POLLINATION SERVICES FOR SUSTAINABLE AGRICULTURE

EXTENSION OF KNOWLEDGE BASE
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POTENTIAL EFFECTS OF CLIMATE CHANGE ON CROP POLLINATION

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Mariken Kjøhl, Anders Nielsen and Nils Christian Stenseth

Centre for Ecological and Evolutionary Synthesis (CEES),
Department of Biology, University of Oslo, Norway

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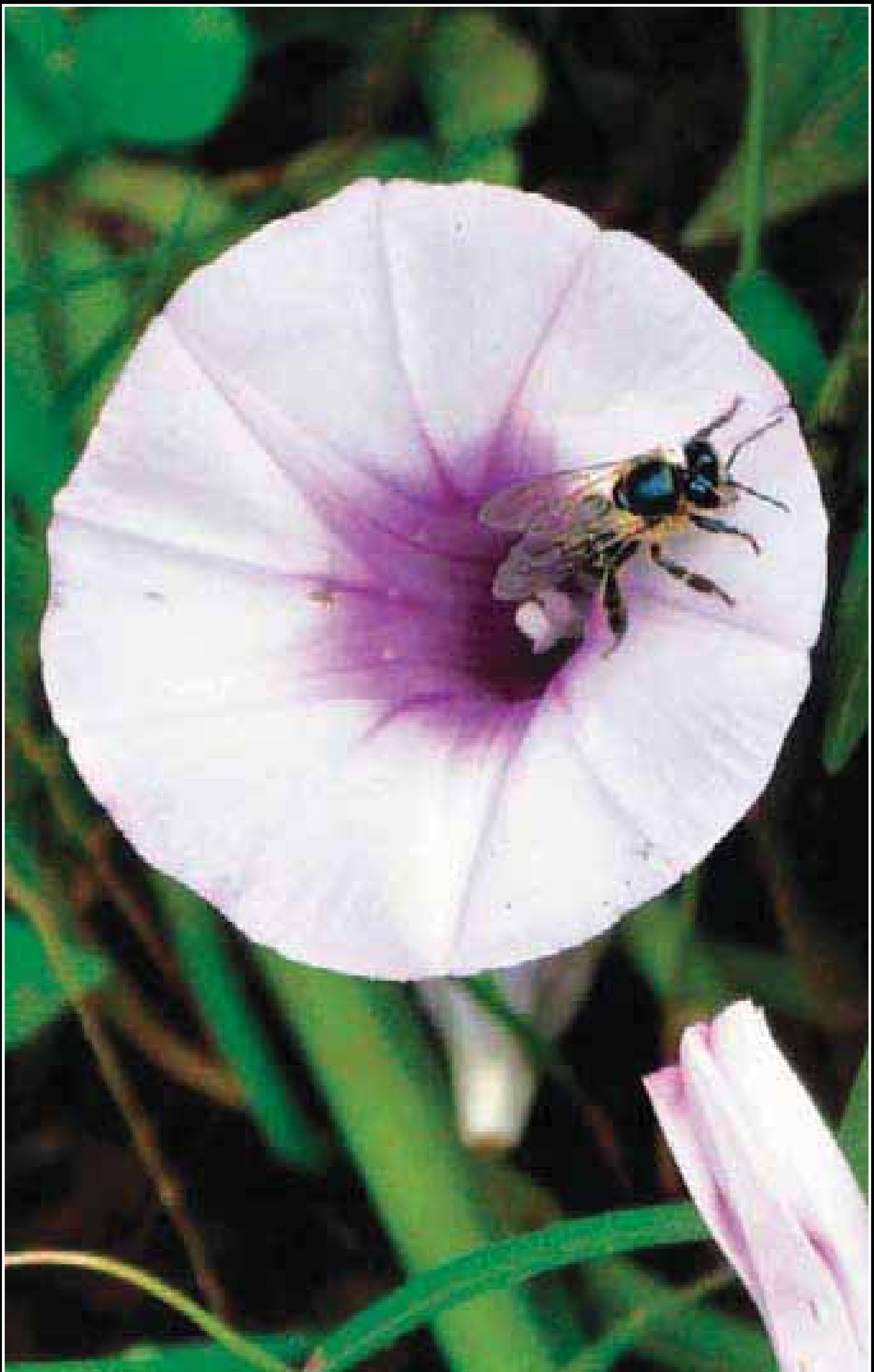
CONTENTS



PREFACE

Crop production must meet the demands of feeding a growing population in an increasingly degraded environment amid uncertainties resulting from climate change. There is a pressing need to adapt farming systems to meet these challenges. One of agriculture's greatest assets in meeting them is nature itself: many of the ecosystem services provided by nature – such as nutrient cycling, pest regulation and pollination – directly contribute to agricultural production. The healthy functioning of these ecosystem services ensures the sustainability of agriculture as it intensifies to meet growing demands for food production.

Climate change has the potential to severely impact ecosystem services such as pollination. As with any change, both challenges and opportunities can be expected. Recognizing that the interactions between climate, crops and biodiversity are complex and not always well understood, the Plant Production and Protection Division of FAO has coordinated this review of the potential effects of climate change on crop pollination. By taking a comprehensive, ecosystem approach to crop production, it may be possible to build in greater resilience in farming systems, and to identify broader options for crop production intensification through the deliberate management of biodiversity and ecosystem services.

Within the context of its lead role in the implementation of the International Initiative for the Conservation and Sustainable Use of Pollinators, also known as the International Pollinators Initiative (IPI) of the United Nations Convention on Biological Diversity, established in 2000 (Conference of Parties decision V/5, section II), FAO has developed a Global Action on Pollination Services for Sustainable Agriculture. This report serves as a contribution by FAO's Global Action on Pollination Services to the objectives of the IPI, specifically its first objective to "Monitor pollinator decline, its causes and its impact on pollination services".

Shivaji Pandey
Director, Plant Production and Protection Division
Agriculture and Consumer Protection Department
Food and Agriculture Organization of the United Nations

INTRODUCTION
Objectives of the report

One of the most important ecosystem services for sustainable crop production is the mutualistic interaction between plants and animals: pollination. The international community has acknowledged the importance of a diversity of insect pollinators to support the increased demand for food brought about by predicted population increases. Insect pollination is threatened by several environmental and anthropogenic factors, and concern has been raised over a looming potential pollination crisis.

The Intergovernmental Panel on Climate Change (IPCC) reports an approximate temperature increase ranging from 1.1-6.4°C by the end of this century. Climate change will exert great impacts on global ecosystems. A recent review has emphasized that plant-pollinator interactions can be affected by changes in climatic conditions in subtle ways. Data on the impacts of climate change on crop pollination is still limited, and no investigation has yet addressed this issue. This report aims to:

- provide a review of the literature on crop pollination, with a focus on the effects of climate change on pollinators important for global crop production;
- present an overview of available data on the temperature sensitivity of crop pollinators and entomophilous crops; and
- identify data needs and sampling techniques to answer questions related to effects of climate change on pollination, and make recommendations on the recording and management of pollinator interactions data. This includes important environmental variables that could be included in observational records in order to enhance the knowledge base on crop pollination and climate change.

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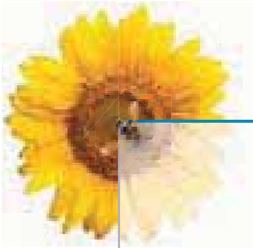


CLIMATE CHANGE AND CROP POLLINATION

Pollination is a crucial stage in the reproduction of most flowering plants, and pollinating animals are essential for transferring genes within and among populations of wild plant species (Kearns *et al.* 1998). Although the scientific literature has mainly focused on pollination limitations in wild plants, in recent years there has been an increasing recognition of the importance of animal pollination in food production. Klein *et al.* (2007) found that fruit, vegetable or seed production from 87 of the world's leading food crops depend upon animal pollination, representing 35 percent of global food production. Roubik (1995) provided a detailed list for 1 330 tropical plant species, showing that for approximately 70 percent of tropical crops, at least one variety is improved by animal pollination. Losey and Vaughan (2006) also emphasized that flower-visiting insects provide an important ecosystem function to global crop production through their pollination services.

