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# How much is a bee worth? Economic aspects of pollination of selected crops in Poland

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S u m m a r y

Scientific studies state that a considerable part of the economic value of crop plant production should be attributed to the free services of pollinating insects. Such calculations are available for several EU and North American countries, and the present paper evaluates the value of pollination services to 19 important Polish crop plants. It is estimated that the market value of 19 entomogamous crops reaches the sum of approx. 7.5 billion PLN (thousand million) (approx. 1.8 billion EUR), 39% of this may be attributed to the insect activities, the most important being bees (the service value of approx. 2.5 billion PLN/0.6 billion EUR) and dipterans (almost 0.3 billion PLN/ 74 billion EUR). The paper discusses also the challenges and pitfalls of similar estimations and the need for conservation actions directed on crop plant pollinators.

Key words: Crop plants, pollination, economic value, bees

## INTRODUCTION

Since 1990-ties there has been much debate in the scientific literature on the so-called pollination crisis, phenomenon which involves many plant species, including the most important for human economy crop plants (B u c h m a n n and N a b h a n , 1996; K e a r n s et al., 1998). Pollination crisis results in decrease in plant yield caused by improper or not sufficient number of insect pollinators (W i l c o c k and N e i l a n d , 2002). Observations (R e d d i , 1987; A l l e n - W a r d e l l et al., 1998;

Kearns et al., 1998; Richards, 2001) and theoretical models (Kevan and Phillips, 2001) show that it may have serious consequences for world economy, since it is estimated that in Europe, for instance, almost 85% of crop plants relies on insect pollinators (Wilcock and Neiland, 2002).

First step in estimations and/or anticipations of economic consequences of pollination crisis is to quantify the value of services of the whole pollinator entomofauna or particular insect species. Such attempts have already been undertaken for the world economy (Richards, 1993; Costanza et al., 1997) and for several national markets, for instance USA (Robinson et al., 1989; Buchmann and Nabham, 1996; Morse and Calderone, 2000) or the UK (Carreck and Williams, 1998). So far the only estimation of this kind for Poland, known to the authors of the present paper, is the work by Banaszak and Cierzniak (1995), who dealt with economic aspects of pollination of alfalfa, apple, buckwheat, red clover, and oil rape. The aim of this paper is to estimate the value of pollination services carried by various insect groups on selection of 19 widely grown important crops in Poland.

Researchers trying to quantify precisely the scale of pollination crisis usually meet major methodological problems arising from the species' biology. For instance, it is said that more than one third of the world crops is directly or indirectly dependent on the pollination by honeybee (Williams, 1995). However, this species is not a sole pollinator available, and its effectiveness is quite controversial (Westerkamp, 1991; Buchmann and Nabhan, 1996; Allen-Wardell et al., 1998; Kearns et al., 1998; Westerkamp and Gottsberger, 2001). Several authors for example compared the pollination effectiveness of honeybee and wild bees, and indicated the superior services of the latter (Westerkamp, 1991; Wilson and Thomson, 1991; Vicens and Bosch, 2000; Stanghellini et al., 2002).

General estimations state that 73% of all crops are pollinated, at least partially, by bees (Apoidea, including honeybee), 19% by different dipterans, 6,5% by bats, 5% by wasps, 5% by beetles, 4% are ornithogamous, and 4% are pollinated by butterflies and moths. According to these numbers, honeybee is a dominant pollinator of only 15% of world crop plants (Buchmann and Nabhan, 1996; Ingram et al., 1996).

One may also add here that many of these species, maybe even majority (at least for Europe), for instance fruit trees of Rosaceae or umbelliferean vegetables, are promiscuous in terms of pollination biology, which means they are visited and pollinated by numerous and diversified groups of insects. In consecutive seasons, such pollinator assemblage may fluctuate in terms of its quality and quantity, which may be caused by weather conditions or other abiotic and biotic factors. Apart from that, great deal of pollination data is based on visitation indices, and not on actual observations of plant biology and ecology, and only experimental studies may truly indicate the importance of particular flower visitor (Williams, 1995; Buchmann and Nabhan, 1996; Waser et al., 1996; Johnson and Steiner, 2000; Pellmyr, 2002; Fenster et al., 2004). In most of cases, we even do not now how many potential pollinators are there. Consider Europe, the best researched region of the world, and the fact that we are still unable to count local bee species, there are probably 2.000-4.500 of them here (Williams, 1995). Other insect groups are even less studied. More or less complete data is only present for the honeybee. This situation is due to logistical and statistical reasons: it is easier to count or estimate the number of colonies of *A. mellifera* in any of the world regions than any other pollinator. We sometimes also underestimate abiotic factors contributing to pollination of crops, traditionally regarded entomogamous (e.g. oil rape). This all means that our knowledge in this field is less than basic and more studies are necessary.

