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# BEES FOR POLLINATION

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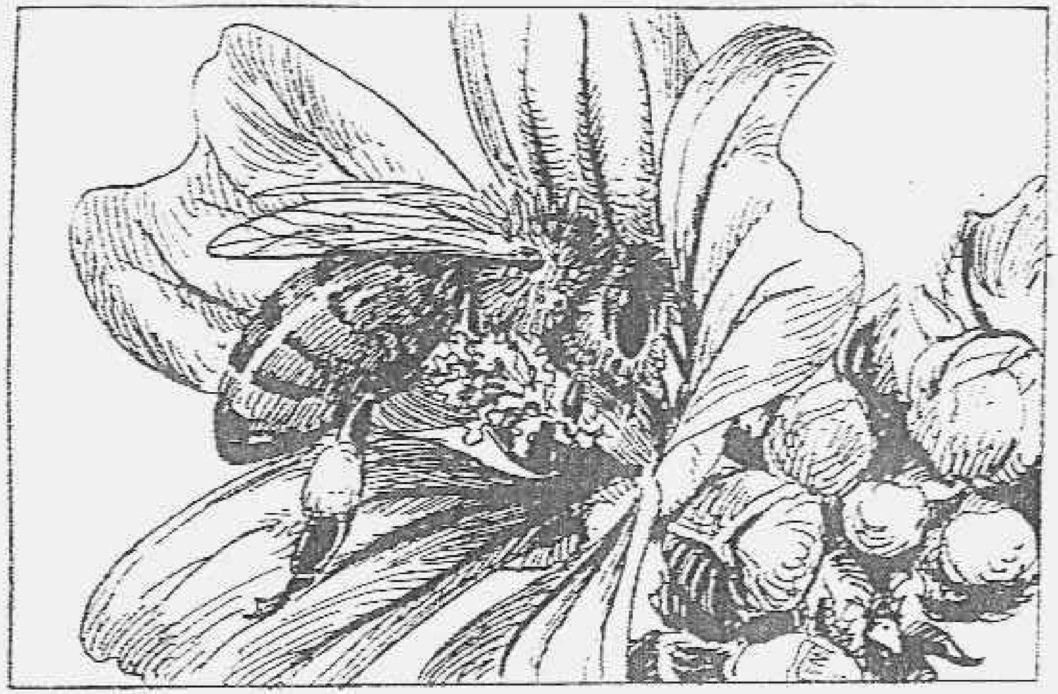

DIRECTORATE-GENERAL FOR AGRICULTURE
Division for the Coordination
of Agricultural Research

GROUP I

# POLLINATION

# RELATIONSHIP : FLOWERS-INSECTS

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# THE INTERDEPENDENCE OF AGRICULTURE AND APICULTURE IN THE EUROPEAN COMMUNITY

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## ABSTRACT

The interdependence of agricluture and apiculture must be more widely recognised if agricultural production of the present diversity of food crops in the EC is to continue.

A list of c. 252 EC crops has been compiled, including those grown for consumption by humans or livestock, for the pharmaceutical and perfumery industries, of gathered from the wild. Their pollination mechanisms are summarised and indicate that 84 % of the 170 species studied are dependent on or benefit from pollination by bees.

Bees need food from the agricultural environment to thrive. The most important nectar and pollen plants for honey bees in the UK of the 1930s, 1940s and 1950s are being compared with those of the 1980s and 1990s. A study of the land use changes (1945-1990) affecting the habitats of the bee forage plants indicates a steady impoverishment of the agricultural environment for honeybees.

Pollination practice in the UK is being investigated through surveys of beekeepers and growers. The colonies of hobbyist beekeepers tend to be static, and their bees provide a free pollination service to growers. Larger scale beekeepers move their colonies for honey production and pollination, and their bees supplement natural pollination of large monocultures. A survey of white clover seed growers revealed that most recognised that pollination was an important factor limiting yield and that both bumblebees and honey bees were important pollinators of their crops but imported further honeybees to supplement local pollinators.

## INTRODUCTION

If agricultural production by the European Community is to be sustained, the interdependence of agriculture and apiculture must be more widely recognised. Agriculture needs bees to pollinate many of its crops and bees need food from the agricultural environment to thrive. Agricultural policies and practices must ensure that the needs of bees within agroecosystems are met if we are to continue to produce the present diversity of food crops.

It has been estimated that about one third of man's diet is derived directly, or indirectly from insect-pollinated plants (McGregor, 1976). The total annual market value of only 30 of the major insect-pollinated field, fruit and vegetable crops grown by the European Community was calculated to be 65,000 million ecus (Borneck & Merle, 1989). Bees are by far the most important pollinators and honey bees are the only available managed pollinators for field crops at present; the contribution by honey bees was evaluated at 4250 million ecus. The contribution of wild bees, known to be better pollinators than honey bees of some crops (Corbet, Williams & Osborne, 1991a; Corbet, present volume), remains unquantified but is undoubtedly considerable. As the recorded distribution and abundance of wild bees has diminished over recent decades in at least some Member States (Williams, 1985; Rasmont, 1988; Day, 1991; Falk, 1991) honey bees are being increasingly relied upon to pollinate crops, and a thriving beekeeping industry must be maintained to ensure that these pollinators remain available.

Concern that changes in land use and beekeeping practice within the Community may result in a shortage of bees for crop and wild flower pollination caused STOA (Scientific and Technical Options Assessment, European Parliament) to commission a report entitled `Bees and the pollination of crops and wild flowers; changes in the European Community' (Corbet, Williams & Osborne, 1991a) to evaluate the situation through a literature review. The report has been made more widely available in abridged version in a series of articles (Corbet, Williams & Osborne, 1991b; Osborne, Williams & Corbet, 1991; Williams, Corbet & Osborne, 1991). In the report we called for appropriate agricultural and environmental policies and co-ordinated research and development programmes to ensure adequate pollination of crops and wild flowers pollinated by bees in the EC and suggested that three complementary objectives should be pursued. Firstly, to determine which crops and wild flowers are pollinated by bees, which species are best at pollinating them and what densities of pollinators are required. Secondly, to develop techniques for managing non-Apis bees as pollinators while promoting a beekeeping industry with appropriate distribution for optimum pollination of both crops and wild flowers. Thirdly to improve habitats for wild and managed bees and wild flowers, by appropriate management of agricultural, forested and semi-natural ecosystems, and to monitor the populations of wild bees and plants therein.

This paper reports on further work to collate published information on EC crops dependent on bees for pollination and on investigations into plant-pollinator interactions, with particular reference to crops, changes in land use and honey bees in the UK.

## E.C. CROPS DEPENDENT ON BEES FOR POLLINATION

The economic evaluation of the importance of bee pollination to EC agricultural crops (Borneck & Merle, 1989) was based on only c. 30 major crops, and in the STOA report (Corbet, Williams & Osborne, 1991a) we listed c. 43 major EC crops in which seed set is dependent on or enhanced by bee pollination.

A more comprehensive catalogue of the EC crops dependent on pollination by honey bees has now been prepared (Williams, 1992). This lists 252 species of crop plant from 59 plant families that are grown in the 12 member countries of the EC (after De Rougemont, 1989), including those grown commercially for human consumption, for forage or fodder for livestock, for the pharmaceutical and perfumery industries, and also those gathered from the wild for human consumption to such an extent that they enter commerce.

Nothing appears to have been published about the pollination requirements of 82 of the 252 species listed, highlighting the considerable need for further research into the basic pollination requirements of our crop plants. However, most (84%) of the remaining 170 crops, whose pollination requirements have been investigated and reported, are dependent on or benefit from insect pollination for fruit or seed production. Only 22 species (9%) are primarily wind-pollinated; these are the cereals, the nuts, hemp, carob bean and stonepine, and seed crops of hops and spinach. A few crops are automatically self-pollinating namely opium poppy, chick pea, peas, lettuce and common vetch grown for seed. Pollination is not required for the production of banana, which is parthenocarpic, or garlic, which is propagated vegetatively.

Adequate pollination is most vital for the production of those crops in which the fruit, seed or nut is the part of the plant that is harvested and the list of these crops is produced here (Table 1). The extent to which crops are dependent on insects for pollen transfer is determined by floral morphology, their degree of self-fertility and the arrangement of the flowers on the plant or plants. Among the most dependent are dioecious and monoecious species, i.e. those with staminate and pistillate flowers on the same or different plants or dichogamous species, in which the sexual organs are effective at different times. The degree of dependence on insects for pollen transfer of crops with hermaphrodite flowers, in which the anthers dehisce while the stigma is receptive, is governed to a large extent by the self-fertility of the species.

The catalogue summarises for each crop what is known about its pollinating agents, pollination mechanism and flower morphology, its dependence on insects, its visitation by honey bees and recommended number of honey bee colonies per unit crop area. Similar information is given where available for the EC crops grown mainly for their vegetative parts, as leguminous forage seed crops, for their essential oils or harvested from the wild, although far less is known about the floral morphology and self-fertility, let alone the pollination requirements of the majority of crops in these categories.

It is hoped that the catalogue will form a database to which new crops and new information can be added by researchers and will highlight those crops about which there is inadequate knowledge. It could also provide a basis for updating the assessment of the total annual market value of bee-pollinated EC crops.

## CHANGES IN LAND USE AND POLLINATION PRACTICE WITH PARTICULAR REFERENCE TO APICULTURE IN UK

### APICULTURE IN UK

The registration of beekeepers is not required in EC and no reliable collated apicultural statistics are available for the EC member countries, although, as pointed out by Corbet, Williams & Osborne (1991b), they are much needed. However, official government beekeeping statistics for England and Wales, obtained through close liaison with local beekeeping associations and county beekeeping officers, have been published annually since 1955 (MAFF, 1955-1990). These show that in 1990, there were estimated to be 33,744 beekeepers owning 163,822 colonies of honey bees in England and Wales.
The density of honey bees (1.0 hive $km^2$) is thus the lowest amongst the EC member states except for Ireland (0.2 hives $km^2$). A sharp decline in colony numbers occurred during the 1950s and 1960s (from 305,507 in 1955 to 152,608 in 1970), followed by a slow and sporadic increase to the mid eighties (194,916 in 1985), since when the number of colonies has declined steadily by 16% and the

number of beekeepers by 8%. They are still much lower than they were in the 1950s. UK and Ireland are at present the only EC countries not yet infested by the parasitic mite *Varroa jacobsoni* but when *Varroa* does reach UK further large colony losses are expected.

For most beekeepers in the UK, as elsewhere in Europe, beekeeping is not the main source of income. Most have a few hives as a hobby, some have more hives as a part-time source of income, and a few only earn their living solely from beekeeping; only 1% own more than 40 stocks of bees. Many amateur beekeepers belong to their local county beekeeping association and most of these are affiliated to the British Beekeepers Association. Larger scale producers with more than 40 hives may belong to the Bee Farmers Association.

## BEE FORAGE AND CHANGES IN LAND USE IN UK

The number of honey bee colonies an area can profitably support is determined largely by its honey productivity, as reflected in the average honey yield per hive, and determined by the quantity and quality of the bee forage in that area.

The major land use changes within Europe have been described by Corbet, Williams, & Osborne (1991a) who identified, in particular, an overall decrease in the availability of natural forage, an important resource for bees because of the widespread multifloral succession of nectar and pollen that it supplies. I am now investigating land use changes (1945©1990) in UK are now being investigated in more detail, mainly through a compilation of available relevant statistics, literature review, survey of beekeepers and further research to establish the current situation.