The total economic value of crop pollination worldwide has been estimated at €153 billion annually (Gallai *et al.* 2009). The leading pollinator-dependent crops are vegetables and fruits, representing about €50 billion each, followed by edible oil crops, stimulants (coffee, cocoa, etc.), nuts and spices (Table 1). The area covered by pollinator-dependent crops has increased by more than 300 percent during the past 50 years (Aizen *et al.* 2008; Aizen and Harder 2009) (Figure 1.1). A rapidly increasing human population will reduce the amount of natural habitats through an increasing demand for food-producing areas, urbanization and other land-use practices, putting pressure on the ecosystem service delivered by wild pollinators. At the same time, the demand for pollination in agricultural production will increase in order to sustain food production.

Table 1

ECONOMIC IMPACTS OF INSECT POLLINATION OF THE WORLD AGRICULTURAL PRODUCTION USED DIRECTLY FOR HUMAN FOOD AND LISTED BY THE MAIN CATEGORIES RANKED BY THEIR RATE OF VULNERABILITY TO POLLINATOR LOSS

CROP CATEGORY	AVERAGE VALUE OF A PRODUCTION UNIT	TOTAL PRODUCTION ECONOMIC VALUE (EV)	INSECT POLLINATION ECONOMIC VALUE (IPEV)	RATE OF VULNERABILITY (IPEV/EV)
	€ PER METRIC TONNE	10^9€	10^9€	%
Stimulant crops	1 225	19	7.0	39.0
Nuts	1 269	13	4.2	31.0
Fruits	452	219	50.6	23.1
Edible oil crops	385	240	39.0	16.3
Vegetables	468	418	50.9	12.2
Pulse	515	24	1.0	4.3
Spices	1 003	7	0.2	2.7
Cereals	139	312	0.0	0.0
Sugar crops	177	268	0.0	0.0
Roots and tubers	137	98	0.0	0.0
All categories		1 618	152.9	9.5

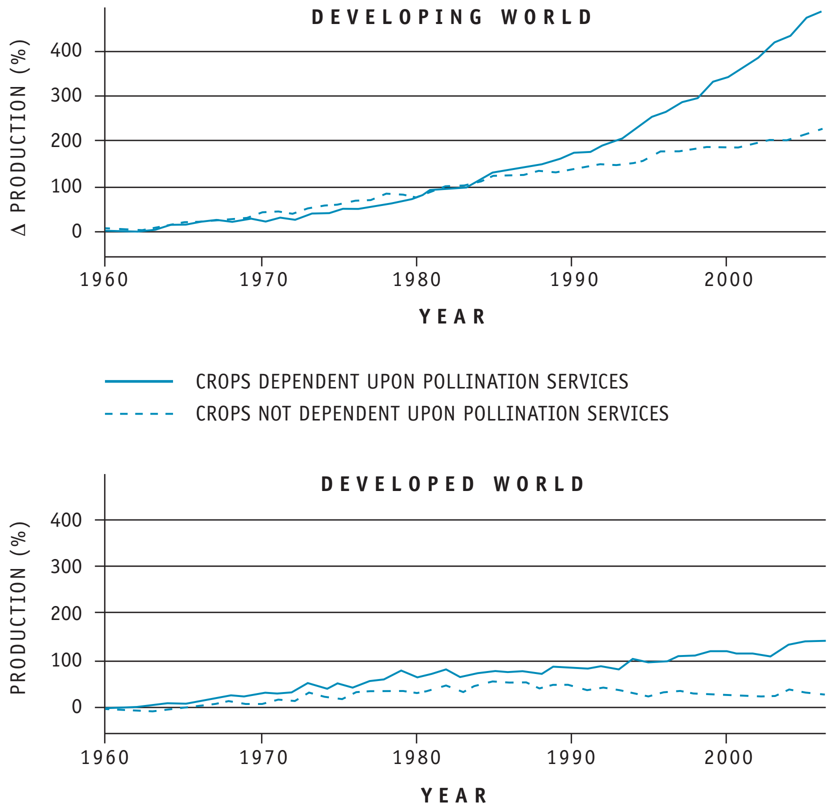
Source: Gallai *et al.* 2009.

Animal pollination of both wild and cultivated plant species is under threat as a result of multiple environmental pressures acting in concert (Schweiger *et al.* 2010). Invasive species (Memmott and Waser 2002; Bjerknes *et al.* 2007), pesticide use (Kearns *et al.* 1998; Kremen *et al.* 2002), land-use changes such as habitat fragmentation (Steffan-Dewenter and Tscharntke 1999; Mustajarvi *et al.* 2001; Aguilar *et al.* 2006) and agricultural intensification (Tscharntke *et al.* 2005; Ricketts *et al.* 2008) have all been shown to negatively affect plant-pollinator interactions.

Climate change may be a further threat to pollination services (Memmott *et al.* 2007; Schweiger *et al.* 2010; Hegland *et al.* 2009). Indeed, several authors (van der Putten *et al.* 2004; Sutherst *et al.* 2007) have argued that including species interactions when analysing the ecological effects of climate change is of utmost importance. Empirical studies explicitly focusing on the effects of climate change on wild plant-pollinator interactions are scarce and those on crop pollination practically non-existent. Our approach has therefore been to indirectly assess the potential effects of climate change

Figure 1.1

TEMPORAL TRENDS IN TOTAL CROP PRODUCTION FROM 1961 TO 2006



Source: Aizen *et al*. 2008.

on crop pollination through studies on related topics. We have focused on the effects of climate change on crop plants and their wild and managed pollinators, and studies on wild plant-pollinator systems that may have relevance.

The Fourth Assessment Report (AR4) developed by the Intergovernmental Panel on Climate Change (IPCC) lists many observed changes of the global climate. Most notably, the IPCC has documented increased global temperatures, a decrease in snow and ice cover, and changed frequency and intensity of precipitation (IPCC 2007). The most plausible and, in our opinion with respect to plant-pollinator interactions, the most important effect of climate change is an increase in temperatures. Therefore, we focus on the impacts increased temperatures might have on pollinator interactions. The fact that 11 years - out of the 12 year period from 1995 to 2006 - rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850) (IPCC 2007) provides high confidence of recent warming, which is strongly affecting terrestrial ecosystems. This includes changes such as earlier timing of spring events and poleward and upward shifts in distributional ranges of plant and animal species (IPCC 2007; Feehan *et al.* 2009).

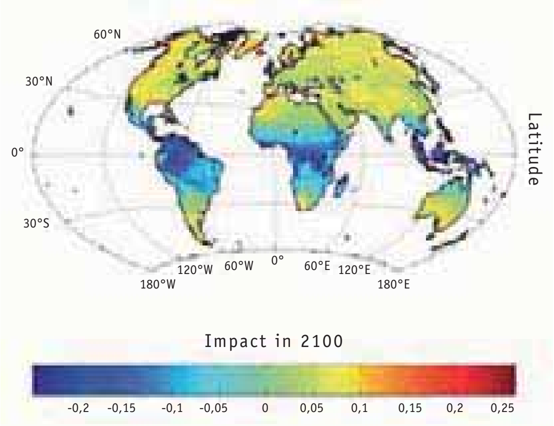
The most plausible and important effect of climate change on plant-pollinator interactions can be expected to result from an increase in temperatures.

