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Eight Years of *Cydalima perspectalis* in Poland—From the First Finding to the Status of Invasive Species †

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Abstract: The box tree moth (*Cydalima perspectalis* Walker; Lepidoptera, Crambidae) originates from East Asia. It was probably brought to Europe in 2005–2007 along with boxwood bushes (*Buxus* spp.) imported from China. In Europe, it was recorded for the first time in 2007 in south-western Germany, Switzerland and the Netherlands. Without encountering any natural enemies, it quickly became an invasive alien species that threaten plants of the genus *Buxus*, both wild and cultured. There is a risk of its migration to other host plants. In Poland, *C. perspectalis* was found for the first time in 2012 in the south-western part of the country. From 2015, it was recorded in subsequent provinces of southern Poland, and a year later it appeared in the east (Outer Subcarpathia). The direction of its expansion eastwards suggests a natural way of expanding the acreage. In 2017, it was found in the central part of the country. In the 2018 growing season, boxwood plants were utterly destroyed for the first time in many Poland regions. In the following years, insects between Poland's western and eastern borders occupied different areas to the north. By the end of 2020, *C. perspectalis* was found all over Poland. As it is not a quarantine pest in the European Union, it is not subject to official monitoring in Poland. Hence the lack of official information on the range of occurrence in the country. The studies conducted in 2018–2020 determined the current range of *C. perspectalis* occurrence in Poland, along with the selection of places with the highest intensity of occurrence. The caterpillars are most harmful in Poland's southern and central part, where their foraging leads to total defoliation. The Polish climatic conditions allow the pest to develop without any obstacles two generations a year. In the warm year of 2019, the third generation was observed in large numbers. The insect poses a real threat to box trees in Poland, including the historic boxwood garden arrangements.

Keywords: Poland; Europe; *Cydalima perspectalis*; box tree moth; invasive species

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1. Introduction

The natural range of the box tree moth (*Cydalima perspectalis* Walker, 1859) is in Southeast Asia's humid subtropical regions. Described in the mid-nineteenth century from China, it was found in India half a century later. At the turn of the twentieth and twenty-first centuries, its presence was confirmed in Korea, Japan and the Far East of Russia [1–3]. *C. perspectalis* was recorded in Europe for the first time in 2007 in Germany (Baden-Württemberg, the city of Weil am Rhein) and in the Netherlands. Considering the size of the damage at the time of its first finding, it should be assumed that it was brought to Europe at least two years earlier. The places of dispersion to Europe are most probably the distribution

centres of ornamental plants imported from China in Germany and the Netherlands [1]. Eggs and caterpillars, especially of the earlier stages, move easily along with the boxwood bushes (including cuttings) transported for commercial purposes. Molecular studies of the mitochondrial cytochrome oxidase I and II genes indicate that the source of European populations is multiple introductions of insects from eastern China due to the rapid, long-distance transport of boxwood shrubs as part of the ornamental plant trade from this country to Europe. The lack of precise legal regulations in the trade of ornamental plants, as well as the liberalization of the existing law and the general process of trade globalization facilitated such a rapid spread of the species to and in Europe [4]. By 2020, *C. perspectalis* had infested almost all of Europe, being recorded from Great Britain through southern Scandinavia, Lithuania, Western Ukraine and Russia in the east, to the Balkans and Portugal in the south [4–13]. It has also been reported in Turkey, Georgia and Dagestan [14–16]. The current range of occurrence of this species in Europe is consistent with the bioclimatic model (CLIMEX®) prepared in 2014 for *C. perspectalis*, in which its potential range was determined based on the lower development threshold temperature, which depends on latitude and altitude (up to 2000 m above sea level in Georgia) [5]. In 2018, *C. perspectalis* was recorded for the first time in Ontario, Canada [10]. Predictive analyses suggest that it is only a matter of time before *C. perspectalis* has been identified in the US, as exemplified by the publication of a guide on identifying and managing this species [17]. The range of *C. perspectalis* in the north is limited by the low temperature, which prevents the closure of one life cycle per year. In the south, this is limited by the requirements related to obligatory diapause [5].