I have identified the most important sources of nectar and pollen in the 1930's, 1940's and 1950's from Herrod-Hempsall (1937), Manley (1930, 1946, 1948), Howes (1945) and Deans (1957). Herrod-Hempsall and Manley were the most prominent amateur and commercial beekeepers, respectively, of their time in the UK. Howes was a professional botanist and beekeeper, and Deans conducted a nationwide melissopalynological survey. Their data is being compared with data on the most important bee forage plants of the 1980's and 1990's. The latter information was partly collected from a survey of beekeepers conducted by the British Beekeepers Association during 1984-86, in which beekeepers nationwide were asked to list their principal honey plants. A new melissopalynological survey to compare the current situation with that reported by Deans (1957) would also be useful if funds could be found to conduct it; such a study would show quantitively which food resources the honey bee is currently utilizing from its environment, show how utilization has changed since the 1950's, identify for which plants the honey bee is probably an important pollinator and provide a sound database from which to monitor future changes.

I have grouped the plant species important as sources of nectar and pollen for honey bees into `habitat' categories, i.e. crops, herbaceous plants of cultivated and uncultivated areas, grassland/pasture plants, woodland and hedgerow plants and plants of inland or maritime moorlands, heaths or marshes. Statistics that show the changes in land use and management of these different plant habitats over the period 1945-90 have been extracted, and pinpoint the major changes that will have had impact on honey bee food sources.

The area of cereals (of no food value to bees, unless producing honeydew from infesting aphids or containing flowering weeds) has increased to dominate many rural landscapes. Many orchards have been grubbed up, removing an important spring food source. On the positive side, the increase in the area of oilseed rape, over the last 20 years, has contributed considerably to spring honey flows, albeit only for a short period, and when not treated with insecticide during flowering. Grasslands have declined in their value for bees; most have been 'improved' by reseeding and the application of herbicides and fertilizers or are cut for silage before any remaining herbaceous species have flowered. The increased use of herbicides for vegetation management has removed not only the flowering plants that were weeds within crops, but also those of field margins, hedgerow bottoms and waysides.

In the past, it was mainly the uncultivated areas within the agricultural landscape that provided the succession of flowers for bees but areas such as field margins, hedgerows, copses, waysides, water courses, ponds and wet areas have gradually been lost. Woodland, although nationally almost doubled in area since 1945, has seen the steady replacement of much broadleaved woodland with useful `bee trees' by fast-growing conifers with little ground flora.

## POLLINATION PRACTICE IN UK

The STOA report (Corbet, Williams & Osborne, 1991a) deplored the absence of published information on pollination practice within the EC and recommended 'collation and rapid publication of annual statistics for each country on the demand for honey bee pollination units, and on the number of colonies available to meet that demand.'

I have now begun to acquire, collate and analyse information on the pollination services provided by beekeepers and the demands for honey bee colonies and pollination practices of growers in UK, largely through surveys of beekeepers and growers.

The survey of beekeepers conducted by the British Beekeepers Association during 1984-86, questioned 500-1000 beekeepers each year about the movement of their colonies, either for honey production or for pollination. Analyses reveal that small-scale amateur beekeepers tend to keep their colonies static close to their homes. Their bees therefore provide a free pollination service to local growers. Larger scale beekeepers, particularly those who seek an income from their bees, frequently move their stocks from apiaries to crops to take full advantage of honey flows or to provide a pollination service to farmers with large crop monocultures requiring import of honey bees to supplement local pollinators. As the populations of wild bees and the density of beekeepers in rural areas have declined it is on this minority of beekeepers, willing and able to move their bees, on whom supplementary pollination depends.

Movement of hives is considerable. For example, in 1986, of a sample of 519 beekeepers owning 3863 colonies, 20% moved some or all of their stocks during the year, either for pollination or honey production. Beekeepers in different counties moved colonies to different extents; in London and Surrey, fewer than 5% did so; in Berkshire, Devon, Kent, Suffolk, Essex and Lancashire 10-24% moved colonies, whereas in Yorkshire, 52% of beekeepers moved colonies during the year, but mainly to heather moors. Overall 14% of the 3863 stocks were moved to crops specifically for pollination; again this practice varied with region, the two counties with most movement were Kent (21%) and Essex (23%). Kent is UK's most important top fruit growing area, Essex is important for both fruit and seed crops. Both counties have active beekeeping organisations with pollination services supplying growers with honey bees, and both organisations have supplied detailed information for this ongoing study.

Useful information about grower demand for pollinators is also being gleaned through survey of growers. As an example, the results from a postal questionnaire sent to white clover seed growers in UK are presented in Table 2. It has revealed that most growers feel that inadequate pollination is an important factor limiting seed yield of their crops, most recognise that both honey bees and bumblebees are important pollinators, and many import and pay for honey bee colonies to supplement locally available pollinators. Research investigations into the pollination requirements of white clover, the abundance of naturally occurring pollinators and the comparative efficacy of bumblebees and honey bees are being undertaken at Rothamsted with the aim of developing husbandry practices to ensure optimum pollination of the crop.

If we are to manage pollinator populations effectively for crop production without environmental damage, the impact on populations of wild pollinators of importing honey bees to pollinate field crops is an area deserving research. Possible competitive interactions between honey bees and wild bees and the possible effects of episodic flooding of crops with honey bees on wild flower pollination and the survival of wild bees are discussed by Williams, Corbet & Osborne (1991a).

For optimal pollination efficiency there is no doubt that it is desirable that bees should live close to or be available from near the crop requiring pollinators. The urbanisation of beekeepers and shift to fewer larger scale beekeepers is divorcing the pollinators from the crops that need them, thereby increasing the cost of production. Competition for impoverished food resources and movement of colonies over long distances also increases disease problems (Ball & Williams, 1992). The distribution of beekeepers and their colonies relative to the distribution of crops requiring pollination is another aspect I plan to investigate at Rothamsted through superimposition of available MAFF beekeeping, agricultural and horticultural county statistics using suitable computer mapping software.

## CONCLUSION

The recent change in EC agricultural policy, away from intensification and the stimulation of production to encouragement of lower input farming and land use diversification may bring benefits for bees and beekeeping (Ball & Williams, 1992) but, it will only do so, if the anticipated land use and management changes are sensitive and sympathetic to their needs. Scientists and conservationists within the EC, concerned to see that the deleterious practices of past decades are discontinued and that efficient, competitive but ecologically and environmentally sound pollination management for our crops and native flora are adopted, must coordinate their research efforts to pursue well-defined complementary objectives and thereby provide a sound information base. Only this will convince policy makers of the necessity to safeguard wild bee populations and the beekeeping industry in the interests of sustaining the diverse food cropping and natural environment of the European Community.

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**TABLE 1. E.C. crops grown for their seed, fruit or nuts that are dependent on or known to benefit from bee pollination.**

| | |
|---|---|
| ACTINIDIACEAE | |
| *Actinidia chinensis* | kiwifruit |
| ANACARDIACEAE | |
| *Mangifera indica* | mango |
| APIACEAE | |
| *Apium graveolens* | celery |
| *Foeniculum vulgare* | fennel |
| *Anethum graveolens* | dill |
| *Coriandrum sativum* | coriander |
| *Carum carvi* | caraway |
| ASTERACEAE | |
| *Helianthus annuus* | sunflower |
| *Carthamus tinctorius* | safflower |
| BRASSICACEAE | |
| *Brassica napus* | oilseed rape |
| *Brassica campestris* | turnip rape |
| *Brassica nigra* | black mustard |
| *Sinapis alba* | white mustard |
| CUCURBITACEAE | |
| *Cucurbita peop* | marrow |
| *Cucurbita maxima* | pumpkin |
| *Cucurbita mixta* | pumpkin |
| *Cucumis melo* | melon |
| *Cucumis sativus* | cucumber |
| *Citrullus lanatus* | water melon |
| EBENACEAE | |
| *Diospyros kaki* | persimmon |
| ERICACEAE | |
| *V accinium macrocarpon* | cranberry |
| *Vaccinium corymbosum* | blueberry |
| FAGACEAE | |
| *Castanea sativa* | chestnut |
| GROSSULARIACEAE | |
| *Ribes uva-crispa* | gooseberry |
| *Ribes nigrum* | black currant |
| *Ribes rubrum* | red & white currant |
| LAURACEAE | |
| *Persea americana* | avocado |
| MALVACEAE | |
| *Hibiscus esculentus* | okra |
| *Gossypium* spp. | cotton |
| MYRTACEAE | |
| *Feijoa sellowiana* | feijoa |
| OLEACEAE | |
| *Olea europea* | olive |
| PAPILIONACEAE | |
| *Lupinus angustifolium* | blue lupin |
| *Lupinus mutabilis* | pearl lupin |
| *Lupinus lutens* | yellow lupin |
| *Lupinus albus* | white lupin |
| *Glycine max* | soybean |
| *Phaseolus multiflorus* | runner bean |
| *Vicia faba* | broad, field bean |
| PASSIFLORACEAE | |
| *Passiflora edulis* | passion fruit |
| POLYGONACEAE | |
| *Fagopyrum esculentum* | buckwheat |
| ROSACEAE | |
| *Rubus fruiticosus* | blackberry |
| *Rubus caesius* | dewberry |
| *Rubus idaeus* | raspberry |
| *Rubus longanobaccus* | loganberry |
| *Rubus phoenicolasius* | wineberry |
| *Fragaria ananassa* | strawberry |
| *Cydonia oblonga* | quince |
| *Eriobotrya japonica* | loquat |
| *Malus pumila* | apple |
| *Pyrus communis* | pear |
| *Prunus armeniaca* | apricot |
| *Prunus persica* | peach, nectarine |
| *Prunus communis* | almond |
| *Prunus avium* | sweet cherry |
| *Prunus cerasus* | morello cherry |
| *Prunus cerasifera* | myrobalan, cherry-plum |
| *Prunus domestica* | plums, damsons, gages |
| *Coffea* sp. | coffee |
| RUTACEAE | |
| *Citrus sinensis* | sweet orange |
| *Citrus aurantium* | sour orange |
| *Citrus aurantifolia* | lime |
| *Citrus bergamia* | bergamont orange |
| *Citrus reticulata* | tangarine, mandarine |
| *Citrus limon* | lemon |
| *Citrus medica* | citron |
| *Citrus paradisi* | grapefruit |
| SOLANACEAE | |
| *Capsicum annuum* | peppers, chillies |
| *Capsicum frutescens* | bird chillies |
| *Solanum melongena* | aubergine, eggplant |
| *Lycopersicon esculentum* | tomato |
| VITACEAE | |
| *Vitis vinifera* | grapevine |

**Table 2.** The pollination practice of UK white clover seed growers 1988-1990

| | 1988 | 1989 | 1990 |
|---|---|---|---|
| **No. of growers in survey** | 40 | 39 | 31 |
| **No. of crops in survey** | 61 | 51 | 48 |
| **% of growers that felt inadequate pollination limited yield:** | | | |
| **Yes** | 68 | 62 | 66 |
| **Sometimes** | 25 | 35 | 34 |
| **% of growers that thought main pollinators were:** | | | |
| **Honey bees & bumblebees** | 82 | 73 | 71 |
| **Honey bees** | 13 | 19 | 23 |
| **Bumblebees** | 2 | 5 | 3 |
| **Unknown** | 1 | 3 | 3 |
| **% of growers that imported colonies of honey bees** | 73 | 69 | 57 |
| **% of growers that imported colonies, that paid for them** | 59 | 63 | 41 |

# RECENT DEVELOPMENTS IN INSECT POLLINATION OF HORTICULTURAL CROPS

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## RECENT DEVELOPMENTS IN GREENHOUSE CROPS

### Tomato

In the Netherlands the most important horticultural crop is greenhouse tomatoes. The value of the tomato crop in 1991 was over 1,000,000,000 dutch guilders. Until 1985 pollination of greenhouse tomato was exclusively done by hand, with the help of an electric device (the electric bee). In 1985 the Ambrosiushoeve initiated research on insect pollination of greenhouse tomato. Tomato flowers are not attractive to honeybees. The flowers do not produce nectar and only a limited amount of pollen is produced. The pollen is difficult to collect, as it is set free inside a tube formed by the anthers.