Estimates from the IPCC indicate that average global surface temperatures will further increase by between 1.1˚C (low emission scenario) and 6.4 °C (high emission scenario) during the 21st century, and that the increases in temperature will be greatest at higher latitudes (IPCC 2007). The biological impacts of rising temperatures depend upon the physiological sensitivity of organisms to temperature change. Deutsch *et al.* (2008) found that an expected future temperature increase in the tropics, although relatively small in magnitude, is likely to have more deleterious consequences than changes at higher latitudes (Figure 1.2). The reason for this is that tropical insects are relatively sensitive to temperature changes (with a narrow span of suitable temperature) and that they are currently living in an environment very close to their optimal temperature. Deutsch *et al.* (2008) point out that in contrast, insect species at higher latitudes – where the temperature increase is expected to be higher – have broader thermal tolerance and are living in cooler climates than their physiological optima. Warming may actually enhance the performance of insects living at these latitudes. It is therefore likely that tropical agroecosystems will suffer from greater population decrease and extinction of native pollinators than agroecosystems at higher latitudes.

Future temperature increase in the tropics, although relatively small in magnitude, is likely to have more deleterious consequences than changes at higher latitudes.

Figure 1.2

PREDICTED IMPACT OF WARMING ON THERMAL PERFORMANCE OF INSECTS IN 2100



On the basis of patterns in warming tolerance, climate change is predicted to be most deleterious for insects in tropical zones.

Source: Deutsch *et al*. 2008.

Coope (1995) gives three possible scenarios for species' responses to large-scale climatic changes:

- Adaptation to the new environment
- Emigration to another suitable area
- Extinction

The first response is unlikely, since the expected climate change will occur too rapidly for populations to adapt by genetic change (evolution). As temperatures increase and exceed species' thermal tolerance levels, the species' distributions are expected to shift towards the poles and higher altitudes (Deutsch *et al.* 2008; Hegland *et al.* 2009). Many studies have already found poleward expansions of plants (Lenoir *et al.* 2008), birds (Thomas and Lennon 1999; Brommer 2004; Zuckerberg *et al.* 2009) and butterflies (Parmesan *et al.* 1999; Konvicka *et al.* 2003) as a result of climate change. Crop species and managed pollinators may easily be transported and grown in more suitable areas. However, moving food production to new areas may have serious socio-economic consequences. In addition, wild pollinators might not be able to follow the movement of crops.

Insect pollinators are valuable and limited resources (Delaplane and Mayer 2000). Currently, farmers manage only 11 of the 20 000 to 30 000 bee species worldwide (Parker *et al.* 1987), with the European honey bee (*Apis mellifera)* being by far the most important species. Depending on only a few pollinator species belonging to the *Apis* genus has been shown to be risky. *Apis*-specific parasites and pathogens have lead to massive declines in honey bee numbers. Biotic stress accompanied with climate change may cause further population declines and lead farmers and researchers to look for alternative pollinators. Well-known pollinators to replace honey bees might include the alfalfa leaf-cutter bee (*Megachile rotundata*) and alkali bee (*Nomia melanderi*) in alfalfa pollination (Cane 2002), mason bees (*Osmia* spp.) for pollination of orchards (Bosch and Kemp 2002; Maccagnani *et al.* 2003) and bumblebees (*Bombus* spp.) for pollination of crops requiring buzz pollination (Velthuis and van Doorn 2006). Stingless bees are particularly important pollinators of tropical plants, visiting approximately 90 crop species (Heard 1999). Some habits of stingless bees resemble those of honey bees, including their preference for a wide range of crop species, making them attractive for commercial management.

Pollinator limitation (lack of or reduced availability of pollinators) and pollen limitation (insufficient number or quality of conspecific pollen grains to fertilize all available ovules) both reduce seed and fruit production in plants. Some crop plants are more vulnerable to reductions in pollinator availability than others. Ghazoul (2005) defined vulnerable plant species as:

- having a self-incompatible breeding system, which makes them dependent on pollinator visitation for seed production;
- being pollinator-limited rather than resource-limited plants, as is the case for most intensively grown crop plants, which are fertilized; and
- being dependent on one or a few pollinator species, which makes them particularly sensitive to decreases in the abundance of these pollinators.

Food production in industrialized countries worldwide consists mainly of large-scale monocultures. Intensified farm management has expanded at the cost of semi-natural non-crop habitats (Tilman *et al.* 2001). Semi-natural habitats provide important resources for wild pollinators such as alternative sources of nectar and pollen, and nesting and breeding sites. Especially in the United States, many of these intensively cultivated agricultural areas are completely dependent on imported colonies of managed honey bees to sustain their pollination. The status of managed honey bees is easier to monitor than that of wild pollinators. For example, bee numbers and diurnal activity patterns can be easily assessed by visually inspecting the hives. Although not commonly used by farmers, scale hives can yield important information on hive conditions and activity, the timing of nectar flow and the interaction between bees and the environment (http://honeybeenet.gsfc.nasa.gov).

In most developing countries, crops are produced mainly by small-scale farmers. Here, farmers rely more on unmanaged, wild insects for crop pollination (Kasina *et al.* 2009). To identify the most important pollinators for local agriculture, data on visitation rate alone does not necessarily suffice. Crop species may be visited by several species of insects, but several studies have shown that only a few visiting species may be efficient pollinators. An effective pollinator is good at collecting, transporting and delivering pollen within the same plant species.

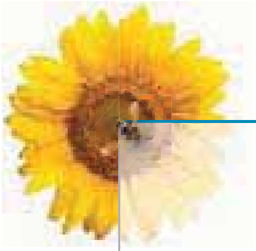
In a recent review, Hegland *et al.* (2009) discussed the consequences of temperature-induced changes in plant-pollinator interactions. They found that timing of both plant flowering and pollinator activity seems to be strongly affected by temperature. Insects and plants may react differently to changed temperatures, creating temporal (phenological) and spatial (distributional) mismatches – with severe demographic consequences for the species involved. Mismatches may affect plants by reduced insect visitation and pollen deposition, while pollinators experience reduced food availability.

We have found three studies investigating how increased temperatures might create temporal mismatches between wild plants and their pollinators. Gordo and Sanz (2005) examined the nature of phenological responses of both plants and pollinators to increasing temperatures on the Iberian Peninsula, finding that variations in the slopes of the responses indicate a potential mismatch between the mutualistic partners. Both *Apis mellifera* and *Pieris rapae* advanced their activity period more than their preferred forage species, resulting in a temporal mismatch with some of their main plant resources (Hegland *et al.* 2009). However, Kudo *et al.* (2004) found that early-flowering plants in Japan advanced their flowering during a warm spring whereas bumble bee queen emergence appeared unaffected by spring temperatures. Thus, direct temperature responses and the occurrence of mismatches in pollination interactions may vary among species and regions (Hegland *et al.* 2009).

Memmot *et al.* (2007) simulated the effects of increasing temperatures on a highly resolved plant-pollinator network. They found that shifts in phenology reduced the floral resources available for 17 to 50 percent of the pollinator species. A temporal mismatch can be detrimental to both plants and pollinators. However, the negative effects of this changed timing can be buffered by novel pollination interactions. Intensively managed monocultures usually provide floral resources for a limited time period. The survival rate and population size of the main pollinators may decrease if the foraging activity period is initiated earlier than the flowering period of the crop species. A loss of important pollinators early in the season will reduce crop pollination services later in the season. In such cases, introducing alternative food sources might be an option for farmers. In more heterogeneous agroecosystems, which are characterized by a higher diversity of crops and semi-natural habitats, pollinators may more readily survive on other crops and wild plants while waiting for their main food crop to flower.

We find the empirical support for temporal mismatches to be weak because of the limited number of studies available in the literature. Spatial mismatches between plants and their pollinators resulting from non-overlapping geographical ranges have not yet been observed. Despite the possibility of moving crop species to areas of suitable climate, we still believe that spatial and temporal mismatches between important crop species and their pollinators are highly probable in the future. Temporal mismatches and lack of synchronicity in plant and animal phenologies are likely because crop plant phenologies probably respond to climate variables in comparable ways to wild plants. Spatial mismatches may also be likely because of the socio-economic costs and consequences of moving food production to new areas, particularly in impoverished countries with high population density and a high degree of pollinator dependence for food production(Ashworth *et al.* 2009). Therefore, it is of the utmost importance for global food production and human well being that we understand the effects of climate change on animal-pollinated crops in order to counteract any negative effects.

