

To Conserve or to Control? Endangered Saproxylic Beetles Considered as Forest Pests

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Abstract: Saproxylic beetles are common in all types of forests, but they are more abundant in natural forests. They are mostly recognized as beneficial insects, as they are involved in decomposition and the recycling of nutrients. On the other hand, traditional forestry practices consider them as pests, as they reduce the value of timber. In Europe, 17.9% of saproxylic beetle taxa are considered threatened. The main threats are the reduction, fragmentation, and loss of connectivity of their habitats, mostly as a consequence of forest management. None of the taxa considered as pests are listed as threatened, but many of them are thought to be in decline or their population trend is unknown. Based on European legislation currently in use and the IUCN Red List, along with other regional and national red lists, we propose a simplified decision-making flowchart that should be followed regarding the adoption of different control measures against severe infestations and pest outbreaks. However, the best way to prevent population decline and keep their populations stable is the sustainable management of their habitats.

Keywords: saproxylic beetles; IUCN Red List; conservation; pest control; decision-making



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1. Introduction

Forests cover almost one-third of the global land area and host most of Earth's terrestrial biodiversity. In Europe, approx. 65% of plant and animal species are located in forest habitats [1]. In particular, arthropods comprise 70%–90% of taxa and dominate the animal biomass in forest ecosystems [2]. Forest biodiversity not only responds to environmental changes but also promotes various ecosystem functions and has a positive relationship with most ecosystem services, which are essential for sustaining human welfare [3,4]. Hence, forest biodiversity can be considered a key forest resource. Despite the fact that old-growth and natural forests are the most valuable for biodiversity [5]—especially for insect biodiversity [6,7]—only a few are left standing, unfragmented, and unaltered [8,9]. On the other hand, it is clear that strictly protected areas alone are insufficient for the achievement of global biodiversity conservation targets [10,11], and conservation management practices must be considered in managed forests as well.

One-third of the world's forest area is used primarily for timber production [12], and forest management regimes have altered natural forest ecosystems over time at varying intensities, altering forests' biodiversity. Unlike natural forests, commercial forests—which make up most forests in Europe—are characterized by low biodiversity [13]. Managed commercial forests do not grow as old as natural forests, as they are generally harvested at the point of economic maturity, with yield and market-based criteria as the main considerations. Consequently, later phases of forest succession, with characteristics of late development, degradation, or stand breakdown—development phases that hold a rich diversity of rare niches and species—are either lacking or rare. Therefore, lower biodiversity of canopy trees and other species reduces the ability to provide certain ecosystem services.

Biodiversity in managed forests depends on the continuity of habitats, the variability of site conditions and tree species, and forestry that mimics natural dynamics. Even though forest cover in the European Union has increased in recent decades, major pressures represent a risk to vulnerable forest species and habitats. Pressures from human activities leading to fragmentation and degradation have already caused much decline and homogenization in biodiversity [14,15].

Saproxylic beetles—insects that range widely in size (from <1 mm for families such as Ptiliidae and Ciidae to >150 mm for certain Scarabaeidae and Cerambycidae) and depend on dead and decaying wood, wood-decaying fungi, or other saproxylic organisms for at least a part of their lifecycle [16]—are a classical example of a group that has been adversely affected by forest management practices [17,18]. Saproxylic beetles are common in all types of forests and woodlands worldwide [19,20], but fragmented and degraded habitats [21,22], along with the decline of deadwood in managed forests, have led their populations to a decline in recent years. Saproxylic beetles are considered to be bioindicators for the maturity and ecological stage of their characteristic habitats [23–26], as they are involved in decomposition processes and the recycling of nutrients in natural ecosystems [27,28], and they interact with other organisms by providing an important food source for birds and mammals [29] and contribute to forest pest control through the action of saproxylic predators on primary xylophagous beetles (i.e., Scolytinae) [30,31]. However, they also include several economically important groups such as bark and ambrosia beetles or wood-boring beetles, which can be major forest pests [32].

Saproxylic beetles can be considered either as beneficial for the forest ecosystem, or as forest pests. Conservation of saproxylic organisms usually requires the designation of protected areas or, at least, substantial changes in forest management practices that result in reduced logging and the preservation of large numbers of dying trees and large amounts of deadwood in forests [24], as well as a conflict with timber production [17]. Furthermore, these conservation measures are not always properly implemented, as can be easily seen from the distribution of rare and threatened deadwood-related species, which are usually absent from managed stands. On the other hand, several species of saproxylic beetles are referred to as “pests” [33]. These species are generally considered to be harmful to trees, as their outbreaks weaken the trees and lead to the development of diseases (e.g., fungal infections), usually resulting in the death of infested trees and/or loss of large forest areas. This group is considered to be one of the most serious problems in timber production and is the reason for many studies aimed at finding methods to prevent or mitigate such outbreaks [34]. Forest management neglects the natural role of these common saproxylic species in forest ecosystems. These organisms are natural elements in the life of trees [35].

The aim of this study is to sum up the current knowledge of the threat status of the saproxylic beetles of Europe, as well as to propose a simplified decision-making flowchart representing a key that should be followed regarding the adoption of different conservation or control measures with respect to saproxylic beetles that are or may be considered as pests.

2. The IUCN Red List

The IUCN Red List of Threatened Species is the world’s most comprehensive information source on the global extinction risk status of animal, fungus, and plant species [36]. It is considered to be a critical indicator of the world’s biodiversity health [37]. The relative threat of extinction of each individual taxon is determined by applying the *IUCN Red List Categories and Criteria*. Species assessed under the categories critically endangered (CR), endangered (EN), and vulnerable (VU) are considered to be threatened and face the highest risk of extinction [36]. The different criteria (A–E) are derived from a wide review aimed at detecting risk factors across the broad range of organisms and the diverse life histories that they exhibit, based on their population size, geographic range, and decline (Table 1).

Insects comprise more than half of all described animal species and are widely recognized as a considerable proportion of all biodiversity on the planet [38,39], yet the majority of insect taxa are understudied, publicly misunderstood, and face numerous environmental

threats [40,41]. Beetles alone may represent almost 40% of all arthropod species [17], but the global status of the IUCN assessment is known for only 1500 species (source: IUCN Red List on 22 September 2022). Among these species, 19.6% are threatened, 33.8% are listed as least concern (LC), and 38.7% are assessed as data-deficient (DD) [42]. There are 19 extinct species globally, while the trend is declining for 193 species and unknown for 1144 [36].

