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Application of the solitary red mason bee, *Osmia rufa* L. (syn. *O. bicornis*), in forest monocultures in Poland

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Abstract

Seed orchards are utilised in forestry to avoid monoculture cultivation in forest areas and also constitute a gene bank for various tree species. In order to meet seed needs, preserve species diversity and genetic resources of forest management of the country, several hundred seed orchards served the purposes in Poland today. The paper presents an innovative solution to increase tree yield by introducing nests of solitary bees *Osmia rufa* L. (syn. *O. bicornis*) into monocultures. These insects are a natural solution that allows increasing the yield of selected tree and shrub species, especially fruit trees and shrubs and selected forest species. In order to determine the suitability of *Osmia rufa* L. to support the seed production process, a several-year research project was pursued consisting in assessing the quality of seeds, bee reproduction and identifying natural populations of insects in forest areas that were already present there before the introduction of bees. The research clearly shows that red mason bee, *Osmia rufa* L., can be employed with great success in forest areas to increase the productivity of selected forest tree species. Additionally, the work presents the results of study of red mason bee reproduction, showing that these bees in forest areas can also develop properly.

Keywords: seed orchards; *Tilia cordata*; *Quercus petraea*; *Prunus avium*; insects; rearing of bees

Introduction

Seed orchards are forest crops laid out to protect the genetic resources of selected tree and shrub species, the primary purpose is to provide new and healthy seeds capable of producing new plants. Such plants are then transferred to forests to increase biodiversity in forest environments and provide food for many animal species. Forests in Poland currently cover 9 million hectares or over 29% of its area. For several decades, crops have been gradually introduced into the country's economic structure to develop a seed base for our country. Currently, the total area of forest seed orchards in Poland is 2,042.25 ha, constituting one of the largest seed base in Europe (Kowalczyk et al. 2011).

According to the Program of Conserving Forest Genetic Resources and Breeding of Trees in Poland for the Years 2011–2035, seed orchards (PN) are selected clones (groups of individuals with the same genetic composition, produced from one individual by asexual reproduction) or families (offspring of the mother tree created through sexual reproduction) to be managed and isolated to minimize pollen flow from external sources as much as possible. The purpose of their development is to obtain abundant yields of seeds with increased genetic value (Kocięcki 1988, Kołtowski 2004, Kowalczyk et al. 2011).

Due to the growing demand for seeds from various species of coniferous and deciduous trees, over the last several decades we have observed in Poland the development of various seed plantations, including seed orchards with tree species providing food for bees, *Osmia rufa* L. By growing plants that produce valuable seeds and providing nests for bees that pollinate crops, we can improve both plant cultivation and bee breeding. This arrangement benefits both plants and animals mutually.

So far, research using *Osmia rufa* L. has been successfully conducted on agricultural and fruit crops (Giejdasz and Wilkaniec 2008, Kołtowski 2007, 2010, 2013), where a deficit of pollinating insects was observed (Kearns et al. 1998, Klein et al. 2007, Radmacher and Strohm 2010). In this way, the reproduction rate was determined, i.e. the ability of insects to multiply in the next season in relation to the initially exposed number of insects (Winfree et al. 2007). *Osmia rufa* L. as a species with a calm temperament and not aggressive towards people (Zajdel et al. 2015), has become an insect that is easy to introduce into not only agricultural and fruit growing areas, but also forestry ones.

The aim of the study was to determine the role of *Osmia rufa* L. for seed orchards and to assess the possibility of using these insects in the forest environment. For this purpose, the rearing conditions of bees in the forest environment and their development were observed, and the number of insects and their mortality were also monitored.