In Poland, *C. perspectalis* was first observed in 2012 in Lower Silesia, in 2015 in the Opole region and Lesser Poland. In 2016 in the Subcarpathian region, it was taking over the entire southern Poland within five years [18,19]. Even though in 2020 it was found throughout Poland, there is no officially confirmed data on this subject so far. One of the reasons for this is that *C. perspectalis* is not covered by the official monitoring of the occurrence conducted by the Main Inspectorate of Plant Health and Seed Inspection because it is not a quarantine organism in the European Union. For this reason, since its first finding in several locations in the south-west and southern Poland in 2012, there is no reliable and systematic information about the directions of the spread of this species. Because box trees are cultivated all over Poland, especially *Buxus sempervirens*, many scenarios for this insect's spread were possible. Additionally, the problem is that in the national database, which is responsible for tracking the spread of various species in Poland, operating as part of the Biodiversity Map conducted by The Polish Biodiversity Information Network (PolBIN, KSIB) in 2018, only one town was listed (Warsaw) as infested by *C. perspectalis* [20].

Since in Poland there is no system for monitoring the spread of the box tree moth, in 2018–2020, the study aims were decided upon to determine the current range of *C. perspectalis* occurrence in Poland, and the pace and degree of its invasiveness. Obtained data will allow a more precise definition of the threats to the cultivated boxwood, especially those of historical and cultural importance. Although in 2020, *C. perspectalis* was recorded almost all over Poland, there are no officially published data on this subject.

An important document that authorized us to undertake monitoring activities is the "Proposal for a resolution of the European Parliament on the boxwood moth (*Cydalima perspectalis*)", which encourages the Commission to:

- recognize the box tree moth as a harmful organism under Directive 2000/29/EC;
- support research into biological controls for the box tree moth through existing funding programs;
- promote joint monitoring of the box tree moth by the competent European authorities [21].

The recognition by the EU of the need to monitor the boxwood moth in Europe indicates that the importance of this species is very high and noticeable in individual countries where *C. perspectalis* can pose a severe threat to boxwood hedges and topiaries as well as wild plants.

2. Experiments

Materials and Methods

Since 2018, the number of reports from gardeners and plant breeders from southern and central Poland about vanishing boxwoods due to the feeding of unfamiliar new boxwood pests has increased dramatically. To identify the current range of *C. perspectalis* occurrence in Poland, the database of the internet website "Allotment and Garden Our Passion" [22], which brings together over 15,000 gardeners from Poland, was used. For this purpose, hobby gardeners gathered around this website providing information via social media about the towns where they found the box tree moth on their plants in 2018–2020. Using the e-mail address provided on the main page of the website using the sub-website "Contact", they provided the name of the place in their e-mail correspondence, including additional information, e.g., the date of the pest's appearance, photographs, or information (photographs) about the condition of the box trees. Each year, these places were verified by analyzing the photos of the damage and/or insects sent and field trips (Figure 1). Inspection visits were carried out annually in the months from April to September. The presence of the box tree moth was verified in all voivodeships from which the reports came. Particular attention was paid to the places farthest from the places where the box tree moth had already been found in previous reports. The resulting maps of the range of the box tree moth do not cover all the places where *C. perspectalis* occurs but show critical areas for subsequent reports of this insect's presence.

(**a**) (**b**)

Figure 1. *Buxus sempervirens* bushes damaged by *C. perspectalis*: (**a**) a box hedge damaged in about 50%; (**b**) completely destroyed small topiary by box tree moth caterpillars (Rzeszów, September 2018). Fot.: P. Bereś.

3. Results

In total, in 2018–2020, with help from gardeners and plant breeders, users of the website "Allotment and Garden Our Passion" collected information from 166 places (towns) in Poland in the form of 674 documented reports on the presence of *C. perspectalis* (Tables 1 and A1, Figure 2a).