Of the 193 extant beetle families, 122 (63%) contain saproxylic members [19,43,44], but the total number of species worldwide remains far from known [45]. It is considered that there are at least twice as many species of saproxylic beetles as there are terrestrial vertebrates [46], but probably many more. Around 56% of all forest beetle species in a region of Germany were considered to be saproxylic [47]. Given the fact that many saproxylic beetle species are considered to be cryptic and, therefore, difficult to sample [48], global species numbers might be underestimated due to cryptic diversity [38,49].

Table 1. Summary of the five criteria (A–E) used to evaluate whether a taxon belongs in an IUCN Red List Threatened Category (i.e., CR, EN, or VU) [36].

Criterion A. Population Size Reduction			
	CR	EN	VU
A1	≥90%	≥70%	≥50%
A2, A3, and A4	≥80%	≥50%	≥30%
A1. Population reduction in the past; causes are reversible, understood, and have ceased	(a) Direct observation		
A2. Population reduction in the past; causes are not reversible or understood, or have ceased	(b) Index of abundance		
A3. Population reduction in the future	(c) Decline in area of occupancy (AOO), extent of occurrence (EOO), and/or habitat quality		
A4. Population reduction in the past and the future; causes are not reversible or understood, or have ceased	(d) Actual or potential levels of exploitation		
	(e) Introduced taxa, hybridization, pathogens, pollutants, competitors, etc.		
Criterion B. Geographic Range			
	CR	EN	VU
B1. Extent of occurrence (EOO)	<100 km ²	<5000 km ²	<20,000 km ²
B2. Area of occupancy (AOO)	<10 km ²	<500 km ²	<2000 km ²
(a) Severely fragmented or number of locations	=1	≤5	≤10
(b) Continuing decline in (i) EOO; (ii) AOO; (iii) area, extent, and/or quality of the habitat; (iv) number of locations or subpopulations; (v) number of mature individuals			
(c) Extreme fluctuations in (i) EOO; (ii) AOO; (iii) number of locations or subpopulations; (iv) number of mature individuals			
Criterion C. Small Population Size and Decline			
	CR	EN	VU
Number of mature individuals	<250	<2500	<10,000
C1. Observed, estimated, or projected continuing decline	25% in 3 years or 1 generation	20% in 5 years or 2 generations	10% in 10 years or 3 generations
C2. Observed, estimated, projected, or inferred continuing decline			
(a) (i) Number of mature individuals in each subpopulation	≤50	≤250	≤1000
(a) (ii) Percentage of mature individuals in one subpopulation	90%–100%	95%–100%	100%
(b) Extreme fluctuations in the number of mature individuals			
Criterion D. Very Small or Restricted Population			
	CR	EN	VU
D. Number of mature individuals	<50	<250	D.1 < 1000
D2. Restricted AOO or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time	-	-	D2. AOO < 20 km ² or number of locations ≤5
Criterion E. Quantitative Analysis			
	CR	EN	VU
Indicating the probability of extinction in the wild	≥50% in 10 years or 3 generations	≥20% in 20 years or 5 generations	≥10% in 100 years

Knowledge about these species is quite extensive due to many studies [50], including recent revisions at various taxonomic levels [51]. Hence, many species have well-known distribution and population demography, reproductive biology, and ecology, including relationships with the environment and other organisms [52,53]. The current IUCN European Red List provides an assessment for 693 species of saproxylic beetles [54]. In 2008, following a two-year project, a total of 436 species were assessed [54]. In 2017, an additional 257 species were assessed, which represents only a preliminary approach to this topic, since there are more than 3500 species of saproxylic beetles in Europe [29]. Overall, 17.9% of species are considered to be threatened in Europe (Table 2). From the total of 93 species classified as endangered,

5 are considered to be CR, while the majority are considered to be EN. Almost all of them depend on forest trees as their habitats, with two species considered to be predators of other saproxylic species. Five of them—*Boros schneideri* (Coleoptera: Boridae), *Buprestis splendens* (Coleoptera: Buprestidae), *Pseudogauritina excellens* (Coleoptera: Cerambycidae), *Limoniscus violaceus* (Coleoptera: Elateridae) and *Propomacrus cypriacus* (Coleoptera: Scarabaeidae)—were included in Annex II of the European Union’s Council Directive 92/43/EEC as *animal species of community interest whose conservation requires the designation of special areas of conservation*. In addition, 89 taxa are listed as near-threatened (NT).

These values assume that a similar relative proportion of the data-deficient (DD) species are likely to be threatened and provide the best estimation of the proportion of threatened species [36]. For almost one-quarter of the species in Europe (168 species—24.4%), there was not enough scientific information to evaluate their risk of extinction, and they were assessed as DD.

Table 2. Saproxylic beetles listed as threatened in Europe and their habitat/host plants; (*) indicates the taxa included in Annex II of the European Union’s Council Directive 92/43/EEC as animal species of community interest whose conservation requires the designation of special areas of conservation.

