ORIGINAL RESEARCH ARTICLE

ECOBEE: a tool for long-term honey bee colony monitoring at the landscape scale in West European intensive agroecosystems

Jean-François Odoux[1]*, **Pierrick Aupinel[1]**, **Sophie Gateff[2]**, **Fabrice Requier[1,3]**, **Mickaël Henry[4]** and **Vincent Bretagnolle[3]**

[1]INRA, UE 1255, Unité Expérimentale Entomologie, Le Magneraud, CS 40052, 17700 Surgères, France.
[2]ADA Poitou-Charentes (ADAPC), Agropole, CS 45002, 86550 Mignaloux-Beauvoir, France.
[3]CNRS, UPR 1934, Centre d'Etudes Biologiques de Chizé, 79360 Beauvoir-sur-Niort, France.
[4]INRA, UR 406 Abeilles et Environnement/UMT PrADE, Site Agroparc, 84914 Avignon, France.

*Corresponding author: Email: Jean-Francois.Odoux@magneraud.inra.fr

Summary

In Central Western France, as in many other areas, traditional apiculture has been replaced by more intensive practices to compensate for colony losses andcurrent decreasing honey yields. One neglected aspect concerns the choice by professional beekeepers of apiary sites in intensive agrosystems, with regard to landscape features, a choice which appears to be largely empirical. ECOBEE is a colony monitoring scheme specifically intended to provide beekeepers and researchers with basic ecological data on honeybees in intensive agrosystems, as well as colony population dynamics. ECOBEE was launched in 2008 as a long-term ecological project with three specific aims: 1. to monitor seasonal and inter-annual population dynamic parameters of honeybee colonies in a heterogeneous farming system; 2. to provide relevant and robust datasets to test specific hypotheses about bees such as the influence of landscape planning, agricultural inputs or human pressure; and 3. to offer opportunities for assessing the effectiveness of agro-environmental schemes or the effects of changes in agricultural policies on honey bee wellbeing. Here we present an overview of ECOBEE, the type of datasets collected over the first four years of monitoring, and their possible application and use. We found that colony dynamics were largely influenced by the phenology of the main mass-flowering crops foraged by bees, namely oilseed rape and sunflowers. Furthermore, we detected a sharp food shortage period in late spring between the flowering of oilseed rape and sunflowers, possibly temporarily constraining colony sustainability. We further discuss the research perspectives offered by ECOBEE, especially with regard to spatial ecotoxicology.

ECOBEE: una herramienta para el monitoreo de colonias de abejas a largo plazo a escala de paisaje en agrosistemas intensivos de Europa Occidental

Resumen

En el centro oeste de Francia, como en muchas otras áreas, la apicultura tradicional ha sido reemplazada por prácticas más intensivas para compensar las pérdidas de colonias y los rendimientos decrecientes de miel actuales. Un aspecto algo descuidado se refiere a la elección por los apicultores profesionales de apiarios en agrosistemas intensivos, en relación con las características del paisaje, una opción que parece ser en gran medida empírica. ECOBEE es un esquema de monitoreo de colonias específicamente destinado a los apicultores e investigadores con datos básicos ecológicos sobre la abeja de la miel en agrosistemas intensivos, así como de la dinámica de población de la colonia. ECOBEE se lanzó en 2008 como un proyecto ecológico a largo plazo con tres objetivos específicos: 1. monitorizar los parámetros dinámicos de temporada y de población interanual de las colonias de abejas de la miel en un sistema de cultivo heterogéneo, 2. proporcionar conjuntos de datos pertinentes y fiables para probar hipótesis específicas sobre las abejas, como la influencia de la planificación del paisaje, los insumos agrícolas o la presión humana, y 3. ofrecer oportunidades para la evaluación de la eficacia de los planes agroambientales o los efectos de los cambios en las políticas agrícolas en el bienestar de la abeja de la miel. Aquí presentamos una visión general de ECOBEE, el tipo de datos recogidos

durante los primeros cuatro años de seguimiento, y su posible aplicación y uso. Se encontró que la dinámica de las colonias se ve influida en gran parte por la fenología de los principales cultivos de floración en masa pecoreados por las abejas, es decir de semillas oleaginosas y los girasoles. Además , se detectó un período agudo de escasez de alimento a finales de primavera entre el florecimiento de las semillas oleaginosas y los girasoles, posiblemente limitando temporalmente la sostenibilidad colonia. Asimismo, discutimos las perspectivas de investigación ofrecidas por ECOBEE, sobre todo en lo que respecta a la ecotoxicología espacial.

Keywords: honey bees, monitoring, floral resources, colony dynamics, agroecosystem landscape, agricultural practices, France, intensive cereal farming, Agri-Environmental Schemes

Introduction

The Common Agricultural Policy (CAP) set up in Europe in 1962 has resulted in profound changes in rural farmland habitats. In particular, farming systems strongly intensified over the past 50 years, which led to a homogenization of agrosystems, now accounting for a high proportion of total land cover (e.g. 46% in France and 61% in the Poitou-Charentes French region (Marot and Maurand, 2012). The homogenization of agricultural lands, particularly in areas of mixed farming, has resulted in an over-mechanization of agricultural practices, along with an increase in field size, a reduction of the number of cropped species at the regional scale, and a more systematic use of agrochemicals. Repeated warnings have been given about the negative environmental impacts associated with agricultural intensification, among others the erosion of biodiversity (Benton *et al.*, 2003; Tscharntke *et al.*, 2005). For instance, in large portions of agricultural landscapes, hedgerows and grasslands have been removed in order to simplify mechanization and farming practices.

