THE QUARRY LIFE AWARD

HEIDELBERGCEMENT

Exploring the bee shelters: the contribution of the quarry of Fongba (Republic of Benin)

Final report submitted for the QuarryLife Award Competition 2018

1. Contestant profile

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2. Project overview

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Contest: (Research/Community)	Research
Quarry name:	Fongba, Republic of Benin

To all of you who keep or like bees

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Abstract

Bees play one of the most important ecological functions on earth and improve livelihoods. Unfortunately they are threatened worldwide and some of them become confined to restricted areas such as quarries as their last shelter. In order to evaluate the contribution of the lime quarry of Fongba to biodiversity conservation and pollination service, the bees and associated insects populations at the quarry and their potential food sources were studied from February to August 2018. The insect diversity was studied by combining transect lines, hand-nest cashing and trapping methods while the pollen and nectar producing plants were assessed through vegetation surveys on systematic fixed area plots. A total of 44 plants species of 15 Families and 41 genera were recorded and most were concentrated at the extraction area which was isolated from bushfire and agriculture. Seven of the 8 surveyed trees were melliferous against 30 of the 36 recorded herbaceous species. The melliferous potential of the quarry was essentially made up of herbaceous (74 % of the melliferous plant density) dominated by *Tridax procumbens* (14 %). This particular area in the global floristically degraded district of Lokossa was host to 8 bee species, 6 pollinator fly species, 4 pollinator wasps and 2 predator wasp species. Dealing with the bees, 2 social bee species (*Apis mellifera adansonii* and *Hypotrigona ruspolii*) and 6 solitary bees (*Seladonia jucunda, Pachynomia amoenula, Megachile cincta, Megachile sp*., *Xylocopa luteola* and *Xylocopa nigrita*) were found. *Seladonia jucunda* was the most frequent (25 %) at the site followed by *Hypotrigona ruspolii* (20 %) and *Apis mellifera adansonii* (20 %). The distribution of the insects indicated that 56 % of the insect density was concentrated at the extraction area and 81.1 % of them were bees. As far as the social bees were concerned in particular, 5 *Apis mellifera adansonii* and 6 *Hypotrigona ruspolii colonies* were found at the extraction area where they established in human facilities and create many discomfort to the staff. A bee bank was created at the quarry to host the bees and the population was trained in bee management. This proved to be a sustainable solution to the accidents that emerges from social bee invasions at industrial quarries. In fact, not only it may help protect the workers and infrastructures at the quarries it also constitutes potential additional income sources to the community for poverty alleviation and sustainable biodiversity conservation.

Key words: Bee, quarry, shelter, pollinator, site restoration, quarry post extraction management.

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1. Introduction

Exposed to numerous extinction factors, many species have succeeded in securing their survival in quarries which are ecologically isolated areas from common human activities. Unfortunately, these ecological functions of quarries are under estimated worldwide. In fact, if some researches analysed the amphibians or water-borne life left behind on quarries (Pamba, 2014), most investigations targeted on the drawbacks of quarries and mitigation actions. Deeper studies are still needed on species which establish shelters in quarries, their interactions, survival strategies and position in the energy flow. Due to the pollination services they perform, the bees play the most important ecological functions, in addition to improving livelihoods. As such, it has been though that life on earth is not possible without bees (Buchmann & Nabhan, 1995; Klein *et al*, 2007). In this respect, following recognition of the core functions of the bees, the international community devoted the 20th May of every year to the bees as the international bee day. The first edition of this important event was celebrated this year, making 2018, the international year of the bees.

While the honeybees are domesticated and benefit from the great care from beekeepers, the solitary bees are abandoned in the wild and are more susceptible to disappearance. In the Republic of Benin where more than 39 % of the populations live under the poverty line in rural areas (INSAE, 2014; UNDP 2014) and where bee mainstreaming is very poor (Amakpe, 2008), securing the rare habitats of the bees is a great challenge for poverty alleviation and improved pollination services. We then set out to verify if the particular environment of the lime quarry of Fongba hosts specific bee populations and other associated insects in order to analyse the strategies for adding ecological and economical values to the bees at industrial quarries.

The research aimed to determine the contribution of industrial quarries to the sustainable development goals though pollination services and biodiversity conservation by:

- Evaluating the available food to the bees at the quarry of Fongba;
- Determining the bee species and associated insects established at the quarry;
- Securing their survival through a functional live bee bank.

2. Materials and methods

2.1. Study area

The study site was the extraction area of the lime quarry of Fongba which covers 109 ha in the district of Lokossa (Mono Department, Republic of Benin). For the investigations, we added around this area, a 400 m buffer (303 ha) making a total research area of 412 ha (figure 1). The quarry is located in the sub-littoral climatic area of the Republic of Benin with 900 mm annual rainfall (ASECNA, 2016). The original vegetation had totally disappeared and was converted into a mosaic of crops and fallows where *Elaeis guineensis, Tectona grandis, Loncocarpus sineserus* and *Mangifera indica* dominate the upper stand while *Imperata cylindrica, Tridax procumbens* and *Chromolena odorata* dominate the under-wood. During the dry season this vegetation is burnt by recurrent bushfires with the exception of rare areas located in quarries and isolated sites such as palm tree plantations, and managed gardens in the swamps.

2.2. Components of the bee shelter

A bee shelter (BS) is a restricted area where a particular set of bee populations survive in a dynamic equilibrium with other insects under the prevailing biotic and abiotic factors. In non scientific language, “bee” is used to refer to the honeybees of the Apidae family, especially *Apis mellifera* (L.). But in this research as in systematics, “bee” is used to refer to a large group of more than 18,191 species of 7 families that make up the Apoidea super family (Danforth *et al.,* 2013). According to Michener (2000) and Hedtke *et al.* (2013) the different bee families are the Apidae (5,700 described species), the Melitidae (200 described species), the Megachilidae (3,170 described species), the Andrenidae (2,900 described species), the Halictidae (4,300 described species), the Stenotrididae (21 described species) and the Colletidae (2,500 described species). They are divided in the group of the social bees (that nest in colony) and the solitary bees which mainly live as individuals.

The associated insects in the department of Mono, are mainly wasps (Hymenoptera) and flies (Diptera). Though the inter-specific relation involving the bees is also determined by bigger predators such as lizards and birds we only targeted on the hymenoptera and Diptera associated with the bees at the quarry of Fongba.

2.3. Dynamic factors of the bee habitat

The bee habitat is impacted by the melliferous plants distribution, the pressure from pests and predators, human induced factors and the bioclimatic conditions. According to Lobreau-Callen & Damblon (1994); the most important factors that determine the bee population distribution are the availability and diversity of melliferous plants. As the bees fly beyond the limited habitat for collecting food, the trophic area of a targeted region covers an additional buffer of at least twice the region (Collevatti *et al*., 2000; Beil *et al*., 2008). The melliferous plants in this total ecological niche are mainly affected by the complex of fire, grazing, tree harvesting and agriculture.

As far as the anthropogenic treats are concerned, the bee population is worldwide threatened by the loss of habitat, habitat fragmentation, agriculture intensification, pesticides and pollutions (Johansen *et al*., 2006, Thomas *et al*., 2004). In the tropical areas, other great threats to the bees are bushfires (Flannigan *et al*., 2009; Jurgen *et al*., 2012). Unfortunately, reliable data on the impacts of these factors are lacking in the district of Lokossa which is exposed to many habitat destruction factors.

In terms of predators or potential enemies, the most important pests to the social bee populations in the West African context are the small hive beetle (*Aethina tumida)*. Mites, fungi, bacteria and viruses are also potential pathogens to the bee populations (Strauss *et al.,* 2015; Ravoet, 2014). But though they can sometimes create big losses in managed apiaries, their impacts on solitary bees are unknown in the Republic of Benin.