## MATERIAL AND METHODS

There are approximately 300 crop plant species in cultivation in Poland (COBORU, 2005; W. Podyma, pers. inf.), and over 60 of them need to be insect pollinated in order to set fruit and/ or increase the yield (Banaszak and Cierzniak, 1995). For the present estimation, we chose 19 major entomogamous or mostly entomogamous crops for which data on yield production and crop value is available (Table 1 and 2).

Based on literature survey (references are given in Table 1), we assessed pollinator entomofauna of the selected plants. Unfortunately, most of available information comes from apicultural observations, which concentrate on *A. mellifera*, and other insect visitors, usually wild bees, are treated as "other pollinators" without detail information on their importance. Even in case of honeybee its effectiveness is usually assessed based on flower visitation ratio, and the information on pollen pickup and deposition is lacking. For these reasons, we did not attributed the value of pollination service of honeybee and other bee species to particular taxon, but to *bees* sensu lato, which includes *A. mellifera, Bombus* spp. and other wild bees.

Then, using statistical data, we assessed the money value of selected crops yield (state for the year 2004) and attributed that to the service of particular group of pollinators. For doing this, the money value of the crop was multiplied by the weighted 'need of insect pollinator' factor (following O'Grady, cited in Robinson et al., 1989), which comes into three values: low (0.1), medium (0.5) and high (0.9), and indicates the dependency of particular crop yield on pollinator activity (Table 1). This is based on published insect dependency levels of plants (Williams, 1994; Carreck and Williams, 1998) and indicates the importance of insect pollinators activity for the plant yield and\or propagation of the next generation. For instance, 'the need for insect pollination' for cucumber (*C. sativus*) and carrot (*D. carota*) is scored as high (0.9) because for both crops the activity of insect pollinators is an indispensable condition of fruit and seed set required either as a crop yield itself and source of seeds (cucumber), or for propagation of the next generation of the crop (carrot).

# RESULTS

Based on published studies and observations (references given in Table 1), the yield of six of the studied crops (*Beta vulgaris* sugar beet and root beet, *Brassica napus*, *B. rapa*, *F. ×ananassa, Rubus idaeus*) was assumed as low-dependent on insect pollination, six (*A. cepa, L. esculentum, P. domestica, P. communis, R. grossularia, Ribes spp.*) as medium-dependent, and seven (*B. oleracea* cauliflower and cabbage, *C. sativus, D. carota, M. domestica, P. avium, P. cerasus*) as highly-dependent on insect pollination.

In most of cases plants depended exclusively or mainly on bees as pollinating agents, with the exception of *A. cepa* and *D. carota* where other insect groups were also important pollen vectors Diptera in case of *A. cepa*, and Diptera and Coleoptera in case *D. carota*. Coleopterans were also involved in pollination of *B. oleracea* (Table 1).

Based on statistical data for 2004, the crop yield value for 19 selected plants was calculated for over 7.5 billion PLN (thousand million PLN), with the highest scores for sugar beet (almost 2.5 billion PLN), *B. napus*/*B. rapa* (almost 1.5 billion PLN) and *M. domestica* (almost PLN 0.9 billion PLN), and the lowest for *R. grossularia* (approx. PLN 50 million) (Table 2).