In 2018, on the basis of confirmed data from the gardening website, the presence of *C. perspectalis* was reported from 57 places. They were located within 10 voivodships (out of 16): Lower Silesian, Greater Poland, Opole, Łódź, Silesian, Lesser Poland, Subcarpathian, Holy Cross, Lublin and Masovian. Most information about damaged box trees came from the Silesian and Subcarpathian voivodeships (Figure 2b).

Table 1. The number of places where the appearance of *Cydalima perspectalis* was recorded and the number of reports of insects in individual voivodships, in 2018–2020 [1].

Voivodeship	Number on the Map	Number of Places			Number of Records		
		2018	2019	2020	2018	2019	2020
Poland	1–16	57	77	148	166	188	320
West Pomeranian	1	0	1	1	0	1	3
Pomeranian	2	0	1	1	0	3	1
Warmian-Masurian	3	0	0	3	0	0	5
Lubusz	4	0	3	6	0	3	6
Greater Poland	5	3	4	12	3	8	23
Kuyavian-Pomeranian	6	0	0	2	0	0	4
Masovian	7	6	5	13	17	17	29
Podlaskie	8	0	0	6	0	0	8
Lower Silesian	9	7	5	8	19	23	19
Łódź	10	4	1	9	4	1	14
Holy Cross	11	2	2	7	2	4	9
Lublin	12	3	4	10	11	11	19
Opole	13	2	4	5	10	4	11
Silesian	14	11	22	26	18	38	42
Lesser Poland	15	8	10	12	28	25	36
Subcarpathian	16	11	15	27	54	50	91

[1] For more details, see Appendix A.

