**CONFIRMED AND POTENTIAL WILD HOSTS OF THE SPOTTED WING DROSOPHILA (*DROSOPHILA SUZUKII*) IN SLOVENIA**Maarten DE GROOT¹, Andreja KAVČIČ¹ & Jaka RAZINGER²¹ Gozdarski inštitut Slovenije, Večna pot 2, 1000 Ljubljana, Slovenia² Kmetijski inštitut Slovenije, Hacquetova ulica 17, 1000 Ljubljana, Slovenia

Abstract The spotted wing drosophila (*Drosophila suzukii* (Matsumura)) is a highly invasive species and attacking different species of berry carrying hosts. Much research has already been done on the crop hosts over the world and in Slovenia, but for wild hosts less is known. On basis of literature and fieldwork we prepared a list of potential and actual known species of wild hosts for Slovenia. In 2019, berries of different species were collected and *D. suzukii* was either reared from these berries or berries were dissected. In total we found in the literature for Europe 99 species which were used as host for *D. suzukii*. For Slovenia we found 71 potential hosts and 14 hosts which were actually infested. In Slovenia there was a broad range of potential hosts from 41 genera. The genera with the most potential hosts were *Prunus*, *Lonicera* and *Vaccinium*. Among the potential hosts were also many species which were invasive alien or alien species. The list was discussed in the context of management implications and further research on *D. suzukii* in Slovenia.

KEY WORDS: Spotted wing drosophila, *Drosophila suzukii*, berries, potential hosts, wild hosts, Slovenia, forests, pest control

Izveček – POTENCIALNI IN POTRjeno NAPADENI DIVJI GOSTITELJI PLODOVE VINSKE MUŠICE (*DROSOPHILA SUZUKII*) V SLOVENIJI

Plodova vinska mušica (*Drosophila suzukii* (Matsumura)) je invazivna tujerodna žuželka, ki napada številne rastline s sočnimi plodovi, zlasti jagodičje. Narejenih je bilo že veliko raziskav v povezavi z gostitelji *D. suzukii*, ki so gojeni kot ekonomsko pomembne kmetijske rastline, malo pa je znanega o divje rastočih, t.j. negojenih gostiteljih te vrste. V naši raziskavi smo na podlagi pregleda literature in lastnih raziskav izdelali seznam potencialnih in znanih divjih gostiteljev plodove vinske mušice v Sloveniji. V sezoni 2019 smo nabrali plodove različnih vrst divjih gostiteljev, ki smo jih v laboratoriju analizirali na prisotnost *D. suzukii*. Literatura navaja, da je v Evropi

101 vrsta rastlin primerna kot gostiteljska za *D. suzukii*. Od teh je v Sloveniji prisotnih 72 vrst, ki spadajo v 41 rodov. *D. suzukii* je bila pri nas potrjena na 16 vrstah. Najpogostejši gostitelji plodove vinske mušice v Sloveniji so iz rodov *Prunus*, *Lonicera* in *Vaccinium*. Med potencialnimi divjimi gostitelji za *D. suzukii* v Sloveniji so tudi rastline, ki so tujerodne ali invazivne tujerodne vrste. Članek obravnava seznam divjih gostiteljev plodove vinske mušice v Sloveniji v luči iskanja novih načinov zatiranja plodove vinske mušice in daje smernice za nadaljnje raziskave na tem področju.

KLJUČNE BESEDE: Plodova vinska mušica, *Drosophila suzukii*, jagodičje, potencialni gostitelji, divji gostitelji, Slovenija, gozdovi, zatiranje

Introduction

The Spotted wing drosophila (SWD) (*Drosophila suzukii* (Matsumura, 1931)), originating from Asia, is highly invasive and damaging of economical crops in EU and USA (Cini *et al.*, 2012; Asplen *et al.*, 2015) (Figure 1). In Europe, it was first found in Spain in 2008 and rapidly spread throughout Europe (Asplen *et al.*, 2015). It was first observed in Slovenia in 2011 (Seljak, 2011). One of the reasons for its invasiveness is the fact that it has multiple generations and a large variety of host plants (Asplen *et al.*, 2015). One of the difference between European Drosophilidae fruit fly species and the SWD is that the SWD female is able to damage healthy, undamaged fruits with its serrated ovipositor, while the females of other species can only feed on rotting fruits (Sasaki in Sato, 1995).