Species	Family	IUCN Red List Category (Europe)	IUCN Red List Criteria (Europe)	Habitat/Host Plants
<i>Boros schneideri</i> (Panzer, 1795)	Boridae	VU *	A2ac	Various conifers mostly and various broadleaves [55]
<i>Xylomedes cornifrons</i> (Baudi, 1874)	Bostrichidae	VU	B2ab (iii)	Various conifers [56]
<i>Buprestis splendens</i> (Fabricius, 1775)	Buprestidae	EN *	B2ab (iii, iv)	<i>Pinus</i> spp., rarely <i>Picea abies</i> [57]
<i>Acmaeops angusticollis</i> (Gebler, 1833)	Cerambycidae	EN	B1a + 2ab (iii)	<i>Pinus</i> spp., rarely <i>P. abies</i> [58]
<i>Acmaeops smaragdula</i> (Fabricius, 1792)	Cerambycidae	EN	B2ab (i, ii, iv)	<i>Picea</i> spp., <i>Pinus</i> spp., <i>Larix</i> spp., <i>Abies</i> spp. [58]
<i>Akimerus schaefferi</i> (Laicharting, 1784)	Cerambycidae	EN	B2ab (i, ii, iii, iv)	<i>Quercus</i> spp. [59]
<i>Anaglyptus luteofasciatus</i> (Pic, 1905)	Cerambycidae	EN	B1ab (iii) + 2ab (iii)	<i>Abies</i> spp. [60]
<i>Anaglyptus praecellens</i> (Holzschuh, 1981)	Cerambycidae	EN	B1ab (iii, v) + 2ab (iii, v)	<i>Quercus coccifera</i> , <i>Berberis cretica</i> , <i>Crataegus</i> spp. [61]
<i>Anisarthron barbipes</i> (Schränk, 1845)	Cerambycidae	VU	A3c	Various broadleaves [61,62]
<i>Calchaenesthes sexmaculata</i> (Reiche, 1861)	Cerambycidae	EN	B2ab (iii)	<i>Quercus</i> spp. [63]
<i>Callergates gaillardoti</i> (Chevrolat, 1854)	Cerambycidae	EN	B1ab (ii, iii) + 2ab (ii, iii)	<i>P. halepensis</i> , <i>P. brutia</i> [64]
<i>Chlorophorus convexifrons</i> (Holzschuh, 1981)	Cerambycidae	EN	B1ab (iii) + 2ab (iii)	<i>Isotis tinctoria</i> [65]
<i>Clytus clavicornis</i> (Reiche, 1860)	Cerambycidae	VU	B1ab (iii) + 2ab (iii)	Various broadleaves [29]
<i>Clytus triangulimacula</i> (Costa, 1847)	Cerambycidae	VU	B2ab (iii)	Not known [66]
<i>Cornumutilla lineata</i> (Letzner, 1844)	Cerambycidae	EN	B2ab (iii)	Various conifers [58,67]
<i>Crotchiella brachyptera</i> (Israelson, 1985)	Cerambycidae	EN	B1ab (iii) + 2ab (iii)	<i>Laurus azorica</i> , <i>Vitis vinifera</i> , <i>Ilex</i> spp. [68]
<i>Delagrangeus angustissimus</i> (Pic, 1892)	Cerambycidae	VU	D2	<i>Cupressus sempervirens</i> , <i>Thuja</i> spp., <i>Juniperus</i> spp. [69]
<i>Delagrangeus schurmanni</i> (Sama, 1985)	Cerambycidae	VU	D2	<i>Juniperus</i> spp. [70]
<i>Drymochaeres cylindraceus</i> (Fairmaire, 1849)	Cerambycidae	EN	B2ab (iii, iv)	<i>Cytisus oromediterraneus</i> [68,71], <i>Quercus</i> spp. [66]
<i>Drymochaeres truquii</i> (Mulsant, 1847)	Cerambycidae	EN	B2ab (iii)	<i>Corylus avellana</i> , occasionally <i>Fagus sylvatica</i> , <i>Alnus</i> spp., <i>Ostrya carpinifolia</i> [72]
<i>Enoploderes sanguineus</i> (Faldermann, 1837)	Cerambycidae	EN	B2ab (iii)	<i>Populus</i> spp., <i>Salix</i> spp. [73]
<i>Glaphyra bassettii</i> (Sama, 1992)	Cerambycidae	EN	B1ab (iii, v) + 2ab (iii, v)	<i>Cedrus brevifolia</i> [74]
<i>Grammoptera viridipennis</i> (Pic, 1893)	Cerambycidae	VU	B1ab (iii, iv) + 2ab (iii, iv)	Various broadleaves [75,76]
<i>Isotomus barbarae</i> (Sama, 1977)	Cerambycidae	VU	B2ab (iii)	<i>O. carpinifolia</i> [77]
<i>Isotomus jarmilae</i> (Slama, 1982)	Cerambycidae	EN	B1ab (iii) + 2ab (iii)	<i>Q. coccifera</i> [78]
<i>Necydalis ulmi</i> (Chevrolat, 1838)	Cerambycidae	VU	B2ab (ii, iii, iv)	Various broadleaves [79]
<i>Neopiciella sicula</i> (Ganglbauer, 1886)	Cerambycidae	VU	D2	<i>Acer campestre</i> , <i>F. sylvatica</i> [61] <i>Quercus</i> spp. [80]
<i>Nivellia extensa</i> (Gebler, 1833)	Cerambycidae	EN	B2ab (iii)	<i>Abies</i> spp., <i>Larix</i> spp. [81]
<i>Nivellia sanguinosa</i> (Gyllenhal, 1827)	Cerambycidae	EN	B2ab (i, ii, iii, iv, v)	Various broadleaves [75,81]
<i>Nothorhina muricata</i> (Dalman, 1817)	Cerambycidae	VU	B2ab (i, ii, iii, iv, v)	<i>P. sylvestris</i> , <i>P. maritima</i> , <i>P. uncinata</i> [72]
<i>Pachyta lamed</i> (Linnaeus, 1758)	Cerambycidae	VU	B2ab (i, ii, iii, iv, v)	<i>Picea</i> spp., <i>Pinus</i> spp. [82], <i>Larix</i> spp. [81]

Table 2. Cont.