Temporal mismatches are likely because crop plant phenologies probably respond to climate variables in comparable ways to wild plants. Spatial mismatches may also be likely because of the socio-economic costs of moving food production to new areas, particularly in impoverished countries.



TEMPERATURE SENSITIVITY OF CROP POLLINATORS AND ENTOMOPHILOUS CROPS

POLLINATORS' SENSITIVITY TO ELEVATED TEMPERATURES

Bees are the most important pollinators worldwide (Kearns *et al.* 1998) and like other insects, they are ectothermic, requiring elevated body temperatures for flying. The thermal properties of their environments determine the extent of their activity (Willmer and Stone 2004). The high surface-to-volume ratio of small bees leads to rapid absorption of heat at high ambient temperatures and rapid cooling at low ambient temperatures. All bees above a body mass of between 35 and 50 mg are capable of endothermic heating, i.e. internal heat generation (Stone and Willmer 1989; Stone 1993; Bishop and Armbruster 1999). Examples of bee pollinators with a body weight above 35 mg are found in the genera *Apis, Bombus, Xylocopa and Megachile*. Examples of small bee pollinators are found in the family Halictidae, including the genus *Lasioglossum*. All of these groups are important in crop pollination.

In addition to endothermy, many bees are also able to control the temperatures in their flight muscles before, during and after flight by physiological and behavioural means (Willmer and Stone 1997). Examples of behavioural strategies for thermal regulation include long periods of basking in the sun to warm up and shade seeking or nest returning to cool down (Willmer and Stone 2004). With respect to the potential effects of future global warming, pollinator behavioural responses to avoid extreme temperatures have the potential to significantly reduce pollination services (Corbet *et al.* 1993).

Endothermic abilities and thermal requirements show a wide variation among different groups of bees. Most bee species have upper critical body temperatures (UCT) of 45-50°C (Willmer and Stone 2004). Although desert and tropical bees face both high solar radiation and high air temperature, there seems to be no major difference in UCT between bees in different biogeographical regions (Pereboom and Biesmeijer 2003). However, because of bees' contrasting abilities to generate heat when active, the maximum ambient temperature at which they can maintain activity may be somewhat below their UCT (Willmer and Stone 1997). The activity patterns of bees during the day also depend on the bees' coloration and body size (Willmer and Stone 1997; Bishop and Armbruster 1999). For example, Willmer and Corbet (1981) found that small, light-coloured *Trigona* bees in Costa Rica foraged on the flowers of *Justicia aurea* in full sunlight, while large, dark-coloured bees foraged in the morning and evening to avoid overheating.

The European honey bee (*Apis mellifera*) is the most widely distributed bee species worldwide and has evolved into several ecotypes adapted to different climatic regions (Figure 2.1). Two of the ecotypes are especially valued by beekeepers: The Carnolian honey bee (*Apis mellifera carnica*) and the Italian honey bee (*Apis mellifera ligustica*).

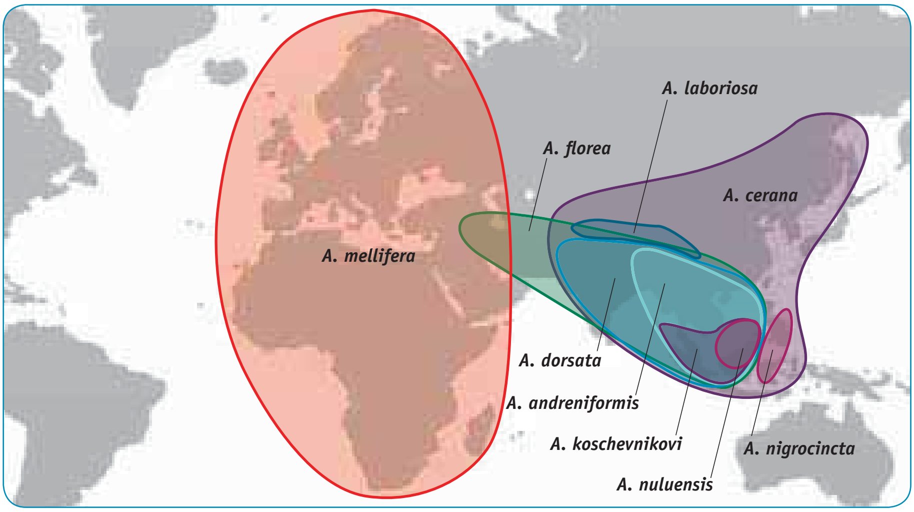
The native distribution of *A. mellifera* extends from the southern tip of Africa to Scandinavia and Russia in the north and from the Caspian Sea and beyond theEastern Ural Mountains in the east to Ireland in the west (Figure 2.1: red patch). *Apis mellifera* includes 25 subspecies or ecotypes (Figure 2.2). Each ecotype has evolved to the climatic and environmental conditions in its region, and therefore possesses a unique genetic variability.

The natural distribution of the European dark bee *(Apis mellifera mellifera)* is found in a region where average July temperatures range from 15-20°C (Figure 2.3), which may represent their thermal tolerance. The Eastern honey bee *(Apis cerana)* is native to parts of Asia (Figure 2.1: violet patch). The giant honey bee *(Apis dorsata)* lives only at tropical and adjacent latitudes in Asia (Figure 2.1: blue patch) and occurs less widely than the Eastern honey bee *(Apis cerana)*, but can live at higher altitudes. The dwarf honey bee *(Apis florea)* is more restricted than that of the larger *A. dorsata* and *A. cerana*. It is also mainly found in Asia (Figure 2.1: green patch).

The effect of climate change on pollinators depends upon their thermal tolerance and plasticity to temperature changes. Our goal was to obtain thermal tolerance data for the most important pollinators worldwide. However, a literature review indicates that this information is missing for most species.

Figure 2.1

GLOBAL DISTRIBUTION OF THE *APIS* GENUS.



Source: Franck *et al*. 2000; Le Conte and Navajas 2008. Figure printed with permission from P. Franck (Franck 1999).

Figure 2.2

MAIN GEOGRAPHIC RACES OF *APIS MELLIFERA*.

A, M, C and O are the four evolutionary branches.

Source: Ruttner 1988; Franck et al. 2000; Le Conte and Navajas 2008). Figure printed with permission from P. Franck (Franck 1999).

Figure 2.3

THE NATURAL RANGE OF *APIS MELLIFERA*.

The natural range of *Apis mellifera mellifera* coincides with the 15-20° zone (July average temperatures).

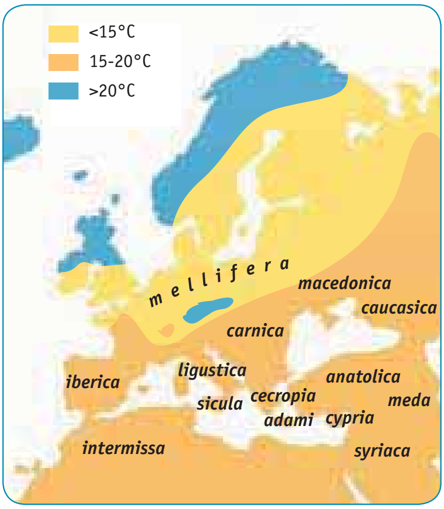


Figure printed with permission from D. Pritchard (Pritchard 2006).

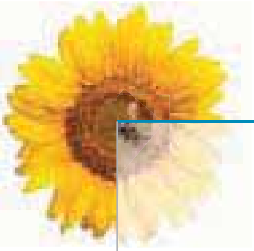
that this information is missing for most species. There is an urgent need to investigate the thermal tolerance of important crop pollinators and differences in thermal tolerance among *Apis* species and sub-species. Some of these are better adapted to warmer climates and may therefore move into new areas where they can function as crop pollinators under future climate conditions.