Our aim was to lure honeybees towards the tomato flowers, using several tricks like spraying a honeysolution, dusting the plants with pollen or using chemical attractants. To our surprise, none of the tricks were necessary. A few days after we had placed honeybee colonies inside a heated greenhouse in February, the bees started to search for food. They visited the tomato flowers and succeeded to collect pollen by shaking the flowers. It became clear that in winter time with the windows of the greenhouse closed, bees had no alternative but to collect pollen from the tomato flowers. Due to the high temperature the colonies started to produce brood, causing an urgent need for pollen. In 1985 and 1986 we conducted experiments in order to find out whether honeybees could replace hand pollination. In 1987 and 1988 we did similar experiments in practice. We found that honeybees could replace hand pollination in greenhouse tomato during winter, until the weather gets better and the windows are opened more frequently (27). Honeybees have a highly developped language. As soon as one individual honeybee has found a better food source outside the greenhouse, the message is spread among the other bees of the hive, not only about the quality of the food source, but also about the direction and the distance it can be found. From that moment on honeybees reject the tomato flowers and start collecting food outside the greenhouse. It is possible to prevent the bees from leaving the greenhouse by providing the windows with gause. In this case honeybees continue to pollinate tomato flowers during the summer (27). Providing all the windows of a greenhouse with gause is very difficult and expensive.

In the meantime dr. De Jonghe in Belgium had been rearing bumblebee colonies for scientific reasons for several years. After he had heard of our initial successes with the use of honeybees for tomato pollination, he placed some bumblebee colonies inside a tomato greenhouse. As bumblebees lack a highly developped language, they continued visiting the tomato flowers during the summer. From then on tomato growers started to demand bumblebee colonies for pollination. The Ambrosiushoeve developped a yearround rearing technique for *Bombus terrestris* colonies (5,11), using the results that had earlier been obtained by several scientists that had been rearing bumblebee colonies for scientific research (12,13,21,22,26). Pollination experiments showed that bumblebee pollination can replace hand pollination during the whole flowering period of tomato, (1, 7, 23, 29). During the experiments of 1990, flight activity of the bumblebees decreased during a heatwave and fruit set decreased as well. At the same time however, the fruit set of plants that were hand pollinated decreased also. Bad pollination was a result of heat damage to the flowers, the bumblebees were not to blame. An extra advantage of bumblebees over honeybees is, that bumblebees leave a clear mark on the flowers they have visited. The tomato grower can get a good impression of the pollination activity of the bumblebees, simply by looking at the brown spots on the anthers. Three commercial firms started to rear bumblebee colonies for practice, two in the Netherlands and one in Belgium. As soon as bumblebee colonies were available, the tomato growers changed over to the new system. At the end of 1991 almost all tomatoes in the Netherlands and in Belgium were pollinated by bumblebees and a significant number of colonies was exported, mainly to England, France and Italy. The three firms mentioned earlier now produce about 95% of the bumblebee colonies. The rest is produced by a number of much smaller firms.

**Sweet pepper**

The succesful use of bumblebees in tomato greenhouses resulted in renewed interest in insect pollination in horticulture. Although sweet pepper is largely self pollinated and fruit setting is no problem during the summer months, fruit setting is not optimal in spring and autumn. The question was raised whether insect pollination could improve fruit setting in these seasons. In autumn 1989 and in spring 1990 experiments were carried out to compare fruit setting of sweet pepper in greenhouses with honeybees to fruit setting in greenhouses without bees. In both experiments honeybee pollination resulted in larger and heavier fruits with more seeds and in less malformed fruits (4). At the moment the use of honeybees for the pollination of sweet pepper has become common practice in the Netherlands.

**Strawberry**

Ever since strawberries have been grown in greenhouses, honeybees have been used for pollination. With bumblebees available yearround, the question was raised whether bumblebees could do the job as well or even better.

In 1991 a comparisson was made between honeybee- and bumblebee-pollination of strawberry. In short the results were as follows: when actively visiting the flowers,both insects pollinate the strawberry flowers. In contrast to the pollination of tomato, in strawberry bumblebee males pollinate the flowers as well. It was noticed in the greenhouse with honeybees, that when the plants were kept too dry, the bees did not visit the flowers, with bad pollination as a result. As soon as more water was given (overdrain increased from 13.4% to 22.4%), the bees started to visit the flowers again and pollination was satisfactory.

**Other greenhouse crops**

Similar to the questions raised for strawberry pollination, in several other crops now the question arises whether bumblebees can do the job that so far has been done by honeybees. In melon, experiments have already been carried out by the Glasshouse Crops Research Institute at Naaldwijk (honeybees and bumblebees) and the Experimental Station at Breda (honeybees). Honeybees and bumblebees prove to be equally succesful. At Breda it was found that giving a surplus of water during flowering resulted in more fruits (4.6 versus 3 melons per square meter) and a better production (3.6 kg versus 2.5 kg per square meter) compared with plants that were kept relatively dry during flowering (30). The Ambrosiushoeve carried out an experiment comparing honeybees and bumblebees for the pollination of cucumbers (seed production). In this case too honeybees and bumblebees proved to be equally succesful (1991). Both in melon and in cucumber, bumblebee males actively visited the flowers and pollinated them. Experiments on the pollination of cantaloup melons in plastic tunnels with honeybees and bumblebees are carried out this year at the INRA institute at Montfavet, France.

In crops that up to now have not been pollinated with the help of insects, growers start to ask questions about a possible effect of insect pollination on the production of their crop. In some crops until now no measures have been taken to ensure pollination. This year we are carrying out an experiment in order to find out whether honeybee pollination decreases the percentage of malformed fruits in climbing French beans. In other crops auxines are being used to ensure fruit set. This year we are doing an experiment in egg plant, comparing fruit set after honeybee pollination, bumblebee pollination or auxine treatment. At the INRA institute at Montfavet phytohormones and/or honeybee pollination of squash is studied this year.

**Seed production**

In order to achieve a good pollination activity in greenhouses, honeybee colonies need sufficient space and a sufficient number of plants to forage on. In plant breeding and seed production often small compartments or cages are being used. Pollination by honeybee colonies in this case is not satisfactory and using many colonies in many small compartments would be very expensive too.

In greenhouses up to 500 $m^2$ honeybee nucleï can be used. The Ambrosiushoeve developped a technique for making nucleï, storing them during the winter period in climate rooms and using them for pollination of seed crops in late winter and early spring (Steen, J. van der, 1992, in preparation). The method was based on a technique developped by Maul for storing queens during winter (18). For even smaller compartments or cages (1 $m^2$ to approximately 100 $m^2$) solitary bees can be used. These bees need less space and can be used in small numbers. The number of pollinating insects can be attuned to the number of flowers to be pollinated. Solitary bees like the alfalfa leafcutting bee (*Megachile rotundata*) and mason bees (*Osmia sp.*) have succesfully been managed and have been used for a long time already for the pollination of field crops (10,16,17,19,32). Holm used *Osmia rufa* as a pollinator in greenhouses (14). Kristjansson succesfully used *Osmia cornifrons* to pollinate sweet pepper in small compartments (16). In the Netherlands *Osmia rufa* was succesfully managed and used for the pollination of different seed crops. (31). At the INRA institute at Montfavet, Rodet is studying the pollination in carrot for hybrid seed production (25).

**Pest control**

It is difficult to combine chemical pest control with the use of insects for pollination, especially in crops that have a long flowering period like tomato and sweet pepper. Biological control was well on its way to replace chemical control in tomato greenhouses at the time bumblebees were first introduced. The introduction of insect polination meant a very strong stimulus for growers that were still hesitating to changeover to biolological control systems. All three big suppliers of bumblebee colonies also market biological control systems. This makes biological control and biological pollination go hand in hand in practice. From an environmental point of view this is a very positive development. Very little is known about the hazards to honeybees of pesticides being used in greenhouses and hardly anything about the effects on bumblebees. What is known about the hazards of pesticides to honeybees in field crops is translated to the greenhouse situation and also to bumblebees. Of course this is very risky. Laboratory tests on the toxicity of pesticides to bumblebees are needed urgently. Just like tests in greenhouses in order to establish the hazard of pesticides to honeybees and bumblebees when used in greenhouse crops. Based on the limited experience that is available at the moment, the dutch advisery service of the Ministry of Agriculture published an advice on the use of pesticides in insect pollinated greenhouse crops.

## PROBLEMS AND RECOMMANDATIONS FOR FURTHER RESEARCH

With the area of insect-pollinated crops increasing and the numbers of wild and domesticated bees decreasing, a shortage of pollinators in Europe is to be expected. The habitat changes during the past decades probably represent an overall decrease in the availability of natural forage and nesting sites for bees (20). Recently management of the vegetation in cities and of road-side vegetation started to change. A more oecological approach of vegetation management is propagated (2, 9, 15), providing forage and nesting sites for bees. In the Netherlands at the moment it is easier to keep bees in cities or villages than in agricultural areas. An ecological approach of the management of all types of vegetation is needed urgently, in order to conserve and restore natural vegetation in different areas.

In a region with a lot of agriculture and with beekeeping being a hobby activity like the Netherlands, a shortage of domesticated bees already exists. Based on the areas of crops in 1989 and on the numbers of colonies per area needed for optimal pollination, the total number of honeybee colonies needed for pollination of agricultural crops is 64,000 per year. Less than 30,000 colonies per year are rented to growers. The number of bumblebee colonies needed for the pollination of tomato in the Netherlands is calculated to be 85,000 per year. Rearing bumblebee colonies has become an important economic activity itself. The production of greenhouse tomatoes has become dependant on the availability of bumblebees. During the rearing phase, bumblebee colonies are fed honeybee collected pollen. So the availability of bumblebees depends on the keeping of honeybees. Because of direct and indirect importance with respect to the pollination of crops, keeping honeybees needs to be supported. The main threads to beekeeping are: a lack of food sources (pollen), bee diseases and the use of pesticides. Research is still needed in these fields. Further research is also needed in order to improve beekeeping techniques. Education of beekeepers has to be improved, especially in regions without professional beekeeping. Bumblebee rearing at a commercial scale is new. Growing pains have been overcome, but if new problems arise, they may cause severe difficulties. Not much is known about diseases and parasites of bumblebees. In honeybees we have seen examples of what may happen when bees are moved to new areas. *Apis mellifera* has picked up *Varroa jacobsoni* in Asia. In order to prevent similar disasters in bumblebees, it is recommanded to use local bumblebee species only. As in periods of shortage of bumblebee queens some breeders have already imported *Bombus terrestris* queens from the Mediteranean area, it is necessary to closely monitor diseases and parasites that show up in breeding stocks of bumblebees. Diseases and parasites that are already known to occur in bumblebees have to be studied in order to prevent them to cause serious trouble in the future.

