investigated species are umbrella species, associated with different kind of deadwood in near-natural, primeval forests. While *Rosalia alpina* and *Cerambyx cerdo* are relatively clearly associated with one or a few tree species (beech and various oak species, respectively), *Osmoderma eremita* shows a broader range of tree species that can be colonised. Similar to the surrounding areas, the range of suitable habitats in South Tyrol is very limited. The hardwood riparian forests with old oak trees that probably existed in the valley floors in the past have been almost completely replaced by agricultural land and settlements. The sub-Mediterranean oak trees (*Quercus pubescens* and *Q. petraea*) on slopes are generally small in size with insufficient deadwood for *C. cerdo* and *O. eremita*. Beech forests, on the other hand, are naturally limited to the more southern, less continental areas of the region and have also been replaced in many cases by other forest types or converted to cultivated land (Provincia Autonoma di Bolzano-Alto Adige 2010). The remaining stands have been used for forestry almost continuously over the centuries, which prevented the development of decay phases. While *O. eremita* has shifted its focus to secondary habitats (orchard meadows, chestnut groves, and other wooded pastures), the populations of *C. cerdo* and *R. alpina* have obviously shrunk to small remnant populations.

The monitoring and surveys carried out confirmed the presence of the target species *Osmoderma eremita* and *Cerambyx cerdo* in the Castelfeder Natura 2000 site and provided new data on the distribution of this species, but they were not suitable for estimating the size of the populations present.

Monitoring methods can also be optimized by using the techniques that have proven most effective and repeating them over several years, as the species' multi-year larval development, population size and detectability can vary considerably from year to year. It is essential to continue long-term monitoring in the future in order to identify demographic trends and enable long-term conservation.

The site Castelfeder, established for the conservation of dry meadows and saproxylic beetle species, still seems to play an important role in the conservation for two of the

most charismatic and protected saproxylic species occurring in the region and to support their population for longer time periods by providing suitable habitat in form of old oak trees. The preservation of ancient and dying trees, even outside protected areas, is nevertheless important to support these species and to create suitable stepping stones biotopes, which could allow the various populations to connect and expand their range.
Monitoring and CMR techniques applied to *Rosalia alpina* have proven highly effective in defining the current distribution of the species. Monitoring must continue and be extended to all potentially suitable areas. Appropriate conservation measures must be implemented within a 2–3 km buffer zone around the central area of occurrence (promoting forest aging, releasing old trees, increasing solar radiation near trees potentially suitable for colonization, etc.). Moreover, we suggest considering the creation of a protected area of at least 150 ha encompassing the central occurrence of this population.
Recent findings, including new locations for *Osmoderma eremita* and the population of *Rosalia alpina*, show that the potential for new discoveries has not been fully exhausted. Our collaborative approach, between a research centre and the institutions responsible for conservation with the cooperation of organizations, experts, and private citizens, has not only expanded regional knowledge of these threatened beetles, but also serves to prepare the next report of the Habitats Directive and above all helps to preserve these species and the associated habitats.

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Table S1: Summary of study areas, sampling design and sampling effort for the three saproxylic beetle species investigated in this study.

Species	Study area	Area / Sites	Objective	Sampling period	Sampling effort	Monitoring type
Osmoderma eremita	Castelfeder	1 site (108 ha)	Population estimation	5 July – 4 Aug 2023	10 BCWT traps; 12 control rounds; 2–3 checks/week	Intensive monitoring (mark–recapture)
Osmoderma eremita	Bressanone/ Brixen area	9 chestnut sites	Presence verification	26 June – 12 Aug 2024	5 BCWT traps (1 per site); relocated after ≥15 days; checks every 2–3 days	Presence search
Osmoderma eremita	Bressanone/ Brixen area	5 chestnut sites	Presence verification	23 June – 8 Aug 2025	5 BCWT traps (1 per site); checks every 2–3 days	Presence search
Cerambyx cerdo	Castelfeder	1 site (108 ha)	Population estimation	26 May – 6 July 2023	10 baited traps; 3–4 checks/week; 20 control rounds; VES transect (1766 m)	Intensive monitoring (mark–recapture)
Cerambyx cerdo	Castelbello/ Kastelbell	1 site	Presence verification	6 and 17 June 2024; 29 May – 11 June 2025	4 field visits (incl. 1 light trap)	Presence search
Cerambyx cerdo	Province of Bolzano–South Tyrol	Prov-ince-wide	Data collec-tion through public reporting	2024–2025	Online call for observations; expert validation of submitted photographs	Citizen science
Rosalia alpina	Caldaro/ Kaltern (Mendola woodland)	9 log stations + 3000 m² patch	Population estimation	13 June – 13 Aug 2025	18 survey days; weekly checks	Intensive monitoring (mark–recapture)