In parallel, professional beekeeping activity in farmland habitats has been considerably modified over the past 20 years. Traditional apicultural practices have been replaced by more intensive practices in order to compensate for colony losses and decreasing honey yields (Maxim and van der Sluijs, 2010; vanEngelsdorp and Meixner, 2010; Robert-Vérité and Bova, 2012). Apicultural adaptations to changing environments include artificial syrup feeding, mass queen breeding, seasonal migration and professionalization (GEM, 2005; Saddier, 2008). Beekeeping sustainability in farming landscapes is currently threatened, and beekeepers tend to seasonally move honeybee colonies away toward areas with less human activity and more diversified natural resources. The underlying causes responsible for these latter changes in beekeeping practices are not fully understood. In particular, the choice of appropriate apiary locations for honey production in intensive agrosystems, which to a large extent must rely on landscape features, remains largely empirical to date.

French agricultural farmlands have traditionally been areas of high honey production. Indeed, some regions have become famous for their honey from sainfoin, sarrasin, or lucerne (Louveaux, 1996). However annual crops such as oilseed rape and sunflower, the cultivation of which has increased threefold in France over the last 30 years (Marot and Maurand, 2012), have had profound consequences for honey bees and beekeeping as these mass flowering crops are very attractive to honey bees. In the recent past, these crops provided economically valuable honey flows in intensive cereal systems. In particular, sunflower honey accounted for up to 80% of total Centre-West France honey production in 1994 (Aubert, 2002; Mollier *et al.*, 2009). This new resource for honey bees has considerably modified the annual bee colony dynamics as well as the professional beekeeping practices and equipment. In particular, some atypical colony behaviours such as brood production stopping or a massive exit of honey bees which then hang below the hive entrance have been described during the sunflower honeyflow (Aubert, 2002).

However, since 1993, i.e. the approximate period when the honey-bee decline began in France, the honey production gradually decreased by half in Central Western French region (Aubert, 2002; Saddier, 2008). The precise reasons for the honey bee decline are hotly debated in France as in other countries among beekeepers, farmers and agricultural industries/companies (Allier *et al.*, 2010). Different possible causes have been suggested, such as pesticides, parasites and diseases, lack of floral resources and biodiversity erosion in cropping landscapes (Maini *et al.*, 2010). Nowadays, about 30% of the beehives have to be restocked every year in agricultural regions (Robert-Vérité and Bova, 2012). Special consideration must also be given to risk assessment of pesticide use in the agricultural environment, since pesticide use may affect both short and long term survival of bee foragers, contribute to the collapse of hives, and decrease floral abundance and richness.

Pesticide risk is not randomly distributed in agricultural landscapes, as it is directly related to the agricultural systems, i.e. crops, their succession, and the farming practices. In addition, since mass floral/mass-flowering species lead to a substantial mobilization of foragers to store honey and pollen, such crops may modify the annual cycle of the colony and generate hazards to the bee health (in short or long term). As shown by recent work on homing failure, risk assessment must take into account the foraging and spatial ecology of honey bees (Henry *et al.*, 2012a; EFSA, 2013).

Currently, a critical question for beekeepers is to understand and predict where to set up their apiaries in intensive agro-ecosystems, i.e. which particular landscape would be optimal. Indeed, potential honey production around an apiary is difficult to predict, and there is a global need to understand honey bee ecology in intensive cereal systems better, in order to fulfil major expectations from beekeepers such as how to ensure year-round food resource availability for bees (Janssens *et al.*, 2006). Beyond spatial disruptions (Briane, 1991; Sande

et al., 2009), it appears that temporal disruptions in food resource availability also arise from the simplification of arable landscapes and the general decrease in weed species. The common agricultural policy of the European Union has encouraged Agri-environmental schemes (AES) dedicated to promote floral resources for bees, such as flowering fallows or field margins. Their effectiveness is however highly variable depending on the local landscape context (Decourtye et al., 2010; Henry et al., 2012c). The quality and quantity of pollen resources is also a keystone issue for honeybee population dynamics. Trees and crop weeds provide most of their pollen supplies (Odoux et al., 2012). Since a deficient pollen intake reduces the ability of the colony to sustain brood production, and may lead to cannibalism of larvae (Schmickl and Crailsheim, 2001), we need to know more about floral resource availability and pollen quality, particularly in intensive agro-ecosystems where the use of chemical and the simplification of crop rotations has resulted in a general decrease in quantity and perhaps, quality, of food resources for bees.

To cope with the numerous concerns of professional beekeepers in modern agricultural environments, and to further provide researchers with basic, accurate, long-term ecological data on honeybees under current beekeeping practices, we have developed a colony monitoring scheme, called ECOBEE. ECOBEE was launched in 2008 in a long-term ecological research territory, with three specific objectives: 1. to monitor the seasonal and inter-annual dynamics of honeybee colonies in a heterogeneous farming system at the landscape level; 2. to provide relevant and robust datasets to test specific hypotheses about bees within the frame of theoretical or applied research, such as the influence of landscape planning, agricultural inputs or human pressure; and 3. to offer opportunities for assessing the effectiveness of agro-environmental schemes or the effects of changes of agricultural policies on honey bee development.