On top of the risk of importing diseases, it is unknown what other influences releasing strange species would have on local bumblebee populations.

Several aspects of the biology of *Bombus terrestris* need further study. If diapause in this species would be understood better, queens could be brought into diapause more efficiently and activated when needed. It would be much easier to store queens and with less losses than is the case now. There is still a lot of variation between individual queens with respect to the time it takes before they start breeding. The maximum size of the colonies and the number of daughter queens is also very variable. The reasons for this variation should be studied. Hopefully this will give clues to improve rearing techniques. The rearing of bumblebee species other than *Bombus terrestris* needs further study. Especially the long tongued species could be very useful for the pollination of "deep" flowers.

Practice orientated pollination research needs more attention. The need for insect pollination has to be established in crops and wild flowers. Optimum pollination densities have to be established. Finding the right combination of crop and pollinating insect also involves studying factors influencing pollination. Bees need a reward (nectar or pollen) if we want them to continue visiting the flowers. The production of pollen and nectar by plants varies with the circumstances. On the other hand flight activity of bees is also subject to several influences. These factors have to be taken into account.

## SUMMARY AND CONCLUSIONS

The importance of pollination has been undervalued for a long time. Until a few years ago inovative pollination research was done exclusively when seed setting was a big problem. In many cases hand pollination or fruit set with the help of auxines were thought to be inevitable. This picture is changing now. Pollination is getting more attention. Recent successes with insect pollination resulted in a renewed interrest in insect pollination.

All bee species feed on pollen. Conserving and restoring natural vegetations, providing forage plants and nest sites for bees is essential. Propagation of the use of a diversity of flowering plants in set aside programmes and in public gardens etc. may help to provide extra food for both wild and domesticated bees. A thriving beekeeping industry is essential to ensure pollination of crops. The availability of honeybee colonies for pollination purposes is a matter of common interest. As a consequence practical research, necessary to ensure the survival of beekeeping, is of common interrest too. Like research on bee diseases, research on the effects of agrochemicals and research on beekeeping techniques. Apart from the traditionally used honeybee, bumblebee colonies are commercially available now. More research is needed to improve rearing techniques and explore the potentials of other bumblebee species. In recent years both in field crops and in greenhouse crops the use of different species of solitary bees started to expand. It can be expected that testing new combinations of crops and solitary bees will prove to be succesful in the near future of a particular crop and a pollinating insect. This work needs to be intensified.

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# SURVEY OF POLLINATORS OF LEGUMES IN PORTUGAL STUDY OF THEIR SPECIFIC FLOWER RANGE

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**ABSTRACT**

Native bees are of particular importance in the pollination of blossoms of legumes, and individuals of several species are numerous enough to constitute an appreciable pollinating force.

In recent years, attention has been increasing towards the role performed by wild bees visiting cultivated legumes, because of their national economic importance.

Collections of native Apoidea were made in the Northwestern region of Portugal from 1981 to 1989 in two localities, in order to determine the existing species and their relative abundance in the fields.

## INTRODUCTION

We have started, in 1986, the study of pollinators of legumes such *Medicago sativa* L., *Trifolium pratense* L., *Trifolium repens* L. and *Vicia* sp. A previous study (MACIEL CORREIA, 1984) rendered into evidence the importance of the main Apoidea families in the Northwestern region of Portugal.

After these preliminary experiments, we began, with the support of D.R.A.E.D.M. (Direcção Regional de Agricultura entre Douro e Minho), an extensive survey work of wild bees located in the same region. This survey was developed for a nine year period, beginning in 1981.

During 1986-1989, a survey was carried out, showing the distribution of pollinators Apoidea in the legume fields of the Northwestern region (*Medicago sativa* L., *Trifolium pratense* L., *Trifolium repens* L. and *Vicia* sp.).

## MATERIAL AND METHODS

To establish the predominancy of Apoidea, we have captured by netting, the active bees on the flora of two short grass prairie sites during nine years and on the legume flowers during four years.

This work was developed once a week, during all the blossoming season, and comprised the two periods of the day - morning and afternoon - each one of three hours duration.

The flight periods of the main species were regularly observed and reported, for several hours during morning and afternoon. This was developed along several years.

The determination of the food source of some of the species of Megachilidae, is based on melissopalynological methods. Small portions of pollen contents of the nest cells are regularly collected and prepared according to Erdtman's method (1960), used in melissopalynology, though slightly modified.

## RESULTS

### A - Observations on the two short grass prairie sites

This nine years survey on bee species allowed the identification of 35 different species, belonging to the following Apoidea families: Andrenidae (3), Anthophoridae (10), Apidae (5), Colletidae (2), Halictidae (4), and Megachilidae (11).

The percentage of these bee species, grouped by family, in these two short prairie sites (0.5 ha each) varies between 53% and 21%.

The more abundant species were: *Andrena flavipes* PANZ., *Anthophora acervorum* L., *Anthophora bimaculata* PANZ., *Colletes succintus* L., *Eucera longicornis* L., *Eucera* sp., *Halictus marginatus* BRUL., *Halictus scabiosae* ROSSI, *Megachile* sp., *Osmia* sp., *Panurgus perezi* SAUND and *Xylocopa violacea* L..

### B - Observations on legume cultures of *Medicago sativa* L., *Trifolium pratense* L., *Trifolium repens* L. and *Vicia* sp.

*Medicago sativa* L.

In the region under study, Lucerne (l ha) suffered a cleaning cut in the very beginning of Spring and blossoming period between May and June. The seed is grown in July.

Table 1 shows the percentage of Apoidea pollinator species. The species collected on the flowers of the Lucerne were distributed as follows: dominant species: *Eucera longicornis* L. (62.80% in 1986, 69.61% in 1987, 58.74% in 1988 and 64.38% in

1989). Exception made for the species of *Osmia* genus which evidenced in 1988 a percentage of 8.60 and 6.71 in 1989, all species belonging to other genera have a little representation.

| APOIDEA / Year | 1986 | % | 1987 | % | 1988 | % | 1989 | % |
|---|---|---|---|---|---|---|---|---|
| *Eucera longicornis* L. | 319 | 62.80 | 307 | 69.61 | 205 | 58.74 | 403 | 64.38 |
| *Eucera* sp. | 42 | 8.27 | 17 | 3.85 | 15 | 4.30 | 13 | 2.08 |
| *Andrena* sp. | 31 | 6.10 | 15 | 3.40 | 17 | 4.87 | 20 | 3.19 |
| *Halictus scabiosae* ROSSI | 28 | 5.51 | 16 | 3.63 | 12 | 3.44 | 31 | 4.95 |
| *Osmia coerulescens* L. | 25 | 4.92 | 22 | 4.99 | 30 | 8.60 | 42 | 6.71 |
| *Megachile lagopoda* SCHCK | 16 | 3.15 | 11 | 2.49 | 10 | 2.87 | 13 | 2.08 |
| *Panurgus* sp. | 10 | 1.97 | 8 | 1.81 | 12 | 3.44 | 15 | 2.40 |
| *Apis mellifera* L. | 12 | 2.36 | 11 | 2.49 | 23 | 6.59 | 30 | 4.79 |
| *Nomada* sp. | 15 | 2.95 | 13 | 2.95 | 11 | 3.15 | 23 | 3.67 |
| *Bombus terrestris* L. | 10 | 1.97 | 21 | 4.76 | 14 | 4.01 | 36 | 5.75 |

**Table 1.** Number and percentage of pollinator insects Apoidea visiting *Medicago sativa* L. in the NorthWestern region of Portugal in 1986/1989

*Trifolium pratense* L.

Cultures are usually cut in the beginning of Spring, and blossoming lasts for about three weeks. As far as this culture is concerned, it is observed that the most frequent insect is the honey bee. However, the wild bees were the most representative ones in this culture during the 4 years period, being the species *Bombus terrestris* L. (24.78% to 33.60%), *Bombus lucorum* L. and *Megabombus (Megabombus) pascuorum* Scop. the most frequently observed. The number of pollinator insects per 1 ha of red clover was subject to a considerable variation. As Table 2 shows, honeybees were greatest in number (an average of 58.75% in 1989 and 42% in 1988). The number of bumblebees *Bombus terrestris* L.was smaller (24.78% and 33.60%) and that of other bees very small (below 2%).

| APOIDEA Year | 1986 | % | 1987 | % | 1988 | % | 1989 | % |
|---|---|---|---|---|---|---|---|---|
| *Apis mellifera* L. | 1200 | 50.87 | 1100 | 43.62 | 1000 | 42.00 | 2300 | 58.75 |
| *Bombus terrestris* L. | 750 | 31.79 | 820 | 32.51 | 800 | 33.60 | 970 | 24.78 |
| *Bombus lucorum* L. | 100 | 4.24 | 130 | 5.15 | 120 | 5.04 | 89 | 2.27 |
| *Megabombus pascuorum* L. | 120 | 5.09 | 207 | 8.21 | 230 | 9.66 | 250 | 6.39 |
| *Andrena* sp. | 30 | 1.27 | 48 | 1.90 | 50 | 2.10 | 70 | 1.79 |
| *Eucera longicornis* L. | 32 | 1.36 | 47 | 1.86 | 28 | 1.18 | 53 | 1.35 |
| *Halictus* sp. | 35 | 1.48 | 40 | 1.59 | 39 | 1.64 | 47 | 1.20 |
| *Megachile* sp. | 36 | 1.53 | 54 | 2.14 | 20 | 0.84 | 35 | 0.89 |
| *Anthophora* sp. | 29 | 1.23 | 36 | 1.43 | 41 | 1.72 | 39 | 1.00 |
| *Colletes* sp. | 15 | 0.64 | 23 | 0.91 | 30 | 1.26 | 33 | 0.84 |
| *Osmia coerulescens* L. | 12 | 0.51 | 17 | 0.67 | 23 | 0.97 | 29 | 0.74 |

**Table 2.** Number and percentage of pollinator insects Apoidea visiting *Trifolium pratense* L. in the NorthWestern region of Portugal in 1986/1989

*Trifolium repens* L.

White clover cultures are largely developed in this region. Pre-cut in the beginning of the blossoming period (May starting), which lasts approximately a month. As it happens with the previous species, it is a culture (1 ha) largely visited by the honey bee (between 57.91% and 67.09%). Among wild bees, *Bombus terrestris* L. is the most important species, having appeared in these 4 years of study in a percentage higher than 25%. Following it, are the species belonging to the genus *Eucera*, between 4.30% and 5.57%. Excepting 1988 and 1989, the species of *Halictus* are of less importance (Table 3).

| Year<br>APOIDEA | 1986 | % | 1987 | % | 1988 | % | 1989 | % |
|---|---|---|---|---|---|---|---|---|
| *Apis mellifera* L. | 1500 | 66.67 | 1700 | 67.09 | 1300 | 57.91 | 2000 | 62.64 |
| *Bombus terrestris* L. | 580 | 25.78 | 630 | 24.86 | 715 | 31.85 | 893 | 27.97 |
| *Eucera longicornis* L. | 72 | 3.20 | 70 | 2.76 | 83 | 3.70 | 90 | 2.82 |
| *Eucera* sp. | 35 | 1.56 | 39 | 1.54 | 42 | 1.87 | 50 | 1.57 |
| *Osmia coerulescens* L. | 37 | 1.64 | 55 | 2.17 | 43 | 1.92 | 80 | 2.51 |
| *Osmia* sp. | 14 | 0.62 | 23 | 0.91 | 41 | 1.83 | 50 | 1.57 |
| *Halictus* sp. | 12 | 0.53 | 17 | 0.67 | 21 | 0.94 | 30 | 0.94 |

**Table 3.** Number and percentage of pollinator insects Apoidea visiting *Trifolium repens* L. in the NorthWestern region of Portugal in 1986/1989

*Vicia* sp.