2.4. Sampling and data collection

2.4.1.Plant survey

The botanic surveys were conducted from March to May 2018 which corresponds to the honey flow period. The trees and shrubs species were surveyed on circular systematic-fixed-area plots of 18 m radius. They were established at a regular distance of 200 m (south-north direction) and 400 m (east-west direction) and only live trees and shrubs that were susceptible to bear flower were recorded. The live herbaceous were recorded in an internal circular plot of 1 m radius to the main 18 m radius plots (Figure 1). The centre of each plot was automatically generated from the south-east extremity of the 400 m buffer (starting point) by the software “grille d’échantillonnage 1.5” developed by the Forestry Economy and Management Unit of the Faculty of Agronomy Sciences of Gembloux, Belgium. The Universal Transverse Mercator (UTM/WGS1984) of the 31 northern meridian geographical coordinates of the starting point were X = 361208 east and Y = 736401 north. The generated points were registered in a GPS (Garmin S64) which helped finding them on the field.

After the accurate determination of the plant species (Ern, 1988, Akoègninou *et al*., 2006; Yédomonhan *et al*., 2012), we classified them in: pollen (P) for pollen producing plants; nectar (N) for nectar producing plants; nectar and pollen (NP) for plants that produce both foods and non melliferous plants (0) (Dongock *et al.,* 2011; Adjare, 1990; Amakpe *et al*., 2015).

2.4.2.Insect survey

The botanic survey plots were used for creating the transect lines in the south-north direction (Figure 1). Each transect line was 200 m long, and determined by two consecutive (south-north) botanic survey plots. With an adapted hand net, a team of two persons (Photo 1) walked straight from one point to another of each transect and all found bees, pollinator flies and wasp were recorded in a band of 3 m large (a total of 0.06 ha per transect). A representative sample of each found species was captured and immediately put in a labelled tube which was afterward, filled with alcohol 70 % till the identification occurred at the International Institute for Tropical Agriculture (IITA) of Benin. After identification, the insects were classified in social bees, solitary bees or associated insects (wasps and flies).

Photo 1: Insect survey team

2.4.3. Live Bee Bank for safety, poverty alleviation and future investigation

Apis mellifera adansonii, a very aggressive social bee species often establishes in offices and dangerous facilities at the quarry and cause many aggressions while the stingless bee *(Hypotrigona ruspolii)* is reported to block doors and windows with propolis. The staffs are constrained to a repetitive and non effective use of pesticides and other chemicals to combat theses bees. We then set to deviate them to adapted hives and artificial nests (Gordon *et al*., 1998; Von Orlow, 2011). This system called the Live Bee Bank helped us introduce beekeeping and increase the awareness of the community for the bee mainstreaming in their activities. The pilot phase we experienced during this investigation was made up of:

Photo 2: Solitary bees and mellipona artificial nests

- 5 hives for the stingless bee *Hypotrigona ruspolii* and 3 honeybee (*Apis mellifera adansonii*) hives nearby offices;
- 20 sets of artificial nests made up of tubular bamboos and soft woods in trees and along the excavated walls for the solitary bees.

Each hive and artificial nest was screened bimonthly and any established bee colony or solitary bee was recorded. In July, the social bee hives and 10 artificial nests were put together under a special shed (Photo 2) to build up the first national bee bank. This reference centre will be used for further investigations on the bee complex in the Republic of Benin. The remaining artificial nests and hives were left at their initial place for the trapping continuum.

2.5. Data analysis

2.5.1. Melliferous plants and insects spectrum at the quarry

A descriptive statistic analysis was performed on the plant and insect biological parameters according to Cottam & Curtis (1956) and Adomou *et al*. (2007). For each recorded plant species, we calculated the plant density (D_p/ha), the relative plant density (D_p%) and the relative frequency (F_p%) as indicated in equations E1, E2 and E3. Similarly, for each insect species, we also calculated the relative frequency (F_i%), the insect density per ha (D_i/ha) and the relative density (D_i%) according to equations E4, E5 and E6.

These parameters were separately calculated for each group of plants (trees and herbaceous) each insect group (bee, flies, wasp), for the extraction area and the additional buffer for comparison.

2.5.2. Insect dynamics at the live bee bank

The diversity in insects at the live bee bank was followed bimonthly from March to July 2018. The sets of solitary bee nests and social bee hives were screened in the morning. Any open/closed mould or insect visit was considered and the species was registered. For the social bees, we counted the number of colonised hives over the investigation period.

As the number of established bees species was very small (less than 10 species), we just targeted the analysis of insect diversity dynamics at the bee bank on the evolution of insect species over the five months of investigation.

$$E1: D_p / ha = \frac{n_s}{S_p} \qquad E4: Di / ha = \frac{\sum_{i=1}^{n} n_{sp}}{\sum_{k=1}^{n} St}$$

$$E2: D_p \% = \frac{n_s}{N_T} \qquad E5: D_i \% = \frac{n_{sp}}{N_i}$$

$$E3: F_p \% = \frac{n_p}{N_p} \qquad E6: Fi\% = \frac{n_t}{N_{sp}}$$

- ns = Number of stems of the considered plant species;
- Sp= Sum of the surveyed plot area in ha
- NT = Total number of surveyed stems;
- np= Number of plots that bear the plant species;
- N_P= Total number of found species
- nt = Number of transect bearing the insect
- Nsp = Total number of found insect species.
- nsp = number of the insect species i surveyed in the targeted area.
- St = Sum of all survey transects area (ha)
- Ni = Total of all found insects

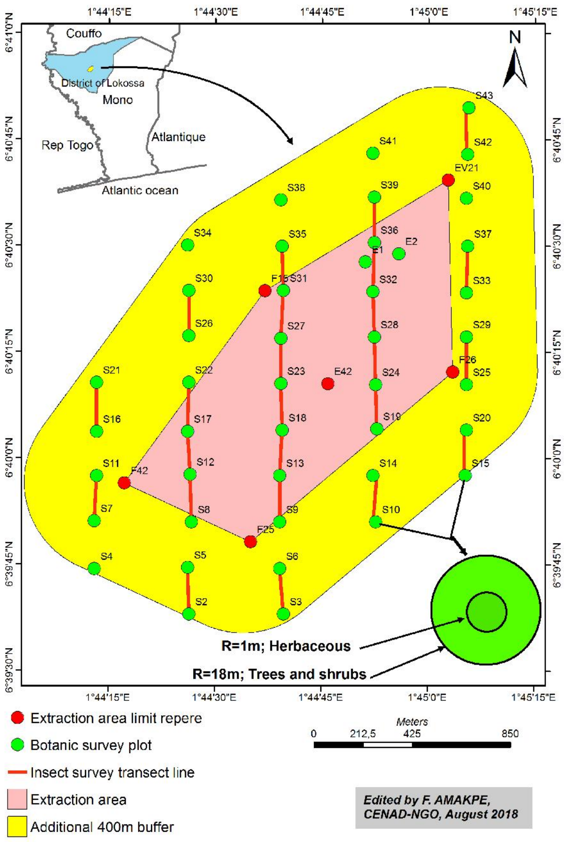

Figure 1: Botanic survey plots and transect lines distribution

3. Results

3.1. Potential nectar and pollen sources

The distribution of plant density per plot indicated that most of the empty plots were surprisingly located outside the extraction area where crops and fallows dominate the landscape. In fact, 26 % of the additional buffer was empty for only 13 % for the extraction area. Regarding the plants diversity, 44 plant species of 15 families were recorded. The richest families were the Asteraceae (6 species) and Fabaceae (5 species). There were 41 genera distributed in 10 (25 %) trees and shrubs, and 31 (75 %) herbaceous plants. As far as the melliferous plants were concerned, seven of the 8 recorded tree species were melliferous (88 % of the total tree species diversity) while 30 of the 36 found herbaceous species were melliferous (83 % of the herbaceous plant diversity). As shown on Figure 5, the melliferous trees were poorly represented (less than 1 % of the melliferous plant density) and the bulk of the melliferous potential of the quarry was made up of herbaceous which represented 74 % of the melliferous plant density in the extraction area. On the other hand, the melliferous trees had higher relative frequency with *Elaeis guineensis* the most frequent plant at the quarry and its surroundings (34 %).

