Long-term changes in the species composition and distribution of Bombini (Apidae) in Cracow since the mid 1850s

Andrzej Kosior [1], Waldemar Celary [2], Wojciech Solarz [1], Pierre Rasmont [3], Jan Fijał [1], Wiesław Król [1], Zbigniew Witkowski [4] & Stéphanie Iserbyt [3]

[1] Institute of Nature Conservation, Polish Academy of Sciences, Mickiewicza Al. 33, 31-120 Cracow, Poland

[2] Institute of Systematics and Evolution of Animals, Polish Academy of Sciences, Sławkowska 17, 31-016 Cracow, Poland

[3] Laboratoire de Zoologie Université de Mons-Hainaut, Place du Parc 20, B-7000 Mons, Belgium

[4] Academy of Physical Education, al. Jana Pawła II 78, 31-571 Cracow, Poland

Abstract. Current distribution of bumblebee species in Cracow was studied in 2000–2003 in 23 atlas squares. The results were compared with historical data available for last 150 years, including published materials and museum collections. A total 28 bumblebee species were recorded throughout that period. Among them, 11 species are currently threatened in the study area. There were stated three tendencies among the studied bumblebee species. After 1850, 10 species were strongly regressing (withdrew from the Cracow area altogether or range contraction); further 11 species were more or less stable in their area; the next 6 species were strongly expanding in Cracow. 6 species were stated as a new for Cracow, including 2 species recorded between 1901–1972 and 4 between 1973–2003. Negative population tendencies by the Bombini in the Cracow area were the result of both natural and anthropogenic factors. Species protection and conservation of the most valuable areas as nature reserves are expected to prevent further decrease of bumblebees in the Cracow area.

Résumé. Changements à long terme de la composition spécifique et de la distribution des Bombini (Apidae) de Cracovie depuis 1850. La distribution actuelle des espèces de bourdons de Cracovie a été étudiée en 2000–2003, dans 23 carrés cartographiques. Les résultats on tété comparés avec les données historiques des dernières 150 années, y compris les données publiées et celles des collections de musées. Au total, 28 espèces de bourdons ont été observées durant l'ensemble de la période. Parmi ces espèces, onze sont menacées dans l'aire d'étude. On a établi trois tendances parmi les espèces de bourdons. Après 1850, 10 espèces ont fortement régressé (éteintes de Cracovie tandis que leur aire se contractait), 11 autres espèces ont été plus ou moins stables dans leur distribution ; 6 espèces se sont fortement étendues dans la région. 6 espèces ont été nouvellement observées : 2 nouvelles espèces durant la période 1901–1972 et 4 durant la période 1973–2003. Les tendances négatives des Bombini de Cracovie ont été le résultat à la fois de facteurs naturels et anthropiques. On espère que les mesures de protection d'espèces et les mises en réserves naturelles des zones les plus intéressantes arrêtent le déclin des bourdons de la région de Cracovie.

Keywords: Bumblebees, Regression, Expansion, Poland, Conservation.

As a result of the important role of bumblebees as pollinators, this group has been receiving a significant deal of attention throughout last decades. Studies into long-term population tendencies of bumblebees revealed a marked decrease in numbers of pollinators in Europe and worldwide (Williams 1982, Aichhorn 1983, Warncke *et al.* 1984, Kosior & Nosek 1987, Rasmont & Mersch 1988, Westrich 1989, Kosior 1992, Allen-Wardell *et al.* 1998, Hagen & Aichhorn 2003, Goulson *et al.* 2005, Williams 2005, Kosior *et al.* 2007). Large-scale landscape changes, including intensification of agricultural practices, and expansion of built-up areas, are regarded as the major factors accounting for these negative trends (Banaszak 1995, Carvell 2002).

The aim of this study was to gather information on the current composition and distribution of *Bombini* in Cracow and to compare it with historical records after 1850. This comparison allowed for estimating long-term trends of *Bombini* in this area and hypothesize about the drivers behind the observed changes.

Material and methods

Historical data were divided into 3 periods: 1851–1900, 1901–1972, 1973–2003. This division corresponds with changes in the city boundaries and availability of data. The earliest data on bumblebees from Poland, i.e. from Cracow and its

E-mail: kosior@iop.krakow.pl, solarz@iop.krakow.pl, fijal@iop.krakow.pl, krol@iop.krakow.pl, celary@isez.pan.krakow.pl, pierre.rasmont@umh.ac.be, stephanie.iserbyt@umh.ac.be, witkowski@skok.awf.krakow.pl

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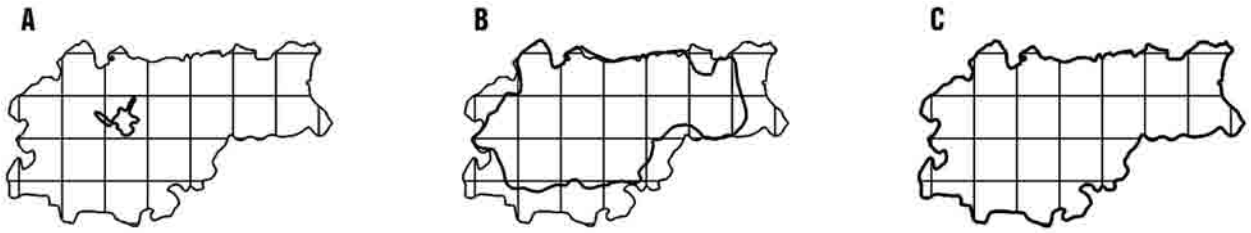


Figure 1
Boundaries of Cracow. **A,** in 1900; **B,** in 1972; **C,** in 2003.

surroundings dates back to the second half of the 19th century. The first papers (Siła-Nowicki 1864, Wierzejski 1868, 1874, Śnieżek 1893, 1899) concentrate on qualitative data on species composition of bumblebees and, to a lesser degree, cuckoobees. Quantitative data or information on habitat requirements is usually very seldom. Further studies into bumblebees (Śnieżek 1910, Łoziński 1920, Dylewska 1957) covered more species and a larger area, as the city expanded. A remarkable collection of individuals was gathered before 1950s in the Museum of Institute of Systematics and Evolution of Animals (ISiEZ), Polish Academy of Sciences in Cracow. These included individuals collected between 1885–1944. First studies concentrating on species biology and population tendencies of some bumblebee species in the Cracow area started only in the 1970s (Banaszak *et al.* 1998) and the second ones in the 1990s (Flaga 1997).

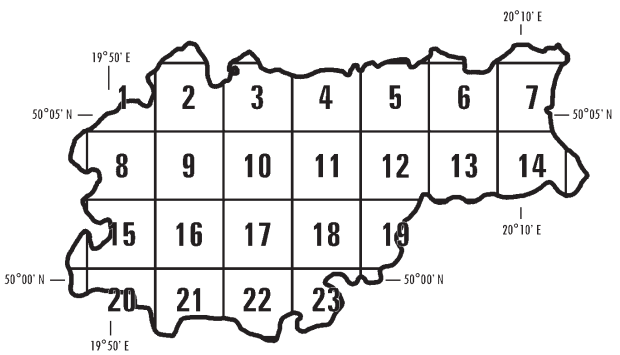


Figure 2
Grid of atlas squares in which the *Bombini* were studied in Cracow between 2000-2003. 1 – Rząska, 2 – Krowodrza, partly Rząska, 3 – Prądnik Czerwony, 4 – Mistrzejowice, 5 – Lubocza, 6 – Lubocza, 7 – Ruszcza, 8 – Wola Justowska, 9 – Nowa Wieś, 10 – Śródmieście, 11 – Nowa Huta, 12 – Nowa Huta, 13 – Pleszów, 14 – Osiedle Wyciąże, 15 – Kostrze, 16 – Borek Fałęcki, 17 – Wola Duchacka, partly Borek Fałęcki, 18 – Wola Duchacka, 19 – Bieżanów, 20 – Skawina, 21 – Opatkowice, 22 – Wróblowice, 23 – Wróblowice.

