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L. Pilati, V. Boatto

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Bio-Economics
Of Allocatable Pollination Services:
Sequential Choices And Jointness In Sites

LUCIANO PILATI *

and

VASCO BOATTO **

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Abstract

The site-chronological regime identifies a sequence of sites to which the pollination service is allocated during the annual biological cycle of the hive. Because each foraging site corresponds to a crop or a wild vegetation, each site-chronological regime identifies a sequence of crops or a cropping regime. The site-chronological regime integrates the space and time dimensions of the economic sequential choice of a farm with a mobile production bio-organism as in the case of migratory beekeeping.

Jointness can arise between the sites pollinated in chronological sequence. A necessary condition for jointness in sites is that they are complementary, i.e. they can enter in sequence in the allocation programme of the pollination service. A sufficient condition for jointness in sites is that the revenue or the variable cost of a site change with the regime. Jointness in sites may arise from the revenues side or from the costs side or from both sides simultaneously. The revenue is a bio-economic source of jointness in sites because it derives from the different dynamics of the population of foraging bees in the site-chronological regimes.

Key words: Bio-economics, Migratory beekeeping, Allocatable pollination services, Sequential choices and regimes, Jointness in sites.
JEL Codes: Q12,Q57

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* Department of Economics and Management - University of Trento.
** Department of TeSAF - University of Padua

1. INTRODUCTION

This paper discusses the allocation of pollination bio-services[1]. There are already numerous theoretical and applied contributions on the topic. Cheung (1973 p. 16) described the practice of beekeepers in Washington State of reallocating their hives from farm to farm and found that the maximum number of crops pollinated per hive was 4 and the minimum 2. Siebert (1980 p. 169) mentioned the competition between beekeepers in California for the pollination of almond tree sites. Sumner and Boriss (2006) presented the *timing* of the pollination service allocation to crops in California. Rucker *et al*. (2012 pp. 958-959) described the sequence of crops pollinated by beekeepers who travel, on truck trailers loaded with 400/500 hives along the highways of the United States, offering their pollination service.

The migration of hives is also a consolidated practice in European beekeeping, although pollination service markets do not exist of a size comparable to those of the U.S. Every agricultural site possesses specific biophysical, abiotic and biotic, and economic characteristics (Antle and Stoorvogel 2001; Wossink and Swinton 2007). Among the sundry site-specific biophysical characteristics, the type of crop or wild vegetation present on the foraging site and its location are of fundamental importance for beekeeping. The most important site-specific economic characteristic is the holder of the property rights of the crops or wild vegetation growing on the foraging site because this determines the transaction.

The chronological sequence of the pollination service allocations to the foraging sites gives origin to site-chronological or cropping regimes according to the definition of Boatto and Pilati (1993). The characterization

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[1] The bee colony generates an eco-system service termed pollination service.

of the site-chronological regime contributes to improving the understanding of the interaction between the bio-physical and economic models of beekeeping, with transfer potential to other sectors with productive migratory bio-organisms (e.g. pastoral farming, migratory birds, fish), because this relates the space and time dimensions in discrete or discontinuous form. The site-chronological regime is also of great interest from the perspective of the multifunctionality of agriculture because, depending on the constituting foraging sites, it provides varying levels of *non-marketed* ecosystem services.

The site-specific characteristics represent an explanatory factor of the different types of jointness in beekeeping: jointness between honey and the other physical goods produced by the hive; jointness between honey and pollination service; jointness between pollination service and agricultural crop; jointness between pollination service (beekeeping) and agricultural crop; jointness between pollination service and environment; jointness between foraging sites.

The jointness of the first type, referable to the well-known example of meat and wool production, exists between honey and beeswax, as well as between honey and other physical goods (propolis, royal jelly, pollen, bee venom and bees) produced by the hive.

The jointness of the second type, between honey and pollination service, is dealt with by the models of Cheung (1973) and Champetier, Sumner and Wilen (2010).

The jointness of the third type, between pollination service and agricultural crop, is dealt with by the models of Siebert (1980), and Wossink and Swinton (2007 p. 301).

