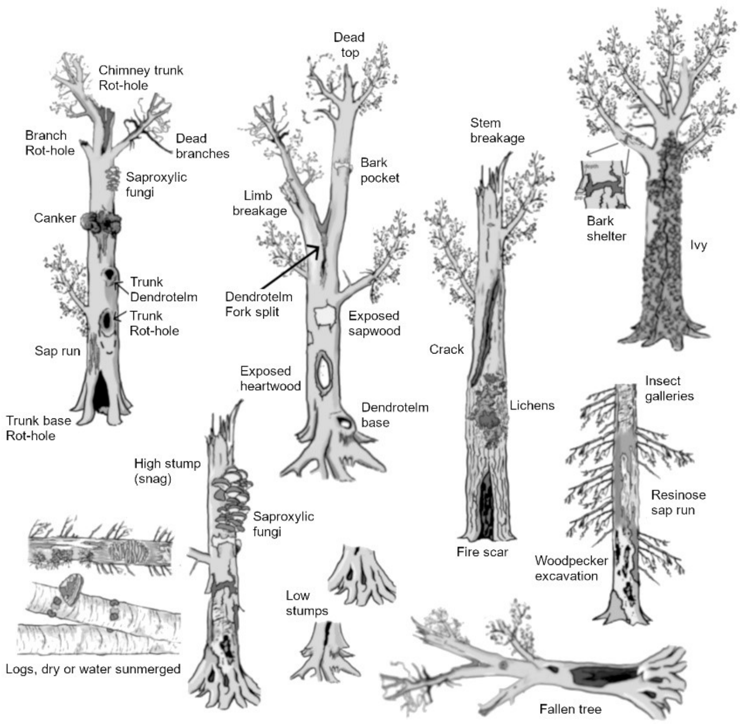
Journaal van Syrphidae

Saproxylic breeding sites for hoverflies (Diptera: Syrphidae): from artificial design to natural habitat management

Jeroen van Steenis



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Saproxylic breeding sites for hoverflies (Diptera: Syrphidae): from artificial design to natural habitat management

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Abstract. This paper introduces the importance of veteran trees, tree related microhabitats (TreMs) and their associated hoverfly (Diptera, Syrphidae) fauna. A broader perspective of creating larval habitat is discussed, based on published and novel insights. It focuses on hoverflies that specialise on veteran trees and reflects upon protection and management regimes to conserve veteran trees, TreMs and associated woody habitats. The lack of veteran trees breeding sites can be resolved by tree veteranisation or by using artificial breeding boxes. Whilst protection of veteran trees is essential, enhancement of open areas with flower resources is also vitally important for the survival of saproxylic hoverflies. The larval and adult ecology of only three out of the 134 known European saproxylic species are properly understood. Thus several suggestions are offered for future research aimed at a thorough understanding of the natural history of this unknown and ecologically relevant group of species. The list includes faunistic surveys and investigations into population dynamics, dispersal capacity and habitat preferences. Alongside this research there is a need to investigate the creation of breeding sites including veteranisation techniques and the use of breeding boxes.

Keywords. breeding boxes, hoverfly lagoons, protection management, Syrphidae in trees, TreMs, veteran trees

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Introduction

As adults, virtually all hoverfly species are known for their importance in pollinating crops and wildflowers all over the world (Ssymank *et al*. 2008; Inouye *et al*. 2015; Moquet *et al*. 2017; Doyle *et al*. 2020; Dunn *et al*. 2020) and the wider interest in this group of insects has increased during the last decades (Fontaine *et al*. 2012; IUCN *et al*. 2022). On the contrary the larvae have a wide range of feeding strategies being from aquatic species to phytophagous, fungivores, and saproxylic species or others predacious on a wide range of preys (Rotheray & Gilbert 2011). Unfortunately, hoverflies are declining at an accelerating rate (Biesmeijer *et al*. 2006; van Eck 2016; Hallmann *et al*. 2017; Gatter *et al*. 2020; Hallmann *et al*. 2021; Morris & Ball 2021; Barendregt *et al*. 2022).

Based on the European Red List of hoverflies which was recently published the 134 species of saproxylic hoverflies represent 15% of the entire European hoverfly fauna of 892 species (Vujić *et al*. 2022). The number of saproxylic species in the different red-list categories, Data Deficient, Least Concern and Near Threatened are 9 (6,7%), 73 (54,5%) and 7 (5,2%) respectively. In the threatened categories Vulnerable, Endangered and Critically Endangered the number of species is 13 (9,7%), 30 (22,4%) and 2 (1,5%) respectively (Vujić *et al*. 2022a). The larvae of saproxylic Syrphidae occupy a wide variety of woody microhabitats in living trees, referred to as TreMs (tree related microhabitats, Fig. 1) and dead wood like stumps and logs (Rotheray 1993; Rotheray & Gilbert 2011).

