Study case- bases for monitoring biodiversity at the farm level

Authors: Escobedo, Mejía, Cardona y Fernández

Introduction

ES frameworks often turns assessing the value of natural resources based on their direct consumption. Examples include wood extraction from forests or carbon sequestration. While quantifying physical outcomes is relatively straightforward, measuring ecological processes can be more complex. For instance, the pollination service is a challenging aspect to quantify, as some authors rely on the cost of replacement based on crop productivity without pollinators, disregarding factors such as morphological resemblance between insects and flowers or the intricate mechanisms of pollination that rely on specific species populations and external factors like climate change and phenology.

Area of interest

To examine the features of these sustainable agriculture practices in the Guatemalan projects, there was a selection of farms from the Resilient Highlands project for the case studies. The main area of analysis was in Chimaltenango, Sololá, and Quiché, on the municipalities of Zaragoza, San Andrés Iztapa Chimaltenango and San Juan Comalapa. The total territory comprises 47.45 within three micro watersheds Balanyá, Pixcayá-Pampumay and Quiejel. To select farms for the study within a stratified random sample was employed, specifically targeting those implementing Ecosystem-based Adaptation (EbA) practices. The selection process utilized the R package rsamplac {sampler} (Lohr, 1991, equation 2.17). The farms meeting the criteria are outlined in Table 1, derived from the "Resilient Highlands" project.

Micro watersheds	Municipalities	Number of farms with EbA actions
Balanyá		**12**
	Comalapa	2
	San Andrés Itzapa	2
	Zaragoza	8
Pixcayá-Papumay		**38**
	Comalapa	34
	Santa Cruz Balanyá	1
	Tecpán Guatemala	3
Quiejel		**426**
	Chichicastenango	413

Table 1. Micro watersheds, municipalities, and number of farms on the intervention area of resilient highlands.

As an additional filter for the farm selection, and considering further usefulness, we verify the non-overlapping presence within a 1.5-kilometer radius, which corresponds to a reasonable foraging distance from the farm to its surrounding areas (Greenleaf et al., 2007). The maps depicting the farm locations and the buffer representing the displacement of pollinators are illustrated in Figure 1. The farm selection intends to serve for other collecting proposes but also to get an Index of agricultural practices favourable to biodiversity.

The characterisation of farms with **EbA practices** keep the following features: a) Soil conservation practices including contour farming (against the slope), terracing following contour lines, individual terraces for fruit trees, crop diversification and rotation, and intercropping between tree species, horticultural, and fruit crops. Additionally, the use of organic inputs for managing diseases and phytophagous insects (those that feed on plants), including the use of organic fertilisers, was identified as a good agricultural practice for biodiversity.

The conventional farms were defined as those with a cultivation cycle primarily synchronized with the rainy season. These farms typically have a limited number of plant species, especially those employing a monoculture scheme. They use fire to clear previous crops, apply chemical fertilizers and pesticides in nearly all cultivation cycles, and do not adhere to specific agrochemical usage guidelines. The classification of these farms as conventional was established through direct information and personal communication with the local landowners.

Finally, we added more criteria to define the study area, which involved observing biological interactions on the farms. These interactions are associated with the ecological contributions of both forest and non-forest plants, the presence or absence of natural enemies for pest control, the presence or absence of negative effects caused by pests, and the presence of pollinators.

Methodology

The methodology for this study case was divided in data collection through surveys and arthropods collection, as well as in the observation of ecological interactions. Then, statistical, and ecological biodiversity analysis take place and were correlated with the previously mentioned surveys.

Data Set

Surveys

The field trips to each of the regions comprising the three hydrographic basins under study were coordinated. Between April 17 and 20 in the Quiejel basin, from April 24 to 27 in the Pixcayá basin, and from May 3 to 5 in the Pixcayá and Balanyá basins, data on biodiversity indicators were collected, and surveys were conducted. Visits to the selected EbA farms were coordinated, and additionally, a farm with traditional management within 1 km of each EbA farm was sought to obtain data for comparing indicators between management types.

Prior to data collection at all farms, visits and obtaining social permissions were verbally coordinated (by phone or in person). Data collection for the indicators involved conducting surveys.