The distinction between jointness of the second and third type is absorbed in the jointness between honey and crop when the pollination service allocation has already been made to the sites. In this sense, Rucker *et al*. (2012 p. 959) formalize a production function where honey and fruit are products jointly from a production process that uses land and bees.

The jointness of the fourth type emerges when the pollination service also produces *non-marketed* ecosystem services in the form of the protection of biodiversity and the rural landscape.

The jointness of the fifth type, between collection sites in the chronological sequence, is a new type. It differs from that of space pointed out by Köhlin and Amacher (2005), as well as by Albers and Robinson (2011) with reference to the role of beekeeping in forest protection, because the collection sites enter and leave the production process according to a precise timing. The jointness in sites also has a different connotation to that of the rotation of the crops because, despite having the cropping sequence in common, it is not formed on the same site.

The jointness in the sites implies complementarity between the allocation periods of the pollination service. There is jointness in sites only when the revenues and/or variable costs change according to the site-chronological regime.

The analysis of the economic aspects of beekeeping will assume, following the approach of Siebert (1980), that the hive (bee colony) is the technical/economic unit of the beekeeping production.

2. ALLOCATIONS OF THE POLLINATION SERVICE TO THE SITES

In general terms there are various classes of bee pollination: B_{11}) of wild vegetation by wild bees; B_{12}) agricultural crops by wild bees; B_{21}) wild vegetation by managed bees; B_{22}) crops by managed bees (beekeeping). The four pollination classes configure in the order: environment-

environment; environment-economics; economics-environment; economics-economics.

The reduction of class B_{12} following the decline in wild pollinators (Bauer and Wing 2010) is potentially compensable, although only in part, acting on class B_{22}. The markets of the pollination service play an essential role in this compensation.

FIG. 1 - CLASSES OF BEE POLLINATION

	WILD VEGETATION	**CROPS**
WILD BEES	ENVIRONMENT-ENVIRONMENT	ENVIRONMENT-ECONOMICS
MANAGED BEES	ECONOMICS-ENVIRONMENT	ECONOMICS-ECONOMICS

The growth of the pollination service markets in class B_{22} nevertheless does not compensate for the reduction of pollination in class $B_{11,}$ contrasted only by any positive externalities of B_{21}, i.e. of the managed beekeeping. The evolution in managed pollination consequently reflects on the biodiversity and landscape according to the consistency of class B_{21}, which depends, as will be clarified later, on the sequence of foraging sites practised by the beekeepers.

The same agricultural crop (and wild vegetation) is present on many sites at the same time and sometimes also in different periods during the same annual biological cycle of the hive. Indeed the same crop flowers at different times of the year depending on the altitude and latitude of the site (Rucker *et al*. 2012). The allocation of the pollination service to a given crop or wild vegetation can thus be made choosing between many foraging sites.

Alongside the static allocation of the pollination service due to the fact that at a given time (period) the hive may be placed on alternative sites with crops and wild vegetation, there is a dynamic sequential allocation because the hive may be moved from one site to another over the course of the production cycle. The choice of site on which to locate the pollination service arises more than once during the annual biological cycle of the hive.

The allocative problem arises in the production phase, while it disappears in the next, chronologically complementary, dormancy phase of the hive. The production phase of the hive can be split into periods of varying length according to the crops present on the collection sites.

Because some crops benefit more than others from the pollination service of the bees, from the static point of view, a level of jointness can be defined for each site between pollination service and crop, variable between 0 (no jointness) and 1 (perfect jointness). Taking the approach of Klein *et al.* (2007), coefficients may be applied that specify the class of dependence of the crop on the pollination service, i.e. the discrete level of jointness between crop and pollination service of the hive.

Also the type of honey produced depends on the crop or vegetation present on the site; the type of honey, its market price and the yield of the hive change with the crop. The lease of the hive, i.e. the market price of the commercial pollination service, differs according to the pollinated crop, so is site-specific. The transaction cost for the pollination of the site is also a site-specific variable, assuming a nil value for some allocations.