The area of Cracow within its present administrative boundaries (Trafas 1988, Fig. 1) was divided into 23 atlas squares 4 × 4 km (Fig. 2). This division was based on the maps of Cracow in the scale 1:10 000, and all the squares were lying inside the Polish geographical grid. Whenever available, the precise locations of historical records (name of species and number of individuals) from published sources and individuals from museum collections were assigned to the 4 × 4 km atlas squares. In many cases, spatial inaccuracy of historical data did not allow to assign them to specific atlas squares. This refers generally to common species, whose precise locations were recorded with less scrutiny than in case of rare species. For this reason, historical distribution maps of species described as common in the original papers are shaded. The same grid was used to study current composition and occurrence of bumblebees in 2000–2003. On the basis of map analysis, in each 4 × 4 km square, a sample plot of 1 × 1 km (1 km^2) was selected, comprising the highest habitat heterogeneity within a given square. Thus, field study was carried out in 23 sample plots of 1 km^2. Each study year, between April and September, each sample plot was surveyed 2-6 times. The surveys were done in favourable weather conditions. During each 1-hour survey, all habitats within sample plots were surveyed. The spectrum of habitats surveyed throughout the study area includes: mixed forests, decidous forests, coniferous forests (planted stands of Scots pine), groups of trees, forest glands, forest roads and paths, alderwoods, willow thickets, dry swards on rocks, heathlands, wet and dry meadows, riparian vegetation, agro-ecosystems – cereal crops, root plants, fields of clover, lucerne and rape, abandoned land, gardens, parks, flood embankments, lawns, flower beds, ruderal communities near buildings, railways, roads. During the counts, all individuals of bumblebees were identified and recorded. Results obtained in 1 km^2 sample plots (number of individual of each species) were assigned to the respective 4 × 4 km atlas squares, for which the data in this paper are presented.

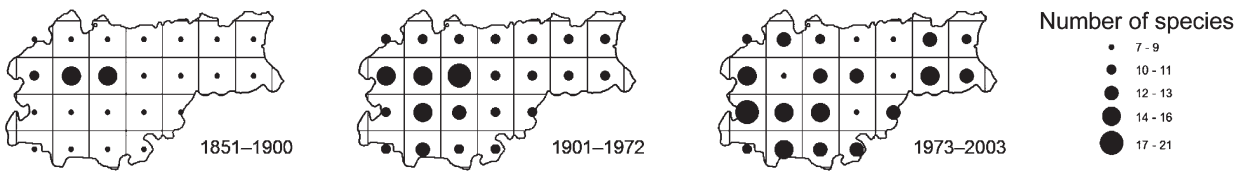
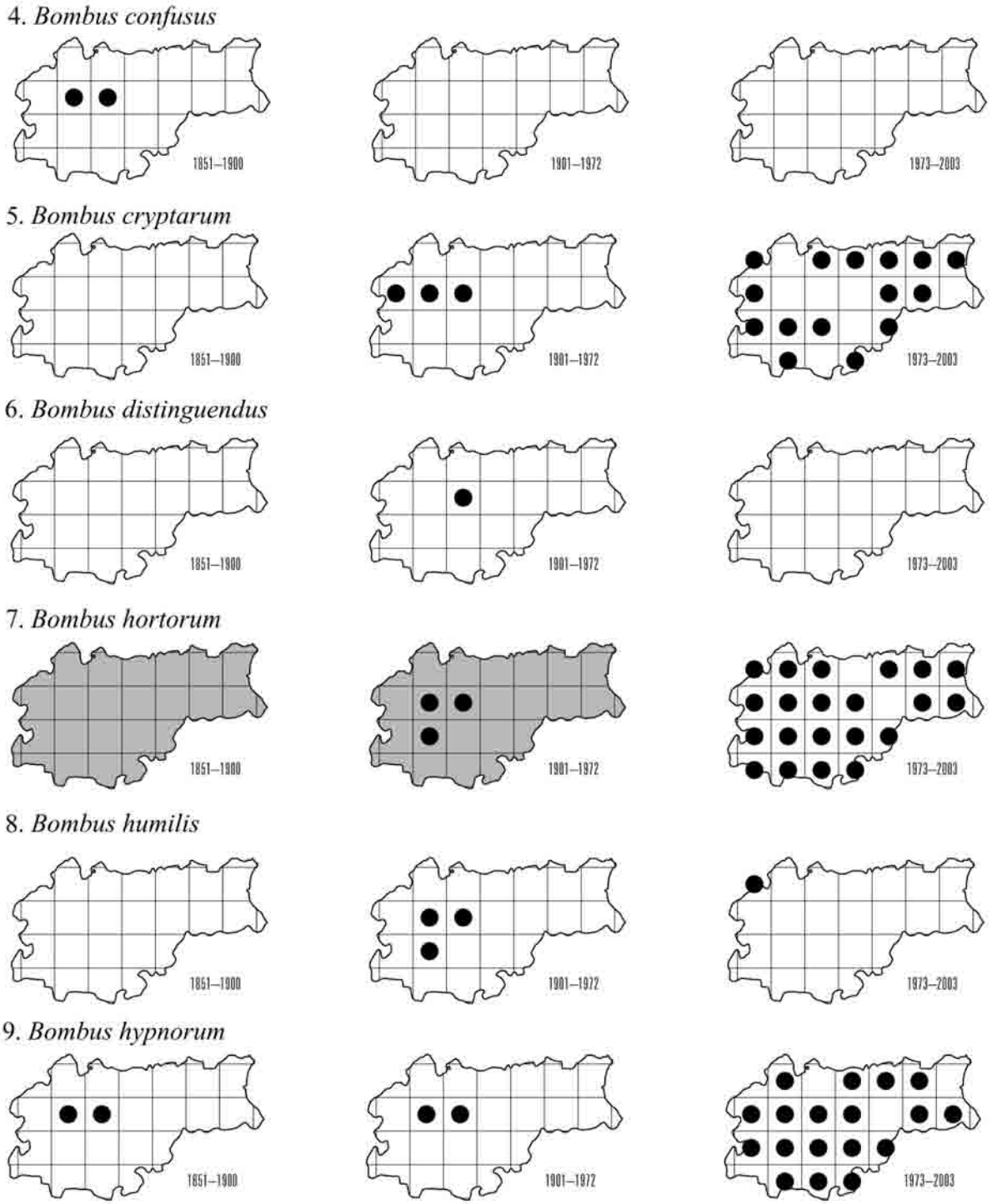


Figure 3
Distribution of the numbers of species for each periods in Cracow.