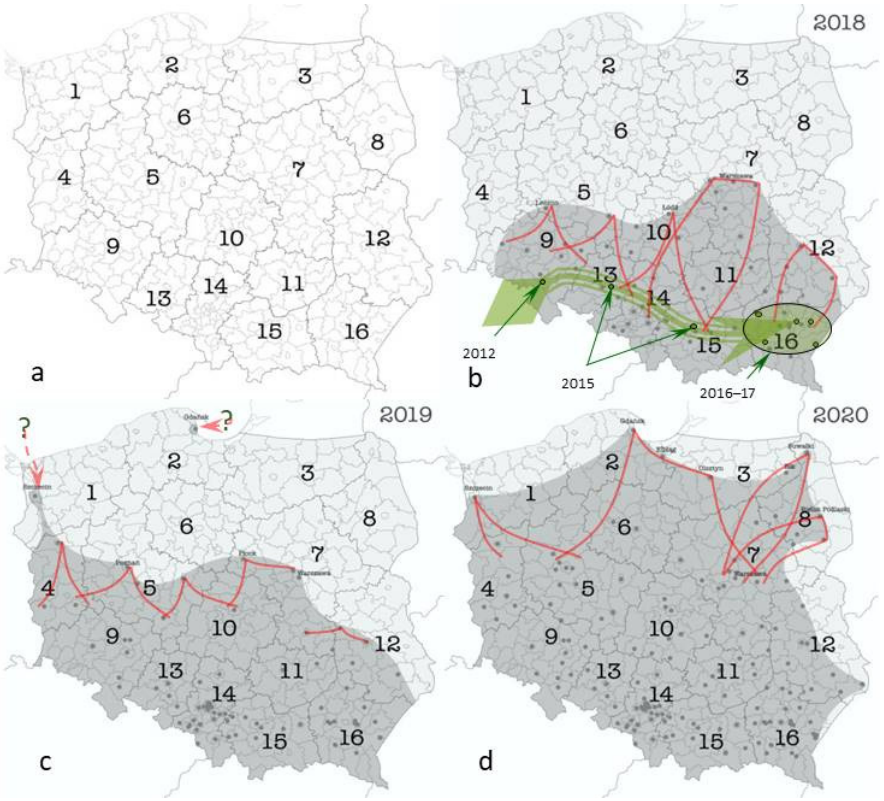

Figure 2. The range of *Cydalima perspectalis* occurrence in Poland: (**a**) administrative division of Poland into 16 voivodeships; (**b**–**d**). The range of *Cydalima perspectalis* occurrence in Poland and its possible routes of spread: (**b**) in 2018; (**c**) in 2019; (**d**) 2020. Each grey point indicates the presence of a pest found in social monitoring in 2018; the green arrow marks the route for insects to spread until 2017; red lines and numbers indicate the main directions of the species expansion to the north in 2018; 1–16: number of the subsequent voivodship (see Table 1).

In 2019, the presence of *C. perspectalis* was found in 77 localities located in 13 voivodships. These were the same voivodships as in the previous years. Additionally, the pest appeared in the west of the country and the north in the following voivodships: Lubusz, West Pomeranianand Pomeranian. The pest's appearance in Szczecin and Gdańsk, on the coast of the Baltic Sea, was a significant surprise. This year, the most information about the species' appearance came from the south of Poland in the following voivodeships: Silesian, Lesser Polandand Subcarpathian (Figure 2c).

In 2020, there was a further large-scale expansion of *C. perspectalis* in Poland. Information about the pest's outbreak came from as many as 148 localities located in all 16 voivodeships that are part of Poland's administrative division. The last three voivodeships are: Kuyavian-Pomeranian, Podlaskie and Warmian-Masurian. In addition to Gdańsk and Szczecin, the pest was recorded in such towns in the north of the country as Elbląg, Olsztyn, Ełk, Suwałki and Bielsk Podlaski. Such a sudden increase in the pest's range, which covered the entire country, may be related to the fact that various media started talking about the appearance of the box tree moth due to the information campaign. For this reason, gardeners were more aware of the presence of a new species of pest and were more likely to observe the boxwood plants, including detecting them more often. The year 2020, however, confirmed earlier observations that *C. perspectalis* was currently most abundant in southern Poland, where it is warmer than in the north and where the vegetation period is slightly longer (Figure 2d).

4. Discussion

The first information about the presence of *C. perspectalis* in Poland comes from the town of Michałków in the Sowie Mountains (south-western Poland, Lower Silesia), where the insect was detected in 2012 [18,19]. Since then, the presence of *C. perspectalis* in Poland is officially dated. On the map of the range of the box tree moth in Europe from 2012, prepared by a team of researchers from CABI, Switzerland [23], Poland was noted as a country where this species does not yet appear. The following data on the places where the pest appeared in Poland come from 2015. This year, Blaik et al. [18] detected *C. perspectalis* in Suchy Bor near Opole (Opole Voivodeship) and in the centre of Kraków (Lesser Poland), which indicates that the pest infested the southern part of the country.

Further confirmed information on the range of *C. perspectalis* in Poland comes from south-eastern Poland (Subcarpathian Voivodship). In the years 2016–2017, the presence of the insect was detected in the following towns: Grabiny, Umieszcz, Rzeszów and Zgłobień [19]. This expansion clearly indicated the latitudinal direction of the insect spread in Poland, parallel to the Carpathian arc.

If it usually takes two years from the first appearance of insects to boxwood until they are entirely defoliated, we can assume that the data sent by users of the gardening website are just a consequence of a two or three-year delay in detecting the pest [24,25]. Information from observers indicates that the natural expansion of this insect in Poland was a secondary factor, an example of which is the 8-year long settlement route in southern Poland in the latitudinal direction along the Carpathian arc. It should be assumed that the main factor was accidental, untargeted transfers of insects with infected plants through the use of road transport and resale of infected plants in subsequent parts of the country. An example is that in 2019 the presence of *C. perspectalis* was noted in Gdańsk, over 300 km from the previous year, the closest place of the outbreak in Płock (Figure 2b,c). It cannot be ruled out that *C. perspectalis* reached the Baltic coast independently by sea transport. The rapid expansion in the last three years was also favored by warmer, above the long-term norms, average daily and monthly temperatures. The hot and long autumn of 2019 was the reason for the third generation of' mass appearance of the insects.