The survey was validated between the consulting team and the project coordination team. Once the tool was fine-tuned, it was applied in the field, with prior authorization from the participants (social license). The survey was conducted individually for each of the owners of the selected EbA farms and for the owners of farms with traditional (conventional) management.

The tool is divided into six major sections, including: 1) general information, which primarily gathered information about the location of the plots and their local equivalent size (cuerdas). 2) supply chains, which collected information about crop destinations, the use of own seeds, or dependence on purchasing them. 3) agricultural practices, mainly obtaining information about the number of crops produced on the plot, their level of association, crop rotation, and fallow periods between crops. 4) crop cover and soil and water conservation practices, with a focus on information about soil cover, irrigation technology level, and perceptions of water availability variation. 5) phytosanitary management, which gathered information about major crop issues (phytophagous insects, diseases), the use of agrochemicals for treatment, and their application methods. 6) Natural vegetation and resources for pollinators, which obtained information about forest perception in relation to crop plots, weed management, insect perceptions regarding their effect on the plot (positive or negative), and knowledge about native and managed bees (apiculture).

Species collection

In the same farms, a survey of the plot and the collection of specimens of insects from the Coleoptera, Diptera, Hemiptera, and Hymenoptera orders were conducted, especially if they were observed using the vegetation present in the plot as habitat or food resource. Only native insect species were considered.

Furthermore, plant species in which plant-insect interactions were observed were recorded. For collections, entomological nets (sleeves) were used, with an emphasis on collecting representative samples of different insects on the flowers in the plot and around it. After the collections, specimens underwent a curation process that included mounting on entomological pins, labelling, and drying. Subsequently, they were identified at the highest possible taxonomic level.

Analysis

Taxonomic information about insect specimens and their interactions with plants was analysed using a Microsoft Excel spreadsheet. An abundance matrix per species per farm was created, which was used to calculate diversity metrics (richness "S," estimated richness "Chao1," total abundance "N," Shannon diversity "H'," and Pielou evenness "J”).

The obtained metrics were compared between management types (EbA or Conventional) using paired tests on the mean (analysis of variance if normality and homogeneity of variances assumptions were met, or Welch's test if **homoscedasticity** assumption was not met) or on the median (Kruskal-Wallis test if residuals did not meet the normality assumption). All analyses were performed using the statistical package "Past 4.09" (Hammer et al. 2001).

Data Collection

A presence and abundance matrix of each identified species and morphospecies in each plot was created, which was used to address **species turnover in insect** communities between plots and different management types (beta diversity). For this, a non-metric multidimensional scaling (NMDS) analysis based on Euclidean distances was performed. Additionally, a clustering analysis using the Jaccard index was conducted to identify similarities based on species presence and absence.

Furthermore, least squares linear models were used to explore the relationship between the diversity (Shannon's H') of insects and plants visited by insects, as well as the corrected richness (Chao1) of insects and the IPAB index calculated from the surveys. Values were transformed to meet the normality assumption, if necessary. All analyses were performed using the statistical package "Past 4.09" (Hammer et al. 2001).

Index of Biodiversity-Friendly Agricultural Practices

Based on the information collected in the surveys, a selection of questions related to the management of the evaluated plots that could have effects on the assessed biological diversity indicators (insects and their ecological interactions) was made. These questions were classified and assigned a positive or negative value to test if there is a relationship between the implemented practices and the indicators of biological diversity. The selected questions and assigned values are detailed in Annex 1. The sum of the values assigned to the answers to each question was used as an "Index of Biodiversity-Friendly Agricultural Practices," based on the one proposed by Taylor and colleagues (1993), referred to in this product as "IPAB”.

Results

254 specimens from the orders Coleoptera, Diptera, Hemiptera, and Hymenoptera. Preliminary identification identified 79 morphospecies from 25 different taxonomic families (see Table 1). Additionally, **232 records of plant-insect interactions were obtained, involving at least 59 different plant species** (see Table 3). The interactions between insects and plants are showed in Figure 1 and 2.