Characteristics of seed orchards

Tilia cordata L. is a numerous tree species in the forests, especially in eastern and southern Poland (Boratyńska and Dolatowski 1991, Faliński and Pawlaczyk 1991, Kowalczyk and Rzońca 2018). It begins flowering at the end of June and ends at the beginning of July. It is characterized by significant yield variability due to rare and irregular seed years, on average every 2–5 years (Boratyńska and Dolatowski 1991), as well as late seed maturity, usually after 30 years. The cause of infertile years is most often the freezing of plants, while reduced yields may be caused by a lack of flowering stimulation (Kowalczyk et al. 2011, Przybylski and Kowalczyk 2014). Plants enter the flowering phase at different ages, which translates into irregular yields of individual plants, depending on the intensity, phenology of flowering, as well as the number of male and female flowers in individual plants. Small-leaved linden seed plantations are located mainly in the western and northern parts of Poland. In total, there are 23 seed orchards with a total area of 96.56 ha (Forest Gene Bank Kostrzyca), which are the source of the most valuable reproductive and vegetative propagation material, located in the country. The state of the seed base in the country for small-leaved linden crops outside seed orchards is quite small. In this relation, it is worth to mention populations of known origin covering 93.5 ha and selected stands covering 2.4 ha (Forest Research Institute 2001).

The second plant species included in the experiment was *Quercus petraea* Liebl., which remained one of the main species in forestry. There are 500 species of oaks (*Quercus* sp.) known in the world, whose range covers the northern hemisphere of the temperate, subtropical and tropical zones (Barżdajn 2006). In Poland, three native species are known: English oak, *Quercus robur* L., sessile oak, *Q. petraea* Liebl., and downy oak, *Q. pubescens* Willd. (Chałupka 2006, Przybylski 2015). Among them, only the first two are of economic importance in the country and found their way in forest farming (Barżdajn 2006). The third one does not play a significant role in economic activity. They are among the basic forest-forming species of deciduous species in Poland (Barżdajn 2006, Chałupka 2006, Andrzejczyk 2009) and characterized by great natural, cultural and economic importance (Chałupka 2006). Irregular fruiting is important from the point of view of forest management and silviculture, which, among other things, is the result of genetic traits (Mazer 1989, Przybylski 2015). Other authors discern the causes in ecological conditions that directly play a role in the process of plant development (Mazer 1989, Parmesan and Yohe 2003, Kowalczyk and Rzońca 2018). It is also commonly believed that seeds with a larger mass have a higher survival rate, germinate faster and are more resistant to unfavourable environmental conditions (Baker 1972, Armstrong and Westoby 1993, Rao et al. 1997, Vera 1997, Bonfil 1998). Larger seeds in oaks are also an element of competition for habitat, light, water and nutrients (Seiwa and Kikuzawa 1991, Everham et al. 1996, Bargali et al. 1998, Smouse and Sork 2004). Smaller seeds have more difficult germination, often depending on the soil moisture and atmospheric factors (Suszka et al. 2000). Some authors (McWilliams et al. 1968, Wulff 1986) suggests that larger seeds have a privileged start over smaller seeds in the period of emergence and germination because they are able to wait out an unfavourable period, e.g. a prolonged growing season. It is also believed that oaks show high variability in the time of emergence and growth of seedlings (Tripathi and Khan 1990). In Poland, abundant fruiting of oak trees is observed on average once every five years and it depends primarily on weather, habitat and nutritional conditions, but above all on genetic traits (Roberts 1973). Droughts are also a common and unfavourable phenomenon, contributing to reduced yield or loss of yield (Finch-Savage 1992) as well as reduced seed viability (Finch-Savage 1992, Finch-Savage and Blake 1994, Sun et al. 1994). In order to secure the seed needs of the State Forests Holding for planting purposes, a base of 14 sessile oak seed plantations with a total area of 84.47 ha (Forest Gene Bank Kostrzyca 2024) was laid out in the country.