3. SEQUENTIAL CHOICES AND SITE-CHRONOLOGICAL REGIMES

The repeated allocation of the pollination service forms chronological sequences of foraging sites. This chronological variant of the managerial regime (Freeman 1991) and cropping regime (Boatto and Pilati 1993) is termed site-chronological regime. The site-chronological regime identifies a sequence of sites to which the pollination service is allocated in chronological order during the annual biological cycle of the hive. Because each foraging site corresponds to a vegetation, each site-chronological regime identifies a sequence of crops or a cropping regime.

For clarity, the sequence of the sites can be simplified to the maximum, dividing the annual biological cycle of the hive into three allocative periods, two of production and one of dormancy, and limiting the vegetation to be pollinated to just two alternatives: crop or wild vegetation.

We assume that each site is single-flower, i.e. covered by just one crop or type of wild vegetation, and that the duration of the allocation of the pollination service is uniform, independent of the site.

We consider only the pure allocations, i.e. pollination of either the crop or the wild vegetation. We ignore split combinations of crops (sites) and the possibility of having successive flowerings on the same site.

We can define:

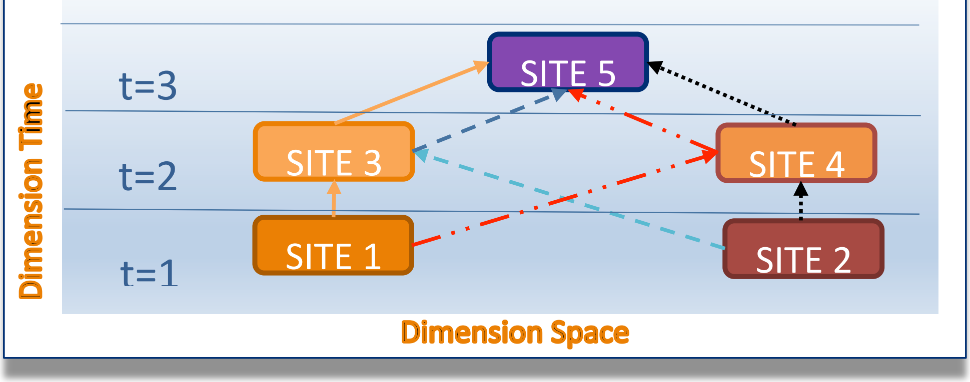
- t=1,2,3 periods: t=1,2 are periods of production; t=3 is the period of dormancy of the hive;
- j=1,2,3,4,5 sites: j=1,3 are sites with wild vegetation; j=2,4 are sites with a crop; j=5 is the dormancy site - base site.
- i = site-chronological regime.

The allocative choice of the pollination service in the first period is, t=1, between sites j=1, j=2 and in the second period, t=2, between sites j=3, j=4. In the period t=3, the hive is always at the base site j=5.

The chronological sequences of the allocations of the pollination service, excluding the four mono-site solutions, as each site is by assumption single-flower, can consist of 4 alternative regimes:

1) Regime 1: t=1: j=1; t=2: j=3, t=3: j=5; allocation to sites with wild vegetation and then the base site;
2) Regime 2: t=1: j=1; t=2: j=4, t=3: j=5; allocation to a site with wild vegetation in the first period, to a site with a crop in the second and then the base site.
3) Regime 3: t=1: j=2; t=2: j=3, t=3: j=5; allocation to a site with a crop in the first period, a site with wild vegetation in the second and then the base site.
4) Regime 4: t=1: j=2; t=2: j=4; t=3: j=5; allocation always to sites with crops and then the base site.

FIG. 2 - SEQUENCE OF SITES AND REGIMES



Each site-chronological regime expresses a space-time combination of sites benefiting from the pollination service, as shown in fig. 2.

If the crop present on the site to be pollinated belongs to the beekeeper or it is subject to a supply contract of the commercial pollination service, the alternatives reduce because an allocative constraint arises. If, for example, the beekeeper allocates the pollination service to site j=2 with a crop of his own, the choice would be reduced to just regimes 3 and 4.

A necessary condition for the site-chronological regime to show economy of scope is that at least one site is growing a crop belonging to the beekeeper. When the pollination service is allocated to a site growing a crop owned by a farmer, he will receive a remuneration composed of honey and/or from the leasing of the hive. This latter remuneration will remain implicit because it will be absorbed into the revenue of the pollinated crop. The role of the site-specific variable emerges here, constituted by the property rights on the crops present on the foraging site.