The ECOBEE monitoring scheme consists of the joint collection of honeybee ecological and environmental data (Table 1). Ultimately, the ECOBEE datasets may be analysed jointly to investigate temporal and spatial issues in the ecology of honeybees in an intensive agrosystem. This includes the assessment of land use and farming practices effects on colony health and dynamics, but also the temporal effects induced by variations in meteorological conditions and floral resource phenology, both at seasonal and inter-annual levels.

Herein, we provide an overview of the datasets acquired during the first four years of ECOBEE monitoring. Detailed descriptive statistics on seasonal colony dynamics, spatial variations in colony size, inter-annual variations in food reserves and harvested pollen species composition are provided, as a prime illustration of the temporal and spatial issues dealt with by ECOBEE.

Table 1. List of the main recorded variables within the frame of the ECOBEE monitoring design. See text for detailed field methods.

1. Honey bee ecological variables	1.1. Colony life history	• Health monitoring, collapse events • Requeening events (swarming, division…) • Beekeeping tasks (artificial feeding, honey yields…)
	1.2. Colony dynamics	• Colony size • Brood area • Drone brood area • Food reserve mass
	1.3. Resource use	• Harvested pollen species composition • Honey-embedded pollen species composition
2. Environmental variables	2.1. Floral resource phenology monitoring 2.2. Land use monitoring 2.3. Climatic data	

Material and methods

The study area

The study area "Zone Atelier Plaine & Val de Sèvre" is a Long-Term Ecological Research (LTER) located in the Poitou-Charentes Region, Western France (46°11′N, 0°28′W, 43 m average altitude; Fig 1). The main interests of this zone lie in its large size and the historical data related to monitoring of land use by the CNRS-CEBC over the past 19 years (1994 onwards). The site is bordered by the town of Niort to the north, and Chizé forest massif to the south. Approximately 28,000 inhabitants live in the area, in c. 40 villages. The study area size is 45,000 ha, of calcareous plains which are subjected to a warm-temperate oceanic climate. With a mean annual precipitation of 840 mm and regular summer dryness, mixed oak forests would be the potential natural vegetation (Bohn et al., 2000, 2003). Rain is scarce in summer, however bees are not supposed to suffer from drought. Woodlands are mostly reduced to small and scattered remnant patches (mean patch size = 1.87 ha) and hedgerows are widespread in some areas, especially in the cattle breeding sectors. Woods are composed of medium-sized trees, maple, ash, cherry or oak (Acer, Fraxinus, Prunus cerasus or Quercus), with a strong presence of elm (Ulmus). Wood edges are major food resources for the honeybees, in particular in spring (Odoux et al., 2012). Some of the main human derived land-scape features of this area are a suburban zone in the north including many garden areas, a motorway on a north-south axis carrying heavy road traffic, and an electricity substation creating a concentration of high voltage power lines in some areas.

Environmental data used by ECOBEE mainly concerns land use, but other data sets of interest include hedges, hydrography or soils.
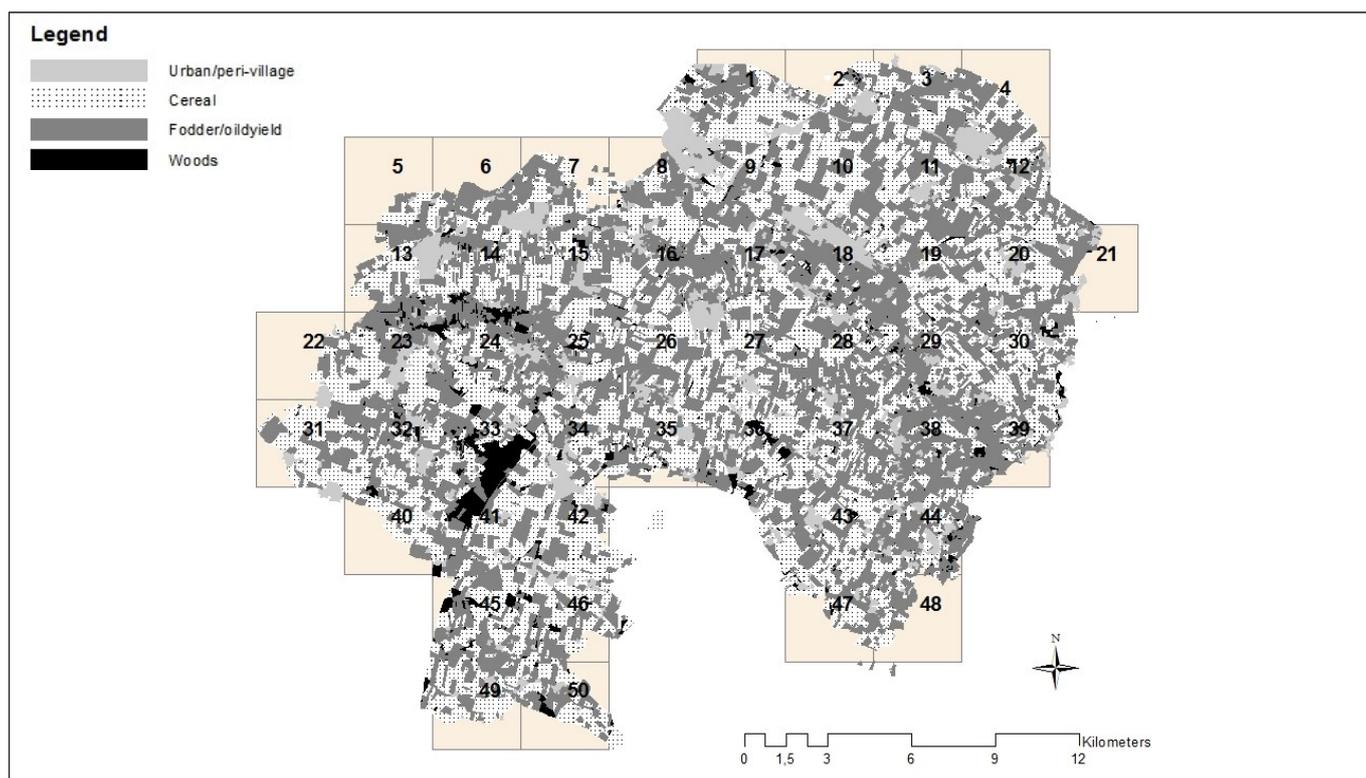
Fig. 1. Study area "Plaine & Val de Sèvre", in Centre West of France.