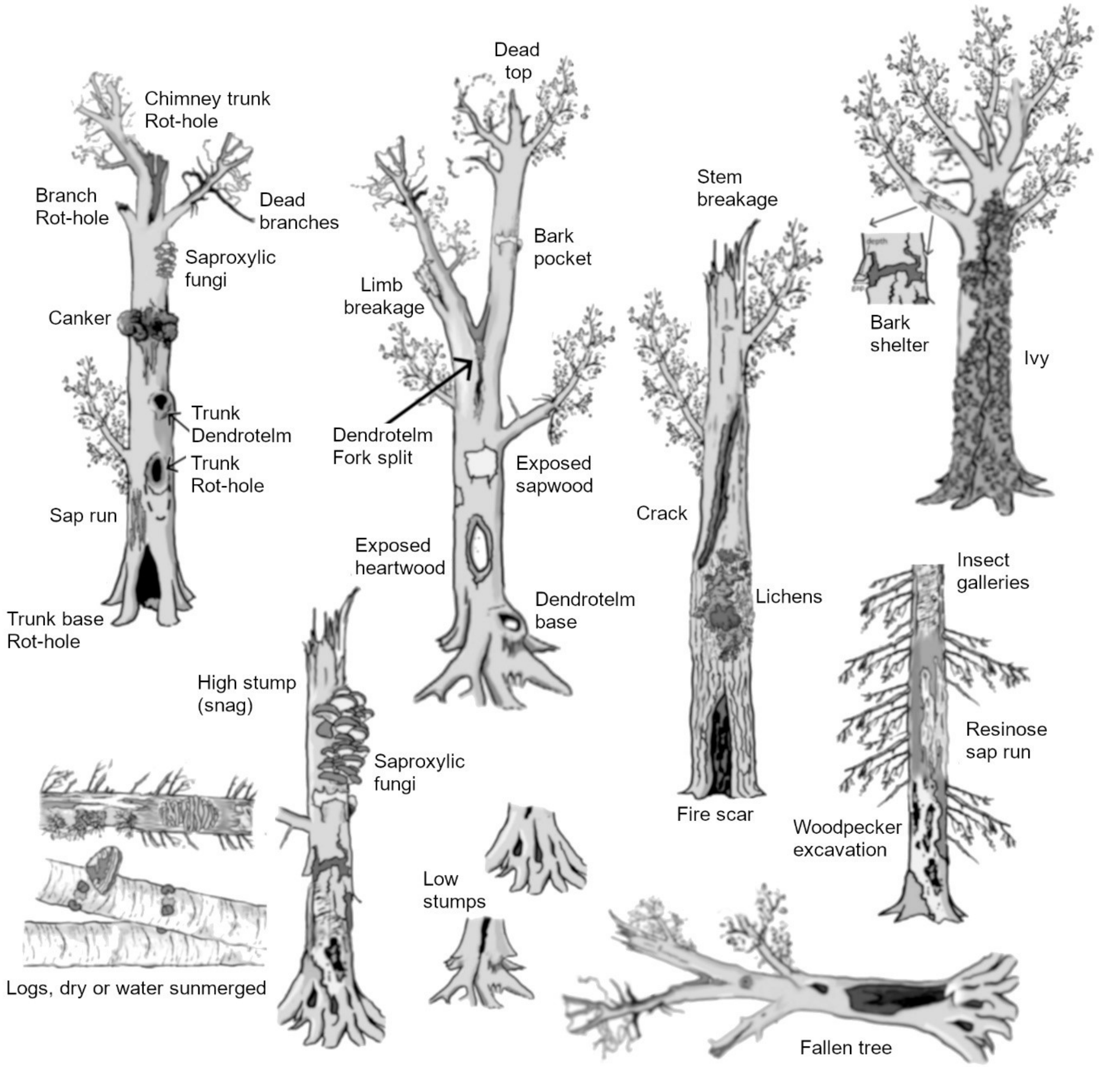

Figure 1. Veteran tree with associated tree-related micro habitats (TreMs). Adjusted from Larrieu *et al*. 2017.

Adults of saproxylic species (Figs 2, 3) have been relatively well investigated, although faunistic information is still lacking for many species. The larvae, have had much less attention and worldwide only 8% of species had been described (Rotheray & Gilbert 2011), however a relevant work exist of several saproxylic species (e.g. Krivosheina & Mamayev 1962; Maibach & Goeldlin 1989; Rotheray 1991, 1993; Rotheray & Perry 1994; Rotheray & Stuke 1998; Rotheray & MacGowan 2000; Krivosheina 2001, 2004, 2018, 2019, 2020; Ricarte *et al*. 2007, 2009; van Steenis 2015; Orengo-Green *et al*. 2023).