For every regime is identifiable: the level of jointness between pollination service and crops; revenues; fixed cost; variable cost; transport cost; transaction cost; profit and gross income of the company.

4. TYPES OF JOINTNESS

The term joint production, or jointness, finds five different specifications in beekeeping.

4.1 - Jointness between physical products

The hive produces honey, but also beeswax and other physical goods: chiefly propolis, royal jelly, pollen and bee venom. The bee colony, being a renewable resource, also produces queen bees and swarms that can become a production factor for the beekeeper or a product that can be sold on the market.

However, the jointness between physical goods produced by the hive does not necessarily signify complementarity between them[2].

A joint production is verified between the physical goods produced by the hive, in agreement with the analytical scheme proposed by Boisvert

[2] The production of propolis for example is stimulated by placing suitable perforated or fissured screens in the hive.

(2001), because a fixed factor, the foraging site with the vegetation to pollinate in this case, is not allocable to each individual physical product of the hive. The allocation of the pollination service to a site covered by a kiwi crop, for example, does not produce honey or beeswax, but favours the gathering of pollen.

In the following, the physical goods produced by the hive will be treated as if they were a single composite good, which is termed honey. This product differs by type according to the crop or wild vegetation present on the collection site. Every type of honey, at least at each site-specific qualitative level, can be associated to a market price.

The type differentiation of the honey deriving from the allocation of the pollination service to the sites has been ignored in the economic analysis of jointness in beekeeping. Honey is in reality not a homogeneous product; the market price of honey changes significantly according to the pollinated crop (CBI 2009, NASS 2011). The amounts of honey produced by the hive on the sites can therefore only be summed if the pollinated crop remains the same.

The simplifying assumption that the hive produces just one physical good, honey, is instrumental to the analysis of the jointness with the pollination service.

4.2 - Jointness between honey and pollination service

The production functions of the honey and pollination service are not, with exceptions, separable, in that, to produce the honey the bee must collect the nectar from flowers, pollinating them. A jointness therefore exists between the physical good honey and the pollination service.

When honey and pollination service are produced jointly, there cannot be a production cost of the honey distinct from that of the pollination service.

The jointness between honey and pollination service does not necessarily imply complementarity between physical good and service. The analysis of Champetier *et al.* (2010) demonstrates that if the number of bees present in the hive represents a *proxy* for the pollination service, a *trade-off* is formed between honey obtained (collected from the hive) and pollination service. Consequently the ratio between the prices of the honey and the pollination service determines the optimal choice on the frontier of the productive possibilities. In the hypothesis that the largest amount of honey collected from the hive is achieved with a supplementary diet for the bee colony it will be the ratio between price of the honey and price of the food substitute that determines the best solution on the frontier of the productive possibilities.

However, in some cases, the pollination service does not denote a jointness with the production of honey. There is no honey production when the pollination service (commercial) is allocated to a site where non-nectariferous crops (e.g. kiwi, almond) are grown. On the contrary there is no pollination service, but there is honey production, when the site is covered by self-pollinating crops (e.g. oranges, lemons, etc.) or is a woodland with honeydew.

The jointness between honey and pollination service depends on the crops that cover the sites. The chronological sequence of the allocations of the pollination service to the sites i.e. to the crops or wild vegetation determines whether or not there is this type of jointness. With given sites and crops, various alternatives are possible. The coordination in time of the allocations of the pollination service, i.e. the choice of the pollination programme of the sites is the pivot of the economics of the travelling beekeeper.

The repetition of the same sequence of sites over the years (i.e. of the same regime) is hampered by the instability of the weather conditions and consequently the variability of the starting and ending date of the pollination service. For example, a particularly wet or cold spring can modify the usual flowering dates of the crops and break the usual complementarity between foraging sites. The management of the pollination programme of the sites in conditions of uncertainty is the pivot of the management of the travelling beekeeper.

The choice of the sequence of sites depends on many factors: durations of flowering, yields of the hive, prices of the honey and fees, variable costs, transaction costs.