Species	Family	IUCN Red List Category (Europe)	IUCN Red List Criteria (Europe)	Habitat/Host Plants
<i>Paracorymbia tessera</i> (Charpentier, 1825)	Cerambycidae	EN	B2ab (ii, iii, iv)	<i>Fagus</i> spp. [83]
<i>Pedostrangalia ariadne</i> (Daniel, 1904)	Cerambycidae	VU	D2	<i>Platanus orientalis</i> [84]
<i>Pedostrangalia revestita</i> (Linnaeus, 1767)	Cerambycidae	VU	A3ce	Various broadleaves [61,62,67,72,75,85,86]
<i>Pseudogaurotina excellens</i> (Brancsik, 1874)	Cerambycidae	EN*	B2ab (ii, iii, iv)	<i>Lonicera nigra</i> [67,75] <i>Lonicera tatarica</i> [87]
<i>Pseudosphegistes bergeri</i> (Slama, 1982)	Cerambycidae	EN	B1ab (iii) + 2ab (iii)	<i>Q. coccifera</i> [61]
<i>Purpuricenus nudicollis</i> (Demelt, 1968)	Cerambycidae	EN	B1ab (iii)	Maquis, forests and orchards [88]
<i>Ropalopus ungaricus</i> (Herbst, 1784)	Cerambycidae	EN	B2ab (i, ii, iii, iv)	Various broadleaves [61]
<i>Schurmannia sicula</i> (Sama, 1978)	Cerambycidae	CR	B1ab (iii) + 2ab (iii)	<i>Acer</i> spp. [62], <i>Q. ilex</i> [89]
<i>Stenopterus atricornis</i> (Pic, 1891)	Cerambycidae	VU	B2ab (iii)	Various broadleaves [90]
<i>Stenurella vaucheri</i> (Bedel, 1900)	Cerambycidae	CR	B1ab (iii) + 2ab (iii); D	<i>Q. canariensis</i> [91]
<i>Stictoleptura erythroptera</i> (Hagenbach, 1822)	Cerambycidae	VU	B2ab (i, ii, iii, iv)	Various broadleaves [61,68,92]
<i>Stictoleptura oblongomaculata</i> (Buquet, 1840)	Cerambycidae	EN	B2ab (iii)	<i>Q. suber</i> [93] <i>Q. ilex</i> [76]
<i>Stictoleptura rufa</i> (Brullé, 1832)	Cerambycidae	VU	B2ab (iii)	<i>Quercus</i> spp. [73]
<i>Trichoferus bergeri</i> (Holzschuh, 1982)	Cerambycidae	CR	B1ab (iii, iv)	<i>Ceratonia siliqua</i> , <i>Quercus</i> spp., <i>Ficus</i> spp. [61,90]
<i>Cerophytum elateroides</i> (Latreille, 1804)	Cerophytidae	VU	B2ab (iii, iv)	Various broadleaves [94]
<i>Cucujus haematodes</i> (Erichson, 1845)	Cucujidae	EN	B2ab (i, ii, iii, iv)	<i>Abies</i> spp., <i>Pinus</i> spp. [95]
<i>Adelocera pygmaea</i> (Baudi 1871)	Elateridae	EN	B1ab (ii, iii) + 2ab (ii, iii)	<i>Quercus</i> spp. [96]
<i>Ampedus assingi</i> (Schimmel, 1996)	Elateridae	EN	B1ab (iii) + 2ab (iii)	<i>P. brutia</i> , <i>P. nigra</i> [97]
<i>Ampedus brunnicornis</i> (Germar, 1844)	Elateridae	VU	B2ab (iii)	<i>Quercus</i> spp., <i>Populus</i> spp., <i>Aesculus hippocastanum</i> [98]
<i>Ampedus corsicus</i> (Reitter, 1918)	Elateridae	VU	D2	Various broadleaves [99]
<i>Ampedus hjorti</i> (Rye, 1905)	Elateridae	VU	A4c	<i>Quercus</i> spp. [98]
<i>Ampedus quadrisignatus</i> (Gyllenhal, 1817)	Elateridae	EN	B2ab (i, ii, iii, iv, v)	<i>Quercus</i> spp. [98]
<i>Ischnodes sanguinicollis</i> (Panzer, 1793)	Elateridae	VU	B2ab (iii, iv)	Various broadleaves [98]
<i>Limoniscus violaceus</i> (Müller, 1821)	Elateridae	EN*	B2ab (i, ii, iii, iv)	<i>Fagus</i> spp., rarely <i>Quercus</i> spp. [99] <i>Fraxinus</i> spp. [100]
<i>Podeonius acuticornis</i> (Germar, 1824)	Elateridae	EN	B2ab (iii)	<i>Quercus</i> spp., <i>Ulmus</i> spp., <i>Fagus</i> spp. [98]
<i>Stenagostus sardiniensis</i> (Reitter, 1914)	Elateridae	EN	B1ab (iii) + 2ab (iii)	Unknown [101]
<i>Tetrigus cyprius</i> (Baudi, 1871)	Elateridae	EN	B2ab (iii)	<i>C. siliqua</i> [102]
<i>Triplax emgei</i> (Reitter, 1885)	Erotylidae	EN	B1ab (iii) + 2ab (iii)	<i>A. cephalonica</i> [103]
<i>Triplax lacordairii</i> (Crotch, 1870)	Erotylidae	EN	B2ab (ii, iii)	Various broadleaves [104]
<i>Hylochaeres cruentatus</i> (Gyllenhal, 1808)	Eucnemidae	EN	B2ab (iii)	<i>P. tremula</i> , <i>Salix</i> spp. [105]
<i>Melasis fermi</i> (Sánchez-Ruiz & de la Rosa, 2003)	Eucnemidae	VU	D2	<i>A. glutinosa</i> [106]
<i>Dorcus alexisi</i> (Muret & Drumont, 1999)	Lucanidae	EN	B1ab (iii)	Various broadleaves [107]
<i>Dorcus musimon</i> (Gené, 1836)	Lucanidae	VU	B2ab (iii)	<i>Quercus</i> spp. [108]
<i>Clinidium canaliculatum</i> (Costa, 1839)	Rhysodidae	VU	B2ab (ii, iii)	<i>Q. frainetto</i> , <i>A. cephalonica</i> [109]
<i>Gnorimus decempunctatus</i> (Helfer, 1834)	Scarabaeidae	EN	B2ab (ii, iii)	<i>Fagus</i> spp., <i>Quercus</i> spp. [29]
<i>Osmoderma cristinae</i> (Sparacio, 1994)	Scarabaeidae	EN	B1ab (i, ii, iii) + 2ab (i, ii, iii)	Various broadleaves [110]
<i>Osmoderma italic</i> (Sparacio, 2000)	Scarabaeidae	EN	B2ab (iii)	Various broadleaves [111]
<i>Osmoderma lassallei</i> (Baraud & Tauzin, 1991)	Scarabaeidae	EN	B2ab (ii, iii)	Various broadleaves [112]
<i>Propomacrus cypriacus</i> (Alexis & Makris, 2002)	Scarabaeidae	CR*	B2ab (iii)	<i>Q. infectoria</i> [113], <i>C. siliqua</i> [113] <i>P. dulcis</i> [114]
<i>Protaetia mirifica</i> (Mulsant, 1842)	Scarabaeidae	VU	B2ab (ii, iii, iv)	<i>Quercus</i> spp. [115]
<i>Protaetia sardea</i> (Gory & Percheron, 1833)	Scarabaeidae	VU	B2ab (ii, iii)	Shrubby forest-pasture [116]
<i>Allecula suberina</i> (Novák, 2012)	Tenebrionidae	EN	B1ab (iii) + 2ab (iii)	<i>Quercus</i> spp. [117]
<i>Alphitophagus carteianus</i> (Castro Tovar, Torres and Baena, 2012)	Tenebrionidae	VU	D2	<i>Q. suber</i> , <i>Populus nigra</i> [118]
<i>Alphitophagus xaxarsi</i> (Reitter, 1914)	Tenebrionidae	VU	B1ab (iii, iv) + 2ab (iii, iv)	<i>P. halepensis</i> [119] <i>C. siliqua</i> [120]
<i>Clamoris crenatus</i> (Mulsant, 1854)	Tenebrionidae	VU	B2ab (iii)	<i>P. pinaster</i> [121]
<i>Coelometopus cobosi</i> (Espanol, 1964)	Tenebrionidae	VU	D2	<i>Q. suber</i> [122]
<i>Corticeus bicoloroides</i> (Roubal, 1933)	Tenebrionidae	EN	B2ab (iii)	Various broadleaves [123]

Table 2. Cont.