Crops consist of cereals (> 45%), spring-sown crops (maize and sunflower), oilseed rape (15%) and grasslands (about 18%). Fodder crops are permanent or temporary, based on legumes (clover, lucerne, sainfoin...), or grasses (rye-grass, fescue, orchard grass, foxtail millet etc.). The farming system encountered is mainly a mixed farming type. The Poitou-Charentes region has been subjected to agricultural intensification over the last fifty years, with traditional mixed farming systems being eventually replaced by cereal systems only, a process that still continues today. Currently 40% of the 650 present farms in the study area are cereal-only farms. Average farm size is 94 ha (Marot and Maurand, 2012) but some reach more than 200 ha.

Half of the study site has been designated as a NATURA 2000 SPA (FR5412007 – Plaine de Niort Sud-Est) under the Bird Directive. This status allows the implementation of (AES), a tool deriving from the second pillar of the CAP. In France, AES are mainly 5-year contracts between volunteer farmers and the government. These contracts are intended to promote the implementation of environmentally friendly agricultural practices in return for an annual subsidy to offset the costs and possible income reductions involved (Berthet *et al.*, 2012). For example, some of the contracts promoted on the study site aim to encourage the return of meadows and grasslands, and agricultural management practices favorable to insects and flowers, imposing in some cases strong constraints with regard to mowing dates in order to protect ground nesting birds. The area under AES in 2011 was nearly 10,000 ha. Plant species diversity and insect abundance has been enhanced, contributing to bird conservation (Bretagnolle *et al.*, 2011).

The study material

All honeybee colonies originated from livestock managed by a local professional apicultural association (ADAPC) using *Apis mellifera mellifera* x *caucasica* strains. At the time of launching the monitoring programme, the queens were one year old. Colonies were checked to ensure they were disease-free. The beehives were Dadant-Blatt model (on 10 brood frames) in pine wood waxed microcrystalline. Colonies were set up and managed as a sedentary apiary according to local professional beekeeping practices. Supers were added as honey reserves grew. They were generally harvested twice a year, after the oilseed rape and the sunflower honeyflows. Queen cells (CFPPA Venours College) from the same strain were introduced for requeening colonies. All colonies were fed with commercial syrup in May and June in order to compensate the apparent food shortage between oilseed rape and sunflower flowering periods (see discussion).

The spatial design

The 450 km^2 study area was divided into 50, 10 km² square plots whose size (Fig.1) was set to encompass the mean foraging distance of honeybees (about 1.5 km in such landscapes (Steffan-Dewenter and Kuhn, 2003). Each year from 2008 onwards, ten new experimental plots were randomly chosen from the 50 available plots. In each selected plot, a 5-hive apiary was set up, as close as possible to the centre (usually ± 500 m), and was monitored during the whole apicultural season, spanning from April to September (see Data collection).

At the end of the apicultural season, the hives were gathered together in a wintering apiary. After overwintering, colonies started the monitoring programme again with a different status in terms of population structure and queen age. Hives were then randomly re-assigned to the new experimental plots. New colonies intended to replace lost ones were equally allocated among plots. The hives were set up in plots in March or April, and remained on site until late September.

Data collection

Since we made regular (twice a month), and sometimes intrusive measurements within the hives that could potentially affect colony dynamics, we systematically kept two hives of the apiary as control (i.e. undisturbed) hives. Thus, only three of the five colonies in each experimental plot were monitored every two weeks during the apicultural season. The two *control* colonies were only checked at the beginning and end of the apicultural season. They were also used as *substitution* colonies because they could have been used to replace *experimental* colonies of the same plot that collapsed in the course of the monitoring season. Parameters measured in the course of the monitoring protocol are detailed below.

Honey bee ecological variables

Colony life history

Every single beekeeping manipulation and survey was stored in a database (software Microsoft Access) to keep track of each colony's history. This included first and fore most the general health status of colonies, i.e. whether they had shown evidence of population weakening, demographic slowdown or diseases. Demographic events such as colony division, swarming or requeening were noted, as well as all the current practices including artificial feeding, honey super set up or harvest, etc.