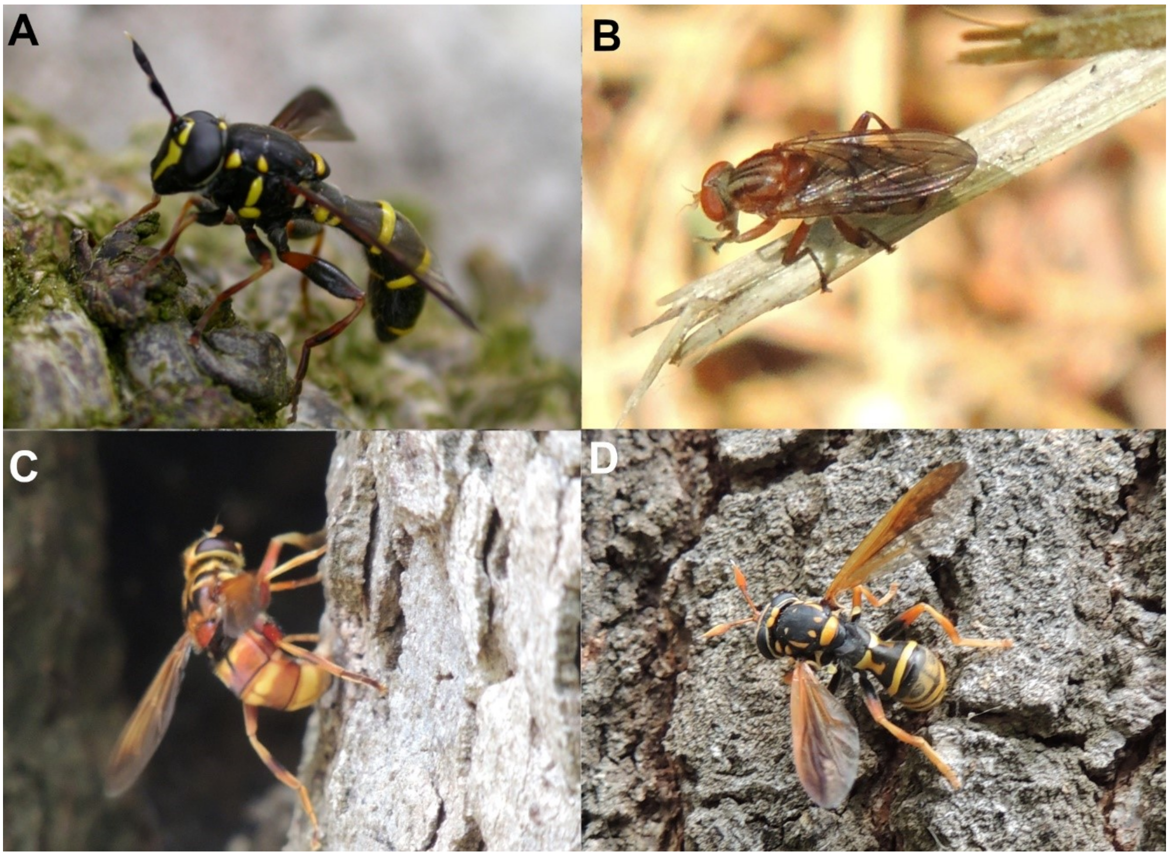

Figure 2. Adult veteran tree specialized Syrphidae, with IUCN Red List category in parentheses. **A**. *Sphiximorpha subsessilis* (Illiger *in* Rossi, 1807) ♂ (LC), defending its territory on *Aesculus hippocastanum* with a sap run. Wijlre, The Netherlands. **B**. *Brachyopa testacea* (Fallén, 1817) ♂ (LC), defending its territory near pine logs (Fig. 6D). Teletskoye Lake, Artybash, Russia. **C**. *Milesia crabroniformis* (Fabricius, 1775) ♀ (LC), egg laying behaviour at a trunk base rot hole on *Platanus orientalis*. (Fig. 5D). Paphos forest, Appides stream, Cyprus. **D**. *Sphiximorpha petronillae* Rondani, 1850 ♀ (EN), egg laying behaviour on *Quercus pubescens* with sap runs (Fig. 5C). Kamenički Park, Novi Sad, Serbia.

Veteran trees are features of natural forests, but also occurring in parks or as single trees, containing many different types of TreMs (Fig. 1), such as trunk cavities, branch holes, exposed heartwood, dead branches and sap-runs (Read 2000, Larrieu *et al*. 2017). This variety of microhabitats has a significant impact on biodiversity, hosting about 2/3 of the terrestrial biodiversity, and enhancing ecosystem functioning (Speight 1989; Read 2000; Grove 2002; Ulyshen 2018; Wetherbee *et al*. 2021; Martin *et al*. 2022; Przepióra & Ciach 2022). Old growth forests provide significant carbon storage and have the capacity to withstand climate change better than young production forests (Hotchkiss 2020). These forests also have a positive effect on retaining water and thus regulation of rainfall and local reduction of temperature fluctuations (Rubino & McCarthy 2003; Sist *et al*. 2014; Hotchkiss 2020; Nolan *et al*. 2020). Veteran trees also play a major role in pest management by providing habitat for pest predator species that reduce economic damage and thus decrease the demand for the use of harmful pesticides (Wetherbee *et al*. 2020).

The following exemplifies the importance of saproxylic insects "Saproxylic insects comprise the largest component of the biodiversity in terrestrial ecosystems. They are responsible for the mechanical breakdown of woody material both directly, by tunnelling and feeding in living trees that are decaying, snags (standing dead trees) and logs (fallen trees, portions of trunk and large branches), or indirectly, through symbiotic relationships with fungi and other microorganisms that humidify wood." (Marcos-García *et al*. 2011). In natural and unmanaged forest TreMs reach a high diversity and are also more numerous compared to managed forests (Martin *et al*. 2022; Przepióra & Ciach 2022).

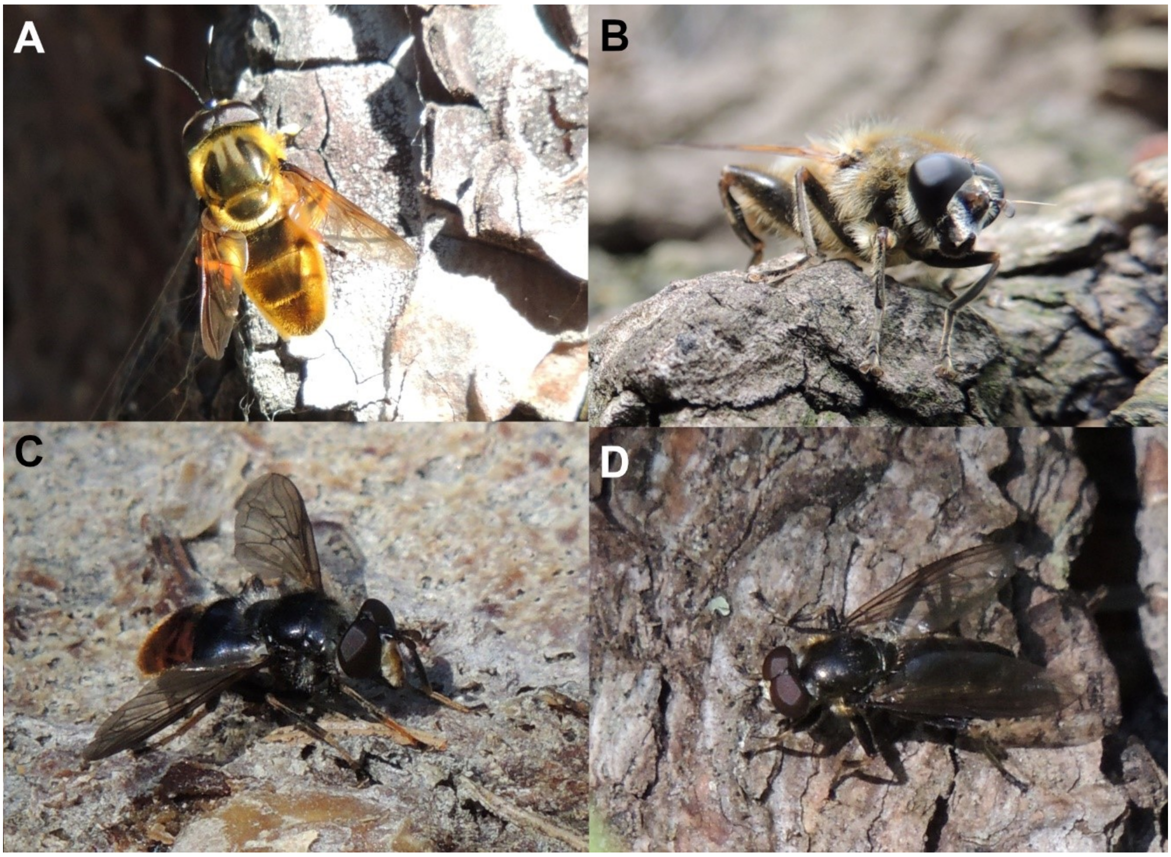

Figure 3. Adult veteran tree specialized Syrphidae, with IUCN Red List category in parentheses. **A**. *Callicera macquarti* Rondani, 1844 ♂ (EN), defending its territory on *Pinus brutia*. Paphos forest, Appides stream, Cyprus. **B**. *Brachypalpus valgus* (Panzer, 1798) ♂ (LC), defending its territory on *Salix alba* (Fig. 5B). University park. Novi Sad. Serbia. **C**. *Blera fallax* ♂ (LC), defending its territory on a pine stump (Fig. 6C). Teletskoye lake, Artybash, Russia. **D**. *Xylota pseudoignava* Mutin, 1984 ♂ (non European), defending its territory on a pine stump (Fig. 6C). Teletskoye lake, Artybash, Russia.