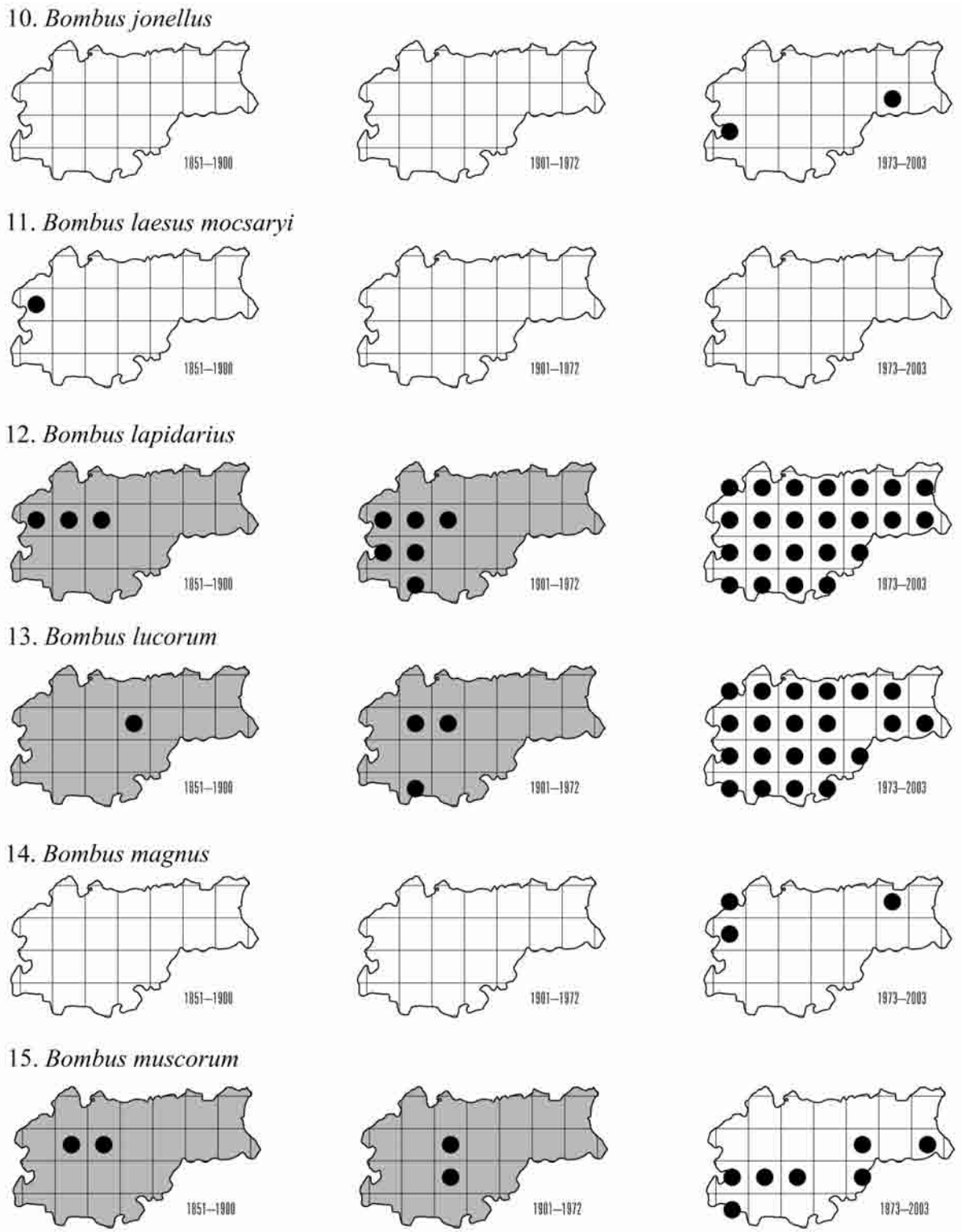
Table 1. List of all *Bombini* species recorded during the whole study period, with data on the number of individuals and the number of occupied atlas squares in 3 time periods (1851-1900, 1901-1972 and 1973-2003), ranks before 1973 and since 1973, delta rank (mathematical difference of ranks between before 1973 and since 1973 for all species present in both periods) and tendency between before and since 1973.

Ps.: *Psithyrus*; *: Number of specimens in Cracow not determined; **: Species reported as common in Cracow; ***: Number of the atlas squares in Cracow not determined; #: Number of specimens in some atlas squares not determined. +: Expanding; 0: more or less stable; NC: not computable; NS: Non significant.

Species	1851–1900		1901–1972		1973–2003		TOTAL		*Rank*		Delta Rank (a - b)	Tendency
	Abundance	Squares	Abundance	Squares	Abundance	Squares	Abundance	Squares	Before 1973 (a)	Since 1973 (b)		
Bombus magnus Vogt 1911	-	-	-	-	3	3	3	3		19	NC	+
Bombus (Ps.) sylvestris (Lepeletier 1832)	-	-	-	-	3	1	3	1		19	NC	+
Bombus jonellus (Kirby 1802)	-	-	-	-	6	2	6	2		17	NC	+
Bombus semenoviellus Skorikov 1910	-	-	-	-	16	5	16	5		15	NC	+
Bombus pratorum (L. 1761)	*	2	2	1	74	15	76+	15	20	8	12	+
Bombus lucorum (L. 1761)	6**	1	6	3	506	21	519+	21	11	3	8	+
Bombus (Ps.) bohemicus Seidl 1837	-	-	4	4	33	6	37	7	18	12	6	+
Bombus ruderatus (Fabricius 1775)	4	***	5	1	28	11	37	11+	16	13	3	NS
Bombus subterraneus (L. 1758)	1	***	1	***	3	3	5	3+	22	19	3	NS
Bombus hortorum (L. 1761)	*	***	11	3	306	21	317+	21+	7	5	2	NS
Bombus (Ps.) rupestris (Fabricius 1793)	*	***	#,5	6	42	7	47+	11+	11	10	1	NS
Bombus cryptarum (Fabricius 1775)	-	-	6	3	35	15	41	17	11	11	0	NS
Bombus lapidarius (L. 1758)	5	3	24	6	531	23	560	23	2	2	0	NS
Bombus pascuorum (Scopoli 1763)	4	***	30	5	1293	23	1327	23	1	1	0	NS
Bombus veteranus (Fabricius 1793)	2	***	3	2	3	2	8	4+	19	19	0	NS
Bombus ruderarius (Müller 1776)	3	2	19	8	276	23	298	23	5	6	-1	NS
Bombus terrestris (L. 1758)	39	***	20	4	318	23	377	23	3	4	-1	NS
Bombus hypnorum (L. 1758)	+*	2	11	2	67	18	78+	18	7	9	-2	NS
Bombus sylvarum (L. 1761)	2	***	20	5	214	21	236	23	3	7	-4	-
Bombus muscorum (Fabricius 1775)	#,1	2	7	2	20	7	28+	9	10	14	-4	-
Bombus (Ps.) vestalis (Fourcroy 1785)	*	***	#,3	6	16	4	19+	8+	11	15	-4	-
Bombus humilis Illiger 1806	*	***	5	3	1	1	6+	4+	16	23	-7	-
Bombus (Ps.) campestris (Panzer 1801)	*	***	#,4	8	6	3	10+	10+	9	17	-8	-
Bombus distinguendus Morawitz 1869	*	***	1	1	-	-	1+	1+	22		NC	-
Bombus laesus mocsaryi Kriechbaumer. 1877	1	1	-	-	-	-	1	1	22		NC	-
Bombus confusus Schenck 1859	4	2	-	-	-	-	4	2	20		NC	-
Bombus (Ps.) barbutellus (Kirby 1802)	*	***	#,1	6	-	-	1+	6+	11		NC	-
Bombus pomorum (Panzer 1805)	*	2	4**	3	-	-	12+	5	6		NC	-
Total number of specimens	**72**		**196**		**3800**		**4072+**					



Figures 4–9
Distribution of bumblebees for each periods in Cracow. **4**, *Bombus confusus* Schenck; **5**, *Bombus cryptarum* (Fabricius); **6**, *Bombus distinguendus* Morawitz; **7**, *Bombus hortorum* (L.); **8**, *Bombus humilis* Illiger; **9**, *Bombus hypnorum* (L.). Due to imprecise data on historical occurrence of species referred to as common in the original papers, maps of these species are shaded.