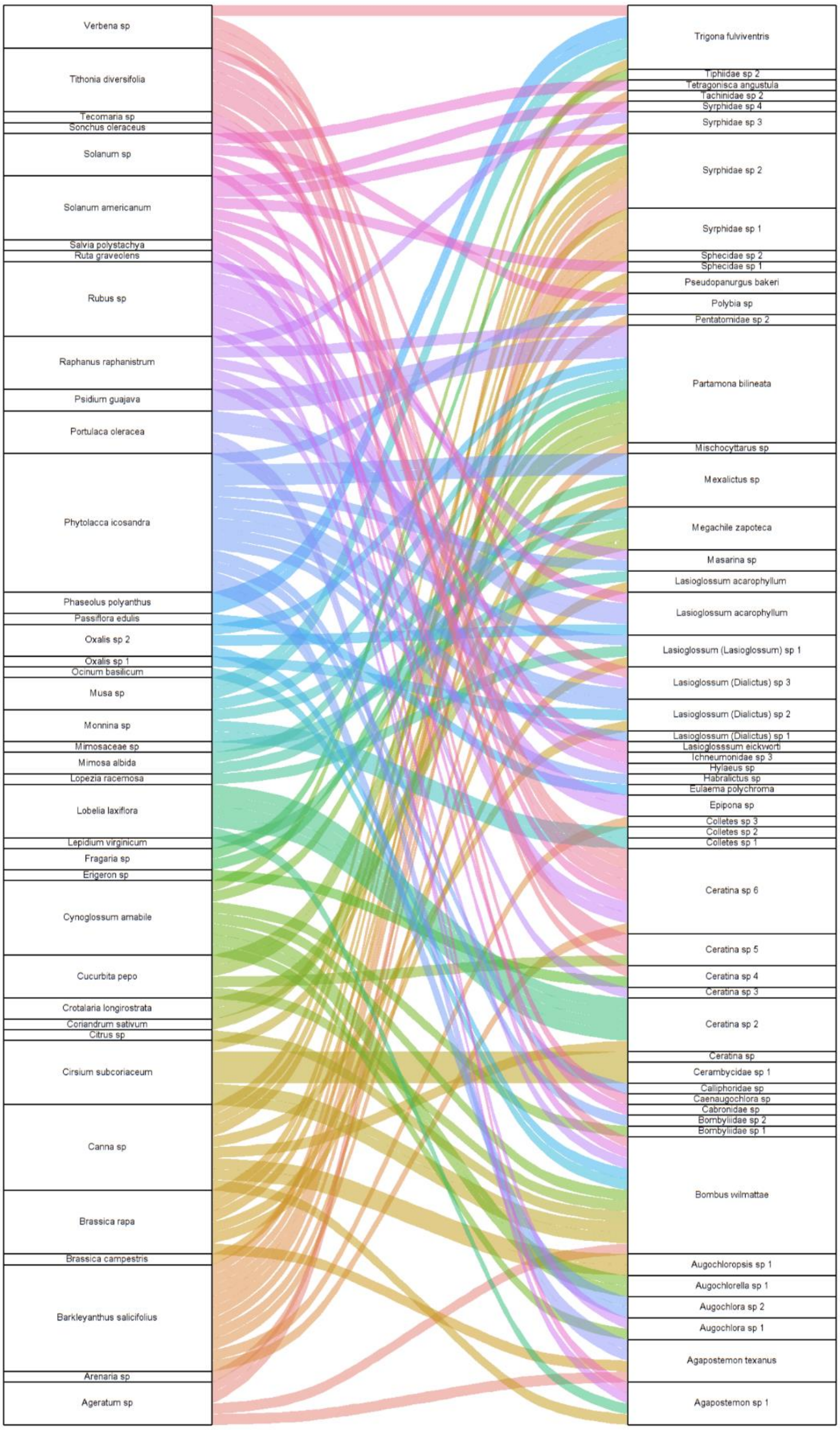


Figure 1. Plant Insect network in farms that implement EbA.