The melliferous tree frequency was also higher outside the extraction area and was dominated by pollen producing trees such as Elaeis *guineensis, Acacia auriculiformis and Tectona grandis*. The herbaceous melliferous plants were dominated by *Tridax procumbens* (14 %), Centrosoma *pubescens* (8 %), *Commelina bengalensis* (3 %) *and Mallotus oppositufolis* (3 %) which were more frequent at the extraction area. Figure 5 presents the spectrum of the melliferous plants at the quarry and table 1 analyses the plant distribution pattern.

3.2. Bee and associated insects diversity

A total of 20 bees and associated insect species belonging to 10 families and 18 genera shared the ecological niche of the quarry of Fongba. The richest families were the Syrphidea (3 species) and the Apidae (4 species). This diversity was shared between 8 (40 %) bee species, 6 (30 %) pollinator flies species, 4 (20 %) pollinator wasps and 2 (10 %) predator wasp species. As far as the bee species were concerned, 2 (10 %)

social bee species were found (*Apis mellifera adansonii*, and *Hypotrigona ruspolii*) and 6 (30 %) solitary bees were found. These solitary bees were 2 Halictidae (*Seladonia jucunda* and *Pachynomia amoenula), 2* Megachilidae *(Megachile cincta* and *Megachile sp.*) and 2 Apidae (*Xylocopa luteola* and *Xylocopa nigrita*).

An average of 66 insects/ha (+-3) was encountered. This was made up of 61.6 % of bees, 24.2 % of pollinator Diptera, 10.0 % of pollinator wasps and 4.1 % of predator wasps. The geographic distribution of the insects indicated that 56% were concentrated at the extraction area and 44 % in the surrounding buffer. The bees also dominated the insect pattern at the extraction area as well as in the additional buffer. In fact, at the extraction area, the bees represented 81.1 % of the encountered insects. The Diptera represented 8.6 %, the pollinator wasps 5 % and the predator wasps represented 5.4% of the insect density. A fair dominance of the bee population was also found outside the extraction area (40 %). They were followed by the pollinator wasps (31 %), the pollinator Diptera (26 %) and the predator wasps represented 3% (figure 2).

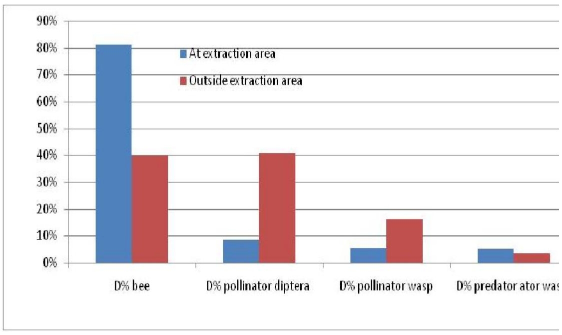

Figure 2: Insect density distribution at the quarry of Fongba

Dealing with the social bees, 5 colonies of *Apis mellifera adansonii* and 6 colonies of *Hypotrigona ruspolii (*stingless bee) were found at the extraction area. This respectively represented a density of 0.05 and 0.06 colony/ha for a total 0.11 social bee colonies per ha, all located at the extraction area. As far as the frequency of the bees was concerned, *Seladonia jucunda* (Halictidea) was the most frequent (25 %) at the entire investigation site followed by the Apidae *Hypotrigona ruspolii* (20 %) and *Apis mellifera adansonii* (20 %). Figure 3 analyses the spectrum of the bees at the quarry of Fongba.

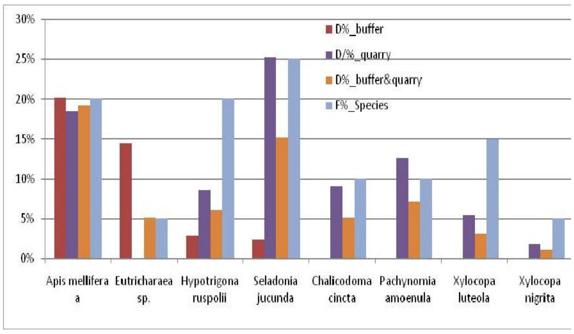

Figure 3: Bee species spectrum at the quarry of Fongba

3.3. The live bee bank

The bimonthly follow up of the artificial solitary bee nests indicated that 5 (25 %) of the 20 sets of nests hosted a metamorphosis or visit of 6 insect species. One set hosted a metamorphosis of *Xylocopa luteola* (Apidae) together with one metamorphosis of Liris sp (pollinator wasp). One set hosted three metamorphosis of *Stilbum cyanurum* (predator wasp) and 3 hosted each, a metamorphosis of Liris sp. It was also found a visit of *Paracyphononyx zonatus,* a pollinator wasp of the Pompilidae family in a tube of an artificial nest. The other nests remained free of any insect activity to now and this proved a slow colonisation of the artificial nests at the site. For the social bees, the entire 4 stingless bee and 3 honeybee hives had been colonised for beekeeping development.

As indicated on Figure 4, the total insect diversity increased at an average rate of 2 (+-1) species per month at the bee bank. But we cannot state how long this may last because the time devoted to the investigation was too short. The wasp species seemed to be more inclined to establish in artificial nests and the predator diversity didn't change over the time. The bee establishment occurred a bit latter after a visible stabilisation of the wasp species.

Though we registered a predator wasp metamorphosis, there was no evidence of wasp preying impact at the bee bank. On the other hand, the lizard *Agama agama* was the predator of great concern which preys on all insects at the site.

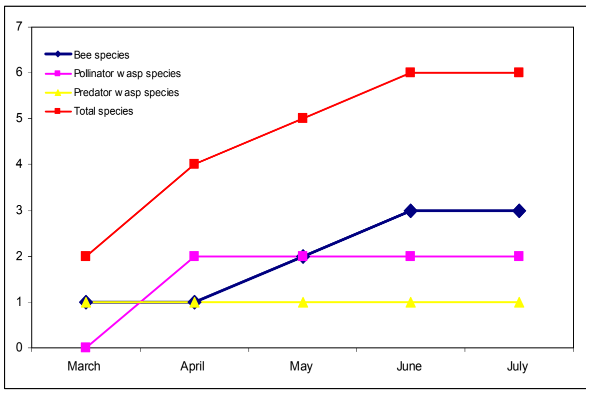

Figure 4: Insect species dynamics at the bee bank

3.4. Capacity strengthening in bee management

From 25 to 26 August 2018, a training session was organised for the surrounding populations (photo 3). This aimed to improve their livelihood through beekeeping and reinforce the pollination services. The following themes were analysed during the training.

- Functions of the pollinators and their management;
- Building and managing cost effective beehives
- Managing mellipona
- Value added to hive products;
- Apiary management with the native bee;
- Establishing artificial nests for solitary bees;
- Honeybee diseases and their management.