SWD has a strong negative influence on the yield of the fruit crops. As it is highly polyphagous most of the fruit crops have problems with this species (Cini *et al.*, 2012; Asplen *et al.*, 2015). Yield losses ranging from 30-40% to 100% have been estimated, depending on the crop and the area. The costs of the SWD damage are estimated on 500 million dollars per year for only the USA (Bolda *et al.*, 2010). In Italy, the costs were estimated on 500.000 Euro in 2010 to 3 million Euro in 2011 (De Ros *et al.*, 2012). In the recent years there has been an increase of management options which increased the outcome but increased the management costs which was estimated to 1857 CHF per hectare (Mazzi *et al.*, 2017). Till now, the number of known hosts of SWD in Slovenia were 23 species, most of which are actually crop hosts (Seljak *et al.*, 2015). All berry crops in Slovenia were strongly negatively affected with in some case more than 50% of the crops (Seljak *et al.*, 2015). Due to the increasing damage caused by the SWD, new approaches and the development of new methods are needed for the control of the populations of this species to avoid large economic damages (Asplen *et al.*, 2015).

It was observed that the species has strong fluctuations over the years, where dry years have low population densities, while wet years have high densities (Seljak *et al.*, 2015). Interestingly, in the wet years also the dynamics change – the pest's flight starts earlier (Kenis *et al.*, 2016).

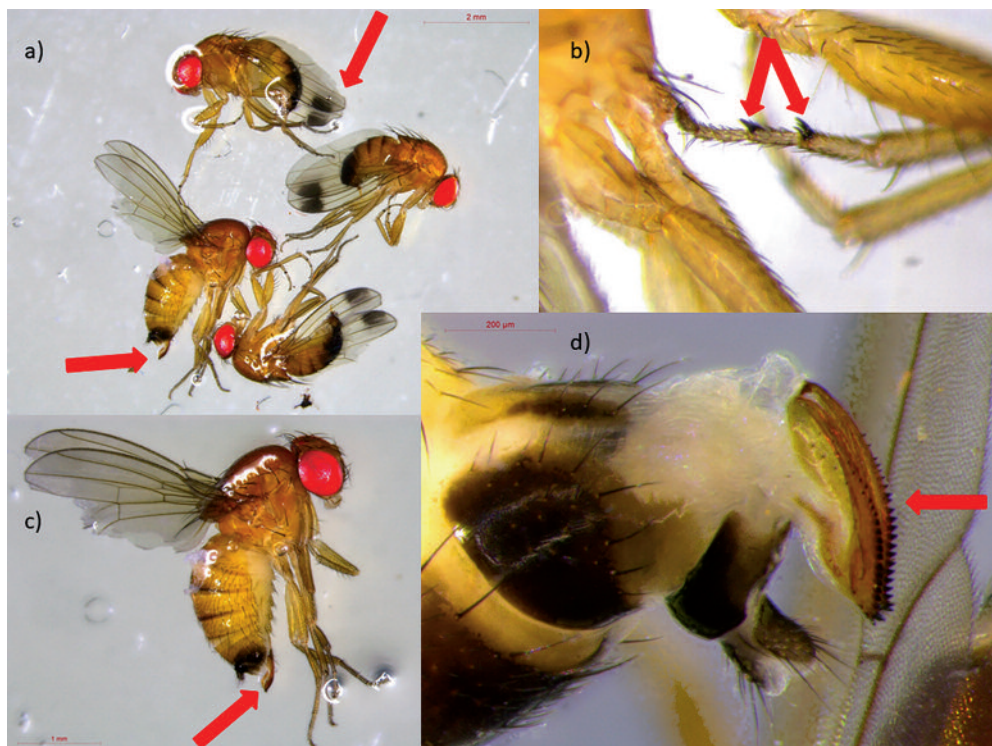


Figure 1: Recognition of the spotted wing drosophila. a) Males have a dark spot on the tip of the wings. b) Tarsomere I and II of male forelegs bear a set of spines each (sex combs). Females (c) have clear wings, and a strongly sclerotized ovipositor with black teeth (d). (photos: Jaka Razinger)

The main focus of the research on SWD management is on crops. However, many wild fruits are taxonomically related to the crop fruits and therefore it is logical to assume that many wild hosts are also infested. Two studies in Europe by Poyet *et al.* (2015) and Kenis *et al.* (2016), showed that there were respectively 33 and 84 wild hosts found. In total this comes to 88 non crop hosts of the SWD in Europe till now. The importance of the wild hosts is shown by the invasive species *Prunus serotina* which was almost 70% infested and is assumed to be a strong factor of the SWD dispersal (Poyet *et al.*, 2014). Although Seljak *et al.* (2015) have performed a preliminary study, in Slovenia the situation with crop/wild hosts has not yet been studied in detail.