Colony dynamics

Studied demographic parameters included: the adult bee population size, the brood (eggs, larvae, pupae) size, and the food reserve quantity. This allowed the derivation of four parameters that are used to describe the state of these demographic compartments: 1. colony size, i.e. the number of adult honeybees; 2. the total brood area, indicating which effort is allocated by the colony to the production of new adult workers; 3. the drone brood area, indicating which effort is allocated to sexual reproduction; and 4. the honey reserve mass.

These colony parameters were assessed at each monitoring visit, either every two weeks for the monitored hives or at the beginning and at end of the season for the control hives, using the following methods: 1. The colony size (number of adult individuals) was assessed by weighing each brood frame with and without bees, as well as the hive bottom and the honey supers. Colony size was then assessed considering an average of 10^{-4} kg/bee. The resulting values slightly underestimated real colony size because it didn't take into account the portion of foraging bees that had left the colony at the time of measurement; 2. Brood surfaces, on both side of each brood frame, were assimilated to ellipses (Fresnaye, 1961; Mallet and Charles, 2001; Vallon *et al.*, 2008) and therefore approximated using length L and width W measurements (cm) following the formula $S\,(cm^2) = \frac{1}{4}\,(L \times W \times \Pi)$. Brood surfaces were then totalled across all the frames of each colony. Isolated empty cells within brood surfaces were ignored; 3. Food reserve mass (stored honey and pollen) was assessed on each frame, both from the main chamber and the honey supers, as the difference between total frame mass and the mass of empty frames before introduction in the hive. Whenever necessary, brood mass was also removed from the resulting mass difference. Brood mass values were derived from brood surfaces, using the formula $m\,(kg) = m_{max} \times S/S_{max}$; where S_{max} is total frame surface (1632 cm^2) and m_{max} is the total brood mass expected for a frame surface entirely covered by brood (0.6385 kg, predicted from the linear regression between 6000 brood surface values and the corresponding full-empty frame mass differences).

Resource use

To assess resource use, palynological analyses were performed on pollen harvest samples and on honey samples. Harvested pollen species composition indicates which floral resources are foraged for pollen. To sample harvested pollen, each of the three monitored hive entrances were periodically fitted with a pollen-trap (24-h sampling every ten days, except when queens were in nuptial flight period). Pollen species composition was assessed at the apiary level after homogenisation of pollen samples among colonies within experimental plots. Palynological analyses for pollen identification followed Louveaux *et al.* (1978) with at least 300 pollen grains identified on both microscope slides taken in each sample (Tamic *et al.*, 2012). The honey-embedded pollen was intended to give information on plants foraged for nectar. Assuming that incidental pollen grains were ingested by nectar foragers and subsequently stored with honey, the most abundant pollen species found in honey were likely to reveal the identity of plant species intensively foraged for nectar (Louveaux *et al.*, 1978). Honey samples from each apiary were processed by an external laboratory.

Environmental variables

Floral resource phenology monitoring

The availability of floral resource species was monitored through phenological surveys conducted in the close vicinity of the study area (20 km west, INRA Poitou-Charentes, UE Entomologie laboratory). The phenological database, called *Apibotanica*, is available on-line (www.poitou-charentes.inra.fr/entomologie) and further described in Odoux *et al.* (2011). Blooming dates were monitored for more than 400 botanical species of interest, including flowering crops.

Land use monitoring

Land cover has been recorded twice a year every year since 1994 on every single field (*c.* 19,000) of the study area, and stored on a GIS database (ArcGIS, version 10). About 50 landcover categories were recorded by observers driving on every single track of the study area (Bretagnolle *et al.*, 2011).

Weather data

Detailed meteorological data for the region was available from a national French meteorological station (Météo-France, 2012) located in Niort, on the northern edge of the study area. Relevant variables likely to influence honeybee foraging activity and colony development was available on an hourly basis, including temperature, precipitation, wind, solar radiation, daylight duration, etc.

Data analysis

Four years after launching the ECOBEE monitoring platform, we are now able to give an overview of the seasonal dynamics of a typical colony in the studied intensive agrosystem. The four main colony dynamic parameters were modelled as a function of time using Generalised Additive Mixed Models (GAMMs) with the R software (the R Foundation for Statistical Computing, version 2.11.1). GAMMs are modelling techniques allowing the fit of temporal splines while giving the possibility of taking into account repeated measurements on statistical units in a nested design (i.e. colonies nested within experimental plots and within years). Models were fitted to data using

the maximum likelihood method. Due to the many zeroes in the drone brood surface dataset, we found it more appropriate to model drone brood occurrence frequency (presence-absence) using a binomial family distribution. In a second step, we focused on colony size and tested whether its temporal dynamics would be further influenced by landscape composition. To do so, we recomputed the colony size temporal GAMM after adding land use covariates that were liable to influence colony dynamics. Relevant land use covariates were the surfaces (ha) of oilseed rape, woody habitats, grasslands, legume fields (alfalfa) or cereal fields, measured within a 1.5 km array from apiaries, i.e. the usual foraging range of honey bees. Possible model improvements were assessed using the Akaike Information Criterion, considering each land use covariate taken separately. More detailed descriptive statistics on: 1. honey reserves; and 2. pollen species richness were further provided to support the colony dynamics results and illustrate temporal and spatial variations, respectively, in colony supply.