The use of social networks and dedicated websites to societies and interest group activities is not the first time that this type of approach has been used in research on the distribution of insects. *C. perspectalis* meets most of the insect criteria suitable for this type of social monitoring. It is a species that feeds close to humans, causes specific and massive boxwood dieback symptoms, visible to everyone, even to people who are not interested in entomology. It is only necessary to consider the time that insects need from the first colonization of plants to their death—about two years [24]. The lack of natural enemies enables a more precise determination of the year the insects appear in a given area. Previously, this type of approach was used in the British Isles where, in addition to the official operating The British and Irish network of County Moth Recorders (CMRs), which was the primary source of fully reliable records of the species, the website of the European Boxwood and Topiary Society (EBTS) provides a facility for users to report occurrences of this species; we have accessed all such data for 2018 (www.ebts.org/bmctracker) (accessed on 22 February 2021) [11]. A similar approach that reflects citizen science ideas has been successfully used in recent years in Toronto (Canada), where the first appearance of *C. perspectalis* was recorded in August 2018 [26].

Observations made by Blaik et al. [18] and Bury et al. [19] were used by EPPO to map the distribution of *C. perspectalis* in Europe [27]. In turn, the map of *C. perspectalis* distribution in Europe conducted by CABI lacks detailed information on the occurrence of the species in Poland, including its first appearance [12].

Due to the lack of nationwide monitoring of the box tree moth's occurrence in Poland, data on the presence of the pest came only from random observations. Without the involvement of state services dealing with the monitoring of alien origin species, it was not possible to create an accurate map of the range of this species in Poland. Our observations in 2018–2020 clearly show the growing range of *C. perspectalis* in Poland. However, it should be noted that most of the obtained data were provided by gardeners and plant breeders, who often did not know about the appearance in Poland in the area where a new, alien species of pest lived. Some gardeners and boxwood growers, as well as institutions dealing with the management of urban greenery and parks, lost their boxwood bushes, topiaries and hedges, which were destroyed by caterpillars. Such a rapid and spectacular invasion of *C. perspectalis* in Poland makes it necessary to undertake research to understand the biology of this species under Polish conditions. In this, it is important to develop comprehensive methods of its control with the use of biological and chemical methods, that take into account the climatic and weather conditions in Poland, as well as the methods of growing boxwood [28–30].

5. Conclusions

The collected data indicate that the box tree moth (*Cydalima perspectalis*), from its first discovery in 2012 in Poland, took over its entire area in 2020. Currently, it is the greatest threat to boxwood in southern and central Poland. The lack of nationwide monitoring of *C. perspectalis* makes it challenging to control its spread and combat it, especially in regions where it appears for the first time. The developed coverage maps, together with the data on recording the presence of *C. perspectalis* allow gardeners and plant breeders to analyze the situation on an ongoing basis and undertake adequate methods of control and eradication.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EPPO	European and Mediterranean Plant Protection Organization
CLIMEX®	CLIMEX Climate Data
PolBIN	The Polish Biodiversity Information Network (KSIB: Krajowa Sieć Informacji o Bioróżnorodności)
DIONP	Allotment and Garden Our Passion (Działka i Ogród Naszą Pasją)
CMRs	County Moth Recorders
EBTS	European Boxwood and Topiary Society

Appendix A

Table A1. Detailed list of places (towns) in which the occurrence of *Cydalima perspectalis* was recorded and confirmed in 2018–2020.