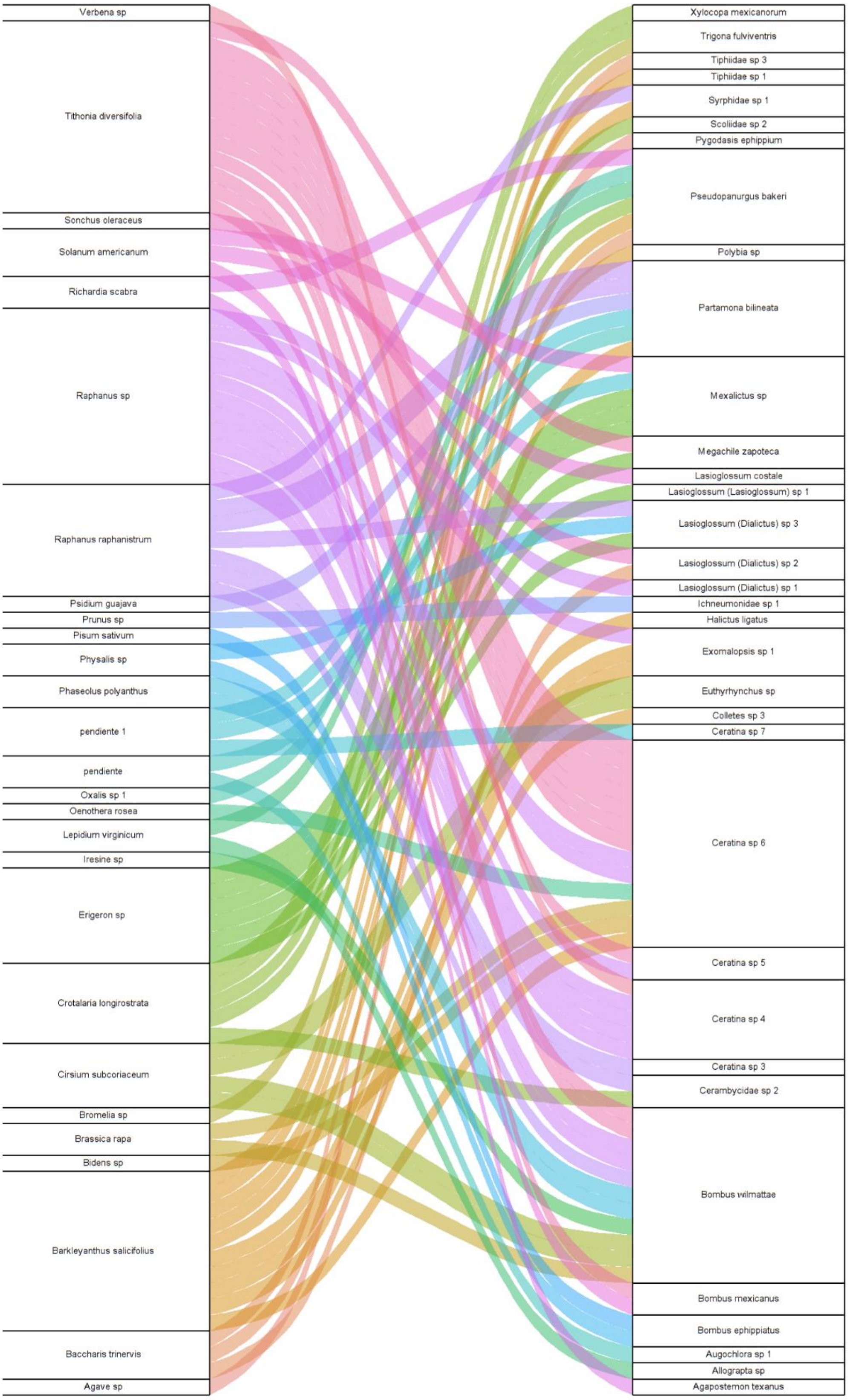


Figure 2. Plant- Insect network in Conventional Farms

Table 1. Final list of species and morphospecies of insects found on the evaluated farms, in different types of management (EbA and conventional).