Landscape is known to affect the population dynamics of the SWD (Santoiemma *et al.*, 2019). It has been shown that there is a strong spill-over effect from non-crop areas to the crops (Santoiemma *et al.*, 2018; Tonina *et al.*, 2018). Especially with the fact that SWD is a strong disperser (up to 9000 m) also forest a bit further away can have strong impacts on the SWD dynamics in crops (Tait *et al.*, 2018) It was found that forests had higher densities of SWD than meadows (Santoiemma *et al.*, 2019). Factors affecting the population densities in Europe are the forest cover (Haro-Barchin

et al., 2018) and the forest edges (Santoiemma *et al.*, 2019). Forests are an important habitat for source population, because of overwintering (many optimal microclimatic conditions) (Santoiemma *et al.*, 2018) and feeding on wild hosts which can provide breeding material during the whole flying season of SWD (Poyet *et al.*, 2015; Kenis *et al.*, 2016). The function of forests should therefore be an important focus for research on the management of SWD. Forests contain most of the wild hosts, however it was shown that there are strong regional differences in the occupancy of hosts by SWD (Kenis *et al.*, 2016).

The aim of this study was to investigate the range of wild hosts on which *Drosophila suzukii* can (potentially) reproduce in Slovenia.

Materials and methods

The preparation of the list of potential hosts of *Drosophila suzukii* in Slovenia consisted out of three steps: First a review was made of hosts used in Europe. Especially the list prepared in Kenis *et al.* (2016), Arnó *et al.* (2016) and Poyet *et al.* (2015) were used here and additional published literature which were not assessed by mentioned sources. In the second step, the flora of Slovenia (Martinčič *et al.*, 2010) was used to determine whether the host actually occurs in Slovenia. In the third step certain hosts were checked in the field whether they were colonized by SWD also in Slovenia. For this literature was checked and fruit from different (potential) host species was collected in the field. Berries were collected in 14 sites over whole of Slovenia in July 2019. The sampling sites were mainly on forest edges. The berries were put into a rearing tent in the laboratory in the Slovenian Forestry Institute, in order to let the adults of *D. suzukii* emerge. When after a week the adult did not emerge, the berries were dissected in order to see if the berries were infested with larvae.

Results

Literature survey showed that in total 101 species were found to be wild hosts of *D. suzukii* in Europe; 72 of these species occur also in Slovenia (Table 1). Of these 72 species, 14 species were found to be colonized by SWD in Slovenia. The total European species list contains 44 genera which include on average a bit more than 2 species. In Slovenia, the host plants were coming from 40 genera with on average of approximately 2 species per genus. The genera with the most host species were *Prunus*, *Lonicera* and *Vaccinium*. 14 species were found to be either used as crop but can also be found in nature.

Discussion

The results show that there are many wild hosts available which can potentially sustain SWD population dynamics in Slovenia. There were in total 71 potential wild hosts found during the literature survey which also occur in Slovenia, and from the field we detected 14 non crop species to be infested by SWD.

Table 1: Wild host species found in Europe and in Slovenia. An asterisk (*) marks species which are either native or alien and are used as crops, but can also be found in nature in Slovenia.

Plant species	Hosts in Europe	Hosts available in Slovenia	Found to be infested in Slovenia
<i>Actinidia chinensis</i> *	1		
<i>Amelanchier lamarckii</i>	1		
<i>Amelanchier ovalis</i>	1	1	
<i>Arbutus unedo</i>	1	1	
<i>Arum italicum</i>	1	1	
<i>Arum maculatum</i>	1	1	
<i>Atropa bella-donna</i>	1	1	
<i>Aucuba japonica</i>	1		
<i>Bryonia cretica</i>	1		
<i>Cornus alba</i>	1		
<i>Cornus kousa</i>	1		
<i>Cornus mas</i> *	1	1	
<i>Cornus sanguinea</i>	1	1	
<i>Cornus sericea</i>	1	1	
<i>Cotoneaster franchetii</i>	1		
<i>Cotoneaster horizontalis</i>	1	1	
<i>Cotoneaster lacteus</i>	1		
<i>Cotoneaster rehderi</i>	1		
<i>Crataegus chrysoarpa</i>	1		
<i>Crataegus monogyna</i>	1	1	
<i>Daphne mezereum</i>	1	1	
<i>Duchesnea indica</i>	1	1	
<i>Eriobotrya japonica</i>	1		
<i>Fragaria vesca</i>	1	1	
<i>Frangula alnus</i>	1	1	
<i>Gaultheria x wisleyensis</i>	1		
<i>Hippophae rhamnoides</i>	1	1	
<i>Ligustrum lucidum</i>	1	1	1
<i>Ligustrum vulgare</i>	1	1	1
<i>Lonicera alpigena</i>	1	1	
<i>Lonicera caerulea</i> *	1	1	
<i>Lonicera caprifolium</i>	1	1	
<i>Lonicera ferdinandii</i>	1		
<i>Lonicera nigra</i>	1	1	
<i>Lonicera nitida</i>	1		
<i>Lonicera periclymenum</i>	1		
<i>Lonicera xylosteum</i>	1	1	
<i>Mahonia aquifolium</i>	1	1	
<i>Malus baccata</i>	1		
<i>Morus alba</i>	1	1	
<i>Morus nigra</i>	1	1	1
<i>Paris quadrifolia</i>	1	1	
<i>Parthenocissus quinquefolia</i>	1	1	
<i>Photinia beauverdiana</i>	1		
<i>Photinia villosa</i>	1		
<i>Photinia prunifolia</i>	1		