To establish conservation action plans, the biology of a species needs to be fully known, including its dispersal capacity, larval stages and the microhabitat preferences (Vujić *et al*. In press). So far, only three species, *Blera fallax* (Linnaeus, 1758), *Callicera rufa* Schummel, 1842 and *Hammerschmidtia ferruginea* (Fallén, 1817), have been included in species recovery plans (Rotheray & MacGowan 2000; Rotheray & Rotheray 2012; Rotheray 2013; Rotheray & MacGowan 2015). Many more such plans need to be included to ensure continuity and extent of the habitats of these species (e.g. Jukes 2009; IUCN *et al*. 2022).

This paper aims to give an overview of research to date on hoverflies that specialise in veteran trees. Other research on management to promote veteran trees and their associated TreMs will also be discussed, together with, proposals for future research.

References used in this paper are presented to stimulate further reading and only represent part of the exhaustive literature that can be found on this topic (van Steenis 2022).

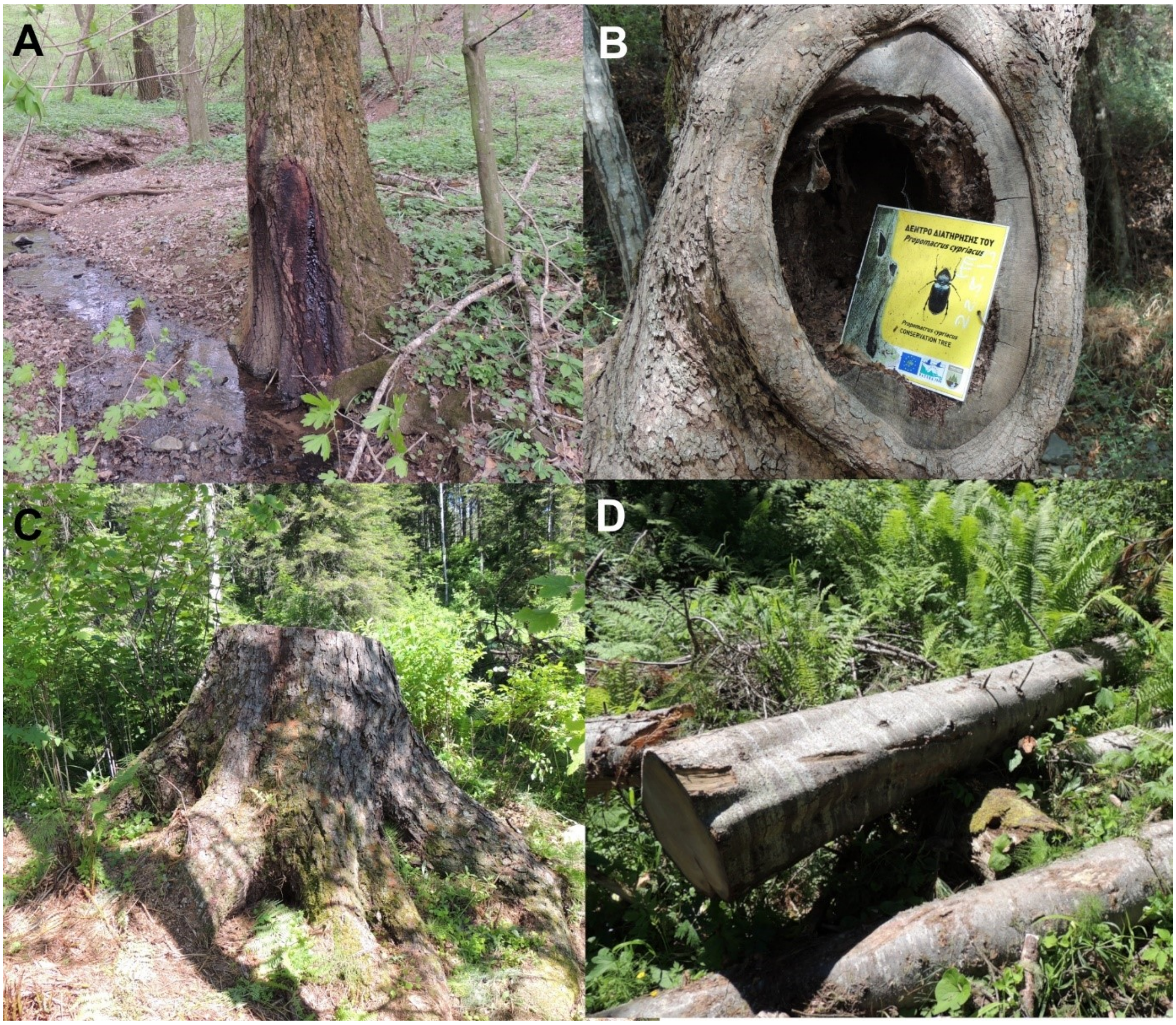

Figure 4. Larval habitat veteran tree specialized Syrphidae. **A**. *Populus alba*, sap run. Fruška Gora, Stražilovo, Serbia. **B**. *Quercus infectoria*, trunk rot-hole. Tzelefos Bridge, Cyprus. **C**. Pine stump, sappy decay and trunk rot-hole. Teletskoye lake, Artybash. Russia. **D**. Pine logs. Teletskoye lake, Artybash, Russia.