The last species that was the subject of research and observations was *Prunus avium* L., which is an increasingly important component of forest stands as a species increasing forest biodiversity and constituting a source of food for animals. There are 11 seed plantations of this species located in Poland with a total area of 47.05 ha (Forest Gene Bank Kostrzyca 2024). According to Suszka et al. (2000), the trees grow to a height of 20 meters with leaves up to 15 centimetres long, obovate and pointed. Its white flowers, hermaphroditic, 2.5 cm in diameter, are grouped in umbels. The flowers are pollinated mainly by bees, but this may also be influenced by the ambient temperature, which determines the proper pollination process (Weinbaum et al. 1984, Patterson et al. 1987, Trojankiewicz and Burczyk 2005). Stamens and pistils along with stigmas are very sensitive to the effects of late frosts (Suszka et al. 2000, Kobliha 2002). The flowers of some bird cherry trees are self-pollinating, so it is important to select trees that enable effective exchange of pollen between them in order to properly pollinate their ovaries (Suszka et al. 2000, Smouse and Sork 2004, Mariette et al. 2006). This affects the selection of trees and their clones for seed plantations and orchards (Fonder 1992, Matras 1992, Mariette et al. 2006). The yield of this species depends on weather conditions during its flowering, which takes place in April and May (Suszka et al. 2000, Parmesan and Yohe 2003, Root et al. 2003). Ripe fruits take a spherical shape and are dark red in colour (Suszka et al. 2000), usually bitter and unpalatable; less common are trees with sweet fruit that ripen, depending on the location, in June–August (Suszka et al. 2000). The bird cherry occurs wild in Europe, western Siberia and central Asia (Suszka et al. 2000, Kobliha 2002). It is a light-demanding species with high soil requirements, preferring dry areas (Suszka et al. 2000). Trees generally begin to bear fruit at the age of 6–8, but abundant fruiting is usually observed at the age of 15 (Suszka et al. 2000). The most common way of harvesting ripe fruits is to gather them by hand. The indicator for assessing ripeness is their colour and consistency. Mechanical shakers are also used on seed orchards to enable faster seed harvesting (Suszka et al. 2000). These and other fruits are particularly valuable for animals living in forest areas; therefore these constitute an important source of food (Jabłoński et al. 2017).

However, the distribution of seed plantations in Poland is uneven and for the purposes of conducting research, 8 locations located in western Poland were selected (Figure 1). Their dispersion throughout the country is particularly related to the problem of selecting places suitable for growing a specific plant species within forest land. Clones of a given species should be planted in areas that are closest geographically and climatically to the mother plants from which they were produced (Information on the state of forests and the implementation of the "National Program for Increasing Forest Cover" in 2014).

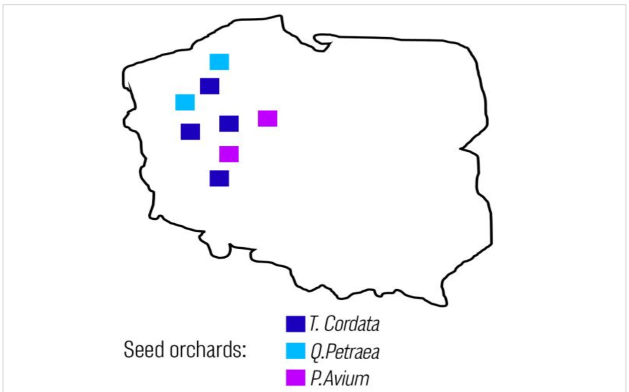

Figure 1. Distribution of seed orchards covered by the research (Poland)

To better understand the issue of laying out seed orchards and their importance for economy and conservation, it is enough to quote information on the size of arable areas maintained for seed raising purposes in Poland. According to the rearing seed database, there are 9,773 mother trees, seed orchards comprising in total 1,260 ha, 699 ha of seed orchards and 62,384 ha of derived crops in the country. This selection database includes 2,670 trees of known origin as seed sources and 219,104 ha of populations of known origin, while only 16,993 ha are selected populations. From "Information on the state of forests and the implementation of the "National Program for Increasing Forest Cover" in 2014" (2014) it follows that conducting forest management in a sustainable and multifunctional way involves significant financial outlays and the preservation and expansion of forest resources and the richness of forest diversity. The priorities include nature conservation and maintaining the seed base of over 200,000 ha of crops. According to the authors of this document, in Poland there are 15,422 ha of excluded seed stands, 178,812 ha of commercial seed stands and 1,884 ha of seed plantations and seed crops. There are 4,540 ha of trees and conservation crops in Poland. Such advanced and developed silviculture aims to maintain the greatest possible diversity of native forest-forming tree species (Białobok 1971, Białobok 1991).