Photo 3: Discussion during the beekeeping training

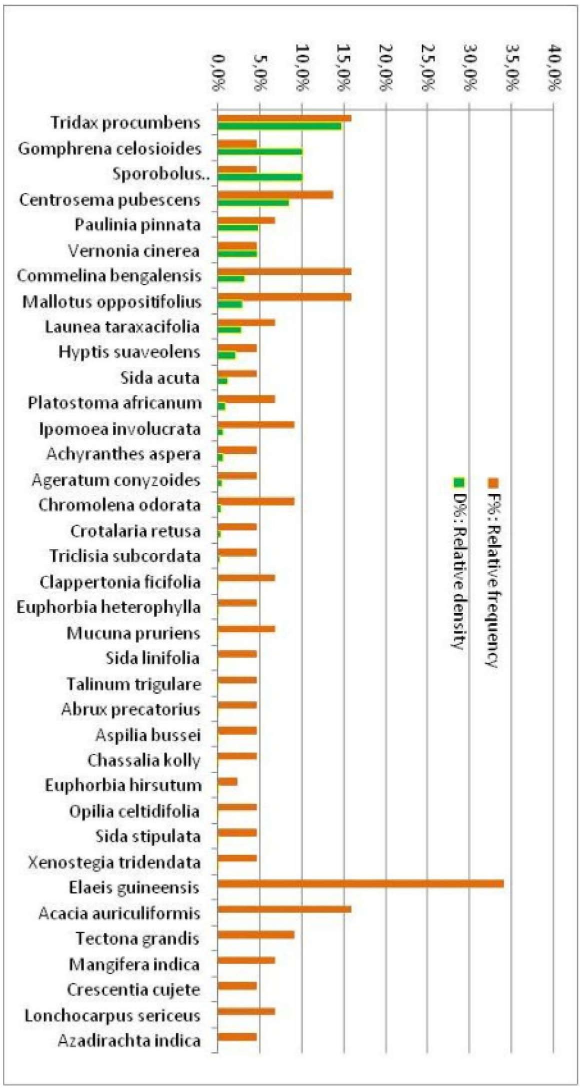

Figure 5: Melliferous plants Spectrum at the quarry

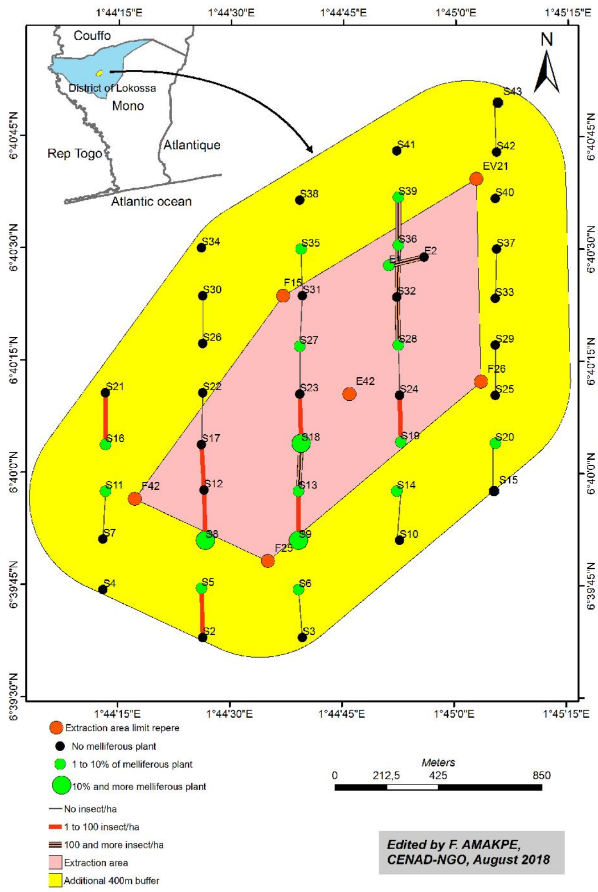

Figure 6: Geographic analysis of insect and melliferous plant density at the quarry

Table 1: Availability and frequency of melliferous plants at the quarry of Fongba

D/ha (density per ha), D%_HorT (relative density in herbaceous or trees), D% H&T (relative density, herbaceous and trees together), F%_HorT (relative frequency in herbaceous or tree), F%_H&T (relative frequency, herbaceous and trees together), NP (pollen and nectar producing plant), P (pollen producing plant), N (nectar producing plant), O (plant that produces nothing to the bee), t (tree or shrub); h (Herbaceous)

Family	Species	Type	D/ha	D%_HorT	D%_H&T	F%_HorT	F%_H&t	food
Amaranthaceae	Achyranthes aspera	h	546,0	0,6%	0,6%	5,6%	4,5%	NP
	Gomphrena celosioides	h	9 099,2	10,2%	10,2%	5,6%	4,5%	NP
Anacardiaceae	Mangifera indica	t	0,3	10,3%	0,0%	37,5%	6,8%	NP
Arecaceae	Elaeis guineensis	t	1,2	38,5%	0,0%	187,5%	34,1%	P
Asteraceae	Ageratum conyzoides	h	455,0	0,5%	0,5%	5,6%	4,5%	P
	Aspilia bussei	h	91,0	0,1%	0,1%	5,6%	4,5%	NP
	Chromolena odorata	h	364,0	0,4%	0,4%	11,1%	9,1%	P
	Launea taraxacifolia	h	2 547,8	2,8%	2,8%	8,3%	6,8%	NP
	Tridax procumbens	h	13 193,8	14,8%	14,8%	19,4%	15,9%	NP
	Vernonia cinerea	t	4 185,6	4,7%	4,7%	5,6%	4,5%	P
Bignoniaceae	Crescentia cujete	t	0,2	5,1%	0,0%	25,0%	4,5%	NP
Commelinaceae	Commelina bengalensis	h	2 911,7	3,3%	3,3%	19,4%	15,9%	NP
Convolvulaceae	Ipomoea involucrata	h	636,9	0,7%	0,7%	11,1%	9,1%	NP
	Xenostegia tridendata	h	91,0	0,1%	0,1%	5,6%	4,5%	NP
Cyperaceae	Cyperus rodundus	h	2 911,7	3,3%	3,3%	8,3%	6,8%	0
Euphorbiaceae	Euphorbia heterophylla	h	182,0	0,2%	0,2%	5,6%	4,5%	NP
	Euphorbia hirsutum	h	91,0	0,1%	0,1%	2,8%	2,3%	NP
	Mallotus oppositifolius	h	2 638,8	3,0%	3,0%	19,4%	15,9%	NP
Fabaceae	Abrux precatorius	h	91,0	0,1%	0,1%	5,6%	4,5%	NP
	Acacia auriculiformis	t	0,6	20,5%	0,0%	87,5%	15,9%	P
	Centrosema pubescens	h	7 643,3	8,5%	8,5%	16,7%	13,6%	NP
	Crotalaria retusa	h	364,0	0,4%	0,4%	5,6%	4,5%	NP
	Lonchocarpus sericeus	t	0,2	5,1%	0,0%	37,5%	6,8%	NP
	Mucuna pruriens	h	182,0	0,2%	0,2%	8,3%	6,8%	NP
Lamiaceae	Hyptis suaveolens	h	1 910,8	2,1%	2,1%	5,6%	4,5%	NP
	Platostoma africanum	h	818,9	0,9%	0,9%	8,3%	6,8%	NP
	Tectona grandis	t	0,5	15,4%	0,0%	50,0%	9,1%	P
Malvaceae	Clappertonia ficifolia	h	182,0	0,2%	0,2%	8,3%	6,8%	NP
	Sida acuta	h	1 091,9	1,2%	1,2%	5,6%	4,5%	NP
	Sida linifolia	h	182,0	0,2%	0,2%	5,6%	4,5%	NP
	Sida stipulata	h	91,0	0,1%	0,1%	5,6%	4,5%	NP
Meliaceae	Azadirachta indica	t	0,1	2,6%	0,0%	25,0%	4,5%	NP
Menispermaceae	Triclisia subcordata	h	273,0	0,3%	0,3%	5,6%	4,5%	NP
Moraceae	Antiaris africana	t	-	0,0%	0,0%	25,0%	4,5%	0
Opiliaceae	Opilia celtidifolia	h	91,0	0,1%	0,1%	5,6%	4,5%	NP
Poaceae	Adropogon ternarius	h	-	0,0%	0,0%	5,6%	0,0%	0
	Cynodon dactylon	h	-	0,0%	0,0%	8,3%	0,0%	0
	Imperata cylindrica	h	-	0,0%	0,0%	16,7%	0,0%	0
	Oryza barthii	h	-	0,0%	0,0%	5,6%	0,0%	0
	Sporobolus pyramidatus	h	9 099,2	10,2%	10,2%	5,6%	4,5%	0
Rubiaceae	Chassalia kolly	h	91,0	0,1%	0,1%	5,6%	4,5%	NP
Sapindaceae	Paulinia pinnata	h	4 367,6	4,9%	4,9%	8,3%	6,8%	NP
Talinaceae	Talinum trigulare	h	182,0	0,2%	0,2%	5,6%	4,5%	NP
Total melliferous herbaceous			66 606,0	74,5%	74,5%			
Total all herbaceous			89 444,9					
Total melliferous tree			3,0	97,4%	0			
Total all tree species			3,1					
Total herbaceous and tree			89 448,0					