Species	Family	IUCN Red List Category (Europe)	IUCN Red List Criteria (Europe)	Habitat/Host Plants
<i>Corticeus fraxini</i> (Kugelann, 1794)	Tenebrionidae	VU	B2ab (ii, iii)	Various conifers mostly [123], various broadleaves rarely [122]
<i>Corticeus suberis</i> (Lucas, 1846)	Tenebrionidae	EN	B2ab (ii, iii)	Various broadleaves [122]
<i>Corticeus vanmeeri</i> (F. Soldati & L. Soldati, 2014)	Tenebrionidae	EN	B2ab (iii)	<i>Abies pectinata</i> [124]
<i>Corticeus versipellis</i> (Baudi, 1876)	Tenebrionidae	EN	B2ab (i, ii, iii, iv)	<i>Ulmus</i> spp. [125]
<i>Hymenorus doublieri</i> (Mulsant, 1851)	Tenebrionidae	VU	B2ab (i, ii, iii)	<i>Pinus</i> spp. [126]
<i>Iphthiminus italicus</i> (Truqui, 1857)	Tenebrionidae	EN	B2ab (iii)	<i>Quercus</i> spp., <i>F. sylvatica</i> , <i>Populus</i> spp., <i>A. cephalonica</i> , <i>P. halepensis</i> [127]
<i>Mycetochara flavipennis</i> (Reitter, 1908)	Tenebrionidae	EN	B2ab (ii, iii, iv)	<i>Fagus</i> spp. [128]
<i>Mycetochara graciliformis</i> (Reitter, 1899)	Tenebrionidae	EN	B2ab (iii, iv)	<i>Quercus</i> spp. [129]
<i>Mycetochara melandryina</i> (Roubal, 1934)	Tenebrionidae	CR	B1ab (iii) + 2ab (iii)	Unknown [130]
<i>Mycetochara roubali</i> (Maran, 1935)	Tenebrionidae	VU	B2ab (iii, iv)	<i>F. sylvatica</i> , <i>Tilia</i> spp., <i>Alnus</i> spp., <i>Corylus</i> spp. [131]
<i>Platydema dejeanii</i> (Laporte de Castelnau & Brullé, 1831)	Tenebrionidae	VU	B2ab (iii)	Various broadleaves [132]
<i>Prionychus lugens</i> (Küster, 1850)	Tenebrionidae	EN	B2ab (iii, iv)	Various broadleaves, rarely conifers [79]
<i>Upinella aterrima</i> (Rosenhauer, 1847)	Tenebrionidae	EN	B2ab (ii, iii)	<i>Quercus</i> spp. [126], <i>F. sylvatica</i> [133], <i>Juglans regia</i> [134]
<i>Leipaspis lauricola</i> (Wollaston, 1862)	Trogossitidae	VU	D2	<i>Laurus nobilis</i> (predator) [135]
<i>Leipaspis pinicola</i> (Wollaston, 1862)	Trogossitidae	EN	B2ab (iii)	<i>Pinus</i> spp. (predator) [136]

3. Major Threats

The main reasons that have led to the decline of saproxylic beetles' populations are reduction in their habitats' area [21] are fragmentation and the loss of connectivity between habitats [22,137], along with the decline of deadwood in forests, in terms of both quantity [138] and quality [139]. In particular, the absence of large-diameter deadwood in managed forests and changes in disturbance dynamics (such as the prevention of forest fires and the removal of trees from storm-damaged areas) can be seen as major factors driving many saproxylic species to the edge of extinction.

Generally, for forest insects, several studies indicate that the number of species does not differ much between managed and unmanaged forest stands, whereas the population levels of certain species differ markedly [140]. Saproxylic beetles are less abundant in mature stands [25,141,142] versus much older ones [143], and early successional stands are richer in primary saproxylics and/or bark dwellers [144]. Hence, saproxylic beetles can be naturally abundant in unmanaged forests, but are mostly rare in long-managed forests and, especially, in monocultures. Despite the fact that some intensively managed forests (e.g., coppice forests) can have high conservation value [145], forest management is the most important driver of saproxylic beetles' diversity and is considered to be their main threat, since they demonstrate sensitivity to timber-harvest practices [146,147]. Forest management practices that drastically reduce the quantity and quality of deadwood available, or alter the habitat structure—usually based on clear felling with site preparation and subsequent planting or seeding, followed by a few thinning operations during the rotation cycle—can be a major threat to these communities [18,138,148,149].

Deadwood plays a major role in forest ecosystems, as it stores carbon, nutrients, and water, influences soil's development and regeneration by reducing erosion, and acts as a reservoir of biodiversity by retaining complex trophic chains and providing microhabitats that host a broad diversity of organisms, including saproxylic species [16,20,29,44,138,150,151]. It has been estimated that deadwood-related biodiversity alone represents about 30% of the global forest biodiversity [152], reaching 50% in groups such as beetles [153]. Depending on the forest type, deadwood quantities ranging from 20 m³/ha to 50 m³/ha have been identified as a threshold to maintain the majority of saproxylic species, while very demanding species require more than 100 m³/ha [154]. Even though all of the deadwood is important, the

size of the deadwood seems to be relevant, since the larger the size of the debris, the higher the environmental suitability for saproxylic insects [20]. This is because a larger diameter and, therefore, a greater volume—or a combination of a large diameter with a significant length—can increase the heterogeneity of available microhabitats and, therefore, the number of potential ecological niches, allowing the more specialized organisms to occupy the same space at the same time [29]. In addition, large fragments take longer to decompose and maintain a more stable microclimate within them, while fragments with greater surface area and volume can support more diversified and consistent fungal communities, to which numerous species of saproxylic insects are linked [20,29]. However, studies have evidenced that high-quality and abundant decaying parts of still-living trees, such as relatively small wood from the dead branches of still-standing trees, can also host peculiarly rich saproxylic fauna—sometimes even richer than that of large fallen trees and logs [29].