Results

Typical colony temporal dynamics

The GAMMs showed a significant time effect on each of the four colony parameters, indicating that measured parameters do not vary randomly among colonies but follow a general temporal pattern (Fig. 2). Brood surface and drone brood occurrence frequency (temporal spline effect:
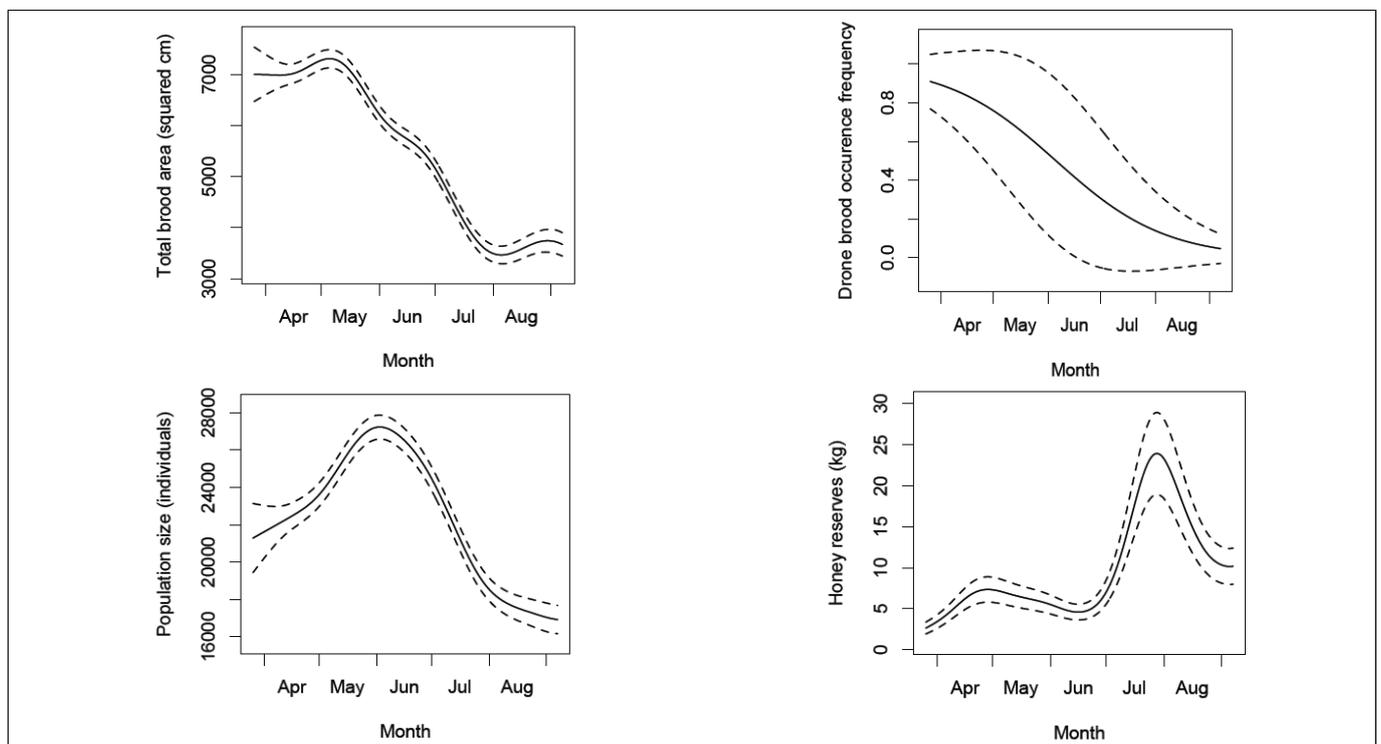

Fig. 2. Average seasonal dynamics of colony parameters predicted by the GAMMs (±1SE), including total brood area, drone brood occurrence frequency, colony size (adult population) and honey reserve mass. Data proceed from 208 colonies monitored over the 2008-11 beekeeping seasons.

$F_{8,1219} = 102.5$, $p < 0.001$ and $F_{1,1226} = 246.6$, $p < 0.001$, respectively) are at their maximum early in the season, when the hives are set up in the study area. They gradually decrease during the season, eventually down to nearly zero for the drone brood occurrence frequency. Colony size, i.e. adult population size peaks later in the season ($F_{7,979} = 41.66$, $p < 0.001$), after the oilseed rape blooming period, with an average of about 27,500 honeybees. Honey reserves ($F_{8,1219} = 114.8$, $p < 0.001$) show two distinct peaks, namely a low one during the oilseed rape blooming period, and a high one during the sunflower period.