We have considered two species, *Vicia villosa* Roth and *Vicia bengalensis* L. (0.5 ha area). The blossoming period of which lasts one month. Regarding this culture, the bumble bee *Bombus terrestris* L. appears in a percentage between 36.99% in 1986 and 45.77% in 1989, being followed by the *Bombus lucorum* L. whose percentage varies between 12.05 in 1986 and 9.04 in 1989 (Table 4).

| APOIDEA / Year | 1986 | % | 1987 | % | 1988 | % | 1989 | % |
|---|---|---|---|---|---|---|---|---|
| *Apis mellifera* L. | 235 | 28.31 | 304 | 32.72 | 297 | 31.80 | 275 | 31.46 |
| *Bombus terrestris* L. | 307 | 36.99 | 372 | 40.04 | 405 | 43.36 | 400 | 45.77 |
| *Bombus lucorum* L. | 100 | 12.05 | 93 | 10.01 | 85 | 9.10 | 79 | 9.04 |
| *Megabombus pascuorum* Sc. | 72 | 8.67 | 56 | 6.03 | 41 | 4.39 | 30 | 3.43 |
| *Pyrobombus pratorum* L. | 52 | 6.27 | 34 | 3.66 | 26 | 2.78 | 17 | 1.95 |
| *Andrena* sp. | 24 | 2.89 | 12 | 1.29 | 23 | 2.46 | 17 | 1.95 |
| *Eucera* sp. | 25 | 3.01 | 31 | 3.34 | 19 | 2.03 | 13 | 1.49 |
| *Anthophora acervorum* L. | 12 | 1.45 | 17 | 1.83 | 23 | 2.46 | 31 | 3.55 |
| *Xylocopa* sp. | 3 | 0.36 | 10 | 1.08 | 15 | 1.61 | 12 | 1.37 |

**Table 4.** Number and percentage of pollinator insects Apoidea visiting *Vicia* sp. in the NorthWestern region of Portugal in 1986/1989

The species of *Megabombus (Thoracobombus) pascuorum* Scop. and *Pyrobombus (Pyrobombus) pratorum* L. are of less importance.

## C. The flight periods of the most frequent native wild bees

Most of the species belonging to the genera surveyed during these 9 years of study, show an activity according to the large number of agricultural cultures. However, their search for a spontaneous flora all the year round cannot help being considered here; thus, it is important to stress the existence of species belonging to the *Anthophora* and *Colletes* genera, who seem to have just one generation each year. Some of these species appear in Spring while others in Summer and even Autumn. In other cases, the species appear early in Spring and only later appear those characteristic of an Autumn period.

In case of the species showing two annual generations (*Megachile rotundata* FABR., *Osmia ferruginea* LATR., *Osmia coerulescens* L.), the second generation corresponds to the highest blossoming period of cultures like the lucerne and red clover.

**D. Composition of some polynic provisions of *Megachilidae* cells**

Many pollen grains cannot be identified as far as their genus or species. If detailed knowledge is not available, we have to associate the pollens in larger groups (families).

The following terms are used in estimates of pollen grain frequencies:

Exclusive - for grains constituting more than 45% of the total
Dominant - for grains constituting between 16-45% of the total
Present- for grains constituting between 3-15% of the total

In some of the studied species *(Megachile rotundata* FABR. and *Megachile* sp.*)* the pollen contents analyzed (73) exhibited the presence of Leguminosae pollen, most exclusively. In some *Osmia ferruginea* LATR. and *Osmia coerulescens* L. collected cells, the results showed that polynic incidence was of Asteraceae and Leguminosae origin.

## DISCUSSION

Though there is no explanation for certain phenomena and the relationship between the appearance of certain pollinating species along the years and the external factors should be duly analyzed and studied in depth, we observe that the native wild bees from the Portuguese northwestern region is extremely diversified.

The periods of insect activity and culture blossoming are timing. However, observation and comparison of those periods of activity with the almost total absence of certain legume pollinators, let us foresee the existence of other factors (most probably internal factors) justifying the insect search for food.

Thus being and after analyzing the nest pollen contents, stored by some Megachilidae species, we may conclude about the presence of pollen grains belonging to a strict range of families.

In some species, the almost exclusive presence of pollens belonging to the Leguminosae family in the pollen contents of nest cells, opens a new pathway for the understanding of the relationship between insect and type of culture (insect diet). It is noteworthy that these species representation during the survey was somewhat reduced.

The presence of a particular pollen, while carrier of valuable information about the local flora looked for by wild bees, is an indicator of the food source.

Though this work is complex, hard, and spares time till we may reach any conclusion, it is desirable to be deeply exploited in the future, viewing further collaboration with other laboratories.

We consider that only a sound knowledge of the biology and flight behaviour of the native wild bees of each region (where they are perfectly adapted), as well as a detailed information about their diet during their several activity periods, will enable us to choose, on good grounds, the more adapted species (efficient in terms of pollinization) to each type of legume.

We may, this way, maximize insect utilization and minimize the costs brought about by industrial mass-rearing.

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# BEE POLLINATION IN PHRYGANA FACTS AND ACTIONS

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**ABSTRACT**
This study on the pollination of phrygana was carried out on the slopes of Mt Aegaleo, near Athens. Phrygana (30 ha) are characterized by a high number of flowering plant species exhibiting a biotic pollination syndrome (133), as well as by a very high number of bee pollinators (262), visiting 97 % of them. The phenologies of both these components are tremendously seasonal. The honeybee is the most active pollinator of the system, both in terms of tropy (number of plants species visited) and duration of activity. Solitary bees are numerous in species (259), although oligolectic with tendency for specialization on one plant species; their role in the pollination of particular plant cases is assessed to be indispensable. Bumblebees do not contribute considerably to the pollination of the system. Phrygana are poor in floral rewards to pollinators, thus, large-sized bees with high energy demands are scarce and restricted early in the flowering period, i.e. February-June. Contrariwise, solitary bees, along with the honeybee, are well adapted to the low-compensating Mediterranean flowers, where pollen constitutes the main reward. Because the honeybee is more competitive in resource utilization than the solitary bees, it is presumed that in heavily exploited phryganic ecosystems for bee-keeping, several solitary bee species may be threatened with extinction.

## INTRODUCTION

Phrygana, i.e. the garrigue of East Mediterranean (syn. tomillares in Spain, gariga in Italy, batha in Israel) occupy ca. 13 % of the Greek territory (Diamantopoulos, 1983), and constitute, along with the evergreen sclerophyll shrubby systems, the commonest ecosystem types of Greece. Because they are restricted to the driest part of the precipitation gradient, phrygana have to face harsh climatic constraints, mainly the prolonged summer drought. The main adaptive feature against water stress is the seasonal dimorphism of their woody representatives. Other phryganic characteristics of this stress-avoiding strategy are the therophytic dominance (Raven, 1973; Margaris, 1980) and the high contribution of aromatic plants (Vokou, 1983). Although there has been a dispute on the origin of phrygana, i.e. whether they constitute a natural ecosystem type or they simply resulted from human-borne degradation, classical Greek literature (Plato) evidences the dominance of this ecosystem type, in connection with honeymaking activity, on Mt Hymettus (Attica, Greece).

Most of the studies on phrygana deal with their structure and function, in particular their adaptive features. Although the high diversities of both flowering species and bees have been pointed out (Polunin, 1980; Michener, 1974, 1979), the research on pollination is very recent, most of it coming from Israel. For Greece, this is the first attempt ever reported.

Pollination research may be carried out either in terms of pure science, i.e. in the context of Theoretical Biology, as well as in terms of applied science in the context of Nature Conservancy or Agriculture. The primary goal of the study, of which the results presented here form only a part, was to investigate the plant pollinator food web and community structure of phrygana, by using all those characteristics related to pollination. However, information concerning conservation of the species studied, both plants and their insect partners, can also be extracted. In addition, the study provides the necessary basis for the evaluation of the melliferous flora of phrygana, to be used as a management basis both for conservation and honey production, an aspect to be particularly emphasized here.

## MATERIALS AND METHODS

The study was conducted at Daphní, situated at approx. 10 km W of the centre of Athens, in an area belonging to the reserve "Diomedes Botanical Garden of Athens University". The dominant ecosystem type is phrygana, covering 130 ha. Substrate is calcareous and stony. The study was carried out in a 30 ha section of the reserve, at 135-215 m (inclination varying between 20 and 30 %), with northern and eastern exposition. Field observations started in 1983, 8 years after a fire, which only partly destroyed the vegetation; it lasted 4 complete years, and totalled more than 6000 hours.

All flowering phryganic plants occuring in the study area and exhibiting an apparent biotic pollination syndrome or visited by insects were included in the study. Ants were not considered at all. All plant species were followed throughout their flowering period and the duration of anthesis, the flower life span, and other floral characteristics were measured. Floral reward to pollinators were estimated as nectar volume per flower (with the aid of Drummond microcaps) and pollen weight per flower. The energetic value of pollen was separately measured by microcalorimetric techniques (Petanidou and Vokou, 1990). Pollinator-oriented observations were carried out in paralell with those of plants. All insect species visiting flowers of the plants under study were collected or simply recorded in the case that the insect identity was known. Observations throughout the day were supplemented by noctural ones only if needed. Monitoring of the plants was carried out in a way that the gap between two consecutive recordings did not exceed 15 days. The major part (ca. 60 %) of the insect specimens collected (18000) were bees. Their identification to the species level was done by the European taxonomists listed in Petanidou (1991a).

All results were estimated on the basis of all four year recordings. It is to be noted that during the whole fieldwork period, the anthropogenic interference was kept at minimum. Grazing, fires, as well as human presence were totally excluded. Management at the study site was limited to introducing and keeping of 3-5 honeybee hives.

## RESULTS AND DISCUSSION

### Plant composition of the phryganic ecosystem

The plant species included in the study totalled 133, and they are listed in Petanidou (1991b). With very few exceptions (4 species) plants bear monoclinous flowers. Anemophily contributes only to a very limited extent to the pollination of the system. Diurnal flower display is the rule. Only the flowers of *Capparis spinosa* var. *inermis* Turra are exclusively noctural, opening from ca. 18.00 to 10.00 of the following day. Nevertheless, their pollination is not accomplished by moths, as expected, but only large Anthophorid bees.

### Flowering characteristics

**Phenology :** As shown in Fig. 1, anthesis is a seasonal phenomenon in phrygana, although plants in flowers are encountered all year round. The main flowering season is from February to June, peaking (Petanidou and Ellis, ms2) in mid April. Summer, along with winter, constitute the difficult periods for anthesis in phrygana. Of remarkable importance is the secondary flowering period (September - November), especially for the autumn flowering geophytes. Phenological attributes, such as duration of anthesis and flower life span vary both between species and with time. Mean duration of anthesis is relativelly high (55 ± 2.2, range 12-157 days). Similarly, the flower life span of phryganic plants may vary from some hours to 15 days. According to Petanidou and Margaris (ms) time attributes fluctuate in a way that the pollination-useful time of flowering in the system is maximized : both take their higher values during winter when pollinators are scarce; contrasting to anthesis duration, flower life span takes its minimal value in summer, a phenomenon to be attributed to the dramatical climatic conditions for anthesis, as well as to the competition of the bee pollinators for floral rewards during this period.