The site-specific characteristics affect the birth and death rates of the bee colony and therefore the number of adult bees and foraging bees that provide the pollination service[3].

4.3 - The jointness between pollination service and crop

The jointness between pollination service and crop arises between two technically separable production processes: beekeeping on the one hand and the agricultural crop on the other.

The production functions of the pollination service and crop are also separable in the short term. The separability is guaranteed by the fact that the pollination service of the hive can be purchased on the market or alternatively generated in an artificial, mechanical or manual way.

[3] Site-specific cultivation techniques (e.g. organic farming) also have an influence on the dynamics of the bee colony population.

Beekeeping can be conducted in an exclusive way by a specialist and the crop by another specialist. The two production processes, of honey and fruit, can be carried out by two specialists with bilateral payment of the services received. The beekeeper could provide the pollination service to the farmer and receive a monetary remuneration and/or in honey. The farmer who grows the crop could lease the flowering site to the beekeeper and receive a rent. In substance, the payment is made by one of the two parties, by the net debtor after provision of the service, generally by the farmer to the beekeeper[4].

Jointness between beekeeping and crop is verified when two technically distinct and separable production processes are conducted together by a farm. This type of jointness can derive from a technical interdependence between the production processes and/or from the greater use of some allocable fixed factor (Boisvert 2001), as well as from the absence of transaction costs for the stipulation of contracts for the commercial pollination service.

In general lines, jointness occurs in the multi-product, or more properly multi-process, beekeeping farm, as the pollination service is made available to the crop site[5]. There are however some examples of inverse functionality, i.e. of a crop practised *ad hoc* on a site for beekeeping purposes. Especially in the autumn to facilitate the accumulation of stores of honey and render a supplementary diet for the bee colony superfluous in the period of winter inactivity, the site of the multi-process beekeeping

[4] The net payment by the beekeeper to the site owner can be observed in some exceptional cases. For example, some forestry companies in Northern Italy lease foraging sites to beekeepers.

[5] Allocation of the pollination service exclusively to one's own crops is an extremely rare exception. The jointness of the third type therefore has a limited duration with respect to the annual production cycle of the hive.

farm is used to grow a crop suitable for increasing the honey production of the hive that pollinates it.

The motivation for the farmer to acquire a hive to pollinate his crop[6], i.e. the jointness between two separable production processes, is easily identifiable in the economy of scope. The sum of the production costs of the two processes disjointed would be higher than those of the joint production (Pilati and Boatto 1999).

4.4 - Jointness between pollination service and environment

Pilati and Boatto (1999) showed clearly that agriculture not only produces goods, but also numerous services often in the form of externalities and that the analysis of the economics-environment relationship in agriculture could not be limited, within the perspective of joint production, to the simple substitution, in the traditional transformation curve, of a product with the environmental service.

When the pollination service (of the managed bees) is allocated to a site covered by wild vegetation, assuming that the site is a common good, there will be no transaction. The revenue for the beekeeper will be constituted only by the honey produced by the hive. However, the pollination will increase the production of the wild vegetation. This greater availability of food will benefit the animals in the area, with widespread effects by virtue of the interdependence of the food chain. Environmental advantages will be derived in terms of the conservation of biodiversity or preservation of the rural landscape.

The allocation of the pollination service to the wild vegetation therefore produces jointly with honey an ecosystem service unrelated to the

6 Economic analyses have ignored the analysis of the sequentiality of the allocative choice of the pollination service and the site-specific characteristics that determine it.

market, which is configurable, from the economic perspective, as a positive externality or a public good (Havlik *et al*. 2005).

Every site-chronological regime can be associated to a level of jointness with the environment quantifiable on the basis of the estimated value of the *non-marketed* ecosystem services. Taking the example in fig.1, from an environmental perspective the hierarchy of the regimes is: 1- 2 or 3 - 4. In the first site-chronological regime the pollination service is in fact always allocated to sites with wild vegetation, in the fourth regime instead always to sites with a crop. In regimes 2 and 3, the wild vegetation is pollinated in one of the two sites, the crop in the other.

4.5 - Jointness in sites

The flowering of the crops does not generally have the same duration on all sites, as represented in fig. 2.