Inter-annual variations in food reserve dynamics

Colony seasonal dynamics are likely to be influenced by meteorological and plant phenology, as revealed by the substantial inter-annual variations found in the ECOBEE datasets. Although food reserve dynamics followed the same general pattern over years (Fig. 3) with a steep increase during sunflower blooming period (mid-June-late July), important temporal lags existed from one year to the next. For instance, a lag of up to >20 days was found between years 2008 and 2011 in sunflower honeyflow (Fig. 3). Inter-annual variations are probably mostly driven by weather conditions, as the earliest sunflower honeyflow was obtained in 2011, i.e. the year with the most precocious spring.
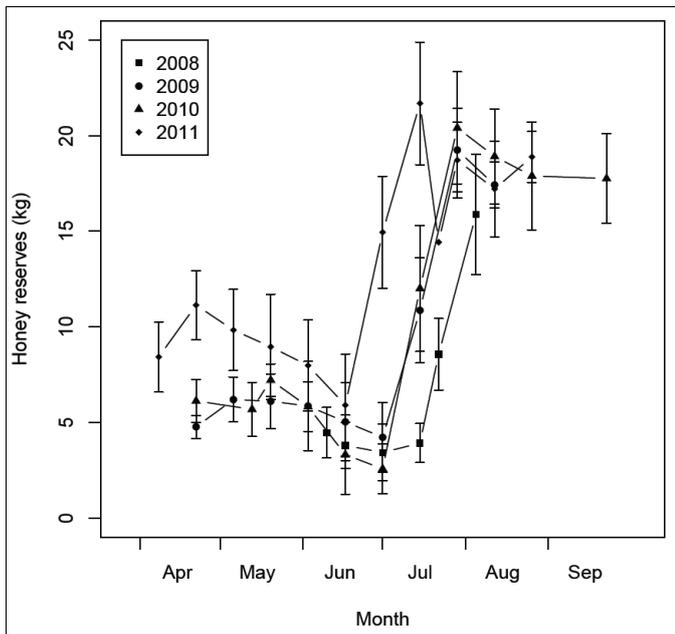
Fig. 3. Inter-annual variations in the dynamics of hive brood chamber food reserves for 30 experimental colonies in years 2008-2011.

Landscape effects and spatial variations in resource use

To better assess how landscape composition might influence the seasonal dynamics of colony size, we rescaled the temporal axis on each year's specific oilseed rape blooming end date, as estimated from phenological surveys, and tested the contribution of the main land use covariates, taken separately, to the improvement of the temporal model.
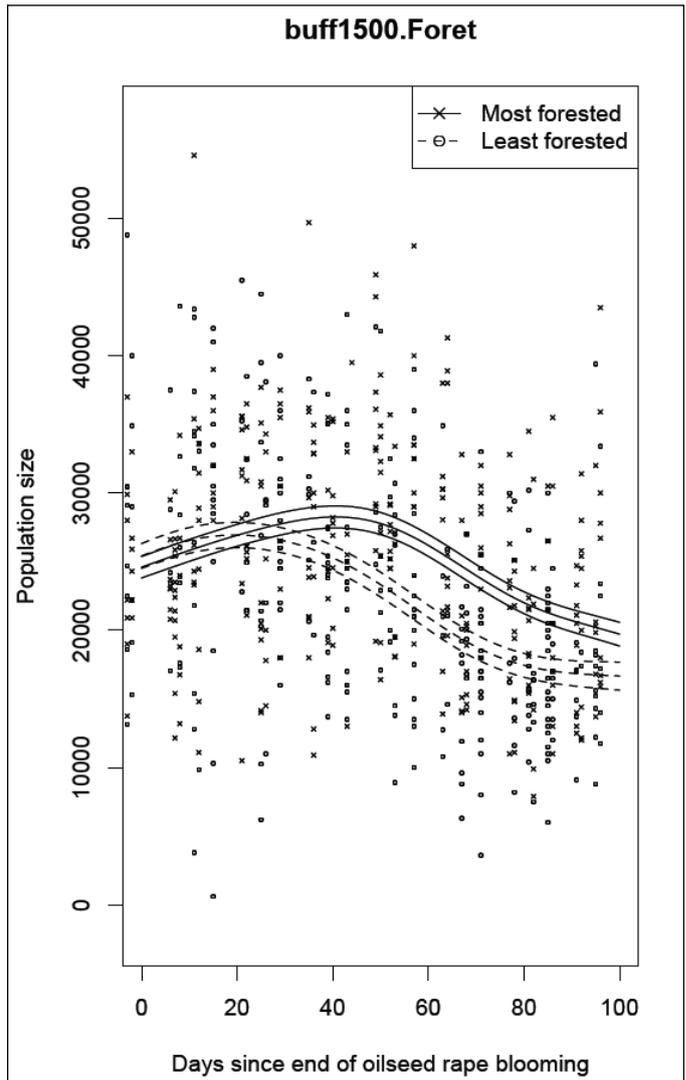
Fig. 4. Influence of woody habitats on the colony size dynamics after oilseed rape period. The temporal axis was rescaled on each year's specific end date of oilseed rape blooming. Curves show the expected colony size (± 1SE) for the least and most forested environments, as defined by the median value of woody habitat surfaces measured within a 1.5-km radius from colonies (1.0 to 15.6 ha vs. 15.6 to 263 ha for the least and most forest areas, respectively).

Compared with the simple temporal GAMM, the "woody habitat" covariate allowed for a substantial improvement of model fit (AIC decrease = 6.9), whereas all the other candidate covariates did not (AIC increases = 1.8, 2.9, 3.8 and 4.1 for grassland, alfalfa, oilseed rape and cereal surfaces, respectively). The effect of woody habitats was highly significant (Likelihood ratio test statistic = 8.88, P = 0.0029), and positively influenced colony size, and possibly sustainability, after oilseed rape blooming period (Fig.4).