Sun exposure is known as an important factor for saproxylic insect species, and many species are primarily associated with Sun-exposed environments [155–157]. However, the importance of Sun-exposed sites may have been overestimated, since invertebrates tend to be more active in Sun-exposed conditions [158]. Species adapted to Sun-exposed deadwood may be particularly vulnerable [147]. Thus, for saproxylic beetles, high stem densities in managed forests can be inappropriate, while shade and low temperatures may render deadwood unsuitable as a habitat [159].

Given the fact that most of these species have low dispersal capability [150,160], spatial and temporal breaks in habitat continuity can lead to population declines and extinctions. Habitat heterogeneity is widely recognized as an important factor driving saproxylic beetles' assemblage, and maintaining their habitats' continuity is crucial [161].

The prevention of forest fires can also affect saproxylic beetles' populations. Fire rapidly changes the species composition [162] and functional diversity of saproxylic beetles [163] and increases their species richness [164]. Fire also supports open-habitat-associated species, including most rare saproxylic species [165,166], as it contributes to the increasing amount of deadwood [167]. However, fire itself, e.g., the burning of rough hillsides to refresh the pastures for grazing and to suppress scrub development, can result in the early death of trees and suppress natural regeneration, which can pose a threat to isolated and vulnerable populations of beetles such as *B. splendens* in the Mediterranean, while fire suppression is a major threat to many boreal beetles, which need the resulting burnt wood [53].

4. Saproxylic Insects as Forest Pests

Despite the fact that saproxylic beetles are considered to be pest species according to traditional forestry practices because they reduce the value of timber, as well as being indicators of forest degradation [20], none of the 93 species assessed as endangered have been reported to damage timber quality or production. On the contrary, many saproxylic beetles considered to be pests have been assessed as NT, LC, or DD. The NT category is assigned when a species does not qualify for one of the threatened categories but is likely to be assigned as such in the near future [168].

The global category may not be the same as a national or regional category for a particular taxon, and population trends may differ between particular regions. For example, the great Capricorn beetle *Cerambyx cerdo* (Coleoptera, Cerambycidae)—a saproxylic beetle known to colonize young or healthy living trees [60,169] and become harmful [170–172]—was listed as VU under criteria A1c + 2c in the assessment of 1996 [173], but in the assessment of the Mediterranean region in 2015 it was listed as LC [174]. The European stag beetle *Lucanus cervus* (Coleoptera, Lucanidae), known to damage mostly logged trees, is listed as NT because although this species is widely distributed in Europe, it is in significant decline in the north and central parts of its range, and future trends of European forests will pose serious threats, making the species close to qualifying for VU [175,176]. Both are incorporated in Annex II of the EU Habitats Directive, which imposes the obligation to determine the status of the species, to monitor it, and to establish special protected areas within the Natura 2000 network,

but not in commercial forests. Re-evaluation of taxa against the criteria should be conducted at appropriate intervals, especially for taxa listed as NT or DD, as well as for threatened taxa whose status is known or suspected to be deteriorating [36]. *Ceruchus chrysomelinus* (Coleoptera, Lucanidae), listed as NT, has a very specific habitat type that is already highly fragmented and subject to continuing significant decline. Although this species has a relatively wide distribution, its area of occupancy (AOO) is small as it is only found in a very specific type of habitat. The AOO of this species has not been quantified, but it may not be much greater than 2000 km². The rate of loss of suitable habitat has not been quantified, but it is significant, and it may potentially increase in the coming years [177].

Data on the population trends of many species are extremely poor at present, and increased efforts are needed in monitoring European saproxylic beetles. In Europe, 12.9% (89 species) of saproxylic beetle populations are thought to be in decline; for half of the species (345 species), the population trend is unknown, while 14.8% of these (51 species) are threatened [41]. Since further assessments for the taxa assessed as DD or NE have to be made, as long as the decline of the current populations continues due to habitat destruction [178,179], the number of threatened taxa considered as pests will increase in the future.

To prevent persecution of saproxylic beetles that are considered to be pests, the use of semiochemicals [180,181] and endotherapeutic treatments (i.e., injection of systemic insecticides into the trunks) [172], are considered to be environmentally friendly forest sanitation methods, since they allow the manipulation of insects to alter their distribution and abundance in forest habitats to meet both forestry and conservation goals [182]. However, the best way to prevent saproxylic beetles' loss and conserve their populations with minimal impacts on timber production is the sustainable management of their habitats [183].

5. To Conserve or to Control?

To answer the question of whether to conserve or to control a saproxylic beetle species, a decision-making approach must be chosen. First, we must consider whether the infested area covers the Natura 2000 network or not (Figure 1). Based on the Habitats Directive, if an area or site is included in the Natura 2000 network, intervention measures negatively affecting conservation and biodiversity cannot be adopted. Otherwise, the adoption of pest control actions can be considered, depending on the evaluation of the presence of threatened and endangered species and on the damage to timber production.

Secondly, we must check whether the species considered as a pest is listed in the IUCN Red List or any other regional red list or national red book. National and regional red lists are high-priority, and taxa listed in a regional or a national list considered to be threatened must be conserved, even if they are listed as NT or LC globally. For example, *C. chrysomelinus* is listed as NT in the IUCN Red List globally, but is ranked on the red lists of many European countries among strongly threatened species (e.g., [184–187]), so it must be conserved in these countries regardless of the damage it causes.