Figures 10–15
Distribution of bumblebees for each periods in Cracow. **10**, *Bombus jonellus* (Kirby); **11**, *Bombus laesus mocsaryi* Kriechbaumer; **12**, *Bombus lapidarius* (L.); **13**, *Bombus lucorum* (L.); **14**, *Bombus magnus* Vogt; **15**, *Bombus muscorum* (Fabricius). Due to imprecise data on historical occurrence of species referred to as common in the original papers, maps of these species are shaded.

Results obtained between 2000–2003 were combined with published and unpublished data from 1973–1999 and compared with earlier data on bumblebees in the Cracow area. For each species, 3 distribution maps were presented, corresponding with 3 time-periods for which the data were analysed (1851–1900, 1901–1972, and 1973–2003).

Due to the scarcity of data from the earliest period, this analysis was only possible between before and since 1973. As the historical data was too scarce to use parametric tests, we used a non-parametric rank correlation test (the Spearman rank correlation, Siegel & Castellan 1988) to compare the two periods. The rank is related to the number of specimens for each species during both time intervals. The rank 1 is given to the most abundant species. Tendencies in bumblebee species distribution were divided into 3 categories: regressing (delta rank worst than -3), more or less stable (from -3 to+3), and expanding (higher than +3).

The nomenclature of bumblebees was presented according to Rasmont *et al.* (1995), Williams (1998), Schwarz *et al.* (1996) and Michener (2000). Therefore, the genus *Psithyrus* was considered to be a subgenus of the genus *Bombus*. The current status of bumblebee species in Poland was given after Banaszak (2002). Additionally, a new category: Extinct (EXKR), was introduced for species that disappeared from the study area. The species strictly protected in Poland were listed according to the Decree of the Minister of Environment (Dz. U. 2004).

Results

The complete list of bumblebees of the Cracow area in each of the three study periods is presented in Table 1, with information on the number of individuals recorded and the number of the atlas squares in which the species occurred. The number of species for each atlas square is presented in figure 3. Distribution of all species presented in figures 4 to 31.

After 1850, a total of 28 bumblebee species were recorded, including 22 bumblebees and 6 cuckoobees. This constitutes approx. 73% of all bumblebee species and approx. 67% of all cuckoobees occurring in Poland (Banaszak 2002). Both in the first (1851–1900) and second (1901–1972) study periods, 22 bumblebee species were recorded, while 23 species were recorded in the third study period (2000–2003). The analysis of species composition in each study period revealed that 5 bumblebee species withdrew from the study area after 1850 (Tab.1, 2), including 1 species (*B. laesus mocsaryi*, Fig. 11) in 1851-1900, another one (*Bombus confusus* Fig. 4) 1901–1972, and 3 more between 1973–2003 (*B. distinguendus* Fig. 6, *B. pomorum* Fig. 17 and *B.* (*Ps.*) *barbutellus* Fig. 26). On the other hand, new species were detected (Tab. 1, 2), including 2 between 1901–1972 (B. *cryptarum* Fig. 5, *B.* (*Ps.*) *bohemicus* Fig. 27), and 4 between 1973–2003 (*B. jonellus* Fig.10, *B. magnus* Fig. 14, *B. semenoviellus* (Fig. 21) and *B.* (*Ps.*) *sylvestris* Fig. 30).

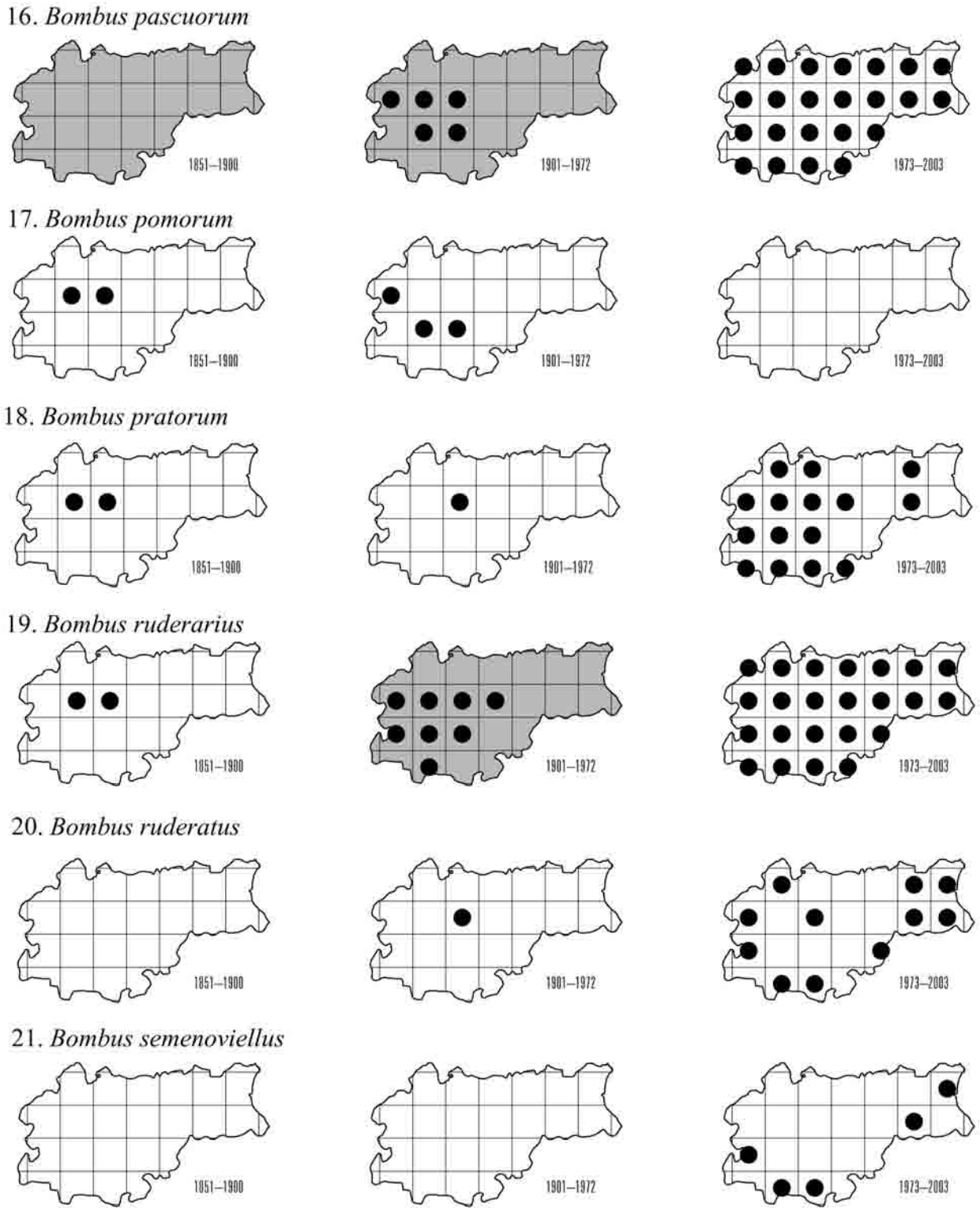
For the remaining species, we can use the non parametric abundance rank comparison between the periods before and since 1973 (Tab. 1). While before 1973, the 2 most numerous species (*B. pascuorum* and *B. lapidarius*) accounted for a quarter of all bumblebee individuals recorded, in the last study period the same 2 species constituted nearly a half (48 %) of all bumblebee individuals. Comparison between the rank of each species for the two study period (Fig. 32) showed that 5 species were regressing: *B.* (*Ps.*) *campestris* (Fig. 28), *B. humilis* (Fig. 8), *B. muscorum* (Fig. 15), *B. sylvarum* (Fig. 23) and *B. (Ps.) vestalis* (Fig. 31). 3 species were expanding after 1973 (Tab. 1, Fig. 32): *B. (Ps.) bohemicus* (Fig. 27), *B. lucorum* (Fig. 13) and *B. pratorum* (Fig. 18). 4 species *B. lapidarius* (Fig. 12), *B. pascuorum* (Fig. 16), *B. cryptarum* (Fig. 5) and *B. veteranus* (Fig. 25), showed stable tendency, thus they maintained their status after 1901 (Tab. 1, Fig. 32).