Table 2: Insect density and diversity at the quarry of Fongba

D/Ha_Buf (density outsite the extraction area), D%_buf (relative density outside the extraction area), D/ha_EXA (density at the extraction area), D%_EXA (relative density at the extraction area), D/ha_WA (Global density per ha), D%_WA (Global relative density), F% (Relative frequency), hym (Hymenoptera), dip (Diptera)

Family	Species	Order	D/ha_ buf	D%_buf	D/ha_ EXA	D/%_ EXA	D/ha_ WA	D%_ WA	F%
Apidae	Apis mellifera adansonii	hym	5,8	20,1%	6,8	18,5%	12,7	19,2%	20,0%
	Hypotrigona ruspolii	hym	0,8	2,9%	3,2	8,6%	4,0	6,1%	20,0%
	Xylocopa luteola	hym	-	0,0%	2,0	5,4%	2,0	3,0%	15,0%
	Xylocopa nigrita	hym	-	0,0%	0,7	1,8%	0,7	1,0%	5,0%
Total Apidae			6,7	23%	12,7	34%	19,3	29%	60%
Halictidae	Seladonia jucunda	hym	0,7	2,3%	9,3	25,2%	10,0	15,2%	25,0%
	Pachynomia amoenula	hym	-	0,0%	4,7	12,6%	4,7	7,1%	10,0%
Total Halictidae			0,7	2%	14,0	38%	14,7	22%	35%
Megachilidae	Chalicodoma cincta	hym	-	0,0%	3,3	9,0%	3,3	5,1%	10,0%
	Eutricharaea sp.	hym	4,2	14,4%	-	0,0%	3,3	5,1%	5,0%
Total Megachilidae			4,2	14,4%	3,3	9,0%	6,7	10,1%	15,0%
Total bee			11,5	39,7%	30	81%	40,7	61,6%	110%
Bombyliidae	Anastoechus sp.	dip	5,8	20,1%	-	0,0%	5,3	8,1%	10,0%
	Triplasius sp.	dip	1,7	5,7%	0,3	0,9%	2,0	3,0%	10,0%
	Bombylisoma senegalense	dip	-	0,0%	0,7	1,8%	0,7	1,0%	5,0%
Total Bombylidae			7,5	25,9%	1,0	2,7%	8,0	12,1%	25,0%
Syrphidae	Eristalinus megacephalus	dip	-	0,0%	0,7	1,8%	0,7	1,0%	5,0%
	Eristalinus sp.	dip	-	0,0%	0,7	1,8%	0,7	1,0%	5,0%
	Eristalis arvorum	dip	0,2	0,6%	6,5	17,6%	6,7	10,1%	15,0%
Total Syrphidae			0,2	0,6%	7,8	21,2%	8,0	12,1%	25,0%
Total dyptera			7,7	26,4%	8,8	23,9%	16	24,2%	50%
Sphecidae	Liris sp	hym	4,7	16,1%	2,0	5,4%	6,7	10,1%	20,0%
	Liris sp. 2	hym	4,2	14,4%	-	0,0%	-	0,0%	0,0%
Total Sphecidae			8,8	30,5%	2,0	5,4%	6,7	10,1%	20,0%
Philanthidae	Philanthus sp.	hym	0,8	2,9%	-	0,0%	0,7	1,0%	5,0%
Pompilidae	Cyphononyx bretonii	hym	0,2	0,6%	0,5	1,4%	0,7	1,0%	5,0%
Total pollinator wasps			9,8	34%	2,5	7%	8,0	12%	30%
Chrysididae	Stilbum cyanurum	hym	-	0,0%	0,7	1,8%	0,7	1,0%	5,0%
	Chrysis lincea	hym	-	0,0%	0,7	1,8%	0,7	1,0%	5,0%
Total Chrysididae			-	0,0%	1,3	3,6%	1,3	2,0%	10,0%
Total Predator	wasps		-	0,0%	1,3	3,6%	1,3	2,0%	10,0%
Total at the quarry			29,0	44%	42,7	56%	66,0	100,0%	100,0%

4. Discussion

4.1. Melliferous plants distribution and impacts on bees

The melliferous tree diversity (8 species) of the site represented only 8 % of the total melliferous trees of the Republic of Benin (Amakpe *et al*., 2015). They belonged to 8 genera and 7 families dominated by the Fabaceae while 90 melliferous tree species of 73 genera and 29 families, dominated by the Caesalpiniacea were found in the entire country. Though there is no reliable data on the herbaceous melliferous plants in the country, our investigations proved that the 28 herbaceous melliferous species represented alone more than 50 % of the total melliferous plant diversity of the site. They belong to 15 families dominated by the Asteraceae as found by Dongock *et al.* (2011) in Cameroon while the dominant family in Senegal were the Combretaceae (Ricciardelli & Compagnucci, 1991). At the country level, from the 2087 plant species (0.2 species per km²) belonging to 1129 genera (0.1 genera/km²) and 185 families (0.0 family per km²) according to Akoegninou *et al*., 2006), the quarry of Fongba hosted alone, 10 melliferous species per ha, 8 genera per ha and 4 families per ha. It was then far richer and more diversified, compared to the entire country.

The department of Mono belonged to the poor south silvo melliferous region of Benin, characterized by Elaeis *guinensis, Tectona grandis*, and *Acacia auriculiformis* plantations (Amakpe *et al.,* 2015). Our investigations also confirmed this poverty in melliferous trees at the quarry of Fongba where pollen producing plants made up the bulk of the melliferous trees. The higher frequency of melliferous trees outside the extraction area was the direct consequence of the fact that the land owners exploited the trees before living behind, empty soils to the quarry administration. But the herbaceous melliferous plants were more diversified and dense at the extraction area than found in the country at the beginning of the rainy season. Such particularity of the extraction area was mainly due to the fact that it was well protected from destructive bushfires, grazing and cropping. This certainly made it, the best attractive area for the bees and other pollinators in the Republic of Benin and there was no significant difference in the diversity and density of bees and associated insects during the investigation period.

4.2. Bees and associated insects distribution at the quarry of Fongba

Out of the 7 described bee families all over the world (Danforth *et al*., 2013; Hadtke *et al*., 2013) the lime quarry of Fongba hosted 3 among which the Apidae and the Megalichidae were the richest. The dominance of these two families was also found in Cameroon by Pando *et al*., (2011) on Fabaceae plants. The bee species diversity (8 species) of the quarry was also higher than what was found in the entire Senegal and Cameroon even though it was far below the 53 species of 9 genera in the European contexts (Le Feon *et al*., 2013). Though the geographic scope of our investigation was very narrow, our finding may be a regional confirmation of the dominance of Apidae and Megachilidae families in West Africa. We can then state that the small area of the quarry of Fongba was a richer and much diversified bee reservoir compared to many other West African countries. As there was no reliable previous data on the solitary bees in the Republic of Benin, our investigations proved to be the first tangible research to describe the Halictidae, Megachilidae and Apidae solitary bee species in the country. This then opened the basis for further investigations on the bee diversity and ecology in the country.