Material and methods

Nests with red mason bee imago (500 females and 500 males) were placed in 2018 and 2019 on the trees of the seed orchards: 4 small-leaved lindens (*Tilia cordata* Mill.), 2 sessile oaks (*Quercus petraea* Liebl.) and 2 bird cherries (*Prunus avium* L.). These crops had a varied area (2–7 ha). The bee rearing method operated was described by Wójtowski et al. (1991). The research space consisted of forest seed orchards, i.e. appropriately selected plant clones (groups of individuals with the same genetic composition, obtained from one individual through asexual reproduction) or families (offspring of the mother tree created through sexual reproduction) subject to management and isolation (Kowalczyk et al. 2011). Homes of bees with imago were installed in each plot, containing 16 nests with reed stalks (*Phragmites australis* (Cav.) Trin. ex Steud.) 18 cm long and about 6–9 mm in diameter, about 45 pieces for each place, along with the bees. The nests were always positioned so that the opening to the reed stalks faced south. The homes of bees were placed in a similar way on each seed orchard, i.e. at the edge of the crops, about 5 meters from the fence, adjacent to other forest or agricultural crops through the fence. The location of the nests was determined by the need to maintain a distance of approximately 300 meters between the experimental and control trees (maximum flight range of red mason bees) in order to conduct the experiment. The exposure of bee cocoons was related to the date of flowering in crops, which was closely related to weather conditions (nests were exposed to crops when the daytime temperature was around 15°C) and differed slightly in both seasons. For bird cherry crops this occurred between April 10–20, for sessile oak between May 20–30 and for small-leaf linden between June 24 and July 4. In October, an analysis of the nests was conducted, assessing the total number of chambers built by the red mason bee, parasitized chambers and those in which dead larvae were found, as well as the number of imago spinons obtained. Additionally, we have assessed the pollen collected by the red mason bee in the breeding chambers, determining the food base of bees on individual plantations. For this purpose, the "per cell" method was used, which involved assessing the frequency and share of pollen of individual taxa, calculated from a minimum of three pollen cells. It determines the share of pollen within four groups: dominant > 45%, accompanying 16–45%, single 3–16%, and occasional < 3%. During the work, insects were collected from traps placed at a height of approximately 1.5 meters above the ground in order to determine the population of insects occurring there.

The work also used materials regarding the establishment and maintenance of seed orchards from Forest Districts. Materials were obtained electronically and in person.

Results

In all the above-mentioned forest tree species covered by our research, irregular seed years are observed, caused by varied factors including weather conditions, genetic variability, tree diseases, animal pests, possible lack of adequate crop pollination, etc. Therefore, actions were taken to increase the yield of these crops as a response to the annual seed deficits observed in forestry. The basic element of the research and analyses was the introduction of the solitary bee, the red mason bee (*Osmia rufa* L.) as a factor increasing the yield of *Tilia*, *Quercus* and *Prunus* crops. So far, this bee species was used to pollinate vegetable crops and fruit crops. So far, research in this area was conducted by, among others, employees of the Department of Apidology at the Poznań University of Life Sciences. Due to the initiated cooperation between specialists of this unit in the field of zootechnics, the need to conduct interdisciplinary research on the rearing of solitary bees in selected forest biotopes was identified.