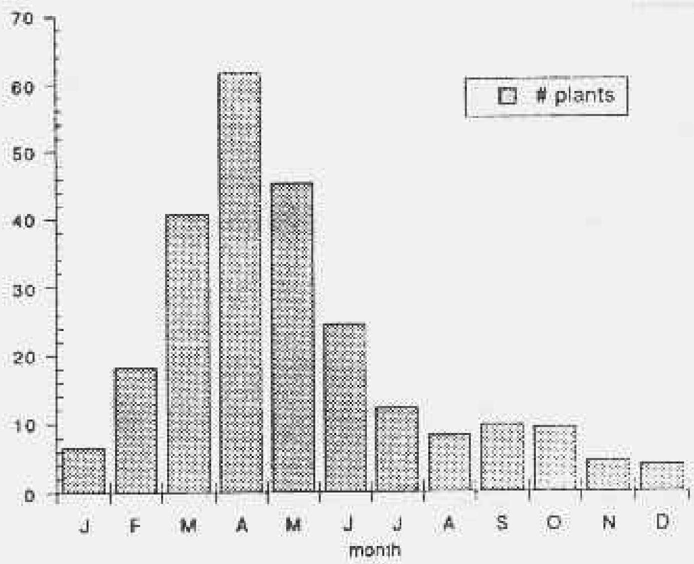


**Figure 1.** Monthly number of phryganic plant species in flowers. Values are averages of the daily numbers of blooming species.

**Floral traits :** Generally, the flowers of the phryganic plants are rather small; in 66 % of the cases plants bear flowers in which the mean of their two main axes does not exceed 2 cm; moreover, in 38 % of the cases it is less than 1 cm. To counterbalance the possible loss in pollinator attractiveness, a considerable percentage (47 %) of plant species do not bear solitary flowers, but have them clustered in Functional Reproductive units, in which at least 5 flowers are simoultaneously open. On the other hand bowl-shaped (open) flowers constitute only the 28 % of the total, the rest having a three-dimensional structure, in some cases rather elaborated to very complicated (e.g. lip, flag, gullet, trap flowers). The above characteristics may be explained in terms of energetic budget deficit (i.e. nectar quantity per flower), which may basically result from the water shortage in phrygana. With few exceptions (including most of the Labiatae species) phryganic plants have generally short-tubed flowers. Only 14 % of the species bear flowers at least 1 cm deep, while 53 % have rather shallow flowers (≤ 4 mm), a fact to be attributed to the lack of really long-tongued bees in the system. As shown in Table 1, phryganic flower colours differ from those of the world distribution; this may be interpreted as a deviation in pollination syndromes occurring in the phrygana from the average world or temperate ecosystems (i.e. melittophily against myiophily), a fact apparently deriving from the extraordinary high number of bee species in the Mediterranean region.

| Colour | Greek phrygana | France | Nether-lands | Sweden | World (8 regions) |
|---|---|---|---|---|---|
| green | 1.5 | 6.5 | 7.5 | 8 | 7.5 |
| white | 21 | 26.5 | 26.5 | 26 | 26.5 |
| yellow | 34.6 | 31 | 32 | 33 | 31 |
| blue | 10.5 | 6 | 5.5 | 6 | 5.5 |
| red/pink/purple/violet | 32.3 | 30 | 29 | 28 | 29 |

**Table 1 .** Comparative plant species composition, according to their flower colour. Plants bearing flowers with undeveloped corollas (such as Graminae etc) were excluded. Data are percentages over the total number of species. The last four columns concern the whole country floras (data from Weevers, 1952).

**Floral rewards to pollinators :** with the exception of Labiatae and very few other species, flower nectar content in phrygana is very little in comparison with other temperate ecosystems (Petanidou and Vokou, ms; Petanidou, 1991b). Besides, it may lack even from the majority of the flowers nominated for being nectariferous. Not surprisingly, the most nectar-yielding species in phrygana is *Capparris spinosa* var. *inermis*, a nocturnally flowering plant. Moreover, the mean nectar production of all phryganic species decreases with time, as the summer drought gets harsher. Noteworhthily, not only phrygana, but also the whole Mediterranean region host a great number of native species, with non nectariferous, deceptive or trap flowers (viz. *Ophrys* spp. and *Arisarum vulgare* Targ.-Tozz).

| FAMILY NAME | NUMBER OF SPECIES |
|---|---|
| Megachilidae | 84 |
| Anthophoridae | 63 |
| Halictidae | 51 |
| Andrenidae | 49 |
| Colletidae | 11 |
| Apidae | 3 |
| Melittidae | 1 |
| **Total** | **262** |

Table 2 . Family composition of the Apoidea flower visitors of phrygana.

On the other hand, in phrygana pollen plays the major role in rewarding pollinators for their flower visiting. There is evidence that pollen, in addition to its nutritive value, may also serve as an energetic supply to the pollinators of phrygana where nectar is limited by the drought (Petanidou and Vokou, 1990).

**Pollinating fauna**

**Composition - Phenology**

Bees are the most important and numerous pollinators of the phrygana. Their family composition is given in Table 2, the complete species list being available in Petanidou (1991a). Four bees, all Megachilidae, are new species. It is to be noted that phrygana under study is one of the richest ecosystems of the world in bee species number, particularly if the limited size of the study sise taken into consideration (Petanidou and Ellis, ms1).

Among all bees, only the honeybee is active throughout the year, the majority of them having a short period of activity. Except for the honeybee, bees are totally absent from the phrygana in winter time, but only for a short period (December-January). Their activity culminates during the main flowering season, in mid April, but they sociality and, concomitantly, their period of activity, three categories can be distinguished :

**1. Solitary bees**. This is the most numerous in species (259) of all the pollinating groups of the phrygana (amounting to 666 species altogether). Its distribution over the year is illustrated in Fig. 2. Their period of activity may be as short as a couple of days, but average may lay between 4 to 8 weeks, according to the bee family. This, along with the actual turnover rates of the pollinating bee fauna (Petanidou and Ellis, ms2) suggest that the pollination of the phrygana is accomplished by distinct time-guilds of bee pollinators.

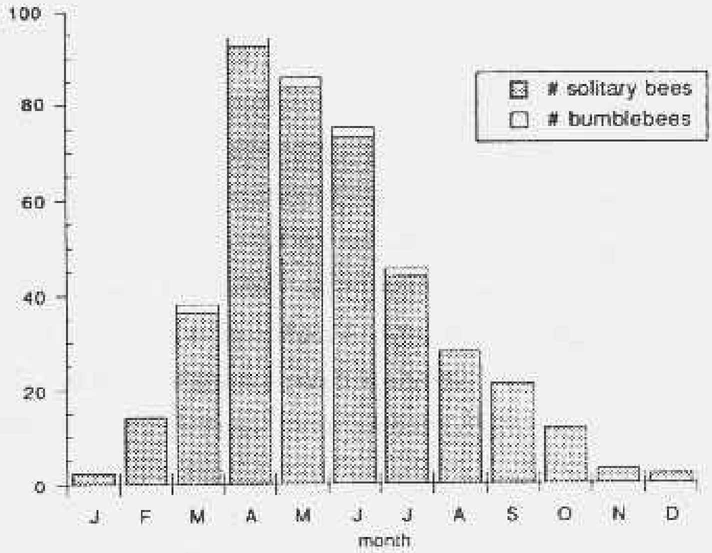


**Figure 2.** Monthly number of bee species in the phrygana (honeybee excluded). Values are averages of the daily numbers of co-occurring species.

**2. Bumblebees.** Not surprisingly, bumblebees do not contribute to the pollination of the system to the extent known from temperate ecosystems. Only two bumblebee species are present, Viz. *Bombus terrestris* (Linnaeus) and *Megabombus argillaceus* (Scopoli). Average period of activity is 108±10 days. Bumblebee queens score higher in flower visiting than their workers do. This, most probably, is to be attributed to their time of emergence (respectively, early and later in the main flowering season), and, thus, the availability of floral resources (viz. nectar).

**3. Honeybee,** finally, constitutes the main, all year round permanent pollinator of the phryganic ecosystem. Its visitation spectrum extends to 105 out of the 133 phryganic species studied.

## Proterandry

The attitude of the males to emerge earlier than their female mates, was presumed as an adaptation of solitary bees to monandry. In this way, the males can effectively compete for mates, securing in this way their immediate fertilization. In phrygana this phenomenon is well manifested, mainly because of the high number of the solitary bees present. Clearly proterandrous species have been found (Petanidou and Ellis, ms2) among the Anthophoridae (excl. Xylocopinae), Andrenidae, and Megachilidae, i.e. in families encompassing only solitary species. Halictidae were found to be definitely non proterandrous.

Despite of the fact that bulk of the pollination work in phrygana is carried out by the female solitary bees, the phenomenon of proterandry was found to have an extreme importance for the pollination of the early flowering orchids. As already mentioned, in the Mediterranean *Ophrys* spp. flowers attract pollinators by sexual deception, and they are visited by male bees only. Out of the whole pollinating fauna spectrum, ten bee species were found to be involved in this procedure, as witnessed by the presence of pollinia on their bodies. They belonged to the familes Anthrophoridae, viz. *Eucera albofasciata* Friese, *E. seminuda* Brullé, and *Ceratina loewi* Gerstaecker, Andrenidae, viz. *Andrena flavipes* Panzer, *A. hesperia* Smith, *A. humilis* Imhoff, *A. mocsaryi* Schmiedeknecht, and *A. rugothorace* Warnacke, and Megachilidae, viz. *Chalicodoma parietina nestorea* (Brullé), and *Chelostoma emarginatume* (Nylander).

## RELATIONSHIPS BETWEEN PARTNERS

Out of the whole phryganic species spectrum (133), only four species were found not to be visited by bees. These were *Arisarum vulgare* Targ.-Tozz, *Romulea linaresii* subsp. *graeca* Beguinot, *Linum strictum* L. subsp. *strictum*, and *Daucus guttatus* Sibth. & Sm. Three of them are regularly visited by other groups of insects, and only *R. linaresii* was found to be visitorless.

Phryganic plants and their bee partners exhibit mutually different strategies in resource utilization in the pollination framework. Contrasting to their pollination partners, bees tend to be oligolectic, and in 36 % of the cases they specialize on one plant species only. On the other hand, the number of plant species visited by very few bees is low. Moreover, these plants are, at the same time, additionally visited by insects other than bees. No plant species is exclusively visited by a bee specialist. In other words, 1 : 1 specialization is lacking from the phryganic pollination web, which means that no critical relationship has been detected in the system. At a first glance, this might be interpreted as a more efficient adaptation the phryganic plants in comparison with their bee partners. Not surprisingly, the most common and basic phryganic representatives lay very highly in bee scoring, viz. *Asphodelus aestivus* Brot. (34, in majority Anthophoridae), and *Thymus capitatus* (L.) Hoffmanns. & Link (44, mainly Megachilidae). On the other hand, not only the effectiveness of each bee species when needed. As shown by Petanidou and Ellis (ms1) quite a few bee species in phrygana may not appear at all during one, and even more, flowering periods. This might be explained as a possible effect of extended overwintering or parsivoltinism (O'Toole & Raw, 1991) and may constitute a general phenomenon in the Mediterranean region, regulated by the particular climatic conditions. Presumably, phryganic plants, by being generalists in pollination aspect, reassure their survival and continuity, which in turn, may safeguard the well being of their bee partners.