Based on the trophic inter-specific relation between the bees and associated insects, the relative density (D%) and frequency (F%) confirmed the classical pyramidal shape of the prey-predator trophic chain in any balanced ecologic area. In fact the predator wasps were less represented than the bees, the Diptera and pollinator wasps. This guarantees a long term balanced energy flow between these insects at the lime quarry. But as for the bees, we found that the predator wasps were more present at the extraction area (5.4 %) than at the buffer zone (4.1 %). This seemed to indicate a positive correlation between the distributions of the bees and wasp predators in which the wasp may have a preference in preying on bees and were more tempted to the bee yards.

4.3. Bee cohabitation as a great challenge at quarries in tropical areas

As found by Klein *et al*. (2007), Adjare (1990) and Arbonier (2002), the most important factors that determine the bees and their associated insects (predators and pollinators) visits in a climatic condition are the melliferous plants density and distribution. This geographic superposition of the melliferous plants and bees distribution was also found at the quarry of Fongba (figure 6). In fact, the bees were more frequent at the extraction site than outside this zone where the flora was very rare. The extraction area also bore numerous water pits where the bees can collect the required water for their biological functions all the year long. The extraction area was then a particular “secured ecological niche” or a shelter in the vast floristically degraded district of Lokossa where the living conditions were more detrimental to the bees.

We also found that the entire social bee colonies (100 %) were only present in human facilities (explosive containers, window and door crevices, roofs, etc.). This antropophile behaviour of the social bees in isolate areas was also found by Gathhmann & Tscharntke (2002) and Gordon *et al*. (1976) in places where their natural nesting sites are missing. In fact as trees, termite huts, rock crevices where they naturally nest, are missing at the quarry of Fongba, the social bees establish their colonies in man-made reservoirs as their shelter habitat. In these surviving strategies, many aggressions and discomforts occurred at the site against which, the staff used pesticides and other destructive methods. But the bees always come back again to the same places after two or three weeks of the previous colony destruction. Our results proved that the most sustainable, cost effective and environmentally smart system for avoiding aggressions and accidents from social bees at quarries is to establish honeybee and mellipona hives. This helped deviate and stabilise the wandering swarms without using chemicals. It was what we initiated by building the live bee bank at the quarry. All the mellipona and bee hives were colonized after three weeks, proving that, more hives should be established at the quarry. The beekeeping system that will emerge from this method will help improve the livelihood of the population and reinforce the pollination services for the whole district. The training we realised for them was a starting point for beekeeping development and solitary bee management around the lime quarry of Fongba.

4.4. Implication for site restoration, biodiversity conservation and improved livelihood

We found that the melliferous plants which determined the bees and associated insect distribution were mainly dominated by herbaceous plants. These plants require then special care for a sustainable melliferous flora at the quarry. In fact though the quarry seemed to be protected from destructive fires, herbaceous are still very sensitive to drought and fires in dry seasons where the bees are more active (Cooper & Schaffer, 1985; Bishop & Armbruster, 1999). Reforestation of post extraction sites should then target on perennial trees to reinforce the melliferous potential of the quarry. For that, a mixture of trees that issues both pollen and nectar should be preferred to pure plantations of pollen producing trees such as *Acacia auriculiformis* and *Tectona grandis*. On the other hand, *Acacia auriculiformis* is highly sensitive to fire and teak plantations don't tolerate any under-wood. In place of these species, we recommend a composite plantation of native multipurpose tree species such as *Triplochiton scleroxylon, Khaya senegalensis, Holarrhena floribunda, Loncocarpus sineserus*, *Zanthoxylum zanthoxyloides,* Spondias *monbin* and *Irvingia gabonensis*.

The water pits scattered over the quarry which is host to many water related-species (Pamba, 2014) are also additional attractive factors for the bee establishment. Excavated areas closing after lime extraction should then secure enough water pits from which the bees may collect water.

In contrast to the common believes, our results showed that invasion of offices and other human facilities by social bees at quarries are good opportunities for improving livelihood for the surrounding populations. In fact instead of destroying the bee colonies, we recommend the use of hives and artificial nests to keep them at quarries in tropical areas. Doing so, not only will help deviate the bees from dangerous areas, but also provide foods and cash for improved livelihoods. In the same line, the bee colonies in containers and roofs should carefully be re-established in adapted hives. The roofs and other materials at quarries should also be rearranged and adequately designed to prevent further social bee intrusions. But, this should be carried out in accordance to the global safety requirement at quarries which remain specific dangerous areas in which many bee populations will survive.

As far as the solitary bees were concerned, we found that their establishment at the bee bank took more time than for the social bees. This may probably be due to their relative scarcity at the site, the challenges in the design of the artificial nests, or to the fact that the time devoted to the investigations was too short to highlight their establishment. We then left at the quarry of Fongba, the bee bank and other artificial nests which must be kept and preserved for long term researches on modelling the bee ecology in industrial quarries.

5. Conclusion and recommendations

The lime quarry of Fongba located in the district of Lokossa (Republic of Benin) was a particular site where the optimum living conditions of the bees were met. The site was characterized by enough melliferous plants, permanent water availability and a protected environment from fires and agriculture. These ecological prevailing conditions made the extraction area, a privileged site that was host to 8 bee species of which 6 were solitary bees that had never been described in the country before. Such ecological conditions need to be improved by special reforestation of post extraction sites. Developing beekeeping is also the safest and economically sound strategies for preventing aggressions and invasions from social bees at industrial quarries.

In order to ensure sustainable bee conservation on industrial quarries, the following actions may be implemented in cooperation with the surrounding populations and in respect of the particular safety requirements at industrial quarries.

- Avoid pure plantation of pollen producing trees species during reforestation of closed sites by targeting on native multipurpose trees that tolerate herbaceous under-wood. This will also help control bush fires in dry season and ensure additional incomes for the communities.
- Secure a permanent bee bank with enough hives and artificial nests for solitary bees as a biological control of the social bee invasion of quarries in tropical areas;
- Associate and train the surrounding populations on beekeeping and on solitary bee management to add value to the bees at quarries;
- The bee bank we built was the first ever established in Benin. It should be kept beyond this competition for further scientific investigations. This will help mobilise additional funds for highlighting and defending the special contribution of quarries in biodiversity conservation and livelihood improvement through the particular bee populations they host.