<i>Physalis alkekengi</i>	1	1	
<i>Phytolacca americana</i>	1	1	
<i>Phytolacca esculenta</i>	1		
<i>Polygonatum multiflorum</i>	1	1	
<i>Prunus avium</i> *	1	1	1
<i>Prunus cerasifera</i> *	1	1	
<i>Prunus cerasus</i> *	1	1	1
<i>Prunus domestica</i> *	1	1	1
<i>Prunus laurocerasus</i>	1	1	
<i>Prunus lusitanica</i>	1		
<i>Prunus mahaleb</i>	1	1	
<i>Prunus padus</i>	1	1	
<i>Prunus serotina</i>	1	1	
<i>Prunus spinosa</i>	1	1	
<i>Pyracantha</i> sp.	1	1	
<i>Pyrus calleryana</i>	1	1	
<i>Rhamnus cathartica</i>	1	1	
<i>Rhamnus fallax</i>	1	1	1
<i>Ribes alpinum</i>	1	1	
<i>Ribes rubrum</i> *	1	1	
<i>Rosa acicularis</i>	1		
<i>Rosa canina</i> *	1	1	
<i>Rosa glauca</i>	1	1	
<i>Rosa pimpinellifolia</i>	1	1	
<i>Rosa rugosa</i>	1		
<i>Rubus caesius</i>	1	1	1
<i>Rubus fruticosus</i> agg. *	1	1	1
<i>Rubus idaeus</i> *	1	1	
<i>Rubus</i> spp.	1	1	1
<i>Rubus phoenicolasius</i> *	1	1	
<i>Rubus saxatilis</i>	1	1	
<i>Rubus ulmifolius</i>	1	1	
<i>Sambucus ebulus</i>	1	1	
<i>Sambucus nigra</i> *	1	1	1
<i>Sambucus racemosa</i>	1	1	
<i>Solanum chenopodioides</i>	1		
<i>Solanum dulcamara</i>	1	1	
<i>Solanum nigrum</i>	1	1	
<i>Sorbus aria</i>	1	1	
<i>Sorbus aucuparia</i> *	1	1	
<i>Symphoricarpos albus</i>	1	1	
<i>Tamus communis</i>	1	1	
<i>Taxus baccata</i>	1	1	
<i>Vaccinium myrtilloides</i>	1		
<i>Vaccinium myrtilus</i>	1	1	1
<i>Vaccinium oldhamii</i>	1		
<i>Vaccinium praestans</i>	1		
<i>Vaccinium vitis-idea</i>	1	1	
<i>Viburnum lantana</i>	1	1	
<i>Viburnum opulus</i>	1	1	1
<i>Viburnum rhytidophyllum</i>	1		
<i>Viscum album</i>	1	1	
<i>Vitis vinifera</i> *	1	1	1
Total	99	71	14

We found a large number of potential host species for Slovenia over a large range of genera. This is in principle not new as it is already shown in previous studies that it is a polyphagous species (Asplen *et al.* 2015, Kenis *et al.* 2016). However, such a study was not yet done for Slovenia. The fact that there was a large number of potential hosts is probably also one of the reasons that the species could invade Slovenia so fast and can be found in large abundances throughout all of Slovenia (Seljak *et al.*, 2015).