If a taxon is listed as LC or NT globally and regionally and exhibits population outbreaks in commercial forests, then we can control it. If it is endangered, it depends on the criteria. Taxa listed as CR must be conserved in both natural and commercial forests. For example, if *Trichoferus bergeri* (Coleoptera, Cerambycidae) becomes a pest for carobs in the future, we must continue our conservation actions, since it is critically endangered, endemic, and its host plants are not threatened. Therefore, protecting their habitat, retaining old-growth trees, and increasing coarse wood debris must be the management methods to be included in commercial forests, regardless of the damage caused to timber production. For taxa listed as EN or VU, the conservation or control approach depends on the criteria under which the taxon is considered to be threatened. Taxa listed as threatened under criterion A (population size reduction) or under criterion B (the size of the geographic distribution range of the species—the most common criterion in saproxylic beetles) can be controlled if their population outbreaks have negative impacts on timber quality and/or quantity, since their overall population is not expected to decline due to our control methods. For example,

if an oak forest has severe damages from *Necydalis ulmi* (Coleoptera, Cerambycidae)—a saproxylic beetle that prefers living trees with hollows—and reduced timber production, we can control the population, since it is listed VU under criterion B. Instead, for taxa listed as threatened under criterion C (small population and decline) and, especially, under criterion D (very small or restricted population), we must conserve the population regardless of the damage caused to timber production. Most of these taxa are endemic in Europe or to a specific country or an isolated island (e.g., *Neopiciella sicula* in Crete and *Ampedus corsicus* in Corsica), and a consideration for enlisting in a national red list is encouraged. Criterion E (quantitative analysis) has not applied to any saproxylic beetle taxon so far.

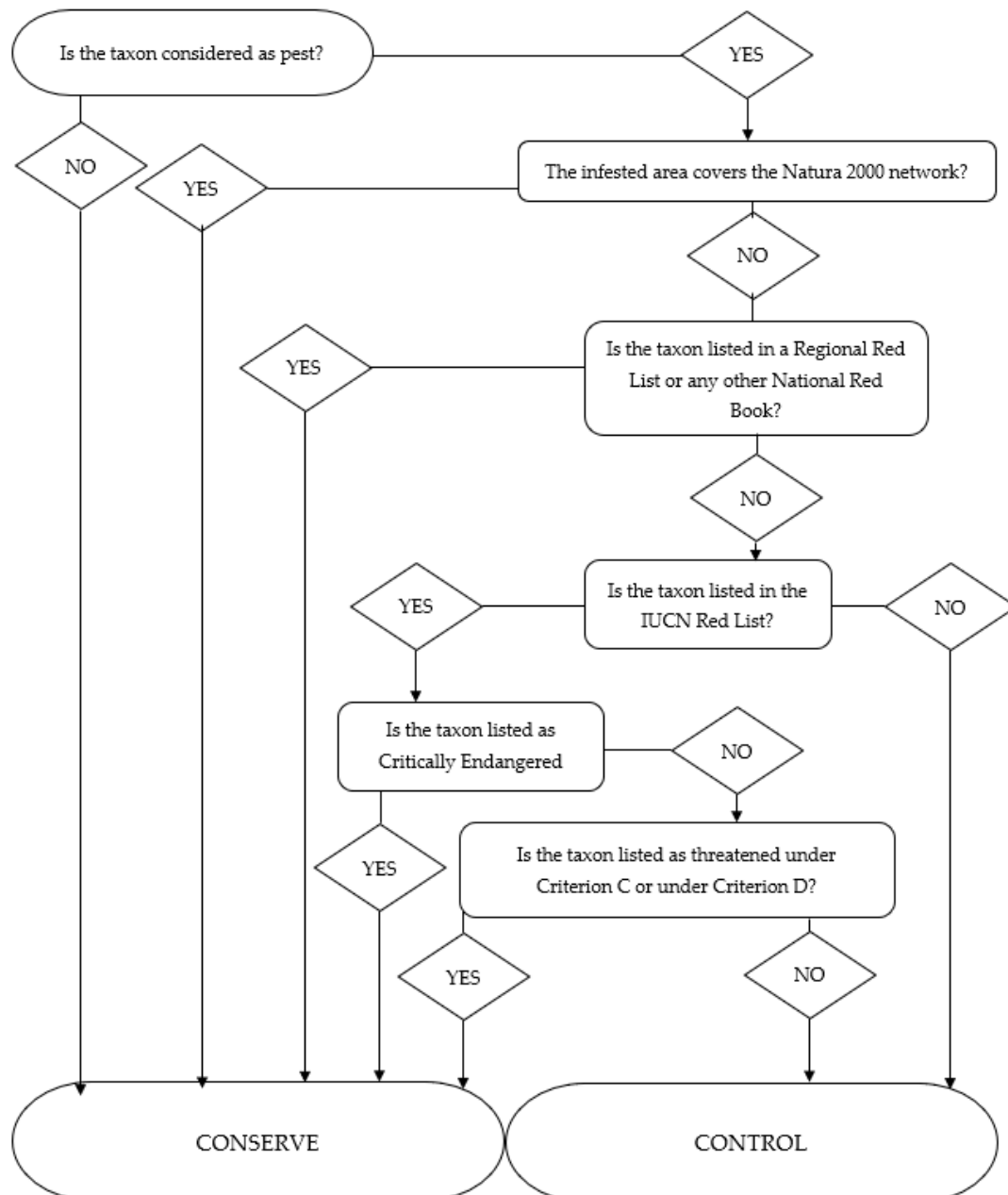


Figure 1. Simplified decision-making flowchart based on European legislation and IUCN Red List of Threatened Species for the application of control measures against saproxylic beetles that are or may be considered as pests.

6. Forest Management Practices for Conserving Saproxylic Beetles' Communities

The conservation and restoration of forest ecosystems is one of the major critical tasks for the protection of global ecosystems [188]. Even though nature reserves are included among the IUCN categories of protected areas aiming at the conservation of biodiversity [189], putting commercial forests under protection does not restore the biodiversity of saproxylic organisms to levels comparable to those of unmanaged natural forests [190].

The best way to prevent saproxylic beetles' loss and conserve their populations is the sustainable management of their habitats [183], with alternative, close-to-nature silvicultural methods that are important for increasing biodiversity in commercial forests [13]. Forest management can be crucial in creating ideal habitats for saproxylic beetles, such as high stumps [155,191] and on logging residues [192], supporting a wide spectrum of saproxylic species. In extensively managed forests, the cutting of trees should be implemented to create artificial stumps and deadwood islands [144].