ENTOMOPHILOUS CROPS' SENSITIVITY TO ELEVATED TEMPERATURES AND DROUGHT

Plant development is mainly determined by mean temperature and photoperiod (Nigam *et al.* 1998). As global temperatures increase, crops will be grown in warmer environments that have longer growing seasons (Rosenzweig *et al.* 2007). An increased temperature of 1-2°C may have a negative impact on crop growth and yield at low latitudes, and a small positive impact at higher latitudes (Challinor *et al.* 2008). Extreme temperatures and drought are short-term events that will likely affect crops, particularly during anthesis (Wheeler *et al.* 1999).

While it is clear that drought and water stress will negatively affect crop growth and yield, their impacts on pollination functions are less well understood. Most of the work carried out on the impacts of drought on crop yield is from research on non-pollinator-dependent crops such as grain crops or wild plants. We do however believe that similar effects may occur with pollinator-dependent crops. Akhalkatsi and Lösch (2005) found reductions in inflorescence and flower numbers in the annual garden spice legume *Trigonella coerulea* when subjected to controlled drought conditions. Flowers with fewer attractants are less attractive to pollinators (Galloway *et al.* 2002; Pacini *et al.* 2003; Mitchell *et al.* 2004; Hegland and Totland 2005) and will experience reductions in pollination levels, with decreased seed quality and quantity (Philipp and Hansen 2000; Kudo and Harder 2005). Crop species experiencing drought stress may also produce lower seed weight and seed number, resulting in reduced yield (Akhalkatsi and Lösch 2005). Yield reduction under drought may also result from a decrease in pollen viability along with an increase in seed abortion rates, which have been identified as the most important factors affecting seed set (Melser and Klinkhamer 2001; Boyer and Westgate 2003).

Drought may impact floral attractants, making flowers less visited by pollinators.



DATA NEEDS AND RECOMMENDATIONS

To be able to sustain (and increase) agricultural production, it is important to provide precise information on the potential impacts of different climate change scenarios on crop pollination. However, research on the potential effects of climate change on crop pollination is limited. It is therefore urgent that targeted data sampling focus on temperature sensitivity of important entomophilous crops, their most important pollinators and the interactions among them. Basic knowledge of species' climate sensitivity will be important to guide policy makers and farmers in sustaining and managing insect-pollinated agroecosystems affected by climate change. A recent review by Hegland *et al.* (2009) suggests the potential for warming-caused temporal mismatches in wild plant-pollinator interactions. We believe this to be a likely outcome for crop pollination as well. Data should be gathered to enable stakeholders to assess the potential for mismatches in pollinator-dependent agroecosystems and suggest actions to minimize negative effects.

It is urgent that targeted data sampling focus on temperature sensitivity of important entomophilous crops, their most important pollinators and the interactions among them.

To enable policy makers, the agricultural industry and local farmers to adapt their practices for production of entomophilous crops under novel climate conditions, we suggest two approaches. The first is to design standardized sampling protocols and gather data on climate sensitivity in crops and their pollinators. The second is to conduct targeted experiments on the temperature sensitivity of entomophilous crops and their most important pollinators. However the extent of data collection required to provide in-depth knowledge on crop pollination may not be feasible in many developing countries because of insufficient financial and human resources. We therefore suggest a simple risk assessment to identify each country's vulnerability to reductions in crop pollination as a result of global warming (Annex 1).

STANDARDIZED SAMPLING PROTOCOLS

Changes in single-species distributions, local species diversity and the status of ecosystem services such as pollination can be difficult to detect because of the large amount of data needed for precise monitoring. For pollination services, this is further complicated by the large spatio-temporal variation in the composition of plant-pollinator systems (Nielsen 2007; Olesen *et al.* 2008; Petanidou *et al.* 2008; Dupont *et al.* 2009; Lazaro *et al*. 2010). Although focusing on wild plants, these studies have shown that the composition of the pollinator community and the interactions between plants and pollinators are highly variable in space and time. Interactions that are extremely important one year might be nonexistent the next, and plants that appear to be specialized to a single pollinator species might show a high degree of generalization if observed over an extended period of time. In agroecosystems that depend on wild pollinators, information on natural variation in pollinator assemblages is critical. If the extent of natural variation is not corrected for, short-term (natural) variation might be interpreted as climate-induced variation, which could lead to premature conclusions. Although not prone to variations in the composition of the pollinator assemblage, agroecosystems that depend solely on domesticated pollinators (honey bees) will need extensive monitoring to cover naturally occurring temporal and spatial variations in levels of pollination service. To meet the challenges that climate change will pose to crop pollination worldwide, standardized research methodologies must be developed to assess the abundance, diversity, interactions, distribution, phenology and temperature sensitivity of global pollinators and crop species. Such standardized sampling protocols will allow direct comparison of records across time and space (Westphal *et al.* 2008).

The aim of monitoring current agroecosystems is to clarify the relationship between crop yield and pollinator services, and determine how this relationship is affected by climate variables. Here we list some important biological, ecological and climatic factors that we believe should be included in monitoring programmes to better understand the impacts of future climate change on animal-pollinated agroecosystems. We suggest that data-sampling protocols focus on gathering data on the following factors.

Pollinator activity

In order to understand the nature of crop pollination, it is necessary to have precise information on the pollinator species involved. There are several ways of assessing the status of pollinator species and communities, and the structure of pollination networks (Committee on the Status of Pollinators in North America 2007). Two effective methods have been identified to estimate bee species richness (a useful proxy for measuring the diversity of pollinator communities in many areas): pan traps and transect walks (Westphal *et al.* 2008). Pan traps passively collect all insects attracted to them without assessing their floral associations or whether they pollinate crop species. They can, however, be an effective method for estimating relative population size and species richness as they collect a large number of individuals with little effort. The effectiveness of pan traps in collecting other types of pollinators such as butterflies and hoverflies has not been assessed to the same extent as for bees.

Since pollination depends upon the number of visits provided by each pollinator as well as the pollinator's effectiveness in transporting pollen from anthers to stigmas, pan traps are an inferior method in pollination studies. The visitation frequency of pollinators can be measured by observing and counting pollinators foraging on flowers. Transect walks, which can be used to capture insects visiting crop flowers, are in some ways a better method than pan traps, although more laborious (Westphal *et al.* 2008; Vaissiere *et al.* 2011).

While bees (especially honey bees) are the most frequent visitors to crop plants worldwide, the composition of pollinator communities may vary both locally and regionally. Therefore, a detailed investigation of the composition of each pollinator community is needed. Transect walks also capture pollinators other than bees without creating extensive sampling bias and provide information on specific pollination interactions - a prerequisite for building pollination networks. We recommend transect walks within agricultural fields to assess the status of pollinator communities of entomophilous crops. It is especially important to train field workers in sampling techniques and pollinator taxonomy since variations in skill have been shown to induce bias and reduce data quality. In addition to visitation frequencies, data on the quality of each visit is important for measuring the effectiveness of pollination. It is crucial to estimate each pollinator species' ability to carry pollen from anthers to stigmas (see section on experiments below, page 21). It may be that the species with the highest number of visits is not the most important to plant reproduction. In addition, information on pollinators' additional habitat requirements (e.g. nesting sites), behaviour, life histories and population dynamics is needed to understand the impacts of climatic change on pollinator services to crop plants.

Temperature sensitivity of pollinators and crops

Local temperature can affect pollinator behaviour, altering the number of visits conducted by a single pollinator and pollinators' behaviour within flowers. On a larger scale, changes in temperature over the entire season may alter the abundance and diversity of pollinators. For example, pollinators with a narrow temperature tolerance may be replaced by other pollinators that are less sensitive to temperature changes or have higher optimal temperatures. Meteorological observations must be recorded to identify correlations between insect activity and climate variables such as temperature, humidity, wind and solar radiation.