Many of the host species listed in Table 1 are autochthonous species in Europe, but some are invasive alien species (Kenis *et al.*, 2016). It was shown that invasive alien species can be an important food source for the SWD (Kenis *et al.*, 2016). *P. serotina* was shown to have 70% of damage (Poyet *et al.*, 2014), while *Phytolacca americana* had the highest number of eggs on the fruits in a survey of 33 host species (Poyet *et al.*, 2015). With the increasing disturbance by wind and bark beetles in the forests of Slovenia (de Groot & Ogris, 2019; ZGS, 2019), many more forest gaps will develop. These gaps are suitable places for invasive alien species to grow when spread by wind or birds and support the SWD populations. On the other hand, ornamental plants which become invasive are introduced into Slovenia via the trade (De Groot *et al.*, 2017). These species, which might escape into the forests and other habitats can also become host plants for the SWD and therefore support the populations of SWD.

The European list of wild hosts mentioned in Table 1 were mainly sampled in France, Italy, Switzerland and the Netherlands (Poyet *et al.*, 2015; Kenis *et al.*, 2016). A majority of the host plant species which are found in these countries have related species in the countries of the Southern Europe. This would mean that the shown number of potential hosts can be still increased by species which are not yet surveyed. It is therefore expected that the total number of 72 wild host species for Slovenia and 101 species for Europe will still increase.

One of the advantages to be a polyphagous species is that the host species are spread in time. Kenis *et al.* (2016) and Poyet *et al.* (2015) showed already that with the combination of plant species the berries are available throughout the year. Most species are fruiting during spring and summer. The winter is a period with not so many berries available. Plant species like *Duchesnea indica*, *Prunus laurocerasus*, *Rosa canina*, *Lonicera nitida*, *Viscum album* and *Aucuba japonica* contain or can contain berries also during the winter which could sustain the population till the next year (Poyet *et al.*, 2015; Kenis *et al.*, 2016). The number of wild hosts of the SWD is expected to grow in the future. Given the trends, this could have detrimental effects on crops and economy due to the expected positive influence on the SWD population levels.

Implications for management

Slovenia is known for its large forest cover (almost 60%). Most of the forest contains host species which are presented in this study. Knowing that there is a lot of host availability in the forest, it becomes clear that the population of SWD could be sustained also from the forests. It remains therefore a question what we could do to

minimize the spillover effect from the forest to the orchards. Kenis *et al.* (2016) proposed to control the amount of wild host in the vicinity of the fruit orchards, but in light of recent research the SWD flies can migrate over long distances (Tait *et al.*, 2018); therefore this action will not have much effect. Instead, it is important to be aware, if there are many wild hosts in the vicinity of orchards and adapt management strategies accordingly. For instance, one could try to use early ripening fruit as crops, as the highest abundance of SWD is reached in the late summer (Seljak *et al.*, 2015; Tonina *et al.*, 2018). Another option is to start growing less susceptible fruit (Wang *et al.*, 2019). A third option would be that in areas with a high amount of wild hosts, monitoring would be intensified and used to time the application of insecticides on the crops to prevent damage by the SWD. A fourth option is to use appropriate nets (1 mm mesh or finer) covering entire orchards. This is mostly applicable for newly established orchards, whereas older orchards could be partially protected by the use of lateral netting (Cini *et al.*, 2012; Leach *et al.*, 2016; Weber *et al.*, 2016).

Our study shows a list of potential host species which can be or already are attacked by the SWD in Slovenian forests and other habitats of wild hosts. We show that many wild hosts are available in Slovenia for the SWD outside crop areas. However, there are concerns that invasive alien plants' abundance and distribution will increase in the coming years and therefore facilitate the population of SWD. On the other hand, climate change can increase disturbance in the forest and increase the amount of hosts in gaps like *Rubus*. Furthermore, it can also decrease the SWD development time and therefore increase the number of SWD generations. In this study the host species of SWD are pin pointed, however to understand the distribution of the host plant would give a better insight on the distribution, abundance and risk of SWD in Slovenia. Integrating wild hosts of the SWD in regard of risk maps and planning of orchards, and the use of very fine protective netting in the development of management strategies for this pest are becoming important aspects in the control of this pest in the future.

Acknowledgments

We would like to thank Zavod za Gozdove Slovenije (ZGS) for the help for collecting berries in the field and dr. Darinka Koron, dr. Nika Weber and dr. Lado Kutnar for their constructive comments. The research was performed within the project "Obvladovanje plodove vinske mušice (*Drosophila suzukii*) z metodami z nizkim tveganjem" financed by the Slovenian Research Agency (ARRS) (grant V4-1802; Agrobiodiversity program group, grant P4-0072) and the Administration of the Republic of Slovenia for Food Safety, Veterinary Sector and Plant Protection (UVHVVR), Ministry of Agriculture, Forestry and Food (MKGP).

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Received / Prejeto: 25. 9. 2020