Bombus (Ps.) campestris is in strong regression whereas its principal potential host (*B. pascuorum)* is strongly expanding and that its other potential hosts are slightly regressing (*B. humilis, B. pomorum*). In the same way, *B. (Ps.) barbutellus* and *B. (Ps.) vestalis* are in strong regression whereas their principal hosts are in strong expansion (*B. hortorum, B. terrestris*) (Tab.1). Conversely, *Bombus (Ps.) bohemicus*, *B. (Ps.) rupestris* and *B. (Ps.) sylvestris*, as their potential hosts, *B. lucorum*, *B. lapidarius* and *B. pratorum*, respectively, are more or less in expansion (Tab. 1).

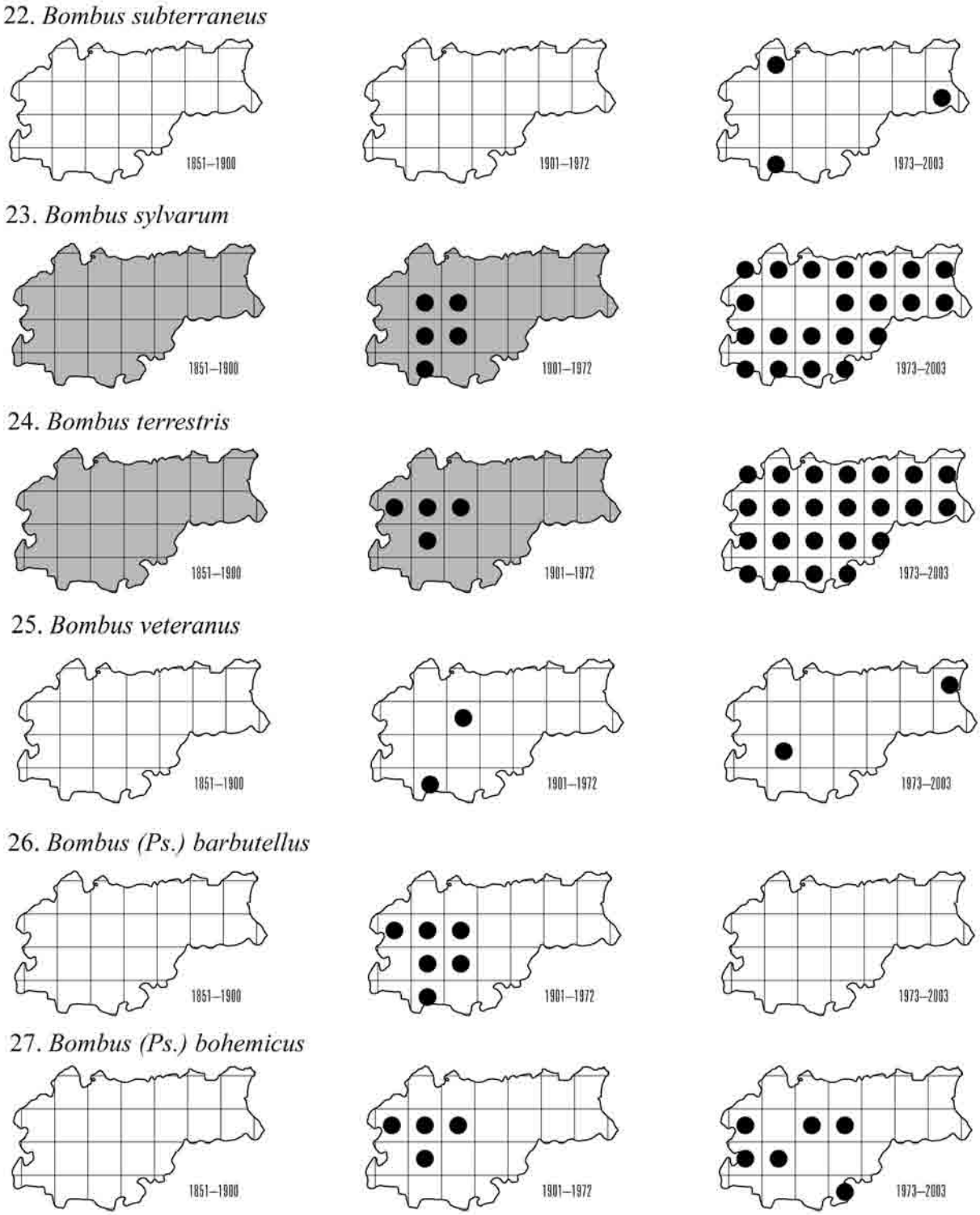
The list of protected, threatened and new bumblebee recorded during the study is presented in Tab. 3. Apart from *B. lapidarius* and *B. terrestris*, all bumblebees recorded in the study area are protected in Poland according to the Decree of the Minister of Environment (Dz. U. 2004). Among threatened bumblebees recorded, 5 were classified as Extinct in Cracow, 9 as Vulnerable, and 2 as Data Deficient (Banaszak 2002). Cuckoobees are not protected in Poland.

Discussion

Studies into long term population tendencies often face the problem of considerable heterogeneity of available datasets, which makes analyses difficult. A major difficulty in analysis of tendencies in species distribution was that there were substantial differences in research effort in the considered time-periods. This in particular refers to the earliest period (1851-1900); data from this period was too scarce to be included into statistical analyses and only could serve for visual comparisons of distribution maps. However, one must remember that precise location of the early records was often lacking, particularly in case of relatively common



Figures 16–21
Distribution of bumblebees for each periods in Cracow. **16**, *Bombus pascuorum* (Scopoli); **17**, *Bombus pomorum* Panzer; **18**, *Bombus pratorum* (L.); **19**, *Bombus ruderarius* (Müller); **20**, *Bombus ruderatus* (L.); **21**, *Bombus semenoviellus* Skorikov. Due to imprecise data on historical occurrence of species referred to as common in the original papers, maps of these species are shaded.