Knowledge of pollinators' temperature sensitivity (see section on experiments below) is especially important since it enables us to predict how different climate scenarios may affect the species' behaviour, phenology and distributional ranges. In addition, microclimatic limits for managed bees can be identified by hive monitoring: the total number of bees absent from the hive or nest is measured rather than the number present at a foraging site. At the hive, the number of bees absent from the colony can be estimated from a continuous sequence of counts of arrivals and departures per unit time.

Temperature sensitivity (ranges) of important crops can be obtained from FAO's ECOCROP database (http://ecocrop.fao.org/ecocrop/srv/en/home). This database contains information on more than 2 000 crop species and is continuously updated and expanded.

Surrounding vegetation (including floral and other critical resources such as nesting sites)

Vegetation surrounding fields of entomophilous crops must be conserved and managed to maintain wild pollinators within agricultural landscapes. It is particularly important to conserve additional food resources for the periods when the crops are not flowering. We therefore suggest that transect walks be conducted in the natural and semi-natural plant communities surrounding agricultural fields (Westphal *et al.* 2008). Quantification of plant and pollinator communities in remnant habitats is needed to assess the viability of pollinator populations, as they likely depend on wild flower resources when crop species are not in bloom. It is also important to monitor ecosystems' resilience to perturbations such as increased temperatures.

In agroecosystems depending on wild pollinators, pollinator diversity and the structure of pollination networks – including wild flowering plants outside agricultural fields – have been shown to buffer against the negative effects of perturbations. Ecosystems with high species diversity are considered to be more resilient to disturbance than less diverse systems. With respect to crop pollination, several studies have indicated that agricultural fields in close proximity to natural habitats may benefit from pollination of native pollinators (Klein *et al.* 2003; Ricketts 2004; Greenleaf and Kremen 2006; Morandin and Winston 2006; Gemmill-Herren and Ochieng 2008) – but see Chacoff *et al.* (2008). Ricketts *et al.* (2004) found that pollination by a diverse group of wild bees enhanced coffee production as several bee species compensated for a drop in honey bee visitation in certain years. Although we could not find any studies on temperature sensitivity in relation to pollination and climate change, we can assume that relying on a few pollinator species is more risky than conserving a diverse pollinator fauna with differing optimal temperature ranges.

A recent study by Thylianakis *et al.* (2010) discusses the properties of pollination networks that might confer robustness in spite of perturbations. These measures, including degree distribution, connectivity and nestedness, can also describe how "healthy" the pollination system appears to be. These indicators should be calculated based on data gathered in monitoring programmes to assess the status of the entire plant pollinator system in the area.

Habitat requirements are species-specific so data must be collected on habitat and food requirements during the pollinators' entire life cycle. Ground-nesting solitary bees and bumblebees seem to prefer sunny, open undisturbed meadows, field margins, sun-drenched, undisturbed patches of bare soil, roadsides, ditch banks and woodland edges (Delaplane and Mayer 2000). Whenever the diversity of native plants is lost, crops that are rich bee forage could be planted to sustain food resources throughout the pollinators life cycles (these include lucerne, clover, oilseed rape and sunflower) (Delaplane and Mayer 2000). Regular mowing is advisable to prevent bee sanctuaries from turning into forests and shrublands. In temperate regions, mowing should be done in winter, when it is less likely to destroy active bumblebee colonies (Delaplane and Mayer 2000).

Non-crop floral resources can be monitored by conducting transect walks in which pollinator interactions in remnant habitats are recorded or by quantifying the amount of floral resources with standardized vegetation-mapping techniques. Monitoring should be undertaken throughout the season (or the entire year in non-seasonal environments) to identify potential periods of floral resource shortage. Bees can be partitioned into guilds on the basis of their nesting habits (Table 2). The availability of nesting sites can be assessed by investigating important habitat characteristics in the surrounding vegetation, such as soil texture, soil hardiness, soil moisture, aspect and slope, amount of insulation, cavity shape and size and diameter of pre-existing holes.

Climate variables

The most relevant climate variables may vary among crop and pollinator species, and among different climate regions. The first step is to identify the most important variables for each, and then record these variables in the most appropriate way. Environmental cues controlling the phenology of important pollinators might include maximum daily temperature, lack of frost, number of degree days (number of days with a mean temperature above a certain threshold), day length and snow cover. It is also important to record climatic data in the area where the crop pollination system is studied (e.g. average temperature, precipitation, snow cover) to identify other areas where the results might be similar.

Table 2

HABITAT REQUIREMENTS AND TAXONOMIC GROUPS OF THE DIFFERENT NESTING GUILDS OF POLLINATORS

NESTING POLLINATOR GUILDS	NESTING HABITATS	TAXONOMIC GROUPS
MINERS	Open habitats. Excavate holes in the ground.	Andrenidae, Melittidae, Oxaeidae and Fideliidae. Most of the Halictidae, Colletidae and Anthophoridae.
MASONS	Pre-existing cavities, pithy or hollow plant stems, small rock cavities, abandoned insect burrows or even snail shells	Megachilidae
CARPENTERS	Woody substrate	Two genera within Apidae (*Xylocopa* and *Ceratina*) and one within Megachilidae (*Lithurgus*)
SOCIAL NESTERS	Pre-existing cavities	Apidae: honey bees, bumblebees and stingless bees

Source: O'Toole and Raw 2004.

Temperature

Pollinators and plants have different climatic requirements, and may therefore respond differently to changes in ambient temperature. Temperature can induce different responses in plants and pollinators. For example, increased spring temperatures may postpone plant flowering time while pollinators might be unaffected. Even if plants and pollinators do respond to the same temperature cue, the strength of the response might differ (Hegland *et al.* 2009). Data on the number of degree days, or maximum temperature during the day or hours with temperature above or below a certain threshold may be more important for crop plants and pollinators than temperature during observations of pollinator activity. Tropical pollinators may respond to different temperature cues than pollinator species at higher latitudes. Temperature-induced activity patterns may also differ depending on pollinator size, age and sex. Winter temperature might also be of importance for pollinators. In recent years, bumble bee hives in Ireland have been able to survive over winter, presumably due to increased winter temperatures (Anke Dietzsch, pers. comm.). These hives will be able to present larger populations of workers at an earlier stage in spring than hives built from scratch by a single queen.

Precipitation

High precipitation may limit pollinators' foraging activity. Optimal foraging conditions for pollinators are sunny days with low wind speed and intermediate temperature. Climate change is expected to alter existing precipitation patterns. Some areas will likely experience decreased rainfall, leading to more extensive drought periods. This water stress may decrease flower numbers and nectar production. Snow cover might also be reduced with increased temperatures. Indeed, bumblebees have been shown to respond more to snow cover than to temperature (Inouye 2008). In each case, the most relevant measure of precipitation must be assessed.

Extreme climate events

Extreme climate events might have detrimental effects on both crop plants and pollinator populations. High temperatures, long periods of heavy rain and late frost may affect pollinator activity either by reducing population sizes or by affecting insect activity patterns. The probability of extreme climate events may change in the future. Risk assessments should be conducted to better understand the changes in frequency of extreme climate events and minimize the effects.

Other threats to pollination services

Pollination is under threat from several environmental pressures. Climate change is only one, and it cannot be seen in isolation, but should be addressed in relation to other pressures affecting plant-pollinator interactions. Here we list some of the most important pressures to be assessed in order to understand how crop pollination might be affected by climate change.

Agricultural practices

Agricultural intensification by covering large areas with monocultures increases agroecosystems' vulnerability to climate change. Adaptation strategies at the farm level can include increased farm diversity, including crop diversity, and changes in sowing date, crops or cultivars. Greater crop diversity can decrease crops' vulnerability to climate variability, as different crops respond differently to a changing climate. Regional farm diversity may also buffer against the negative effects of climate change at a large scale as it entails a large variability in farm intensity and farm size (Reidsma and Ewert 2008).