Threatened veteran tree specialized Syrphidae found in the surroundings, IUCN category in parentheses.
A: *Brachyopa maculipennis* Thompson, 1980 (EN) and *B. plena* Collin, 1939 (NT).
B: *Ceriana glaebosa* van Steenis & Ricarte *in* van Steenis *et al*. 2016 (EN).
C and D: *Blera eoa* (Stackelberg, 1928) (EN), *Callicera aenea* (Fabricius, 1777) (VU), *Chalcosyrphus femoratus* (Linnaeus, 1758) (VU), *C. rufipes* (Loew, 1873) (EN), *Sphecomyia vespiformis* (Gorski, 1852) (NT), *Temnostoma angustistriatum* Krivosheina, 2002 (EN) amd *T. apiforme* (Fabricius, 1794) (NT).

Creating breeding sites for Syrphidae

Creation of hoverfly breeding sites has happened since humans started to shape the environment to meet its own needs. Examples include felling wood for cooking, creating tools and housing and thus creating coppice and also stumps and logs. These actions were not directly intended to create valuable habitat but have influenced the occurrence of saproxylic species (Rösch 2012; Fazan *et al*. 2020). More recently, creation of artificial breeding places for birds (Onur Erman 2014) and bats (Rueegger 2016) has become standard conservation tools, whilst bee-hotels have become a popular addition to the list of artificial breeding sites (MacIvor 2017). Many papers have been published about the differences between natural tree-holes, man-made tree-holes and artificial breeding boxes in a wide variety of research setups. These investigations all demonstrate the value of breeding boxes and the composition of the breeding medium that is used (Jansson *et al*. 2009; Carlsson *et al*. 2016; Griffiths *et al*. 2018; Dulisz *et al*. 2022). Creation of artificial breeding sites for Syrphidae was first investigated by Maibach & Goedlin (1989) and MacGowan (1994), followed by many attempts to enhance the effectiveness of the artificial breeding medium (e.g. MacGowan & Rotheray 2007; Rotheray & MacGowan 2015; Foster & Leach 2021; RZSS 2022). Several of these attempts only had very limited results, mostly attracting *Myathropa florea* (Linnaeus, 1758) or an inability to maintain a population with larvae dying before reaching maturity (Rotheray 2004; Schmid & Moertelmaier 2007; van Steenis 2015; Wetherbee *et al*. 2022). In other cases it was possible to maintain moisture over several years and produce continuing generations of saproxylic Syrphidae (Rotheray 2013; Taylor *et al*. 2021). These examples suggest that larval biology of saproxylic species requires more detailed understanding microhabitat preferences and the specific nutritional, physical and chemical composition of its breeding medium, thus, much more research is needed (Sánchez-Galván *et al*. 2014; Ulyshen 2018; IUCN *et al*. 2022; Wetherbee *et al*. 2022).

Artificially created breeding sites need maintenance (Lindemayer *et al*. 2009) with special attention paid to ensure suitable humidity (Rotheray 2004). Personal experience suggests that this process is demanding. Artificial sites are therefore imperfect for species protection (Jansson *et al.* 2009). Instead, they should be seen as a means of enhancing short term survival, thus making research possible without risking local extinction of the species under investigation. A more sustainable way of protecting saproxylic Syrphidae species depends upon habitat protection of larval and adult and through preservation of veteran trees, their associated TreMs and food sources for the adults.

Practices to sustain saproxylic species

Forestry management

In forestry practice clear-felling large areas is commonplace, but it often leads to the creation of stumps, snags and living tall stumps that maintain, at least some of, the habitat utilised by saproxylic faunas (e.g. Jonsell *et al*. 2004; Sandström *et al*. 2019). Most of the research conducted so far has involved Coleoptera. It shows that the most important factor in maintaining high biodiversity of saproxylics is the creation of tall and low stumps (e.g. Jonsell & Weslien 2003; Lindhe & Lindelöw 2003). Felling, preferably during winter, or at least well before the start of the season has a positive impact on beetle abundance (Foit 2012). Species abundance and composition does not differ much between low or tall pine stumps (Hjälten *et al*. 2010); however, in broadleaved trees, it seems that tall stumps represent a more favourable habitat (Jonsell *et al*. 2004; Lindhe & Lindelöw 2004). Leaving long logs of either tree species increases biodiversity even more (Jonsell & Weslien 2003). Saproxylic beetles and Syrphidae respond differently to forestry management. For example, longhorn beetles prefer dense oak-dominated areas with a high volume of snags and veteran trees, while saproxylic hoverflies are more limited to open-stands with large veteran trees and a well-developed, species rich herb layer (Fayt *et al*. 2006; Nol *et al*. 2006). Diptera and especially Syrphidae larvae need moisture to develop like dendrotlems (water filled rot-holes), here differentiated from dry rot-holes (Fig. 1), sap-runs and moist decaying stumps and logs.