Voivodeship	Number on the Map	Places/Towns (Number of Records)		
		2018	2019	2020
POLAND	1–16	166	188	320
West Pomeranian	1		Szczecin (1×)	Szczecin (3×)
Pomeranian	2		Gdańsk (3×)	Gdańsk (1×)
Warmian-Masurian	3			Elbląg (1×), Ełk (1×), Olsztyn (3×)
Lubusz	4		Gorzów Wielkopolski (1×), Lubsko (1×), Nowa Sól (1×)	Gorzów Wielkopolski (1×), Lubsko (1×), Nowa Sól (1×), Świebodzin (1×), Zielona Góra (1×), Żagań (1×)
Greater Poland	5	Kalisz (1×), Kępno (1×), Leszno (1×)	Konin (1×), Ostrów Wielkopolski (1×), Poznań (5×), Zaniemyśl (1×)	Dopiewo (1×), Kalisz (3×), Kiekrz (1×), Konin (1×), Kościan (1×), Leszno (3×), Ostrów Wielkopolski (3×), Poznań (6×), Rawicz (1×), Swarzędz (1×), Szamotuły (1×), Zaniemyśl (1×)
Kuyavian-Pomeranian	6			Bydgoszcz (1×), Toruń (3×)
Masovian	7	Grodzisk Mazowiecki (1×), Grójec (1×), Kampinos (1×), Mińsk Mazowiecki (4×), Radom (4×), Warszawa (6×)	Łomianki (1×), Płock (1×), Radom (4×), Solec nad Wisłą (1×), Warszawa (10×)	Brwinów (1×), Garbatka-Letnisko (1×), Grodzisk Mazowiecki (1×), Łomianki (1×), Mińsk Mazowiecki (3×), Ostrołęka (1×), Płock (3×), Radom (4×), Siedlce (3×), Sochaczew (1×), Solec nad Wisłą (1×), Warszawa (8×), Wieliszew (1×)
Podlaskie	8			Białystok (3×), Bielsk Podlaski (1×), Ciechanowiec (1×), Łomża (1×), Suwałki (1×), Szepietowo (1×)
Lower Silesian	9	Bolesławiec (1×), Legnica (1×), Oleśnica (1×), Oława (3×), Świdnica (1×), Trzebnica (3×), Wrocław (9×)	Legnica (1×), Niemcza (1×), Oborniki Śląskie (1×), Trzebnica (5×), Wrocław (15×)	Kobierzyce (1×), Legnica (1×), Niemcza (1×), Oleśnica (1×), Strzelin (1×), Trzebnica (4×), Wałbrzych (3×), Wrocław (7×)
Łódź	10	Łódź (1×), Piotrków Trybunalski (1×), Sieradz (1×), Wieluń (1×),	Łódź (1×)	Aleksandrów Łódzki (1×), Bełchatów (1×), Łódź (4×), Opoczno (3×), Piotrków Trybunalski (1×), Radomsko (1×), Sokolniki (1×), Tomaszów Mazowiecki (1×), Wieluń (1×)