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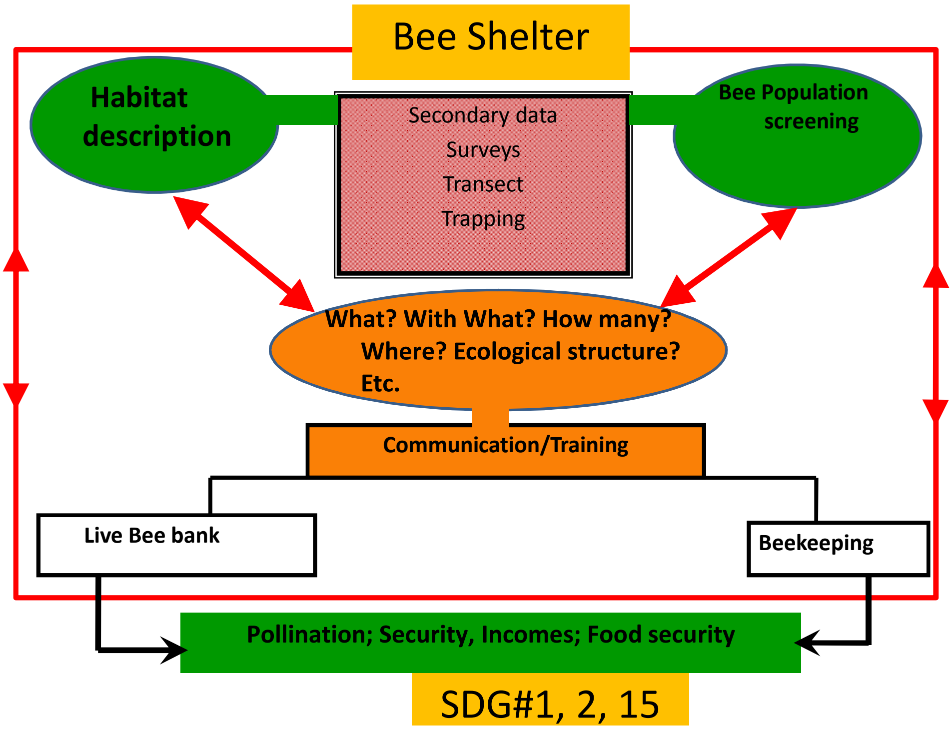
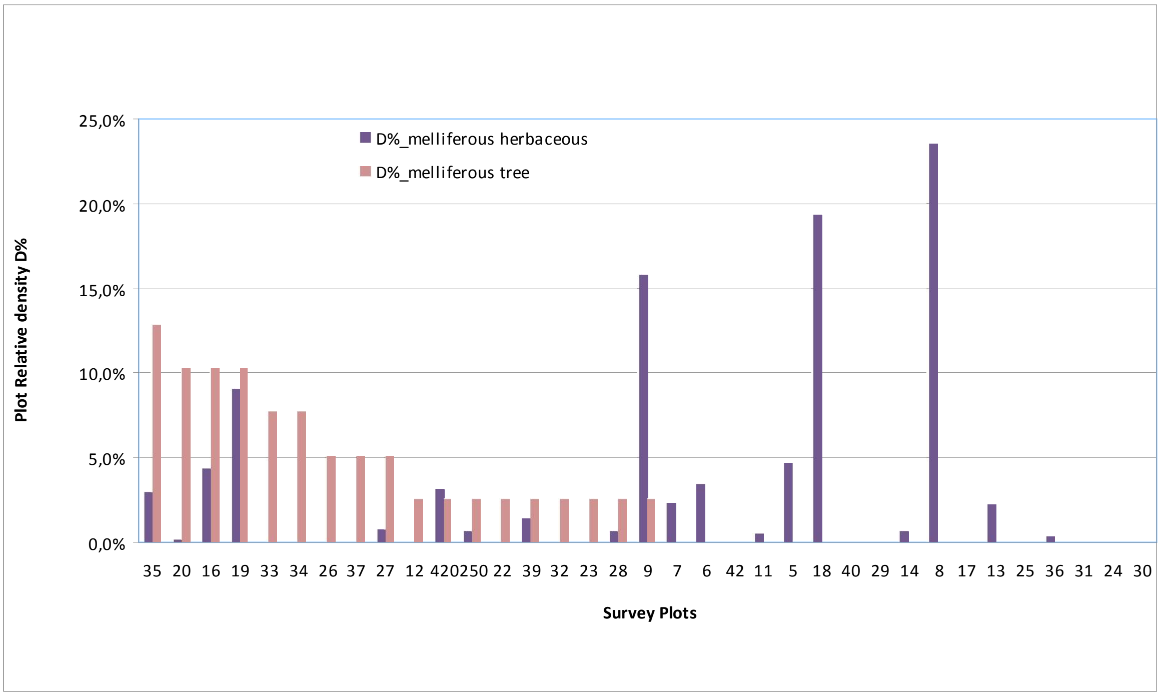
7. Annex

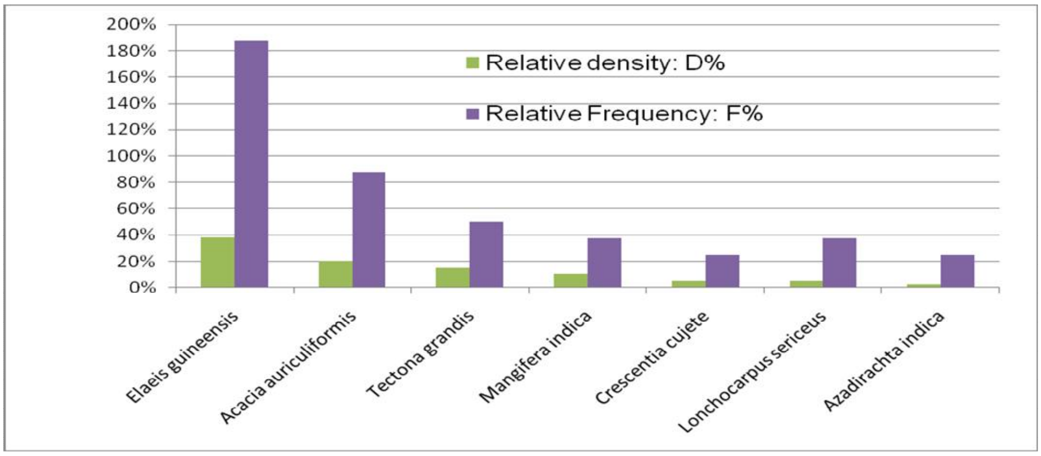
1- Research conceptual framework



2- Melliferous status of the surveyed plots



3- Distribution pattern of tree melliferous plants at the quarry of Fongba

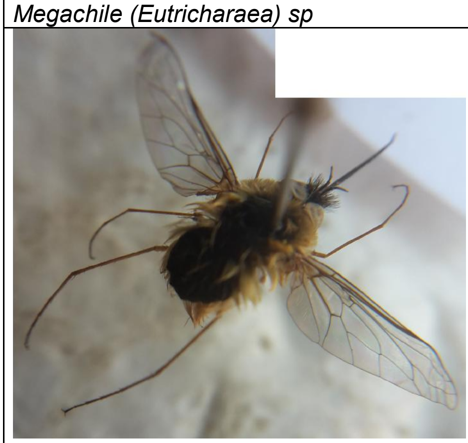
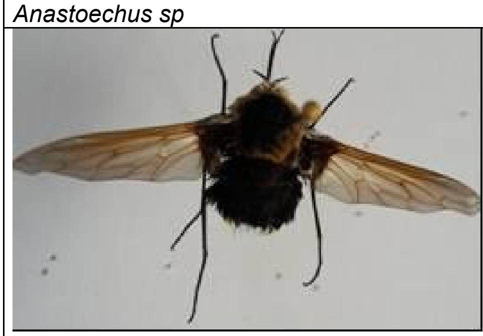


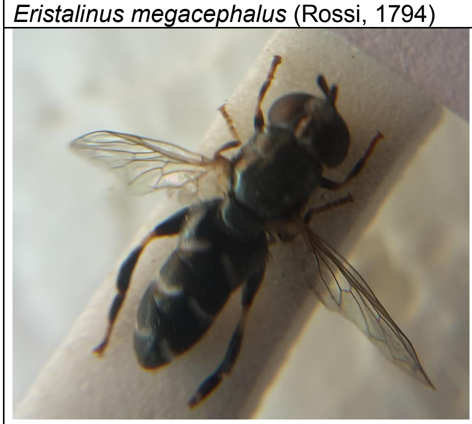
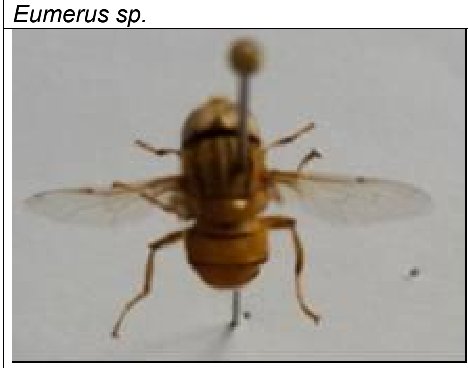
4- The bee and associated insects atlas of the quarry of Fongba

D/ha_buf	D/ha_EXA	D/ha_WA	D%_WA	F%
Density outside extraction area	Density at the extraction area	Total density extraction and buffer include	Relative density	Relative frequency of insect