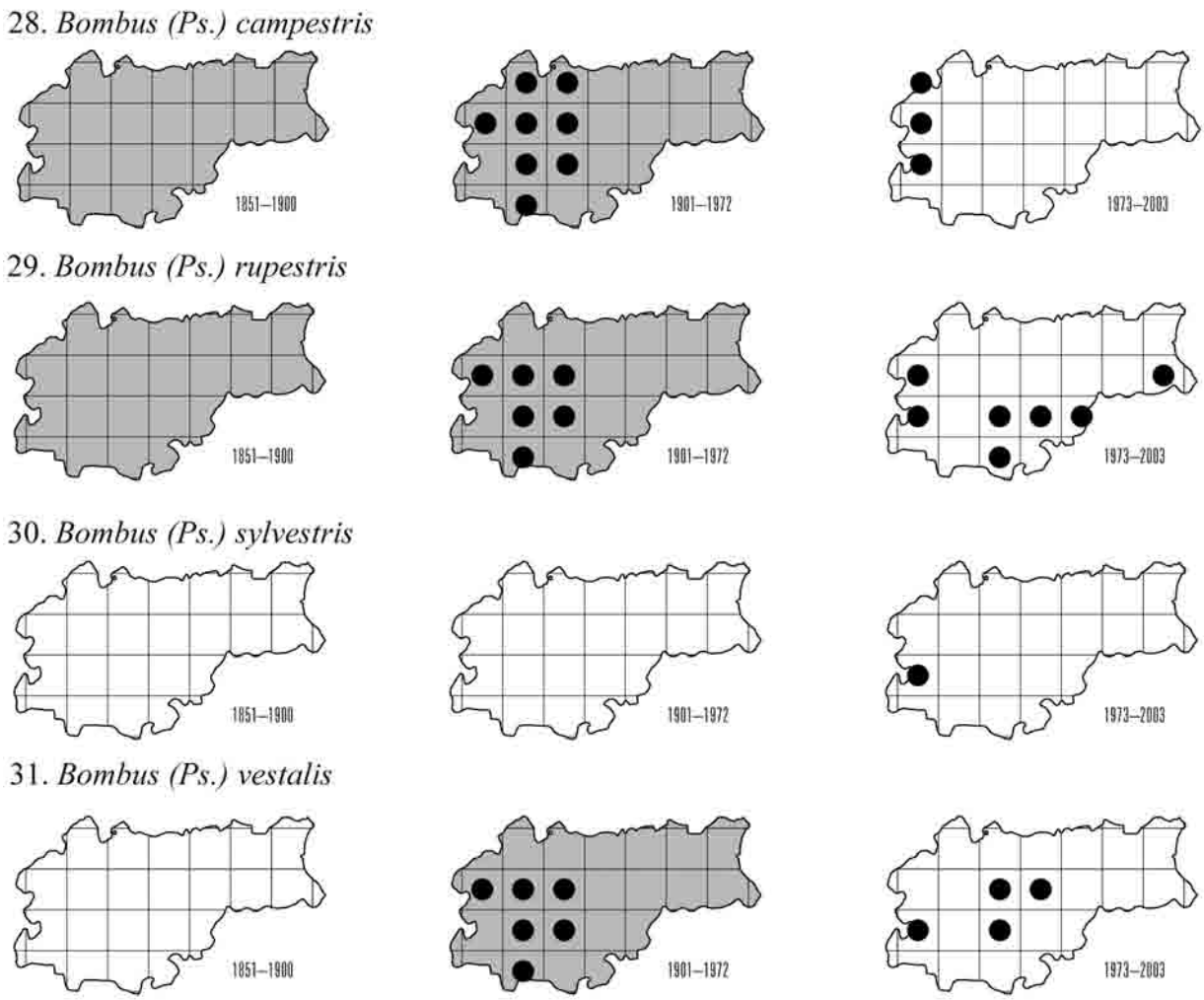
Figures 22–27
Distribution of bumblebees for each periods in Cracow. **22**, *Bombus subterraneus* (L.); **23**, *Bombus sylvarum* (L.); **24**, *Bombus terrestris* (L.); **25**, *Bombus veteranus* (Fabricius); **26**, *Bombus* (*Ps.*) *barbutellus* (Kirby); **27**, *Bombus* (*Ps.*) *bohemicus* Seidl. Due to imprecise data on historical occurrence of species referred to as common in the original papers, maps of these species are shaded.

species, therefore past distribution of these species was, to some extent, approximated. In addition to scarcity of the historical data, methodology applied by the early authors differed significantly from that applied later, particularly between 2000–2003.

For these reasons, statistical analyses of the datasets proved to be difficult. Chi-square analysis was not possible, as a result of scarcity of the historical data. For some species (e.g. *B. pascuorum*) the expected chi-square values for number of occupied atlas squares exceeded the actual number of atlas squares used during the study.

Despite the statistical difficulties, it seems unequivocal that there was a drop in total species richness of bumblebees. A clear indication of a strong diversity loss was obtained in rank correlation analysis. The total share of the 2 most numerous species showed almost a two-fold increase (from 25% to 48%) between 1901–1972 and 1973–2003, although this result may partly be due to the fact that older records from museum collections are likely to be biased towards rarer species. It is noteworthy, however, that these species, *B. pascuorum* and *B. lapidarius* were among the species for which the tendency was determined as stable.

Overall, negative trends prevailed in the species recorded during the study. These trends were shown in distribution of 13 species, of which 10 were strongly regressing, while a positive tendency was shown only for 11 species.



Figures 28–31
Distribution of bumblebees for each periods in Cracow. **28**, *Bombus* (*Ps.*) *campestris* (Panzer); **29**, *Bombus* (*Ps.*) *rupestris* (Fabricius); **30**, *Bombus* (*Ps.*) *sylvestris* (Lepeletier); **31**, *Bombus* (*Ps.*) *vestalis* (Fourcroy). Due to imprecise data on historical occurrence of species referred to as common in the original papers, maps of these species are shaded.

Table 2. Changes in the number of *Bombini* species in the Cracow area in 3 time periods (1851–1900, 1901–1972 and 1973–2003).

	Time period			
	1851–1900	1901–1972	1973–2003	Since 1851
Number of Extinct species	0	2	3	
Number of New species	-	**2**	4	
Total number of species	**22**	**22**	**23**	**28**

In the group of bumblebee species which were strongly expanding, 4 species were recorded for the first time in the study area during intensive field studies in 2000–2003. *B. jonellus* (Fig. 9) is the glacial relic in the mountains of the Middle Europe (May 1959). Finding *B. magnus* (Fig. 13) in the Cracow area accompanied a recent new record of this species in the Czech Republic (Přidal 2004), which may be a sign of this species expansion. Similarly, first records of *B. semenoviellus* (Fig. 20) in the study area confirm expansion of the range of this species in Europe towards the west (Smissen & Rasmont 1999, Přidal 2004). The fourth new species, *B.* (*Ps.*) *sylvestris* (Fig. 30) accompanies its host *B. pratorum* (Fig. 18) in its strongly expanding tendency. Interestingly, expansion of another cuckoobee species, *B. (Ps.) bohemicus*, was also accompanied by expansion of its host, *B. lucorum*. This confirms close relations between population trends of hosts and parasites.

However, whereas a decrease in 3 cuckoobees was detected,: *B. (Ps) barbutellus, B. (Ps.) campestris, B. (Ps.) vestalis,* no negative trend was shown in their host bumblebee species. This may suggest that cuckoobees are more susceptible to factors decreasing population numbers then are bumblebees, e.g. pollution of environment. Use of chemicals in agrocenoses was found a limiting factor for cuckoobees in the Bieszczady Mountains (SE Poland; Kosior 1980, 1987).