Management	Order	Family	Species or morphospecies	Abundance
EbA	Coleoptera	Cerambycidae	Cerambycidae sp 1	2
		Scarabaeidae	Cetoniidae sp 1	2
	Diptera	Asilidae	Asilidae sp	1
		Bombyliidae	Bombyliidae sp 1	1
			Bombyliidae sp 2	1
		Calliphoridae	Calliphoridae sp	1
		Pipunculidae	Pipunculidae sp	1
		Syrphidae	Syrphidae sp 1	4
			Syrphidae sp 2	8
			Syrphidae sp 3	2
			Syrphidae sp 4	1
		Tachinidae	Tachinidae sp 1	1
			Tachinidae sp 2	1
	Hemiptera	Pentatomidae	Pentatomidae sp 1	1
			Pentatomidae sp 2	1
	Hymenoptera	Andrenidae	*Pseudopanurgus bakeri*	3
		Apidae	*Bombus ephippiatus*	1
			Bombus wilmattae	12
			Ceratina sp	1
			Ceratina sp 1	2
			Ceratina sp 2	5
			Ceratina sp 3	2
			Ceratina sp 4	3
			Ceratina sp 5	3
			Ceratina sp 6	9
			Eulaema polychroma	1
			Partamona bilineata	11
			Tetragonisca angustula	1
			Trigona fulviventris	7
		Cabronidae	Cabronidae sp	1
		Colletidae	*Colletes* sp 1	1
			Colletes sp 2	1
			Colletes sp 3	1
			Hylaeus sp	1
		Halictidae	*Agapostemon* sp 1	4
			Agapostemon texanus	4
			Augochlora sp 1	2
			Augochlora sp 2	2
			Augochlorella sp 1	4
			Augochloropsis sp 1	2
			Caenaugochlora sp	1
			Habralictus sp	1
			Lasioglosssum eickworti	1

Management	Order	Family	Species or morphospecies	Abundance
			Lasioglossum (Dialictus) sp 1	1
			Lasioglossum (Dialictus) sp 2	3
			Lasioglossum (Dialictus) sp 3	3
			Lasioglossum (Lasioglossum) sp 1	3
			Lasioglossum acarophyllum	6
			Mexalictus sp	6
			Paralictus sp	1
		Ichneumonidae	Ichneumonidae sp 1	1
			Ichneumonidae sp 2	1
			Ichneumonidae sp 3	1
			Ichneumonidae sp 4	1
			Ichneumonidae sp 5	1
		Megachilidae	*Megachile zapoteca*	4
		Scoliidae	Scoliidae sp 1	1
		Sphecidae	*Chlorion* sp	1
			Sphecidae sp 1	2
			Sphecidae sp 2	1
		Tiphiidae	Tiphiidae sp 1	1
			Tiphiidae sp 2	1
		Vespidae	*Epipona* sp	2
			Masarina sp	3
			Mischocyttarus sp	3
			Polistes sp 1	2
			Polistes sp 2	1
			Polybia sp	2
Convencional	Coleoptera	Cerambycidae	Cerambycidae sp 2	2
	Diptera	Syrphidae	*Allograpta* sp	1
			Syrphidae sp 1	2
	Hemiptera	Pentatomidae	*Euthyrhynchus* sp	2
	Hymenoptera	Andrenidae	*Pseudopanurgus bakeri*	6
		Apidae	*Bombus ephippiatus*	2
			Bombus mexicanus	2
			Bombus wilmattae	11
			Ceratina sp 3	1
			Ceratina sp 4	5
			Ceratina sp 5	2
			Ceratina sp 6	13
			Ceratina sp 7	1
			Exomalopsis sp 1	3
			Partamona bilineata	6
			Trigona fulviventris	2
			Xylocopa mexicanorum	1
		Colletidae	*Colletes* sp 3	1
		Halictidae	*Agapostemon texanus*	1
			Augochlora sp 1	1
			Halictus ligatus	1

Management	Order	Family	Species or morphospecies	Abundance
			Lasioglossum (Dialictus) sp 1	1
			Lasioglossum (Dialictus) sp 2	2
			Lasioglossum (Dialictus) sp 3	3
			Lasioglossum (Lasioglossum) sp 1	1
			Lasioglossum costale	1
			Mexalictus sp	5
		Ichneumonidae	Ichneumonidae sp 1	1
		Megachilidae	*Megachile zapoteca*	2
		Scoliidae	*Pygodasis ephippium*	1
			Scoliidae sp 2	1
		Tiphiidae	Tiphiidae sp 1	1
			Tiphiidae sp 3	1
		Vespidae	*Polybia* sp	1