Species and image	Systematics	D/ha_buf	D/ha_EXA	D/ha_WA	D%_WA	F%
 *Apis mellifera adansonii* (Linnaeus, 1758)	Kingdom: Animalia Phylum: Arthropoda Class: Insecta Order: Hymenoptera Family: Apidae Subfamily: Apinae Tribe: Apini Genus: Apis	5,8	6,8	12,7	19,2 %	20,0%
 *Hypotrigona ruspolii* (Cockerell, 1934). Inside the nest of the stingless bees indicating food and broods. The black dots on the photo are the bees	Kingdom: Animalia Phylum: Arthropoda Class: Insecta Order: Hymenoptera Family: Apidae Subfamily: Apinae Tribe: Meliponini Genus: Hypotrigona	0,8	3,2	4,0	6,1%	20,0%

 *Xylocopa luteola* (Latreille, 1802)	Kingdom: Animalia Phylum: Arthropoda Class: Insecta Order: Hymenoptera Family: Apidae Subfamily: Xylocopinae Tribe: Xylocopini Genus: Xylocopa	-	2,0	2,0	3,0%	15,0%
 *Xylocopa nigrita*	Idem	-	0,7	0,7	1,0%	5,0%
 *Seladonia jucunda* (Smith, 1853)	Kingdom: Animalia Phylum: Arthropoda Class: Insecta Order: Hymenoptera Family: Halictidae Subfamily: Tribe: Genus: Seladonia	0,7	9,3	10,0	15,2 %	25,0%
 *Pachynomia amoenula*	Kingdom: Animalia Clade: Euarthropoda Class: Insecta Order: Hymenoptera Family: Halictidae Subfamily: Halictinae species: Pachynomia amoenula	-	4,7	4,7	7,1%	10,0%

 *Megachile (Chalicodoma) cincta* (Fabricius, 1781)	Kingdom: Animalia Clade: Euarthropoda Class: Insecta Order: Hymenoptera Family: Megachilidae Genus: Megachile Species: M. cincta Megachile cincta	-	3,3	3,3	5,1%	10,0%
 *Megachile (Eutricharaea) sp*	Kingdom: Animalia Clade: Euarthropoda Class: Insecta Order: Hymenoptera Family: Megachilidae Genus: Megachile Species: Eutricharaea sp.	4,2	-	3,3	5,1%	5,0%
 *Anastoechus sp*	Kingdom: Animalia Phylum: Arthropoda Class: Insecta Order: Diptera Suborder: Brachycera Infraorder: Asilomorpha Superfamily: Asiloidea Family: Bombyliidae Genus: Anostoechus	5,8	-	5,3	8,1%	10,0%
 *Triplasius sp.*	Kingdom: Animalia Phylum: Arthropoda Class: Insecta Order: Diptera Suborder: Brachycera Infraorder: Asilomorpha Superfamily: Asiloidea Family: Bombyliidae Genus: Triplasius	1,7	0,3	2,0	3,0%	10,0%

 *Bombylisoma senegalense* (Macquart, 1840)	Kingdom: Animalia Phylum: Arthropoda Class: Insecta subclass: *Pterygota* Order: Diptera Family: Bombyliidae Genus: Bombylisoma Species: E. megacephalus[1] Macquart, 1840	-	0,7	0,7	1,0%	5,0%
 *Eristalinus megacephalus* (Rossi, 1794)	Kingdom: Animalia Phylum: Arthropoda Class: Insecta Order: Diptera Family: Syrphidae Genus: Eristalinus Subgenus: Eristalodes	-	0,7	0,7	1,0%	5,0%
 *Eumerus sp.*	Kingdom: Animalia Phylum: Arthropoda Class: Insecta Order: Diptera Family: Syrphidae Genus: Eumerus	-	0,7	0,7	1,0%	5,0%
 *Eristalis arvorum* (Fabricius, 1787)	Kingdom: Animalia Phylum: Arthropoda Class: Insecta Order: Diptera Family: Syrphidae Subfamily: Eristalinae Tribe: Eristalini Subtribe: Eristalina Genus: Eristalinus	0,2	6,5	6,7	10,1 %	15,0%

 *Liris sp 1*	Kingdom: Animalia Clade: Euarthropoda Class: Insecta Order: Hymenoptera Superfamily: Apoidea Family: Sphecidae Genus: Liris	4,7	2,0	6,7	10,1 %	20,0%
 *Liris sp. 2*	Kingdom: Animalia Clade: Euarthropoda Class: Insecta Order: Hymenoptera Superfamily: Apoidea Family: Sphecidae Genus: Liris	4,2	-	-	0,0%	0,0%
 *Stilbum cyanurum* (Förster, 1771)	Kingdom: Animalia Clade: Euarthropoda Class: Insecta Order: Hymenoptera Family: Chrysididae Genus: Stilbum	-	0,7	0,7	1,0%	5,0%
 *Chrysis lincea* (Fabricius)	Kingdom: Animalia Clade: Euarthropoda Class: Insecta Order: Hymenoptera Family: Chrysididae Tribe: Chrysidini Genus: Chrysis Linnaeus, 1767	-	0,7	0,7	1,0%	5,0%

 *Philanthus sp.*	Kingdom: Animalia Clade: Euarthropoda Class: Insecta Order: Hymenoptera Family: Phylanthidae Genus: Philanthus	0,8	-	0,7	1,0%	5,0%
 *Cyphononyx bretonii* (Guérin, 1843)	Kingdom: Animalia Clade: Euarthropoda Class: Insecta Order: Hymenoptera Family: Pompilidae Subfamily: Pepsinae Genus: Cyphononyx	0,2	0,5	0,7	1,0%	5,0%
 *Paracyphononyx zonatus (* Illiger)	Kingdom: Animalia Clade: Euarthropoda Class: Insecta Order: Hymenoptera Family: Pompilidae Genus: *Paracyphononyx* *Pollinator*	Established at the bee bank in artificial solitary bee nests. Not found during insect survey				

5- Insecticide application against bees at the quarry: This consisted in filling a piece of fabrics with insecticide and apply it against the entrance the bee colony uses to inter the roof)


6- Female and male (red headed) of *Agama agama*, common predator to all insects at the quarry of Fongba

7- Building low cost hives from used materials during the training

8- A set of artificial solitary bee nests in a tree at the extraction area

To be kept and filled in at the end of your report

Project tags (select all appropriate):

This will be use to classify your project in the project archive (that is also available online)

Project focus:

- ☒Beyond quarry borders
- ☒Biodiversity management
- ☐Cooperation programmes
- ☒Connecting with local communities
- ☒Education and Raising awareness
- ☐Invasive species
- ☐Landscape management
- ☒Pollination
- ☐Rehabilitation& habitat research
- ☒Scientific research
- ☐Soil management
- ☒Species research
- ☐Student class project
- ☐Urban ecology
- ☐Water management

Flora:

- ☒Trees & shrubs
- ☐Ferns
- ☒Flowering plants
- ☐Fungi
- ☐Mosses and liverworts

Fauna:

- ☐Amphibians
- ☐Birds
- ☒Insects
- ☐Fish
- ☐Mammals
- ☐Reptiles
- ☐Other invertebrates
- ☐Other insects
- ☐Other species

Habitat:

- ☒Artificial / cultivated land
- ☐Cave
- ☐Coastal
- ☐Grassland
- ☒Human settlement
- ☐Open areas of rocky grounds
- ☐Recreational areas
- ☐Sandy and rocky habitat
- ☐Screes
- ☐Shrub & groves
- ☐Soil
- ☐Wander biotopes
- ☐Water bodies (flowing, standing)
- ☐Wetland
- ☒Woodland

Stakeholders:

- ☐Authorities
- ☒Local community
- ☒NGOs
- ☐Schools
- ☐Universities