Although results obtained in the Cracow area are fairly robust, it is interesting to compare them with results obtained in other countries of Europe. For this comparison, we used data obtained for the whole of Belgium. Originally, this data was analysed with method which is based on relative abundance (Rasmont & Mersch 1988), and then recalculated according to Stroot & Depiereux method (Rasmont 1989), using chi-square logical by (Rasmont *et al.* 1993). We re-analysed these data once again, using a non-parametric

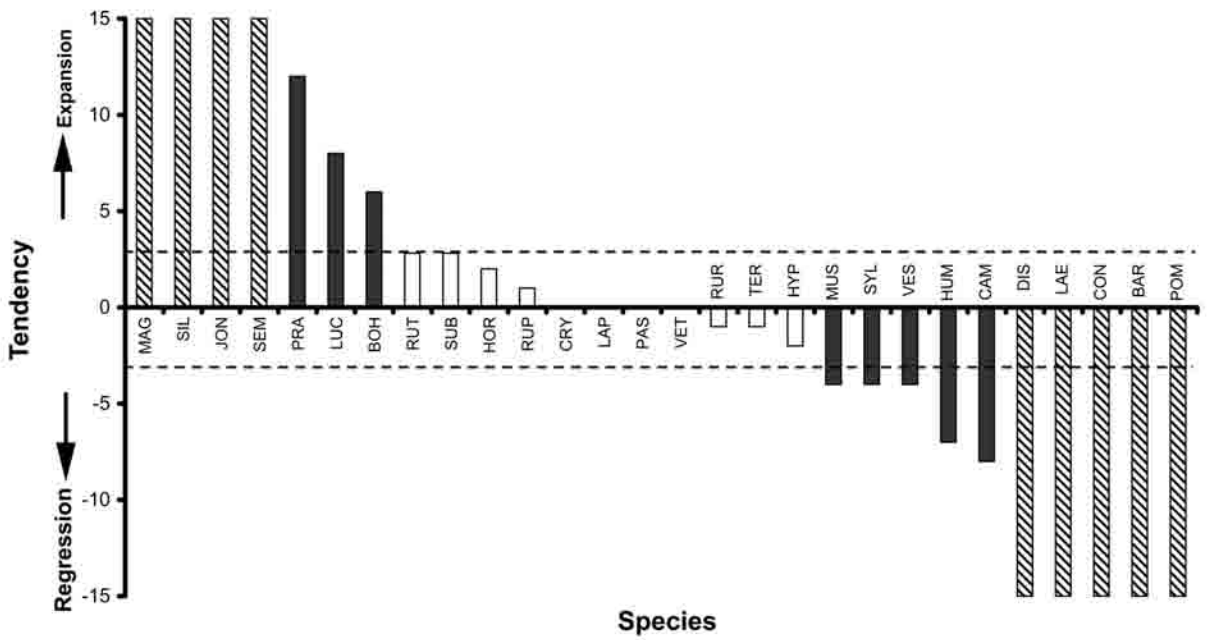


Figure 32
Specific trends during the study period (tendency between before and since 1973). **BAR**, *Bombus (Ps.) barbutellus*; **BOH**, *B. (Ps.) bohemicus*; **CAM**, *B. (Ps.) campestris*; **CON**, *B. confusus*; **CRY**, *B. cryptarum*; **DIS**, *B. distinguendus*; **HOR**, *B. hortorum*; **HUM**, *B. humilis*; **HYP**, *B. hypnorum*; **JON**, *B. jonellus*; **LAE**, *B. laesus mocsaryi;* **LAP**, *B. lapidarius*; **LUC**, *B. lucorum*; **MAG**, *B. magnus*; **MUS**, *B. muscorum*; **PAS**, *B. pascuorum*; **POM**, *B. pomorum*; **PRA**, *B. pratorum*; **RUR**, *B. ruderarius*; **RUT**, *B. ruderatus*; **RUP**, *B. (Ps.) rupestris*; **SEM**, *B. semenoviellus*; **SUB**, *B. subterraneus*; **SYL**, *B. sylvarum*; **SIL**, *B. (Ps.) sylvestris*; **TER**, *B. terrestris*; **VES**, *B. (Ps.) vestalis*; **VET**, *B. veteranus.* NC: not computable. (Captions see Table 1).

rank correlation, in the same way as was done for data obtained in the Cracow area. We compared species strongly expanding or strongly regressing in the Cracow with trends determined for these species in Belgium originally and after reanalysis (Tab. 4). Surprisingly, the level of compliance was significantly lower if the datasets were analysed with the same method (rank correlation). Higher level of compliance can be observed when the Cracow data obtained with rank logical are compared with the original Belgian data obtained using different methods (Rasmont & Mersch 1988, Rasmont *et al.* 1993; Tab. 4).

We also compared bumblebee species strongly regressing or expanding in the Cracow area, with country-wide status of the same species assessed for several European states: Belgium (Rasmont 1989), the Netherlands, Denmark, Germany, Switzerland, Austria, the Czech Rep., Slovakia, Hungary, and Poland (Kosior *et al.* 2007). In most cases, the tendencies found in the present study were concordant with status of the respective species elsewhere. Out of 7 species expanding in the Cracow area, 4 were relatively not threatened at the country scale elsewhere. The two exceptions were *B. jonellus* and *B. magnus* – in the majority of the countries surveyed their status was assessed as endangered, vulnerable or nearly threatened. Similarly, out of 10 species strongly regressing ("-" tendency in Tab. 1) in the Cracow area, 5 were generally reported as also threatened in the surveyed countries, except for *Bombus (Ps.) vestalis* and *Bombus (Ps.) campestris* (Kosior *et al.* 2007).

Table 3. Conservation status of *Bombini* species in Poland (legal protection and endangerment) and their status in the Cracow area.

*: Species strictly protected in Poland according to the Decree of the Minister of Environment (Dz. U. 2004); **: Status of the species in Poland according to Banaszak (2002); VU: Vulnerable; DD: Data deficient; #: Species extinct in the Cracow area in 1851–1900, ##: Species extinct in the Cracow area in 1901–1972, ###: Species extinct in the Cracow area in 1973–2003; @: New species in 1901-1972, @@: New species in 1973–2003.

Species	Status in Poland		Status in Cracow	
	Protected*	Endangered**	Extinct	New
Bombus confusus	+	VU	##	
Bombus cryptarum	+	DD		@
Bombus distinguendus	+	VU	###	
Bombus hortorum	+			
Bombus humilis	+	VU		
Bombus hypnorum	+			
Bombus jonellus	+	VU		@@
Bombus laesus mocsaryi	+	VU	#	
Bombus lapidarius				
Bombus lucorum	+			
Bombus magnus	+	DD		@@
Bombus muscorum	+			
Bombus pascuorum	+			
Bombus pomorum	+	VU	###	
Bombus pratorum	+			
Bombus ruderarius	+			
Bombus ruderatus	+	VU		
Bombus semenoviellus	+			@@
Bombus subterraneus	+	VU		
Bombus sylvarum	+			
Bombus terrestris				
Bombus veteranus	+	VU		
Bombus (Ps.) barbutellus			###	
Bombus (Ps.) bohemicus				@
Bombus (Ps.) campestris				
Bombus (Ps.) rupestris				
Bombus (Ps.) sylvestris				@@
Bombus (Ps.) vestalis				
Total number of species	**20**	**11**	**5**	**6**

Due to heterogeneity of available data and study methods, it is difficult to draw sound conclusions about factors accounting for different tendencies found in this study. This is particularly true for species of stable and strongly expanding tendencies. Expanding species were more or less hylophilous, connected with wood or heathers. Some of these species were rarely recorded in the early studies, thus expanding tendency may in fact be a result of a bias due to high research effort in 2000-2003 field study, and therefore may not reflect real population tendencies. On the contrary, smaller number of recent records, despite intensive field study, is likely to reflect the real negative population tendencies. It is worth noticing that the highest number of species went extinct in the study area after 1973, which confirms the threat for this group of species found both in the Cracow area and elsewhere.