The attempt to introduce this bee species as a pollinator to forest seed orchards was pioneering. So far, no research was conducted using the red mason bee in forest areas to assess its suitability for pollinating forest crops. In addition to determining the possibility of increasing tree yield with its participation, the following elements were assessed: seed weight, seed sum, the impact of insects on selected tree clones and the impact of the habitat on the rearing of the red mason bees (Kęsy et al. 2023). So far, fruit orchards were mainly used to breed these bees, where the trees bloomed during the period of the highest activity of these insects. An attempt to introduce the red mason bee into forest areas at various times of the year (following the development of flowers on forest trees) also allowed us to determine the possibility of introducing the red mason bee to effectively pollinate crops also later than in spring.

The collected data show that the highest self-pollination of trees is for the *Tilia* species and the lowest for the *Prunus* species. However, the flowers were limited by a tulle mesh insulator placed on the branches. Then, a few weeks after the end of flowering, the insulators were removed and the number of fruits on the tree branches was counted.

Table 1. Self-pollination of trees without insects in forestry

Species of plant	Year	Self-pollination of trees without insects (under the insulator), %	
Tilia cordata Mill.	2018	0–84	± 21
	2019	8–54	± 43
	2020	21–60	± 40
Quercus petraea Liebl.	2018	0–67	± 20
	2019	0–7	± 0.5
	2020	0–8	± 1
Prunus avium L.	2018	0–2	± 1
	2019	0–7	± 2
	2020	0–10	± 2

Table 2. Pollination of trees by *Osmia rufa* L. and other insects in forestry

Species of plant	Year	Pollination of trees by wild insects and bees: *Osmia rufa* L., %	
Tilia cordata Mill.	2018	0–63	± 22
	2019	14–68	± 42
	2020	20–62	± 40
Quercus petraea Liebl.	2018	8–54	± 24
	2019	0–12	± 3
	2020	0–24	± 5
Prunus avium L.	2018	0–8	± 4
	2019	0–8	± 3
	2020	0–16	± 4

When insulators were not used on tree branches, the pollination of trees by insects of various groups, including bees artificially introduced into the monoculture area, was the highest in the case of the *Tilia* species and the lowest in the case of the *Prunus* species, i.e. similarly to the case of the use of insulators.

Subsequently, a study was carried out consisting in the adaptation of *Osmia* to forest conditions and observations of bee behaviour and subsequent laboratory analyses allowing determining the degree of reproduction of these insects and the success of their rearing in forest areas (Tables 3–5).

Table 3. Results regarding the reproduction of *Osmia rufa* L. in the forest seed orchards (*Tilia cordata* Mill.)

Area	Year	Total number of nesting sites constructed	Number of nests with parasites	Number of nests with dead larvae	Number of empty nests	Number of nests with healthy adult insects
Świerczyna	2018	2,656	49	464	86	2,067
	2019	28	20	6	0	2
Jastrowie	2018	1,455	222	208	94	925
	2019	132	80	9	0	43
Pniewy	2018	1,166	0	329	16	828
	2019	26	22	2	0	2
Łopuchówko	2018	2,135	192	875	9	1,001
	2019	15	8	0	0	7

Table 4. Results regarding the reproduction of *Osmia rufa* L. in the forest seed orchards (*Quercus petraea* Liebl.)

Area	Year	Total number of nesting sites constructed	Number of nests with parasites	Number of nests with dead larvae	Number of empty nests	Number of nests with healthy adult insects
Tuczno	2018	3,273	2	848	14	2,393
	2019	1,401	290	460	0	640
Złocieniec	2018	5,212	68	657	11	4,478
	2019	1,330	210	520	20	570

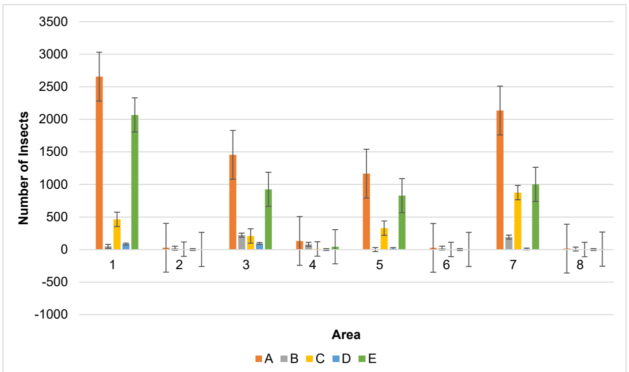

Figure 2. Results regarding the reproduction of *Osmia rufa* L. in the forest seed orchards (*Tilia cordata* Mill.)