## CONCLUDING REMARKS

The pollination related characteristics to be underlined in the framework of management of the phryganic ecosystems are the following :

1. The strikingly diverse bee fauna of phrygana, along with that of the flora. There is evidence that floral diversity of this type of ecosystem not only is not reduced by occasional fires, but it is positively influenced, at least as far as annuals are concerned (Moldenke, 1979; Arianoutsou-Faraggitaki and Margaris, 1981). Similarly, bee diversity seems to be increased in post-burnt ecosystems, either as absolute number of species, or as the percentage of bees over the whole pollinator spectrum (Linsley, 1958; Moldenke, 1979).

2. The extraordinary high flower visiting activity of the honeybee in phrygana. No study in phrygana has, up to now, determined honeybee's pollination effectiveness, in other words, to what extent phryganic plants' survival depends upon honeybee. Contrariwise, the extreme foraging efficiency of the honeybee and, concomitantly, its competitiveness, may hinder, and thus, exclude other shortliving solitary bees from foraging. Such phenomena of bee extinction due to the lower foraging efficiency of the native solitary bees have been conjectured from California where, though, honeybees were introduced some 300 years ago (Moldenke, 1976).

Though astonishing at first sight, phrygana are ecosystems in danger. Besides the agriculture-oriented human mismanagement (fires, overgrazing), phrygana envisage a future of extensive tourist exploitation. In the framework of a wiser and more effective use of their natural resources, along with the conservation of their genetic variability, the following measures are suggested, as far as pollination is concerned :

• Intensification of the pollination studies in phrygana, with emphasis in their post-burnt response on the one hand, and undisturbed reserves on the other.

• Study of the actual honeybee carrying capacity of the phrygana, both in economic (honey production) and conservation context.

• Control of honeybee-keeping in reserve areas of phrygana, for the protection of the indigenous solitary bees.

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# PROBLEMS AND PERSPECTIVES OF ENTOMOPHYLOUS POLLINATION IN ITALY

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**ABSTRACT**
Problems and perspectives of entomophylous pollination in Italy are presented. Relationship between farmers and beekeepers is reported. A new monitoring service using bees is being carried out and risks for pollinators in the agricultural environment are explained. The most important entomophylous crops and their pollination problems are described. New major studies about pollinators of many wild medicinal and feeding plants are projected. Introduction of melliferous flora into the environment as alternatives to exceeding traditional crops has been started

In Italy the relationship between farmers and beekeepers has recently improved. Previously farmers had no consideration toward pollinator insects, honeybees and wild entomofauna and their role in agricultural production. The beekeeper always had to pay the farmer to be allowed to put hives in cultivated fields (this is still a usual practise in some central and southern Italian regions). Today there is a new awareness in this respect and farmers finally admit that honeybees and wild pollinators are useful and must be protected. Concerning the problem of the use of agricultural chemicals and their consequences on apiculture and on the pollinating entomofauna, some steps have been taken in Italy. In the past years, a large number of bee colonies have been lost because of the indiscriminate use of pesticides which were sometimes administerd during flowering, especially in central-northern Italy. As control measures, more severe laws were issued concerning the sale of some pesticides, and their use during flowering was forbidden.

Furthermore, a project on the national scale sponsored by Ministery of Agricultural and Forestry was started. It is an environmental monitoring service using the honeybee as a tester to indicate the presence of synthetic pesticide molecules in the environment. The bodies of dead bees and the products of the hive are analyzed for pesticide residues; with this information it is then possible to draft a sort of map of the chemical risk for the bee and, indirectly, for man. Our Institute is also involved in this research. The number of poisoning cases have actually been reduced, but risks remain because of the scarcity of inspections. Regarding main crops and their synecological relationship with the pollinators, today the following reality and problems can be ascertained.

**Orchards (*Prunus, Malus* etc.)**

They are very widespread in Trentino Alto Adige and Veneto (northern Italy); they have no problem concerning pollination. Thanks to modern technology, there is a good pollination service. Slighty earlier crops (almond, apricot etc.) need pollinators able to work at lower temperatures (in northern and central Italy). *Osmia cornuta* Latr., (presently reared at Pisa University) is being considered. The problem of pollination of *Actinidia deliciosa* Chev. seems to have been resolved by the use of forced air (the use of insects resulted neither easy nor useful in Italy).

**Forage and seed Leguminosae.**

There are problems for pollination of *Medicago sativa* L. in central and southern Italy as there are no other crops covering such a large surface area. Moreover honeybees are not very attracted to this plant because it gives little nectar in the summer in these regions. In any case, honeybees are not considered effective for this crop's pollination. It has been observed that the best solution to this problem could be the rearing of *Andrena flavipes* Panz and other solitary bees or by favouring their increase in nature. In the north, however, honeybees and bumblebees enssure pollination. Creating hybrid cultivars by using male sterile lines has not yet been dealt with in Italy. A collaborative study with the Institute of Plant Breeding of the University of Perugia will probably start next year. There are no problems for clover : *T. pratense* is pollinated very well by bumblebees; in some zones they could be increased but they are not yet reared in Italy. *T. incarnatum* L. is cultivated very much in central Italy where sufficient hives are present each year at flowering (six/per hectare); in fact in Italy, honeybees are its best pollinators. No problem for *Onobrychis*, either; honeybees have a perfect synecolgical relationship with this species (two hives per hectare); away from intensively cultivated zones, many wild pollinators also ensure fecundation *(Melitta, Osmia, Bombus). Vicia faba* L. is completely ignored by beekeepers; fortunately it seems not to need pollination, as no male-sterile varieties are cultivated; in such case, a specific entomofauna (*Bombus, Eucera,* etc) should be provided. *Lupinus* spp. are well assisted due to the sufficient cross rate for seed production. Soy-beans have been cultivated in Italy for only a few years and no studies have been carried out on them. We hope that appropriate studies will be conducted as it seems to be self-compatible. A cultivation trial of *Cajanus cajan* L. has started in Umbria; the only pollinator observed till now has been *Xylocopa violacea* L., if this crop spreads, its pollination will also have to be enssured. Practically no other Leguminosae are cultivated in Italy. *Hedysarum coronarium* L. (not cultivated very much today) deserves just a mention. It was once a famous forage species with the best pollinator being the honeybee (4 hives per hectare).

To obtain the best survival conditions for pollinators in the agricultural environment, i.e. by forestry, trying to change the actual line (Pine) with melliferous trees (*Tilia, Acer, Prunus avium* L., etc). At the same time we intend to introduce into marginal lands some melliferous crops (*Coriandrum, Fagopyrum, Lavandula* etc.), as alternatives to exceeding traditional crops, in order to recover zones which would surely be abandoned. A pilot project will start next year on a hill farm in Umbria: herbaceaus and arboreous cultivations are recommended, as well as traditional monocultures, as "refuge zones" for pollinating insects, and to allow them to complet their biological cycle.

**Oil seed**

Cultivation of *Brassica napus* L. v. *oleifera* D.C. is increasing in Italy. There are no pollination problems (honeybees). Others Cruciferae are not widely cultivated except for rocket cress (*Eruca sativa* L.). *Helianthus annuus* L., sunflower, actually has some problems : a few recent cultivars are not very nectariferous and are not greatly attractive for honeybees : seed production is consequently lower, because of the great shortage of pollinators, so if the honeybee is attracted by a competitive flora, it does not assure an effective pollination. We will soon have to deal with this problem : an investigation will start in 1993. On the contrary, *Carthamus tinctorius* L., which is still cultivated only at the experimental level, protogynic, seems to have no problems. From a study carried out 3 years ago, I recommend bringing in 2-3 hives per hectare into this crop. Wild pollinators are poorly represented.

**Exotic fruits**

Exotic fruits (Babaco, Papaya, Mango, Avocado, Fejoa, etc.) have been cultivated in central and southern Italy for only a short time. Some studies have been carried out only on Fejoa, but no solution has been found for its pollination problems. For the other crops, we expect to start studying them too.

**Small fruits** : (*Rubus, Ribes, Vaccinium* etc.).
They are cultivated on very limited surface area.

**Citrus fruits**
Where necessary, honeybees are the best pollinators (6-8 hives per hectare).

**Cucurbitaceae**
In the open air, zucchini, cucumbers and melons are well pollinated by honeybees (2-4 hives per hectare).

**Solanaceae**
Very little is known about pepper and egg plant.
A project about pollinators, together with biological and integrated pest management is in being planned.

**Horticulture** : (Garlic, many Umbelliferae, artichokes, cabbages)
Very few studies have been carried out to date. We recently solved the pollination problems of *Eruca sativa* L. (8 hives/hectare). The work will soon be published.

**Glasshouse**
Until now the honeybee has bee used for crops which need pollinators (Strawberry, Papper, Mellon, etc.) A project involving the use of bumblebees will soon be implemented.

For a short time we have been dealing with two major themes, in Italy :

1) Studies about pollinating insects of wild plants, that is to say forage species of natural pastures, and herbaceous edible plants used in human feeding:
2) Studies about pollinating insects of medicinal plants, used by herbalists and in medicine, both cultivated and natural (more than 200 species).

These two major topics will have to be studied further, because they are incomplete agreement with environment protection. The agricultural environment can no longer be considered alien to other environmental problems. It is necessay to know which insects are responsible for the conservation of those of pastures as well as those plants which could be employed to obtain seeds of more resistant species. Although today there are no more than a hundred cultivated officinal plants, man still uses nature, that is, those plants which for centuries preceded synthetic medicine. Our Institute has been studying these plants for just a few years, and all is still to be discovered. In practice in Umbria we recently completed an important four-year survey about pollinating insects of 60 forage Leguminosae, only 8 being suitably cultivated.

The following main pollinators have been identified.
Among the Hymenoptera Apoidea : 2 Colletidae, 15 Halictidae, 16 Andrenidae, 3 Melittidae, 23 Megachilidae, 31 Apidae of which 22 species are bumblebees. A few of these insects are very specific for a few Leguminosae for example *Anthidium* for *Lotus, Megachile* for *Medicago, Eucera* for *Astragalus, Bombus* for *Vicia, Melitta* and *Apis* for *Onobrichis* etc.; others are more polyleptic.
Main *Lepydoptera Rhopalocera* (34) have been identified too, and some *Dyptera* (above all Muscidae, Callyphoridae, Sysphidae and Bombylidae). All together they give some aid to cross mating also. The work will be soon published. I can anticipate that in the first and second class environment the solitary bees and bumblebees are largely represented (except for rare cases), that is to say they are effective for pollination of wild species and for their conservation and, if necessary, their expansion in the environment. In the agricultural environment, besides wild pollinators unfortunately in small number, the honeybee has an important role in the majority of cases in assuring seed production. We have been able to quantify the optimum number of hives per hectare of each crop. Regarding the officinal plants, only twenty species largely cultivated have been studied. Useful indications have been obtained on the role of both honeybees and wild pollinators and which of them could be reared. These important topics will carefully be examined in the near future. We are also open to accepting some active form of collaboration with other Institutes of Organisations believing in the usefullness of these studies, which are carried out also in the interest of the protection and preservation of the environment. We hope it will be possible to consider an intensive work in Italy under our auspices and with the collaboration of other Institutes. Some kind of bilateral project or other solution could also be thought of an order that these two large research projects could be substantially completed in four to five years. Otherwise, in the present state of affairs, we can just continue step by step. I hope that the present colleagues will pay attention to these problems which, I think, should be common to other countries in the European community. I sincerely hope it will be possible to operate and collaborate in the future, in the interest of the European community, of Agriculture and for the Protection of the environment.