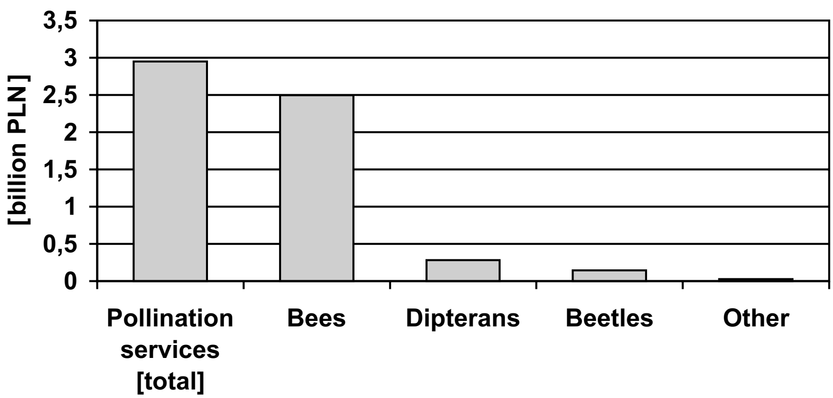


Fig. 1. Money value of insect pollination services (in PLN billion) to 19 selected Polish crop plants. For details on plant species selection see Table 1.

Table 1

Selected Polish crop plants and their pollination biology based on literature survey. *Beta vulgaris and Brassica oleracea* denote sugar beet and root beet, and cabbage and cauliflower respectively, while *Ribes* spp. stands for all cultivated *Ribes* species except for *R. grossularia.*

| Crop plant | Need for insect pollination[a] | Pollinating agents | | | | References |
|---|---|---|---|---|---|---|
| | | Bees | Diptera | Coleoptera | Other | |
| *Allium cepa* | 0.5 | 0.5 | 0.5 | | | Knuth, 1899; Jabłoński, 1997; Witter & Blochtein, 2003 |
| *Beta vulgaris* | 0.1 | 1 | | | | Maletskii & Maletskaya, 1996; Jabłoński, 1997 |
| *Brassica napus/ B. rapa* | 0.1 | 0.8 | 0.2 | | | Knuth, 1898; Banaszak & Cierzniak, 1995; Varis, 1995; Carreck et al., 1997; Carreck & Williams, 1998 |
| *Brassica oleracea* | 0.9 | 0.8 | 0.1 | 0.1 | | Knuth, 1898; Jabłoński, 1997 |
| *Cucumis sativus* | 0.9 | 1 | | | | Jabłoński, 1997; Stanghellini et al., 1997, 2003; Carreck & Williams, 1998 |
| *Daucus carota* | 0.9 | 0.1 | 0.4 | 0.4 | 0.1 | Knuth, 1898; Koul et al., 1987; Jabłoński, 1997; Lamborn & Ollerton, 2000 |
| *Fragaria ×ananassa* | 0.1 | 1 | | | | Carreck & Williams, 1998; Richards, 2001 |
| *Lycopersicon esculentum* | 0.5 | 1 | | | | Carreck & Williams, 1998; Richards, 2001 |
| *Malus domestica* | 0.9 | 1 | | | | Banaszak & Cierzniak, 1995; Jabłoński, 1997; Carreck & Williams, 1998; Vicens & Bosch, 2000; Richards, 2001 |
| *Prunus avium* | 0.9 | 0.9 | 0.1 | | | Knuth, 1898; Westerkamp & Gottsberger, 2001 |
| *Prunus cerasus* | 0.9 | 1 | | | | Knuth, 1898; Carreck & Williams, 1998; Jabłoński, 1997 |
| *Prunus domestica* | 0.5 | 0.9 | 0.1 | | | Knuth, 1898; Carreck & Williams, 1998; Jabłoński, 1997 |
| *Pyrus communis* | 0.5 | 1 | | | | Knuth, 1898; Jabłoński, 1997; Carreck & Williams, 1998; Maccagnani et al., 2003 |
| *Ribes grossularia* | 0.5 | 1 | | | | Knuth, 1898; Jabłoński, 1997; Carreck & Williams, 1998 |
| *Ribes spp.* | 0.5 | 1 | | | | Knuth, 1898; Jabłoński, 1997; Carreck & Williams, 1998; Kołtowski et al., 1999; Denisow, 2003 |
| *Rubus idaeus* | 0.1 | 1 | | | | Knuth, 1898; Jabłoński, 1997; Carreck & Williams, 1998; Neira et al., 2000 |