Invasive species

Invasive species may benefit from climatic changes and proliferate in their new habitats. Climate change is predicted to increase invasion of alien species, especially in northern regions. However, the effects of climate change on invasive species and pollination interactions may vary depending on the species and ecosystem in focus (Schweiger *et al.* 2010). It is necessary to assess the controllability of invaders in order to assist policy makers in ranking threats from different invasive species for more effective use of limited resources (Ceddia *et al.* 2009).

Pest species, pesticides and pathogens

Some invasive insect and plant species are pest organisms, which may cause severe damage to agricultural production. It is expected that climate change will affect various types of pests in different ways (Garrett *et al.* 2006; Ghini and Morandi 2006). Increased temperatures may speed up pathogen growth rates. Warming may also favour weeds in comparison to crops and increase the abundance, growth rate and geographic range of many crop-attacking insect pests (Cerri *et al.* 2007). Increased demand for control of plant pests often involves the use of pesticides, which can have negative impacts on human health and the environment (Damalas 2009), including ecosystem services such as pollination. Diffenbaugh *et al.* (2008) assessed the potential future ranges of pest species by using empirically generated estimates of pest overwintering thresholds and degree-day requirements along with climate change projections from climate models.

Pollinators are also negatively affected by predators, parasites and pathogens. Natural movements of pollinator species and exchanges of domesticated bees among beekeepers will bring them into contact with new pathogens. Pests and pathogens may find new potential hosts (Le Conte and Navajas 2008). It is therefore important to conserve the genetic variability among and within important pollinator species (including races and varieties) to decrease disease-mediated mortality. Managed pollinators may need veterinary aid and appropriate control methods to prevent catastrophic losses (Le Conte and Navajas 2008).

EXPERIMENTS ON EFFECTIVENESS AND CLIMATE SENSITIVITY OF PARTICULAR SPECIES

The most important pollinators for particular crop species can be identified through monitoring programmes, at least in terms of visitation frequencies. Natural and laboratory experiments can then be conducted to identify the optimal climate conditions and climate toleration limits of target species, and their most important pollinators. When the relationships between climate variables and crop species phenologies have been established, these results can be coupled with those from experiments on single-pollinator species responses with the same climatic variables. From these experiments, it will be possible to assess the potential for mismatches and other altered pollination services resulting from climate change.

Experimental manipulations of climate variables on crop plants and their pollinators enable us to more precisely forecast the impacts of future climate change on crop pollination as they may reveal precise estimates of species' climate sensitivity and the interactions among them. Here, we list potential responses to climate change that can be assessed in experiments on crop plants and their pollinators. We do not provide any detailed experimental setup, but present focal areas where targeted research should be done.

Identification of important pollinators

Through intensive monitoring, the most frequent visitors to a particular crop species can be identified. However, pollinators vary in their effectiveness in initiating seed set. Fidelity to particular plant species, body size and morphology, and physical movement within and among flowers all affect pollination quality. The importance of each pollinator species is a product of the visitation frequency and the quality of each visit. Visitation quality of the most frequently observed pollinators should be investigated by presenting flowers to single visits of particular pollinator species.

Crop plant responses to climate change scenarios

Changes in nectar and pollen amounts and quality

Pollen quality may change along with climatic conditions. It can be assessed by measuring post-pollination events such as counting the pollen germination rate on stigmas, measuring pollen tube growth and competition, and counting the survival of fertilized ovules, developed embryos and seed and fruit abortions (Dafni 1992). Changes in nectar quantity and quality can be measured at controlled temperatures in climatic chambers. Nectar volume can be measured by inserting calibrated microcapillaries into each flower and nectar concentration can be measured with a pocket refractometer (Petanidou and Smets 1996).

Changes in phenology

Crop flowering phenology can be manipulated by altering climatic variables (temperature, precipitation, etc.). Important phenological events include the timing of flowering (e.g. duration and date of the first and last flowering), and frequency of flowering. Climate change can be simulated by distributing experimental plots along natural climatic gradients or by creating different climatic conditions in artificial environments such as laboratory or greenhouse experiment.

Pollinator responses to potential climate change scenarios

Pollinators may respond to climate change in different ways, depending on the system under study and climatic variable in focus. Pollinators may also respond in different ways depending on whether the scale is individuals vs. populations or local vs. landscape.

Changes in pollinator behaviour

Pollinators may change behaviour in response to shifts in climate. Observations of pollinators in experimentally warmed greenhouses reveal behavioural responses to climate change that may be important for flower visitation. The time taken for thermoregulation at higher temperatures comes at the cost of foraging, with negative consequences for pollination. It is likely that pollinators will change their activity patterns as temperature increases, in turn changing the efficiency of pollen removal and deposition. For this reason, it is important to investigate taxonomic differences in pollinators' ability to regulate body temperature and avoid overheating.

Climate change may also impact activity patterns of pollinators. As temperatures increase, pollinators are at risk of overheating, particularly in regions where current ambient temperatures are high and climatic conditions are stable. In these regions, pollinators such as bees have a body temperature close to the ambient temperature and have a narrow thermal tolerance. Bees have different mechanisms for avoiding overheating, such as shade seeking and prolonged time spent in the nest. Bumblebees are particularly prone to overheating if temperatures increase because of their large size, dark colour and hairy bodies.

Visitation quality

Experimental manipulation of pollinator assemblages and simulated pollinator species shift can reveal changes in pollination quality. Numerous measures can be used to assess the visitation quality of pollinators (Dafni 1992), but for crop pollination, we suggest focusing on variables related to food production (e.g. seed set or fruit set).

Changes in pollinator distribution

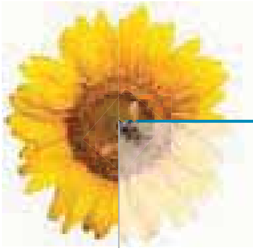
Studying changes in entire pollinator communities is extremely difficult because of the large space and time requirements of such experiments. We have been involved in several studies in which the pollinator activity in plots of wild plants was experimentally reduced (Totland and Lazaro unpublished data). Our preliminary results show that by using "semi-exclosures" around vegetation plots, the number of flower visitors was reduced significantly but not completely. Such alterations in the pollinator community can provide data on the potential effects of changes in the distribution and abundance of pollinator species. Seasonal shifts within (Stone *et al.* 1995) and across species (Potts *et al.* 2003a; Potts *et al.* 2003b) have also been detected in regions with distinct seasons and may simulate species turnover when local climatic conditions change.

Corbet *et al.* (1993) have developed a robust predicative model to obtain a comparative index of pollinator microclimate tolerance based on simple field measurements that do not require specialized instrumentation. They recommend measuring the thermal threshold for profitable foraging flight. Bee activity and microclimate should be recorded at intervals over time. Regression analysis can then be used to model the observed relationship between the available pool of active bees and microclimatic conditions. Estimation of the magnitude of the pool of potential foragers on a given day in a colony of social bees can be expressed by instantaneous counts of active individuals as a percentage of the highest count for that species in each dataset. The ultimate microclimatic limits for sustained flight activity are species specific, and may also differ between subspecies, races and populations of pollinators. Pollinators use several patches during the day for activities such as foraging, and the microclimatic limits may differ between these patches.

The economic value of crop pollination

Information on visitation frequency and subsequent seed set is valuable when categorizing crops according to their degree of dependence on crop pollination (Delaplane and Mayer 2000). However, the total value of pollinators' ecosystem services at both local and larger scales is little understood. A protocol for assessing pollination deficits in crops has been developed by FAO in collaboration with other institutions (Vaissière *et al.* 2011). Experiments carried out using such protocols will identify crop species under threat of pollination failure in different regions. Further research focused on vulnerable species can identify actions to minimize negative effects.