The chronological sequence of the collection sites is defined first of all by the flowering dates of the crops present. When flowering is simultaneous the sites are alternative, when they are staggered the sites are complementary, therefore practicable in a chronological sequence.

Sumner and Boriss (2006) report the pollination periods of some crops in a table and discuss the *timing* of the allocation of the pollination service, noting the rivalries and complementarities with the pollination of almond trees.

A necessary condition for a jointness in sites is that they are complementary, i.e. they can enter the allocation programme of the pollination service in sequence. The chronological sequence is therefore ranked on the basis of jointness in sites.

The jointness in sites arises from different sources.

The first and most elementary source of jointness is the transport cost of the hive. Computing the transport cost of the hive to sites j=3,4 in proportion to the distance to be travelled, it is obvious that this depends on the allocation made in the first period. The transport cost to site j=3 chosen in period t=2 is lower if in the first period t=1 the pollination service was allocated to site j=1, the nearest one. The transport cost to site j=5 also depends on the choice of the site made in the preceding period.

The transport cost to a site in period t=2 is therefore quantifiable only after having allocated the pollination service to a site in the preceding period t=1. It follows that each site corresponds to a transport cost dependent on the site that precedes it and therefore variable with the site-chronological regime.

The average transport cost of a hive from one site to another critically depends on the number of hives transported. There is generally an economy of scale in the transporting of hives.

The potential migration range (distance) of the hive from the base site diminishes, *ceteris paribus,* as the average transport cost rises, but increases with rent and with the price of the honey.

The other source of jointness in sites emerges on the side of the revenues. This jointness is bio-economic in that it derives from the evolution of the numbers of the bee colony population in the annual biological cycle. The hive, intended as the bee colony, is a biological unit, a living thing, characterized by birth and death rates of the population. The number of bees present in the hive modifies in both the production and dormancy phase. The bee colony is therefore not really a fixed factor but rather a renewable wild resource that provides a pollination service allocable to the sites or crops.

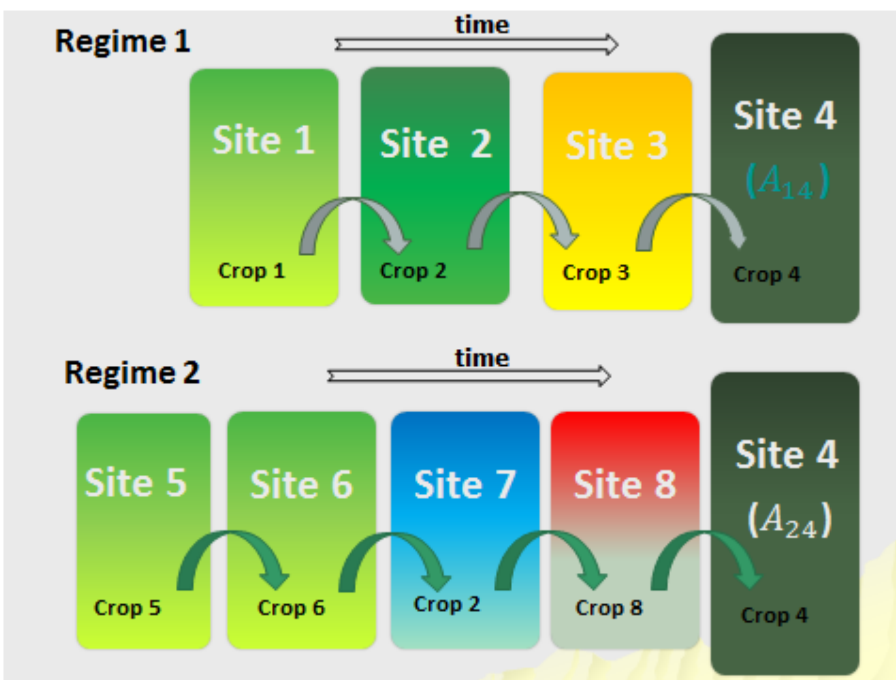
The type of crop or wild vegetation present on the site to be pollinated is one of the variables that affect the dynamics of the bee colony population (Schmickl, Crailsheim 2007). Some crops favour the growth of the colony population more than others, but it is the starting date of the production phase of the colony that shows most effect on the population dynamics of the bees. Starting the production phase in January, by moving the bee colony down to the plain, rather than in early March, keeping it on the mountains, affects the numbers of adult bees and the capacity of the colony to pollinate the cherry or apple crops in the period between March and April. The beekeeping literature provides a demonstration of the effect of the different diet resulting from the allocation of the colony to a crop (site) but does not offer a specific demonstration of the effect of the anticipation of the production phase. Mountain beekeepers offering a pollination service on the market can demonstrate the effect on the bee colony of the anticipation of the production phase with winter migration of the colonies down to the plain.