The most important part in conserving saproxylic beetles' populations is the maintenance of deadwood in the forests, which is sensitive to habitat modifications and management practices [193–196]. In commercial forests, deadwood is under-represented compared to natural forests, with different allocation to size and decomposition classes, and follows different production and decomposition dynamics [197]. Deadwood management, also known as morticulture [198], with a wide variety of types of deadwood, should cater for saproxylic insects. Saproxylic insects use dead and decaying wood as a habitat or as a breeding substrate, often at a particular stage of decay. This results in a limited time window within which a habitat may be colonized [44,138,199–201]. At the landscape level, the bottom line is that management should retain sufficient elements of natural forest dynamics to maintain the ecological processes in which mature the timber habitat is involved. Large branches and other decaying parts of trees must be left on the ground because they have a high “attractive power” to egg-laying females as fresh deadwood [128], due to the major importance of small-diameter deadwood for saproxylic beetles' populations [202–205], influenced by both forest management and canopy cover, and it is highly recommended to forbid the collection of deadwood for fuelwood by the local residents [206]. In general, forest managers have to leave small-diameter debris, larger branches, and trunks on the ground, increase the number of snags as “habitat trees”, and ensure the continued coexistence of different types of deadwood [144].

Although many saproxylic insects have been classified as specific to host tree genera—and some even as monophagous to a single tree species—the evidence is often weak [192,207,208]. Earlier research concluded that almost 30% of the invertebrates found in *Q. robur* were considered to be monophagous [209]. However, host specificity seems to be rare at the tree species level, although it is common at higher plant taxonomic levels [210]. In addition, the degree of host specificity in an assemblage decreases with increasing wood decay [20,209,211], since most saproxylic beetles tend to prefer the early and medium stages of wood decay [18,103,205].

Since heterogeneity of the habitats is directly correlated with trees' age, silviculture practices must transform from even-aged to uneven-aged practices. Uneven-aged silviculture has the capacity to maintain almost similar (or at least better than even-aged approaches) beetle composition to unmanaged forests [212]. Selective felling and retention are preferred over the clear-cut practices that are usually applied in even-aged stands for maintaining species that are normally found in forests with old-growth characteristics, such as saproxylic beetles [213–215]. Retention can be a useful tool to maximize both forest production and saproxylic beetles' conservation. Despite the fact that the benefits of standard retention on saproxylic beetles are small, since overall species richness peaks within a few years from felling and then declines rapidly to the pretreatment level [163], late-stage xylophages remain abundant for at least 10 years [216]. Retention levels per se have minor effects on saproxylic beetles [217,218], which can be beneficial for pest management. In Finland, high levels of retention were found to protect pine saplings from pine weevil (*Hyllobius* spp.) attacks, through providing alternative food sources [219,220].

Mixed forests provide increased tree diversity and higher structural complexity of mixtures, which are associated with improved habitat conditions for many species [221–223] but can also provide better production and economic outcomes than monocultures [224–226]. Increasing tree species diversity is likely to result in more complex forest structure and composition, thus providing more habitats for predators and parasitoids that may regulate pest populations through top-down biotic interactions [4]. One of the key management issues for saproxylic insects is the maintenance of ecological continuity in space (connectivity) and in time, since many studies indicate that spatial and temporal continuity of deadwood is more important than the amount or variety of deadwood at any particular time and place [160,227–229].

Overall habitat heterogeneity is an important factor, both at small scale as well as at landscape scale. While uneven-aged forest management maximizes within-stand heterogeneity, it was found that applying this system at the landscape scale can lead to overall lower biodiversity compared to an even-aged shelter wood system, which ensures a higher dissimilarity of environmental conditions and resources among forest stands [230]. Hence, a management target should be to increase the number and width of openings and prolong the rotation times to ensure deadwood in intermediate or later stages of decay [144]. Factors such as canopy openness and the structural heterogeneity of stands found in uneven-aged mixed forests are major drivers of saproxylic beetle diversity [147]. High stem densities in managed forests can be inappropriate in general, but canopy closure can provide suitable environmental conditions for active dispersal of many saproxylic beetles [231]. However, given the fact that Sun exposure is crucial for maintaining forest biodiversity, and that exposure generally declines with increasing forest layers, the forest layers and species richness have been found to have negative relationships at the local scale [232]. The preservation or restoration of high forests with closed canopies and increased structural heterogeneity is important for saproxylic beetle conservation [206]. Patch-scale mixtures may allow for more Sun-exposed microsites to develop and may be more favorable for the diversity of saproxylic insect species [233]. Sufficient trees or patches should be retained to allow for some landscape-level temporal and spatial habitat continuity [20,234]. Because of the ephemeral nature of their habitat, saproxylic species often have good dispersal abilities [235,236], and the spatial scale at which mixtures are created is unlikely to have an effect on the probability of colonization per se. Habitat fragmentation occurs for saproxylic beetles on a local scale—specifically, when the distances between deadwood pieces become too large—and high deadwood connectivity should be achieved throughout the whole forest area to support them [160], since the contribution of patch-scale mixtures to saproxylic beetles' diversity is nullified in the absence of adequate coarse woody debris [237].

In some rare cases, where there is no possible way to protect the species in nature in a particular place [238], it is possible to preserve or repopulate the species in the wild or maintain them in zoological and botanical gardens [239]. To avoid loss of the population of these species when the inhabited tree is felled and has to be replaced or destroyed, the only option for the larvae is their relocation in the laboratory and rearing by artificial feeding, followed by their reintroduction [240]. Reintroduction is also the only option in regions where species are regionally extinct as a result of a history of forest fragmentation and intensive use [20].

7. Conclusions

Even though saproxylic beetles are considered to be forest pests, none of the taxa of Europe listed as threatened in the IUCN Red List seem to have a negative impact on timber production. Most of them have minor impacts on timber production, while some species are predators of other saproxylic beetles or even pests, contributing to forest pest control. Species considered to be pest species according to traditional forestry practices—such as the great Capricorn beetle or the European stag beetle—were recently excluded from the *European Red List of Saproxylic Beetles*, mainly because their unstable taxonomy strongly hindered data collection and conservation monitoring. However, given the fact that many

taxa have not been assessed for the IUCN Red List, along with population and habitat decline, this status is expected to alter in the future.

The decision-making flowchart suggested in this paper can be utilized at both global and regional levels, where conservation goals may differ. It may also be a useful tool in the future, when assessment of unevaluated taxa and re-evaluation of NT- and DD-listed taxa will update the status of the current red list.

However, the best way to prevent saproxylic beetles' loss and conserve their populations in commercial forests is the sustainable management of their habitats, with alternative, close-to-nature silvicultural methods. Forest management has to adopt sustainable practices to conserve their habitats and, hence, their populations, as well as to maximize timber production. By adopting those practices, no population outbreaks should occur in the future, and their populations should remain stable.

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