Pollen diversity

Landscape heterogeneity is further expected to influence floral resource availability, and therefore honeybee foraging activity. This can be shown by comparing species composition in pollen samples among contrasted

experimental plots. Available pollen data suggests that the diversity of collected pollen varies markedly among apiaries. For instance, in the absence of mass-flowering crops (e.g. week #21, between oilseed rape and sunflower flowering periods, Fig. 5), the most diversified pollen samples displayed twice as many species as the least diversified ones. Harvested pollen diversity gradients may be further compared with landscape heterogeneity gradients.
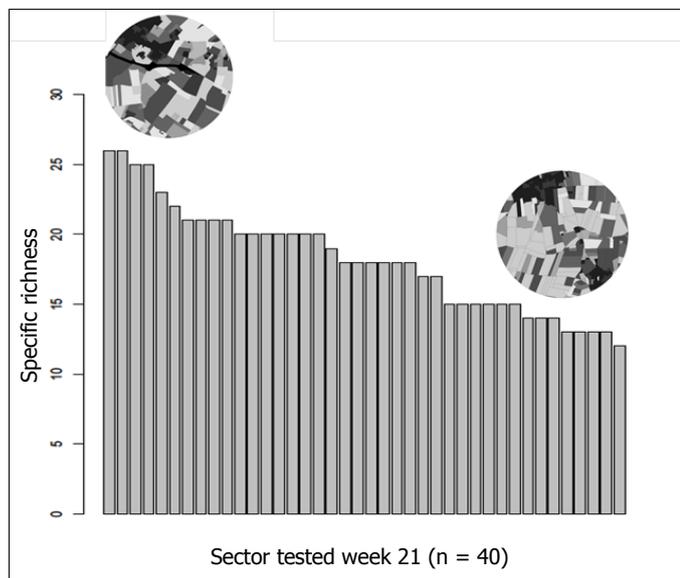
Fig.5. Pollen species richness for week #21 in pollen samples from 40 experimental plots. The two 1500m landscape buffers illustrate land use heterogeneity in the environment of the apiaries with the most and least diversified pollen samples.

Discussion

Up to now, the ECOBEE platform monitoring scheme has allowed identification of important patterns regarding the ecology of honeybees in our studied intensive agrosystem. First, colony temporal dynamics follow a strong temporal pattern, most likely scaled on the phenology of the two main mass flowering crops in the region, namely oilseed rape and sunflower. Second, the seasonal food storage dynamics appears to be largely influenced by mass-flowering crop phenology, itself driven by year-specific meteorological conditions. Third, floral resource use varies tremendously among colonies, probably reflecting the environmental conditions of each local landscape context.

We further suspect that colonies undergo a food shortage period between the two mass-flowering crops, encompassing the late May to early July period. Honey supers are removed by beekeepers early in this period, after oilseed rape blooming, while colony size reaches its seasonal peak. During this period, food reserves available to bees in the hive gradually decrease (in June; see Fig. 3), indicating that the colony as a whole might deplete honey at a faster rate than foragers actually store it. Yet, the diversity of wild floral resources is high during

this period, as indicated by the phenological surveys (Odoux *et al*, 2012). We further suggest that woody habitats, intensively used by honey bees for pollen early in the beekeeping season (Requier *et al.*, (unpublished studies)), buffer the population decrease after the oilseed rape period (Fig. 4), possibly improving the resilience of colonies and their overall size later on during the sunflower honeyflow. Further analyses remain to be done to document the food shortage hypothesis and assess the economic benefits of maximizing woody habitats in the close vicinity of apiaries early in the season.

ECOBEE is a monitoring scheme that allows a detailed characterization of honeybee temporal and spatial dynamics according to landscape, seasonal and yearly variations. Our quasi-experimental scheme is able to provide considerable amount of data on honeybee colonies ecology and behaviour in relation and response to environmental constraints. Each year, over 6,000 observations are collected from 50 hives, in parallel to landscape data (19,000 crop fields coupled with farming and environment features), which allow us to investigate relationships between bee life history traits, apidology and farmland landscapes. In addition, the spatial and temporal variability of landscape parameters in the study area offers the possibility of testing the effects of different cropping systems, including experimental ones (AES), on honeybee ecology and performances with regard to food reserve (honey) acquisition. We believe our scheme is a robust experimental tool for beekeeping observations and for ecological research of honeybee traits in intensive farming landscapes. ECOBEE is also a tool that may provide guidance for beekeepers searching for suitable environmental contexts to set up healthy apiaries.

The coupled land use - colony monitoring data on a large scale will provide a strong background to test for different environmental factors related with food resources as well as some stressors like diseases, predators or the use of agro-chemicals. With regard to the latter, we have initiated standardised data collection through large-scale surveys of farming practices, with the objective of evaluating possible relationships between the use of pesticides and colony sanitary state in a spatially explicit approach, using for example "Treatment Frequency Indicator" (TFI) (Allier, 2012). The ECOBEE survey also offers the opportunity to foster model-based assessment of pesticide effects at the colony level through demographic simulations (Henry *et al.*, 2012b). Finally, our experiments are currently serving as a reference work for the conception of innovative farming systems favourable to pollinators (POLINOV project, coordinated by ACTA), in collaboration with INRA (INRA SPE Dept), CNRS, ADAPC, and French technical institutes (ITSAP, CETIOM, ARVALIS, Chambre d'Agriculture). This research therefore contributes to both the preservation of threatened apicultural activities and to the development of new and innovative agricultural policies (see Berthet *et al.*, 2012).

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