The cropping techniques practised on the site also sometimes influence the dynamics of the bee colony population in that they affect the death rate of the population. There has been ample discussion on the impact of pesticides on the health of bees and the precautions that beekeepers take against the risk of partial or total loss of the colony because of pollution in a site. Siebert (1980) considered the negative externality due to the reduction of the bee colony population on a site caused by pesticide use in the surrounding sites.

The effect of the site-specific variables on the numbers of bee colony honeybees usually emerges with a delay of some weeks caused by the development of the bee cohorts structured by age classes; the productive life of a honeybee lasts around 5 weeks; the honeybees present on the sites pollinated in chronological sequence are therefore not always the same ones. The effect of the site-specific characteristics, first of all of the crops, on the numbers of honeybees shows a delay with respect to the period that the hive stays on the site.

Given that the honey production and the commercial pollination service of the bee colony depends on the number of honeybees, the revenue obtained on a site will not necessarily be unvaried with the site-chronological regime. Taking the example in fig. 3, the substitution of the sequence of sites 1,2,3 with the sequence 5,6,2,8 has repercussions on the number of adult bees and foraging bees (A_{14}, A_{24}) that provide the pollination service on site 4 - is this common to the two regimes? Is anticipation of the production phase of the second regime (site 5) without any effects on the number of foraging bees active on site 4?

FIG. 3 - THE HONEYBEES DYNAMICS IN THE REGIMES



If the number of foraging bees A_{14} does not coincide with A_{24}, then the revenues obtained on site 4 will also change with the chronological sequence of the sites, i.e. with the site-chronological regime.

If the revenue obtained by the hive on a given site, site 4 in the example in fig. 3, changes following the substitution of one or more sites that precede it in the site-chronological regime or the anticipation of the production phase, then there is a jointness in sites on the side of the revenues. This is a bio-economic jointness.

The jointness in sites therefore arises from the revenues side or from the costs side or from both simultaneously.

6. CONCLUSIONS

The sequential allocation of the pollination service to the sites determine the site-chronological regimes. Given that each site is associated to a crop or wild vegetation, the site-chronological regime also identifies a cropping regime.

The regime integrates the space and time dimensions of the economic choice of a farm with a mobile production bio-organism as in the case of migratory beekeeping.

When the allocation of the pollination service to a site is constrained, because the beekeeper has decided to pollinate his own crop or has stipulated pollination contracts, the number of practicable regimes reduces and the economic choice simplifies.

The site-chronological regimes can be put in hierarchical order according to the profits obtained, but also according to the estimated value of the *non-marketed* ecosystem services that they generate.

Jointness can arise between the sites pollinated in chronological sequence.

A necessary condition for jointness in sites is that they are complementary, i.e. they can enter in sequence in the allocation programme of the pollination service.

A sufficient condition for jointness in sites is that the variable cost of a site, typically the transport cost of the hive to the site, changes with the regime.

A sufficient condition for jointness in sites is that the revenues of a site change with the regime. This source of jointness is bio-economic because it derives from the different dynamics of the population of adult bees and honeybees in the site-chronological regimes.

The bee colony is a renewable wild resource and allocable to the sites. The concept of allocable fixed factor does not really suit an economic analysis of the bee colony (hive). The impact of the site-specific characteristics on the dynamics of the bee colony population during the annual biological cycle can become a cause of jointness in sites.

The jointness in sites may therefore arise from the revenues side or from the costs side or from both sides simultaneously.

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