Comparison of the bumblebee composition in the present study with results obtained in other Polish cities, including Poznań (Wójtowski & Szymaś 1973, Banaszak (1974), Lublin (Anasiewicz 1971), Warszawa (Banaszak 1982), Katowice (Miszta *et al.* 2002) and Toruń (Pawlikowski & Olędzka 1996), shows that the species richness in the Cracow area was relatively high. However, loss of pollinators in the Cracow area recoreded in the present study confirmed results

Table 4. Comparison the tendencies found in *Bombini* species of the Cracow area, calculated with rank logical, with data for the whole Belgium, calculated in 3 different ways: rank test (data from Rasmont *et al.* 1993), Stroot & Depiereux method (data from Rasmont et. al. 1993), and relative abundance method (data from Rasmont & Mersch 1988).

++: Strongly expanding; +: Expanding; --: Strongly regressing; 0: Stable; ?: Unknown; NP: Not present (out of distribution range *Bombus soroeensis* (Fabricius), *B. (Ps.) norvegicus* (Sparre Schneider) and *B. cullumanus* (Kirby) are known from Belgium but not from Krakow region). NS: Non significant (Captions see Table 1).

Species	Cracow	**Rasmont & Mersch 1988**	**Rasmont *et al.* 1993**	**Rasmont *et al.* 1993 re-analysed with Rank logical**
Bombus magnus	+	?	?	?
Bombus (Ps.) sylvestris	+	+	++	+
Bombus jonellus	+	0	--	+
Bombus semenoviellus	+	NP	NP	NP
Bombus pratorum	+	+	++	+
Bombus lucorum	+	?	?	?
Bombus (Ps.) bohemicus	+	+	++	+
Bombus ruderatus	NS	-	--	-
Bombus subterraneus	NS	-	--	0
Bombus hortorum	NS	0	--	0
Bombus (Ps.) rupestris	NS	-	--	0
Bombus cryptarum	NS	?	?	?
Bombus lapidarius	NS	0	--	0
Bombus pascuorum	NS	0	+	0
Bombus veteranus	NS	-	--	-
Bombus ruderarius	NS	0	--	0
Bombus terrestris	NS	?	?	?
Bombus hypnorum	NS	+	++	+
Bombus sylvarum	-	-	--	+
Bombus muscorum	-	-	--	-
Bombus (Ps.) vestalis	-	0	--	0
Bombus humilis	-	--	--	0
Bombus (Ps.) campestris	-	0	--	0
Bombus distinguendus	-	--	--	-
Bombus laesus mocsaryi	-	NP	NP	NP
Bombus confusus	-	--	--	0
Bombus (Ps.) barbutellus	-	--	--	0
Bombus pomorum	-	--	--	-

obtained by Banaszak *et al.* (1998). Long-term negative population tendencies in bumblebee species have been recorded also in other parts of Poland (Banaszak 1974, Kosior *et al.* 2003). In the Cracow area, negative population tendencies were revealed in butterflies (Razowski & Palik 1969, Skalski 1976, Dąbrowski 1979, Dąbrowski & Krzywicki 1982, Razowski 1985). According to Razowski (1985), the decrease in the butterfly populations in the Cracow area has been observed since 1950s.

Lack of comparative data in the Cracow area does not allow drawing solid conclusions about causes of the decline of these species. Species for which regressing tendency was found were eremophilous and thermophilous, connected with wood-edges and neighbouring areas (Rasmont 1988). Among natural causes of the *Bombini* loss, ecological succession, severely affecting species of open habitats (Williams 1988, Westrich 1989, Banaszak *et al.* 1998, Kosior *et al.* 2007), food availability (Williams 1989, Kevan 1999, Pelletier 2003, Kosior *et al.* 2007), destruction of nesting sites (Kevan 1999, Kosior *et al.* 2007) and mortality due to parasitism on wintering young females (particularly *Sphaerularia bombi* Dufour, Alford 1975, Pelletier 2003, Kosior *et al.* 2007) were reported.

In urban areas, however, anthropogenic factors may have a more severe impact on bumblebee species than natural ones. These factors include significant changes in landscape management, such as expansion of built-up areas and melioration of wetlands (Wergin 1977). Environmental pollution due to industrial development (Wergin 1977, Warncke *et al.* 1984, Hagen & Aichhorn 2003) and heavy traffic (Kosior 1987, Kosior & Nosek 1987, Kosior 1992, Hagen & Aichhorn 2003) probably had an additional negative effect.

Mortality of bumblebees under the influence of collisions with vehicles could directly affect population numbers, especially in the early spring, when the young females are flying to find and build a nest, thus contributing to dying out of the potential annual generations of bumblebees (Donath 1985, Kosior *et al.* 2007). Another factor seriously diminishing the numbers of all insect species is setting on fire dry meadows in the spring and stubble in the autumn (Dąbrowski 1979, Hagen & Aichhorn 2003). Species occurring in agricultural land were affected by changes in land management such as intensive use of fertilizers and machines (Wergin 1977, Else *et al.* 1979, Aichhorn 1983, Warncke *et al.* 1984, Valenta & Arbačiauskas 1988, Kosior 1992, Banaszak 1995, Hagen & Aichhorn 2003) and introduction of monocultures, leading to habitat homogeneity, and consequently, to shortage of food plants and nest sites (Riess *et al.* 1976, Else *et al.* 1979, Aichhorn 1983, Warncke *et al.* 1984, Westrich 1989, Kosior 1992, Achterberg pers. comm. 2002, Chlebo pers. comm. 2002, 2004, Neumayer 2002, Hagen & Aichhorn 2003, Goulson *et al.* 2005).

Locally intensive grazing by cattle, sheep, goats and horses (Else et al. 1979, Kosior 1990, 1992, Hagen & Aichhorn 2003), could also have contributed to pollinator loss in the Cracow area. Collection of individuals, particularly young females, for private and museum collections played only very small role in the study area, what stated also during their investigation in Belgium (Rasmont & Mersch 1988; Rasmont 1995).

The only 2 species of bumblebees that are not strictly protected in Poland (*B. lapidarius* and *B. terrestris*) did not show negative tendencies in the study area, although one must bear in mind that these species were protected until 2004. At the same time, all bumblebees on decline in the study area are strictly protected. This suggests that legal protection of bumblebees in not an effective measure for preventing them from decline. Nevertheless, legal protection should be considered for 3 cuckoobee species, declining at least in the Cracow area.

As species legal protection is not sufficient conservation measure itself, it is essential that it is accompanied by habitat protection (Rasmont 1995, Williams 2005). The network of protected areas in the study area, currently comprising 5 nature reserves, should be extended by designation of new nature reserves, particularly to protect remnants of wet meadows in Kostrze, Sidzina, Mydlniki, Tonie, Os. Kliny and on flood embankments of the Vistula river. Management of the existing and new nature reserves should include regular mowing (every 2 years) in order to inhibit natural succession. It is also very important to strictly enforce the ban on setting dry meadows and stubble on fire.

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