Legend: 1–2 Świerczyna, 3–4 Jastrowie, 5–6 Pniewy, 7–8 Łopuchówko.
A – Total number of nesting sites constructed, B – Number of nests with parasites, C – Number of nests with dead larvae, D – Number of empty nests, E – Number of nests with healthy adult insects.

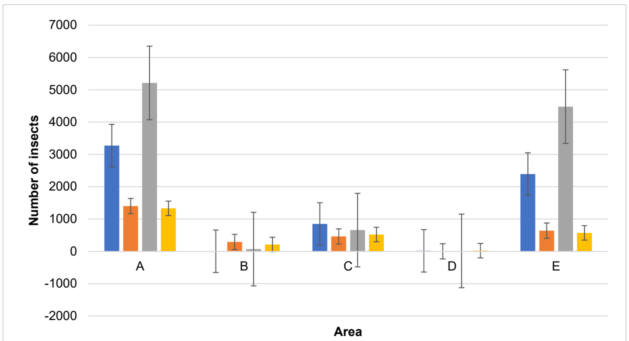

Figure 3. Results regarding the reproduction of *Osmia rufa* L. in the forest seed orchards (*Quercus petraea* Liebl.)

Legend: A – Total number of nesting sites constructed, B – Number of nests with parasites, C – Number of nests with dead larvae, D – Number of empty nests, E – Number of nests with healthy adult insects.

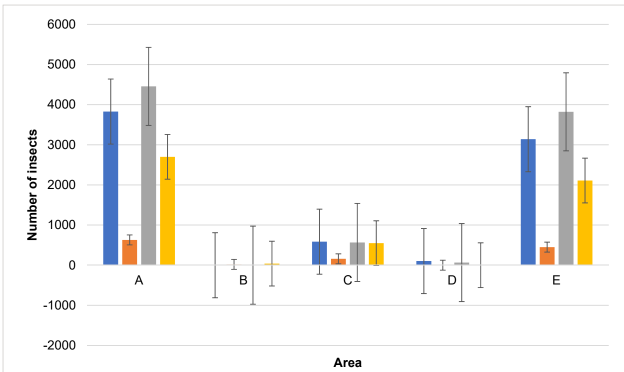

Figure 4. Results regarding the reproduction of *Osmia rufa* L. in the forest seed orchards (*Prunus avium* L.)

Legend: A – Total number of nesting sites constructed, B – Number of nests with parasites, C – Number of nests with dead larvae, D – Number of empty nests, E – Number of nests with healthy adult insects.

Table 5. Results regarding the reproduction of *Osmia rufa* L. in the forest seed orchards (*Prunus avium* L.)

Area	Year	Total number of nesting sites constructed	Number of nests with parasites	Number of nests with dead larvae	Number of empty nests	Number of nests with healthy adult insects
Świerczyna	2018	3,828	0	586	103	3,139
	2019	630	20	160	0	450
Łopuchówko	2018	4,455	0	567	66	3,822
	2019	2,700	40	550	0	2,110

So far, we have managed to collect preliminary research results from the two-year period of activities (2018–2019). The research carried out in 2018 shows that when using the red mason bee to pollinate small-leaved linden, a significantly higher number of seeds can be obtained from experimental trees than from control trees with insect reproduction at the level of: 206% (Świerczyna), 92% (Jastrowie), 82% (Pniewy) and 100% (Łopuchówko). This year, in almost 67% of tree pairs, the seeds had a higher weight, and their higher germination capacity was demonstrated in 75% of cases. In 2019, when the experiment was repeated, high temperatures (over 30 degrees Celsius) were observed, which contributed to very low insect activity. The reproduction of *Osmia rufa* L. was then: 0% (Świerczyna), 0% (Jastrowie), 4% (Pniewy) and 0% (Łopuchówko). As a result of this phenomenon, more seeds were collected from control trees than from experimental trees (7 out of 12 pairs of experimental trees). There were also opposite results compared to 2018 in terms of seed weight.