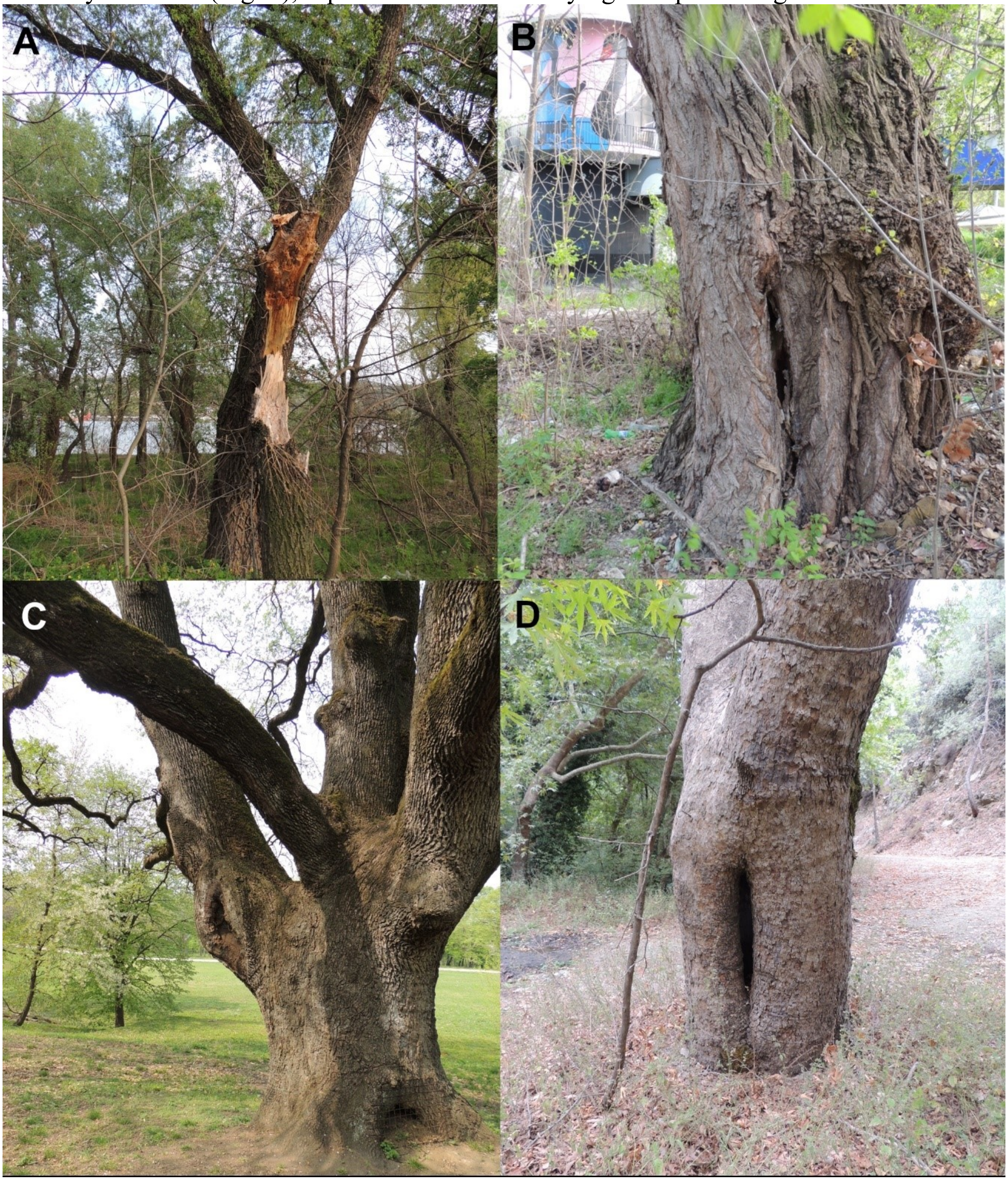

Figure 5. Larval habitat veteran tree specialized Syrphidae. **A**. *Salix alba*, limb breakage and sap run. University park, Novi Sad, Serbia. **B**. *Salix alba*, sap runs, cracks and trunk base rot-holes. University park, Novi Sad, Serbia. **C**. *Quercus pubescens*, several limb breakages, sap runs and trunk rot-holes. Kamenički Park, Novi Sad, Serbia. **D**. *Platanus orientalis*, trunk base rot-hole. Paphos forest, Appides stream, Cyprus.

Threatened veteran tree specialized Syrphidae found in the surroundings, IUCN category in parentheses.
A and B: *Brachyopa maculipennis* (EN).
C: *Brachyopa grunewaldensis* Kassebeer, 2000 (EN), *B. silviae* Doczkal & Dziock, 2004 (EN), *Brachypalpus* aff *valgus* (possibly CR) and *Sphiximorpha petronillae* (EN).
D: *Callicera macquarti* (EN).

Sap-runs and partially water submerged logs are almost exclusively inhabited by larvae of this order (Maibach & Goeldlin de Tiefenau 1992; Jukes 2009; van Eck 2016; van Eck *et al*. 2016;

Wolton & Luff 2016). Thus, not only veteran trees but the entire forest habitat needs conservation (Hotchkiss 2020). Several of the important tree species such as oak, beech and pine can take more than 100 years to become a multiple TreMs tree (Hövemeyer & Schauermann 2003; Drobyshev *et al*. 2008; Piovesan & Biondi 2021) able to host a wide variety of saproxylic insects, while they can reach an age of more than 1000 years (Gandy 2019; van Steenis *et al.* 2019; Nolan *et al*. 2020). Also, the time span in which wet decay, a suitable medium for the larvae of many saproxylic Syrphidae, will be formed or will last depends also on the actual tree species (Rotheray & Gilbert 2011). Conversely, fast growing trees such as birch (*Betula* spp.), poplars and aspen (*Populus* sp.) mature at a faster rate (Nieuwenhuis & Barrett 2002; Ninufu 2008; Myking *et al*. 2011; Caudullo & de Rigo 2016) and logs can be productive as breeding sites within just 20–50 years when diameters have reached 10–25 cm (Rotheray 1993; Krivosheina 2004; Drees 1999; Rotheray *et al.* 2008). There is a succession in the species composition in decaying logs in which the first years sappy decay develops under intact bark, which turns into bark loosing hardwood logs and eventually become wet soft wood decay. The sappy decay may persist from 2–7 years after which the hardwood period will last an additional 2–5 years (Derksen 1941; Hövemeyer & Schauermann 2003; Rotheray *et al*. 2008; Krivosheina 2018, 2019).