Table A1. *Cont.*

Voivodeship	Number on the Map	Places/Towns (Number of Records)		
		2018	2019	2020
Holy Cross	11	Jędrzejów (1×), Ostrowiec Świętokrzyski (1×)	Kielce (3×), Ostrowiec Świętokrzyski (1×)	Busko-Zdrój (1×), Jędrzejów (1×), Kielce (3×), Opatów (1×), Ostrowiec Świętokrzyski (1×), Starachowice (1×), Tokarnia (1×)
Lublin	12	Kraśnik (4×), Lublin (4×), Zamość (3×)	Kraśnik (1×), Lublin (6×), Puławy (3×), Zamość (1×)	Biłgoraj (1×), Kraśnik (1×), Lublin (5×), Łęczna (1×), Poturzyn (1×), Puławy (4×), Radzyń Podlaski (1×), Świdnik (1×), Tomaszów Lubelski (3×), Zamość (1×)
Opole	13	Opole (6×), Strzelce Opolskie (4×)	Krapkowice (1×), Kędzierzyn-Koźle (1×), Opole (1×), Tułowice (1×)	Brzeg (3×), Kędzierzyn-Koźle (1×), Krapkowice (1×), Opole (5×), Tułowice (1×)
Silesian	14	Bielsko Biała (1×), Bytom (1×), Chorzów (4×), Częstochowa (1×), Katowice (3×), Lubliniec (1×), Racibórz (3×), Rybnik (1×), Tychy (1×), Wodzisław Śląski (1×), Zabrze (1×)	Bielsko-Biała (3×), Bytom (1×), Chorzów (4×), Cieszyn (1×), Czeladź (1×), Częstochowa (5×), Gliwice (1×), Jastrzębie-Zdrój (1×), Jaworzno (1×), Katowice (3×), Lubliniec (1×), Mysłowice (1×), Racibórz (3×), Radlin (1×), Ruda Śląska (1×), Rybnik (3×), Świętochłowice (1×), Tychy (1×), Wodzisław Śląski (1×), Zabrze (1×), Ząbkowice Śląskie (1×), Żory (1×)	Bielsko-Biała (3×), Bytom (1×), Chorzów (5×), Cieszyn (1×), Czeladź (1×), Częstochowa (4×), Gliwice (1×), Jastrzębie-Zdrój (1×), Jaworzno (1×), Katowice (4×), Lubliniec (3×), Mysłowice (1×), Oborniki Śląskie (1×), Racibórz (3×), Radlin (1×), Ruda Śląska (1×), Rybnik (1×), Siemianowice Śląskie (1×), Świętochłowice (1×), Tarnowskie Góry (1×), Tychy (1×), Wodzisław Śląski (1×), Wojkowice (1×), Zabrze (1×), Ząbkowice Śląskie (1×), Żory (1×)
Lesser Poland	15	Bochnia (3×), Chrzanów (1×), Kraków (12×), Myślenice (1×), Oświęcim (1×), Skawina (1×), Tarnów (8×), Wieliczka (1×)	Andrychów (1×), Brzesko (3×), Kraków (10×), Krzeszowice (1×), Libiąż (1×), Myślenice (1×), Tarnów (5×), Trzebinia (1×), Wadowice (1×), Wieliczka (1×)	Andrychów (1×), Brzesko (4×), Gorlice (1×), Kraków (15×), Krzeszowice (1×), Libiąż (1×), Myślenice (1×), Nowy Sącz (1×), Tarnów (6×), Trzebinia (1×), Wadowice (3×), Wieliczka (1×)
Subcarpathian	16	Albigowa (6×), Jarosław (4×), Krosno (1×), Łańcut (3×), Mielec (1×), Tarnobrzeg (3×), Przeworsk (3×), Rzeszów (21×), Sanok (1×), Sokołów Małopolski (8×), Stalowa Wola (3×)	Albigowa (1×), Dynów (4×), Góra Ropczycka (1×), Husów (1×), Jarosław (4×), Krosno (1×), Leżajsk (3×), Łańcut (4×), Mielec (1×), Przemyśl (6×), Ropczyce (1×), Rzeszów (17×), Sanok (1×), Sędziszów Małopolski (4×), Stalowa Wola (1×)	Albigowa (1×), Bolestraszyce (3×), Brzozów (1×), Dębica (3×), Dukla (1×), Dynów (1×), Góra Ropczycka (1×), Husów (1×), Jarosław (3×), Jasło (1×), Krosno (3×), Lesko (1×), Leżajsk (4×), Łańcut (5×), Mielec (1×), Nienadówka (4×), Orzechowce (1×), Przemyśl (10×), Ropczyce (3×), Rudnik nad Sanem (1×), Rzeszów (36×), Sanok (1×), Sędziszów Małopolski (1×), Sokołów Małopolski (1×), Stalowa Wola (1×), Tarnobrzeg (1×), Żurawica (1×)

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