When growing sessile oak, more collected acorns was recorded in 2018 in as many as 9 out of 10 (83%) experimental groups. This year, observed bee reproduction was 447% (Złocieniec) and 239% (Tuczno), respectively. In 2019, due to spring frosts, the experiment could not be repeated because the flowers froze and did not produce seeds. Observed bee reproduction was 56% (Złocieniec) and 63% (Tuczno), respectively.

The current results regarding the cultivation of *Prunus avium* L. also seem to be very promising, because in 2018, almost 10 times more cherries were harvested from the tree next to which the red mason bee was located than from the control tree. Bee reproduction was 382% (Łopuchówko) and 313% (Świerczyna), respectively. In 2019, the experiment could not be carried out due to spring frosts, which resulted in the destruction of flowers and, consequently, a lack of seeds. That year, bee reproduction was recorded at the levels of 211% (Łopuchówko) and 45% (Świerczyna), respectively.

In 2018, the parasitization of bee rearing nests was the following: 0–15% in *Tilia*, 0–1% in *Quercus* and 0% in *Prunus* trees, while in 2019 it was 53–80%, 17–21% and 1–9%, respectively.

Summary and conclusions

Preliminary research results clearly indicate a positive impact of *Osmia rufa* L. on the pollination process of plants in selected forest seed orchards. The on-going activities require continuation to determine the extent to which bees can be employed in the process of increasing the yield of trees in forest areas by assessing habitat conditions and paying attention to the rate of insect reproduction, which determines the profitability of the activities carried out when introducing the red mason bee into forestry as a permanent element in the process of production of seed material for forest districts. Considering the current situation in forestry and the deficit of seeds of various tree species, the pursued research would help reduce the scale of the problem. However, further research is necessary to clearly assess the impact of these bees on forest trees and their fritification. In this respect, it is necessary to conduct experiments on larger groups of control and experimental trees, based on which it would be determined what number of insects should be used to pollinate a given crop per hectare of seed orchards. Solving this task is necessary in planning the optimised course of seed production using forest seed orchards.

The success of the research allowed us to better understand the relationship between *Osmia rufa* L. and selected forest species. Perhaps thanks to this research, foresters will be able to use this solution permanently in silviculture practice, because for many years foresters have had problems with obtaining a sufficient amount of seeds of sufficiently good quality for seed reproduction of forest crops. Especially in the cultivation of bird cherry and sessile oak, irregular seed years are observed and, as a result, there is a lack of good quality crops, causing losses for forest districts (including: fixed costs of maintaining seed orchards, costs of workers handling crops, plant protection products, protection against forest animals). Additionally, continued research will allow us to determine in the future whether *Osmia rufa* L. can be successfully employed to pollinate plants flowering in the summer (i.e. outside their natural period of occurrence in nature).

Currently, we can say with great confidence that the presence of bees in forest areas during the flowering of forest crops is a favourable element for growing trees and leads to an increase in tree yields, which was assumed in one of the hypotheses for the author's doctoral thesis and which was confirmed in the research. Also, an important element of the studies was to learn more about extremely rare insect groups occurring on plantations. Monocultures provide such changed habitats and nesting sites that insects probably prefer more diverse areas to inhabit.

Author Contributions

M.K. conceptualized the review and wrote the manuscript, collected the data for analysis included to the manuscript.

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This work and research was founded by the author.

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