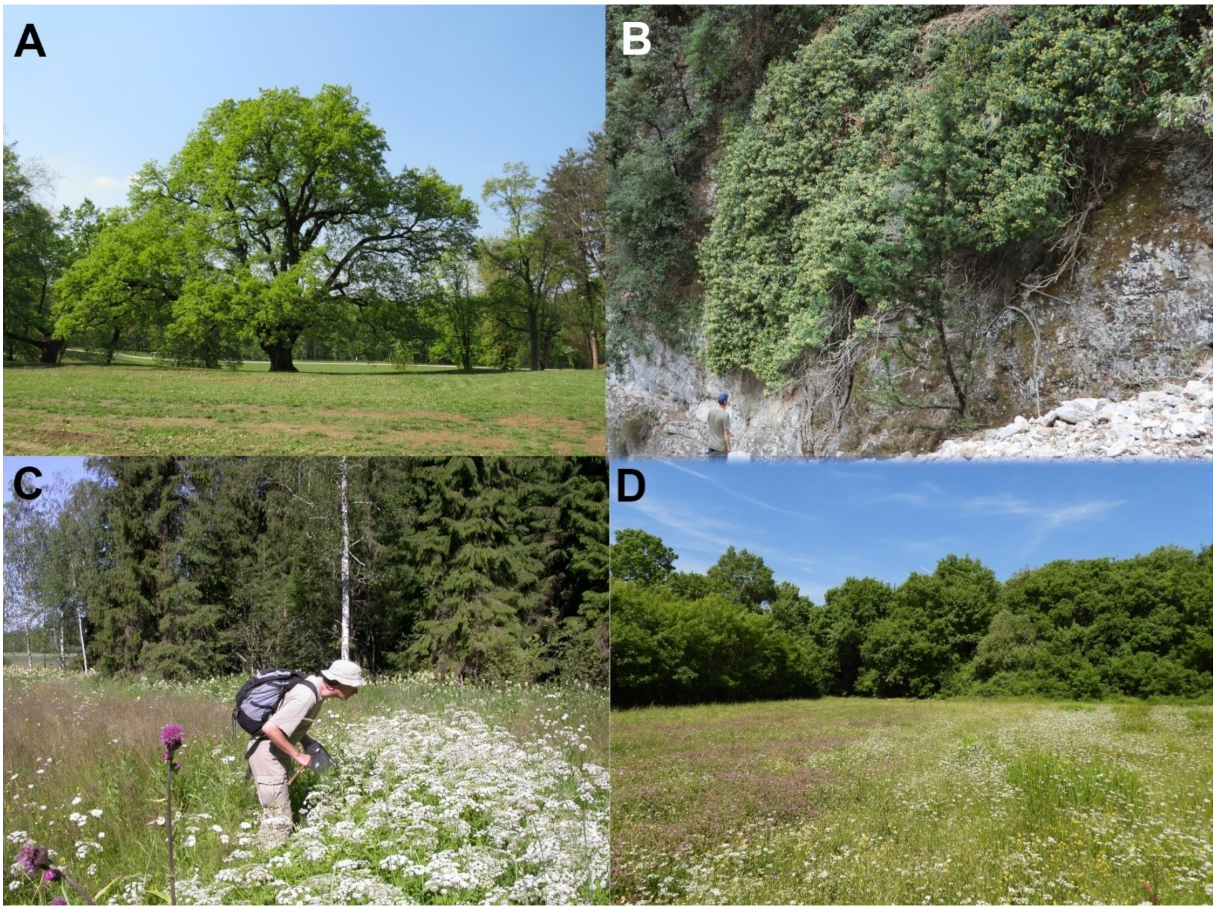

Figure 6. Adult habitat veteran tree specialized Syrphidae. **A**. Kamenički Park, Novi Sad, Serbia. **B**. Flowering *Hedera helix*. Imbros Gorge, Crete, Greece. **C**. Flower rich forest glade. Riikanmaa, Joutseno, Finland. **D**. Flower rich forest glade. Strandzha; Sinemorets, Bulgaria.
Threatened veteran tree specialized Syrphidae found in the surroundings, IUCN category in parentheses.
A: see Fig. 5C.
B: *Callicera macquarti* (EN), *C. rufa* (VU), *C. spinolae* Rondani, 1844 (VU) and *Milesia cretica* Bot & van Steenis *in* Bot *et al*. 2022 (possibly VU).
C: *Temnostoma apiforme* (NT) and *Temnostoma sericomyiaeforme* (Portschinsky, 1887) (VU).
D: *Chalcosyrphus pannonicus* (Oldenberg, 1916) (EN) and *Psilota nana* Smit & Vujić, 2008 (EN).

Veteran trees and their remnant stumps and logs play a key role in the survival of saproxylic species (Figs 1, 4, 5), however, in Syrphidae much more is needed than the protection of these trees. Without adequate flowering resources (Fig. 6) the adults will not be able to mature, nor to develop their eggs for which nectar and pollen are essential (Ssymank & Gilbert 1993; Moquet *et al*. 2017; Nicholas *et al*. 2018). The problem with forestry conservation is that a closed canopy diminishes the development of TreMs on veteran trees (Miklín *et al*. 2018) and also hinders the growth of flower resources for the adult Syrphidae (van Steenis 2016; Hotchkiss 2022).

Preservation of veteran trees outside forests

Saproxylic Syrphidae are mostly associated with forest habitats, but urban parks and even single (hedgerow) trees can harbour many saproxylic Syrphidae (Coe 1953; Ahnlund 1996; Andersson 1999; Sjuts 2004; van Steenis *et al*. 2019). As such, they have the potential to form important islands and steppingstones in an otherwise forest free environment. The protection of forest habitats, trees in city parks and single trees is therefore of considerable importance. Trees in floodplain forests (Figs 5A, 5B), in city parks (Fig. 5C) or single trees also known as trees outside of forests (TOF) hold many TreMs with a large diversity of saproxylic species and need protection (Coe 1953; Andersson 1999; Schlaghamerský 2003; de Foresta 2013; Alexander *et al*. 2015; Miklín *et al*. 2017; Gandy 2019; van Steenis *et al*. 2019). Protection management should thus be directed to ensuring the continued presence of veteran trees, open areas and enhancing hydrology (Peterken 2002; Davies *et al*. 2008; Hotchkiss 2022).

Breeding boxes

In areas where there are very few old or veteran trees, the use of breeding boxes could help to overcome the lack of suitable breeding habitat. It should be noted that the maintenance of these breeding boxes is time consuming and it should only be used as short-term solution or in enhancing populations for research purposes. The effectiveness of these artificial breeding sites has never been fully tested, although several efforts have been made to produce these so-called breeding boxes with varying degrees of success (Maibach & Goledlin 1992; Rotheray 2004; Schmid & Moertelmaier 2007; Rotheray & MacGowan 2015).