# FORAGE LEGUMES IN EUROPE STATUS OF RESEARCH ON THEIR POLLINATION

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**ABSTRACT**

In 1988, the authors made a survey by contacting 252 European workers of 24 countries. Only 14 of them gave informative data on the matter concerned. Though crop acreages cultivated for seed can't be appraised accurately, they have been estimated at about 79,000 ha for lucerne and 88,000 for red clover.

Lucerne seed is mainly produced in Bulgaria, CSSR, France, Spain, Hungary, Italy, USSR, and Yougoslavia. Red clover is grown for seed in France, Italy, Poland and CSSR and white clover in Denmark. Soil moisture and climate are usually considered as the most prominent factor of seed yields. Pollinators are placed on the 2nd rank, phytophagous insects on the 3rd and cultivation techniques on the 4th. Wild bee species are effective pollinators of legume flowers. They belong to several apoïdea families. Their density is seldom above 2,000 bees/ha. European laboratories have been working since the 60's on legume pollination, mainly lucerne and red clover. During this period, 152 papers have been published in 9 countries, 131 coming from 5 countries : Poland, France, Denmark, CSSR and Bulgaria. The three major research subjects are : 1. surveys of native bees, 2. biology and ecology of *Megachile rotundata, M. alpicola, M. centuncularis, Osmia coerulescens, Anthidium florentinum, Anthophora parietina, Rhophitoides canus* and *Bombus sp.*, 3. domestications of these bees.

## INTRODUCTION

As a result of a survey which was conducted on a European scale in 1988 and by analyzing 53 questionnaires from 21 countries, it was possible to highlight the relative importance of the various types of leguminous plants, both for fodder as well as for seed production purposes.

The answers also evoked the limiting factors of seed production and the research programmes dealing with the pollination of legumes and pollinating insects. In short, we are able to compile a catalogue of legume pollinating species within Europe.

## ECONOMIC FACTORS

Despite a few gaps in the replies to the questionnaire, the compilation of all data relating to forage legume surfaces has shown that 2 species predominate quite clearly : red clover (*Trifolium pratense*) and in particular, lucerne (*Medicago sativa*) which covers an area of 3,650,000 ha in the 14 countries that provided statistics. Red clover comes second with 1,147,000 ha. The way these 2 crops are spread out in each country can be seen in Figure 1, which also depicts lucerne as the dominant crop, except in Poland, Western Germany and Switzerland.

| | M.S | T.P. |
|---|---|---|
| Belgium | 1.7890 | 1.780 |
| Bulgaria | 400.000 | 15.000 |
| Switzerland | | 80.000 |
| Denmark | | |
| Spain | 300.000 | |
| France | 550.000 | 72.000 |
| Federal Republic of Germany | 29.000 | 50.000 |
| Hungary | 330.000 | ? |
| Italy | 655.000 | 69.000 |
| Poland | 240.000 | 600.000 |
| CSSR | 343.500 | 258.900 |
| USSR (Krasnodar) | 450.000 | |
| Yugoslavia | 350.000 | |
| Portugal | | 3.000 |

**Figure 1.** Lucerne and red clover fodder production in 1987 in Europe (ha).
M.S. = Medicago sativa
T.P. = Trifolium pratense

As for seed production, - despite the fact that it was no easy task to conduct the surveys and that some figures were missing - the following estimates were reached : for red clover, 88,000 ha, mainly in Czechoslovakia, Denmark, France and Poland (fig.2).; for lucerne, seed production reaches 79,000 ha, mainly in Czechoslovakia, France, Hungary, Spain and Yugoslavia (fig.2).

| | M.S. | T.P. |
|---|---|---|
| Belgium | | 2 |
| Bulgaria | | |
| Switzerland | | 100 |
| Denmark | | 1.200 |
| Spain | 8.000 | |
| France | 14.000 | 8.000 |
| Federal Republic of Germany | 3 | 200 |
| Hungary | 15.000 | ? |
| Italy | | |
| Poland | 1.000 | 40.000 |
| CSSR | 31.000 | 38.780 |
| USSR | | |
| Yugoslavia | 10.000 | |
| Portugal | 300 | |

**Figure 2.** Lucerne and red clover seed production in 1987 in Europe (ha).
Same caption as Figure 1.

## LIMITING FACTORS OF SEED PRODUCTION

According to the empirical knowledge of scientists who were questioned during the survey, it would seem that the restricting factors which have a considerable impact on leguminous seed yield are agro-climatical characteristics and pollinating insects. Indeed, 46 % of the 53 researchers participating in the survey evoked rainfall and temperature as major factors in seed production ; 31 % of them also considered the density of pollinating insects to be a major factor. Phytophagous insects tops the list in 14 % of cases and crop techniques in 9 %.

## RESEARCH PROGRAMMES DEALING WITH THE POLLINATION OF LEGUMES AND POLLINATING INSECTS

European researchers are currently focusing their attention on lucerne and red clover pollination in particular. Nevertheless, other species have also been studied, namely *Trifolium repens*, *Lotus corniculatus*, *Onobrychis sativa*, etc. in Bulgaria, France, Denmark, Italy and Portugal (Table 1). Various aspects pertaining to entomophily pollination are taken into consideration. The work can be divided into 6 major themes, as depicted in Table 2. It would seem that so far, the most advanced area of research is biology and ecology of wild pollinating species. The second most advanced area is technical research which aims to domesticate these wild species and to draw up an inventory of the fauna. However, with regard to mutual adaptation of plants and bees, only 2 countries have devoted their attention to research programmes, namely, France and Czechoslovakia. In both cases, these programmes analyze changes in flower morphology by selection or by chemical means with a view to improving pollination.

| COUNTRY | Bu | CSSR | DK | FI | F | H | I | PL | PT | SP | SW | USSR (K) | Y (1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plant | | | | | | | | | | | | | |
| Medicago sativa e | X | X | X | | X | X | X | X | X | X | | X | X |
| Trifolium pratense | X | X | X | | X | | X | X | X | | X | X | X |
| Trifolium repens | | | X | | | | X | | | | | | |
| Lotus corniculatus | X | | | | | | X | | | | | | |
| Onobrychis sativa | X | | | | | | X | | | | | | |
| Others | | | | | X | | X | X | | | | | |

**Table 1**.Legumes concerned by pollination research in Europe.
(1) Legend as Figure 1 (FI = Finland).

| SUBJECT COUNTRY | Bu | CSSR | DK | FI | F | H | I | PL | PT | SP | SW | USSR (K) | Y (1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fauna survey | X | | | | X | | X | X | X | X | X | X | X |
| Biology and ecology of wild bees | X | X | | X | X | X | | X | X | X | | X | X |
| Management techniques | X | X | X | | X | | | X | X | X | | X | X |
| Effects of bee foraging on plants | X | X | | | X | | | | X | | | X | |
| Floral biology | | X | | | X | | | X | | | | | |
| Plants-bees mutual adaptation | | X | | | X | | | | | | | | |

**Table 2.** Objectives of pollination studies on legumes in Europe.
(1) Same legend as Table 1.

Besides the honeybee, the other pollinating insects which are currently being studied belong, by and large, to the following 2 families : *Apidae* and *Megachildae.* Indeed, insects of the *Bombus* family are studied in many countries on account of their ability to pollinate legume and red clover plants in particular. As far as the *Magachilldae* family is concerned, experiments are especially carried out in roughly 10 countries on the *Megachile rotundata*, an acknowledged lucerne pollinator. It is important to remark upon the interest shown by 5 lucerne-producing countries with regard to other insects of the same family which could be domesticated, i.e. *Megachile alpicola, Megachile centuncularis, Anthidium florentinum* and *Osmla coerulescens.* Two other Apoidal families are also concerned : earth bees *Halictidae*, represented by *Rhophitodies canus* which is evoked in 5 countries of Central Europe, and by *Anthophoridae*, represented by *Anthophora parletina*, currently being examined in Poland, with a view to pollinating *Vicia genus* (Table 3).

| Country | Bu | CSSR | DK | F | H | I | PL | PT | SP | USSR (K) | Y (1) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bee | | | | | | | | | | | |
| Megachile rotundata | X | X | X | X | X | X | X | | X | X | X |
| Megachile alpicola | | | | | | | X | | | | |
| Megachile centuncularis | | | | | | | | | | X | |
| Osmia coerulescens | X | | | | | | | X | | X | |
| Anthidium florentinum | | | | | | | | | X | | |
| Rhophitoides canus | X | X | | | X | | X | | | X | |
| Bombus | | | X | X | | | X | X | | | |
| Anthophora parietina | | | | | | | X | | | | |

**Table 3.** Insects concerned by pollination research in Europe.
(1) Same legend as Table 2.

A quick review of all publications dealing with legume plant pollination shows that out of 148 articles, 82 come from France and Poland (Table 4).

| Country (1) | Nbr. papers | Year of 1st publication | Plants concerned |
|---|---|---|---|
| Bu | 14 | 1981 | M.S. |
| CSSR | 16 | 1973 | M.S. + T.P. |
| DK | 19 | 1961 | M.S. + T.P. + T.R. |
| F | 38 | 1965 | M.S. + T.P. |
| PL | 44 | 1962 | M.S. + T.P. + V |
| PT | 5 | 1980 | M.S. + T.P. |
| SP | 6 | 1972 | M.S. |
| USSR | 6 | 1978 | M.S. |

Table 4. European publications of results on legume pollination.
(1) Same legend as Table 3.
(2) M.S. = Medicago sativa - T.P. : *Trifolium pratense*
T.R. = *Trifolium repens* - V. = *Vicia*.

## INVENTORY OF POLLINATING SPECIES

Legume pollinating fauna is somewhat varied because it is made up of over 20 main species, belonging to 5 Apoidal families : *Apidae, Andrenidae, Halictidae, Anthophoridae* and *Megachillidae*. These species are fairly well represented, depending on the country and the flowering date of legume plants. In Table 5, there is a list of the main legume pollinating insects. The insect density for legume plants very rarely reaches 2000 bees per hectare.

| APIDAE | MELITTIDAE | ANDRENIDAE |
|---|---|---|
| Bombus terrestris L. | Melitta leporina P.Z. | Melitturga clavicornis Latr. |
| B. pascuorum Sep. | | Andrena ovatula Kirb. |
| B. ruderarius Müll | | A. labialis K. |
| B. lapidarius L. | | A. flavipes Pz. |
| B. pratorum L. | | A. variabilis Sm. |
| B. sylvarum L. | | |
| **ANTHOPHORIDAE** | **HALICTIDAE** | **MEGACHILIDAE** |
| Eucera longicornis L. | Halictus marchali Vach. | Megachile pilidens Alfk. |
| E. clypeata Erichs. | Rhophitoides canus Ev. | M. centuncularis Latr. |
| E. tuberculata F. | | M. rotundata F. |
| | | Osmia aurulenta P.z. |
| E. interrupta Baer | | O. rufohirta Latr. |
| | | O. coerulescens L. |
| | | Anthidium florentinum |

**Table 5.**Pollinator species of legumes in Europe.