[a] based on data from Williams (1994), and Carreck and Williams (1998) or estimations of the authors

Table 2

Market value of selected entomogamous crops in Poland in 2004, and the estimated value of pollination services.

| Crop plant | Yield in 2004 [$\times 10^3$t][b] | Market price [for $10^{-1}$t] | Market value [million PLN] | Value of pollination service [million PLN][c] |
|---|---|---|---|---|
| *Allium cepa* | 865.7 | 45 | 389.58 | 194.79 |
| *Beta vulgaris* (sugar beet) | 12 499.2 | 20 | 2 448.59 | 244.86 |
| *Beta vulgaris* (root beet) | 356.9 | 35 | 124.91 | 12.49 |
| *Brassica napus/ B. rapa* | 1 632.9 | 90 | 1 469.63 | 146.96 |
| *Brassica oleracea* (cabbage) | 1 371.0 | 20 | 274.19 | 246.77 |
| *Brassica oleracea* (cauliflower) | 205.7 | 85 | 174.83 | 157.35 |
| *Cucumis sativus* | 255.9 | 150 | 383.79 | 345.41 |
| *Daucus carota* | 927.9 | 31 | 287.66 | 258.89 |
| *Fragaria ×ananasa* | 185.6 | 108 | 200.43 | 20.04 |
| *Lycopersicon esculentum* | 212.7 | 80 | 170.13 | 85.07 |
| *Malus domestica* | 2 521.5 | 35 | 882.53 | 794.28 |
| *Prunus avium* | 48.4 | 190 | 92.04 | 82.84 |
| *Prunus cerasus* | 201.7 | 100 | 201.73 | 181.56 |
| *Prunus domestica* | 132.6 | 65 | 86.20 | 43.10 |
| *Pyrus comunis* | 87.3 | 140 | 122.21 | 61.11 |
| *Ribes grossularia* | 19.9 | 250 | 49.74 | 24.87 |
| *Ribes spp.* | 194.5 | 40 | 77.80 | 38.90 |
| *Rubus idaeus* | 56.8 | 170 | 96.62 | 9.66 |
| | | | 7 532.61 | 2 948.95 |

[a] Vegetable and fruit market prices based on Ogrodniczy Informator Cenowy (2004), oil rape prices based on weekly Internet service Rynek roślin oleistych (2004), sugar beet prices based on Skarżyńska et al. (2004)
[b] GUS 2004
[c] Result of multiplication of the 'Need for insect pollination' from Table 1 and 'Market value' from the fourth column of this table.

The calculated value of pollination services (a result of the multiplication of 'the need for insect pollination' times 'market value' for particular crop plant) to all studied crops reached in 2004 the sum of almost PLN 3.0 billion (thousend million). The highest result were obtained for *M. domestica* (approx. PLN 0.8 billion) and *C. sativus* (approx. PLN 0.35 billion) (Table 2).

The most important pollinators, in term of the economic value of pollinated crops, were bees (including *A. mellifera*), which were the chief pollinators of most of the studied crops. The pollination service of these insect is estimated for 2.5 billion PLN, second being Diptera with the service value of almost 0.3 billion PLN. The remaining 0.17 billion PLN was attributed to beetles or other pollinators (Fig. 1). The service value of bees accounted for almost 85%, and the dipterans for almost 10% of the crop value of studied plants.

## DISCUSSION

The value of the plant yield from 19 crops selected for the present study was estimated for over 7.5 billion PLN, and over 39% of this sum may be directly attributed to the service of pollinating insects. This means that solely for these crops, the free pollinator service brings the Polish economy almost PLN 3.0 billion each year, the sum comparable to approx. 20% of the state budget expenditures in the 1st quarter of 2005 (Ministry of Finance, 2005) or the value of twelve new F-16 planes. The most important share (approx. 85% of yield value, which is PLN 2.5 miliard) comes from the activity of bees, this number is not far from the estimations of Buchmann and Nabhan (1996), and Ingram and co-workers (1996), which state that 73% of world crops is pollinated by these insects, although these authors' calculations are based on species number, and not the crop value. The same value range may be shown for Diptera (10% crop value for Poland, and 19% world crop plants pollinated by flies) and Coleoptera (4.9% crop value for Poland, and 5% world crop plants pollinated by beetles).