Ideally, most effort should focus upon veteranisation of trees instead of maintaining less reliable and more time consuming artificial habitats. Nevertheless, creating easily made and maintained hoverfly lagoons for saprophagous aquatic Syrphidae has been very successful in Great Britain (Buzz Club 2018). The breeding medium used consisted of different decaying matter, mostly grass (Fig. 7A), but also decaying vegetables such as potatoes and carrots, fresh sawdust, or droppings of different small or large herbivores. In my own experience, most species were attracted to hoverfly lagoons positioned on the ground and filled with decaying vegetables. The lagoons and pet-bottles with sawdust attached to trees at different hights only attracted *Myathropa florea*. When a more robust breeding box (Figs 7B, 7C) was trialled, incorporating different sawdust mixtures, again *M. florea* was almost exclusively the occupant. Breeding medium mixture will probably make a great difference in attracting different species and this needs to be investigated in greater detail.

Figure 7. Artificial breeding sites. **A**. Hoverfly lagoon for aquatic Syrphidae (from the Buzz Club, 2018). **B, C**. Breeding boxes from "Syrphidae in trees" for saproxylic Syrphidae. B. Breeding box in pine, Soest, The Netherlands. **C**. From left to right: "internal" Pet-bottle surrounded by saw-dust (back-panel not mounted); saw-dust filled box (back panel not mounted); lateral view; frontal view, with closed back panel, before hanging the box in the tree a seconf Pet-bottle filled with saw-dust and water was placed into the "internal" Pet-bottle.

Recommendations for preservation of saproxylic species

In the literature, different recommendations are suggested for conservation of saproxylic species. In aiming for 4–16 veteran trees per hectare there is a need to ensure a supply 5–20 young trees per hectare: 'legacy trees' that will become veteran trees. They should be protected from felling or other damage causing decline in the number of TreMs and these trees should be marked in an unambiguous way, not like in Fig. 8. In some cases, intentionally damaging trees might enhance the formation of TreMs (e.g. Lewis 1998; Jonsell *et al*. 2004). Maintaining or even creating "open" space such as forest edges, glades or places around legacy trees is also needed to increase the species richness of adult feeding sources like flowering herbs, shrubs and trees as in Syrphidae adult flower visiting occurs close to the larval tree-related habitats, typically on the forest margin itself and up to 100-200 m into open meadows (Ssymank 1991, 2001; Falk 2021). About 10–15% of trees should be decaying snags or stumps and logs. Other action might include blocking drainage ditches and leaving trees and logs in certain parts of the river system (Fig. 8C), in which this last action has a positive effect on *Chalcosyrphus eunotus* (Loew, 1873) (Read 2000; Boesch *et al*. 2007; Jukes 2009; Soszyńska-Maj *et al*. 2009; Sebek *et al*. 2013; Hotchkiss 2022). However, these protection measurements are general, and little is known about the true habitat preferences of many saproxylic Syrphidae and for this further research is needed.

Figure 8. Larval habitat veteran tree specialized Syrphidae. **A**. *Pinus sylvestris*, dendrotelm fork split. Lange Duinen, Soest, The Netherlands. **B**. Same tree cut down for "nature conservation" despite being marked with red and white tape. Both the stump and log were later removed and destroyed. **C**. Rivulet with dead trees and partly water submerged logs. "Bunderbos, Zuid-Limburg, The Netherlands.
Threatened veteran tree specialized Syrphidae found in the surroundings, IUCN category in parentheses.
A, B. *Callicera rufa* (VU).
C. *Chalcosyrphus eunotus* (VU).

Discussion

Remarks on future research

The following suggestions offer ideas on future research needed to investigate the habitat preferences of saproxylic Syrphidae in order to practical habitat management for saproxylic hoverflies. Some research has already been done on these issues and examples of references are given after each research task. Extensive research has been done concerning Coleoptera as regards to the micro-habitat requirements, dispersal capacity and the effects of creating breeding sites and some of these references will sometimes be given here alongside those dealing with saproxylic Syrphidae.

1. Review the knowledge on faunistics of the target species or genera (Rotheray, 2013; Pérez-Bañón *et al*. 2016; van Steenis *et al.* 2020; Falk 2021).
2. Search for additional populations of the species through targeted search for suitable habitat, host trees or accompanying species such as the European velvety tree ant (*Liometopum microcephalum* (Panzer, 1798)) in the case of *Sphiximorpha petronillae* (Birtele 2003; Del Toro *et al*. 2009; Sebel *et al*. 2013; Mei 2016; Miklín *et al*. 2017; Griffiths *et al*. 2018; Tăuşan 2018; van Steenis *et al*. 2019; Bütler *et al*. 2020; Petermann & Gossner 2022).
3. Investigate dispersal capacity as vital factor for implementing habitat restoration efforts (Reenema 2000; Rotheray *et al*. 2014; Komonen & Müller 2018, Martínez-Pérez *et al*. 2022).
4. Investigate the influence of flower resources on fitness and fecundity of adults and a possible link to larval survival rates (Ssymank 1991; Branquart & Hemptinne 2000; van Rijn & Wäckers 2016).
5. Undertake practical investigation into veterinisation of trees by creating dendrotelm trunk holes, "open" dendrotelm (base or fork-split) holes, sap-runs, broken off branches with wound healing, high and low stumps, snags, logs investigating the effects of size, humidity etc. (MacGowan 1994; Cavalli & Mason 2003; Rotheray & Rotheray 2012).
6. Study the effect of grazing on veterinization or destruction of the TreMs (Rotheray & MacGowan 2000; Stiven 2009; Pérez-Bañón *et al*. 2016; Ramón Arévalo *et al*. 2021).
7. Review literature or targeted field research on xylobiont insects creating or enhancing breeding habitat for Syrphidae (Quinto *et al*. 2012; Sánchez-Galván *et al*. 2014; Krivosheina 2019, 2020).
8. Creating breeding boxes to be used during population dynamic studies or in young growth forests to establish jumping populations to and from isolated wild populations (Maibach & Goeldlin 1992; Rotheray 2004; Carlsson *et al*. 2006; Schmid & Moertelmaier 2007; Jansson *et al*. 2009; van Steenis 2015; Landvik *et al*. 2016).
9. Investigate how to incorporate nature conservation actions with raising awareness to the people through social media and citizen science (Read 2000; Flint *et al*. 2009; Thorn *et al*. 2020; Falk 2021).

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