A recent report published by FAO can be used as a tool for assessing the value of pollination services at a national or larger scale, and vulnerabilities to pollinator declines (Gallai and Vaissière 2009).



CONCLUSIONS

Although concern has been raised about negative effects of climate change on the services provided by pollinating insects, there is still a paucity of scientific literature regarding how pollination interactions may be affected. In line with the recent review by Hegland *et al.* (2009), we found few studies on this topic with respect to crop pollination. The scientific literature provides numerous examples of climate-driven changes in species distribution and several bioclimatic models have been developed. However, when it comes to research on species interactions – especially interactions between pollinators and crop plants, which account for 35 percent of global food production – there is still a lack of information.

In this report, we have focused on types of data that should be collected to fill gaps in our knowledge of how crop pollination may be affected by climate change. An important first step will be to develop standardized protocols for data collection, including precise definitions of sampling techniques, to compare data through time and between countries. Climate change may affect the phenology and distribution ranges of both crop plants and their most important pollinators, leading to temporal and spatial mismatches. It is therefore important to identify the temperature sensitivity of the most important pollinators and their crop plants, and the environmental cues controlling the phenology and distribution of the identified species. Long-term monitoring of agroecosystems and experimental assessments of species' climate sensitivity may enhance our understanding of the impacts of climate change on crop pollination. Collecting data for these studies is time and resource intensive, which presents a major challenge in countries where the effects of climate change on crop pollination are expected to be most severe (i.e. developing countries in the tropics). In light of the lack of comprehensive information, we have outlined a simple risk-assessment procedure to determine a country's vulnerability to climate-driven effects on crop pollination in the absence of extensive data (Annex 1). It is hoped that through this review, and the tools and approaches suggested, a pro-active risk evaluation approach can assist countries to plan against losses of pollination services due to climate change.

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ANNEX 1
ASSESSMENT OF THE POTENTIAL VULNERABILITY OF NATIONAL POLLINATOR LOSS TO CLIMATE CHANGE

SUGGESTIONS OF IMPORTANT NATIONAL DATA:

Crop information

- Important crop species and cultivars
- Main system of farming; small scale versus large scale
- The value of pollinator-dependent crops by using FAO's tool for national valuation of pollination services at a national level (http://www.internationalpollinatorsinitiative.org/jsp/documents/documents.jsp)
- Number of hectares planted to pollinator dependant crops
- Pollen and nectar flowers
- Temperature sensitivity of the most important pollinator dependant crops obtained from http://ecocrop.fao.org/ecocrop/srv/en/home. The metric for the risk assessment: the number of of crops in the top 20 that have an upper max temperature of ≥30°C.
- Important environmental cues controlling the phenology of the crop plants (e.g. degree days, day length or other factors important in controlling flowering time)

Beekeeping

- Beehive stocks (FAO estimates)
- Honey bee subspecies
- Thermal tolerance of managed honeybees
- Data from scale hives

- Assessment of the potential of introducing alternative pollinators better suited for novel climates
- Understanding of the biology and ecology of alternative pollinators

Wild/Native pollinators

- Knowledge of the most common wild pollinators of important crops
- Thermal tolerance of native pollinators derived from distributions (http://www.discoverlife.org/mp/20m?act=make_map). Upper and lower temperature averages for the locations where the wild pollinators have been collected
- Identification of groups of bees above and below the body mass limit capable of endothermic heating – 35 mg
- Important environmental cues controlling the phenology of the most important pollinators (e.g. degree days, day length, snow cover or other factors important in controlling insect activity)
- Periods of activity
- Status of surrounding vegetation, including diversity and abundance of alternative floral resources and nesting sites for wild pollinators
- Proximity to natural surroundings
- Parasites and diseases
- Trends in pesticide use

ASSESSMENT OF THE NATIONAL POTENTIAL VULNERABILITY OF POLLINATOR LOSS TO CLIMATE CHANGE

Country:

RISK FACTOR		RISK FACTOR RATING	SCORE
1	CROPPING SYSTEM CHARACTERISTICS		
a	Diversity of crops		
High (>50 primary food crops)		1	
Med (20-50 primary food crops)		3	
Low (<20 primary food crops)		5	
Comment:			
b	Main system of farming		
Large		1	
Medium		3	
Small scale (<10 ha)		5	
Comment:			
c	Dependence of pollinators for primary crop production		
Low (0-20%)		1	
Medium (20-40%)		3	
High (>40%)		5	
Comment:			
d	% of agricultural land planted to pollinator dependant crops		
Low (0-20%)		1	
Medium (20-40%)		3	
High (>40%)		5	
Comment:			
e	Pollen and nectar flowers		
Well understood for specific crops, and not threatened		1	
Well understood for specific crops, threatened by env. changes or pressures		3	
Not well known, no known specific threats		4	
Not well known, threatened by env. changes or pressures		5	
Comment:			
f	Temperature sensitivity amongst the 20 most important pollinator dependent crops		
<5 have opt.max temp <30		1	
5-10 have opt. max temp <30		3	
>10 have opt. max temp <30		5	
Comment:			
2	BEEKEEPING		
a	Hive numbers		
Increasing		1	
Static		3	
Declining		5	
Comment:			

RISK FACTOR		RISK FACTOR RATING	SCORE
b	Honeybee subspecies with range of thermal tolerances		
Yes		1	
No		5	
Comment:			
c	Alternative managed pollinators		
1 or more used commercially, biology well understood		1	
1 or more used commercially, biology not well understood		3	
None		5	
Comment:			
3	WILD/NATIVE POLLINATORS		
a	Knowledge base of wild pollinators		
Well known		1	
Not well known		5	
Comment:			
b	Thermal tolerances of key pollinators		
Well known and "largely tolerant"		1	
Well known and "not largely tolerant"		3	
Not well known		5	
Comment:			
c	Environmental cues influencing phenology/periods of activity		
Well known and "largely tolerant " of CC		1	
Well known and "largely tolerant"		3	
Not well known		5	
Comment:			
4	THREATS TO POLLINATORS		
a	Perceived threat level to pollinators from habitat change/fragmentation		
Low		1	
Medium		3	
High		5	
Comment:			
b	Perceived threat level to pollinators from agrochemical use		
Low		1	
Medium		3	
High		5	
Comment:			
c	Perceived threat level to pollinators from pests and diseases		
Low		1	
Medium		3	
High		5	
Comment:			

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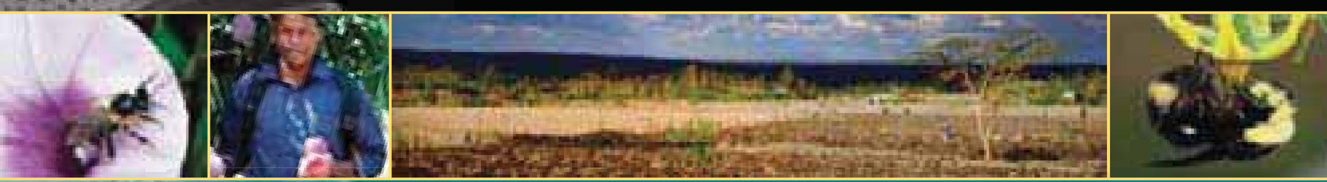
Climate change has the potential to severely impact ecosystem services such as pollination. As with any change, both challenges and opportunities can be expected. Recognizing that the interactions between climate, crops and biodiversity are complex and not always well understood, the Plant Production and Protection Division of FAO has coordinated this review of the potential effects of climate change on crop pollination.



GLOBAL ACTION ON **POLLINATION SERVICES** FOR **SUSTAINABLE AGRICULTURE**

Food and Agriculture Organization of the United Nations
Viale delle Terme di Caracalla, 00153 Rome, Italy

www.fao.org/ag/AGP/default.htm
e-mail: GlobalAction-Pollination@fao.org

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