The biggest challenge in similar estimations is an assessment of the importance of particular insect visitor. In many cases literature on crop pollination describes honeybee as a principal pollinator. This data is however based on apicultural research which, by definition, are focused on *A. mellifera*. Such observations usually include visitation frequency or analyses of the corbiculae loads, and this kind of data may be misleading. Different studies proved that in many cases the most numerous visitors are the least important pollinator, and visitation frequency should be treated as one (not the most important!) of the factors of pollinator effectiveness (Waser et al., 1996; Johnson and Steiner, 2000; Pellmyr, 2002; Fenster et al., 2004). In this context, honeybee may be regarded a very ambiguous pollinator (an "ugly pollinator" as termed by some authors). It is very efficient in pollen pickup, but it does not transfer it to other plants (Westerkamp, 1991; Wilson and Thomson, 1991), either because the pollen packed in corbiculae is not available to further pollinations (Parker, 1981; Buchmann and Nabhan, 1996) or due to honeybee preferences for male phase flowers of dichogamous or dioecious species (Goulson, 1999; and lit. cited.), which is condition *sine qua non* of effective pollination. Some other bee species may also behave in similar manner, for instance, studies of *Campanula rapunculus* showed that the consumption of pollen by *Chelostoma* bees covers 95% of the total pollen production of this species, for pollination only about 4% is left (Schlindwein et al., 2005). Such insects, similarly to honeybee, may also prefer one sexual form of flowers (Lau and Galoway, 2004; and lit. cited). The latter has also been showed for some Syrphidae (Zych, 2003). Detail analyses of flower visitor importance are available for minority of crop species and wildflowers, and our knowledge is based on fragmentary observations, which does not allow precise generalizations and true evaluations of the pollination agents.

Apart from economic, from the present paper one may also draw important conservation conclusions. If we extrapolate that almost three quarters of entomogamous crop plants is pollinated by bees, these insects should be of special care in any of the national conservation issues or programs. Of course, some of this number may be attributed to managed *A. mellifera*, but definitely a considerable part of the pollination services is conducted by numerous wild bees. It was indicated by several authors (e.g. Banaszak, 1992; Williams, 1995; Buchmann and Nabhan, 1996; Ingram et al., 1996, Allen-Wardell et al., 1998; Kremen and Ricketts, 2000 and lit. cit.) that these insects are under particular strong human pressure. In Poland, due to diversification of agricultural landscape, their situation seems to be stable (Banaszak 1992), in Western European or North American countries however populations of wild bees suffer from modern agricultural techniques and urbanisation (e.g. Steffan-Deventer and Tscharntke, 1999; Richards and Kevan, 2002; de Ruijter, 2002; Williams, 2002; Kremen et al., 2003) and the problem of under-pollination is probably one of the most important to be taken into account in future directions of agricultural sciences and conservation practices.

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## Ile warta jest pszczoła? Ekonomiczne aspekty zapylania wybranych upraw w Polsce

### Streszczenie

Badania wskazują, że znacząca cześć pieniężnej wartości plonów roślin uprawnych powinna być przypisana aktywności dzikich owadów zapylających. Opracowania w tej dziedzinie zostały wykonane dla kilku krajów Unii Europejskiej i Ameryki Pn., natomiast niniejsza praca ocenia wartość usług zapylaczy 19 gatunków roślin uprawnych w Polsce. W myśl danych statystycznych wartość rynkowa 19 ważnych upraw owadopylnych wynosi około 7,5 miliarda PLN (1,8 mld EUR), 39% tej sumy (prawie 3 mld PLN) jest pochodną aktywności owadów zapylających, z których najważniejszą grupę stanowią pszczołowate (wartość usług około 2,5 mld PLN/ 0,6 mld EUR) oraz muchówki (prawie 0,3 mld PLN/ 74 mln EUR). W pracy dyskutowane są także trudności i ograniczenia napotykane w podobnych oszacowaniach oraz potrzeba działań ochronnych, które powinny objąć owady zapylające uprawy.