Species Richness, Abundance, and Rarefaction

The comparison of diversity metrics between management types showed significant differences in the values of species richness "S" and insect abundance, with both being higher in EbA farms (F=5.85, df=12.87, p=0.03, and F=7.99, df=17, p=0.01, respectively). Estimated species richness "Chao1" and Shannon diversity "H'" also showed higher values for EbA farms, although the difference was marginal (F=3.57, df=17, p=0.076, and F=3.59, df=17, p=0.076, respectively).

There was no significant difference in evenness "J" between management types (Figure 3). Comparisons were also made between diversity metrics of the plants involved in interactions with insects. Higher mean values were found in EbA farms for raw species richness "S," abundance "N," and Shannon diversity, but only marginal significant differences were found between management types for species richness and abundance (F=3.36, df=17, p=0.084, and F=4.77, df=10.53, p=0.052, respectively). There was no significant difference in estimated species richness "Chao 1," Shannon diversity "H'," or Pielou evenness "J'" (Figure 4).

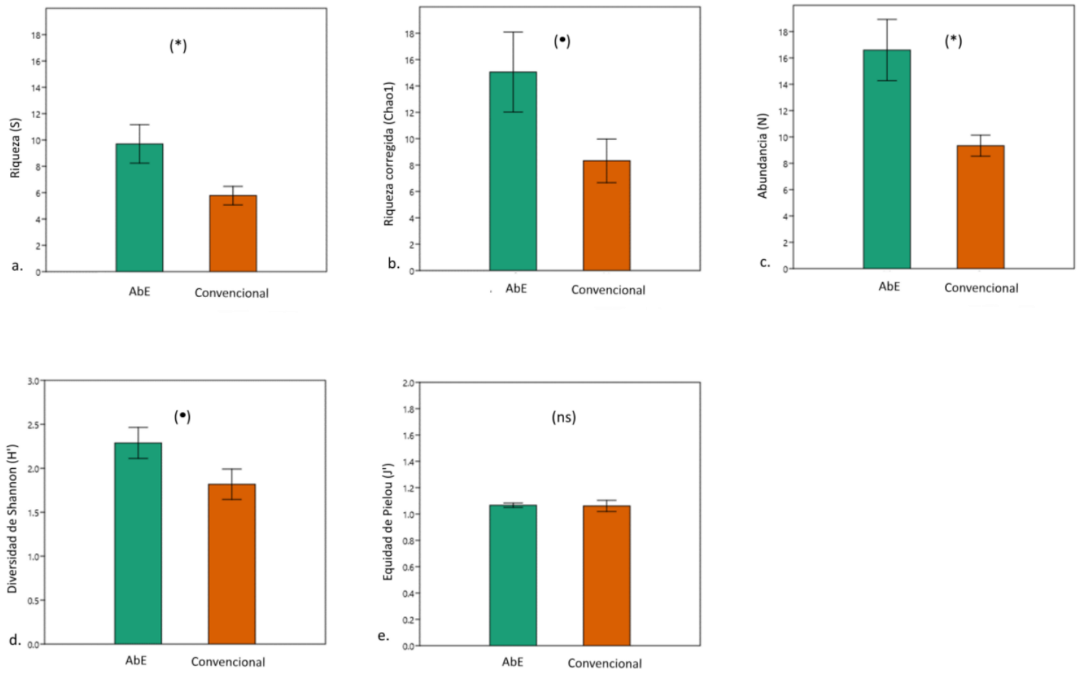


Figure 3. Diversity metrics of recorded insects, by type of management: a) species richness (number of species recorded per plot); b) richness corrected by rarefaction using the Chao1 estimator; c) individual abundance; d) Shannon diversity; e) Pielou evenness. The bars represent the mean plus/minus the standard error. "*" significance, p > 0.05 "." =marginal significance, p<0.1 "n" no significance.

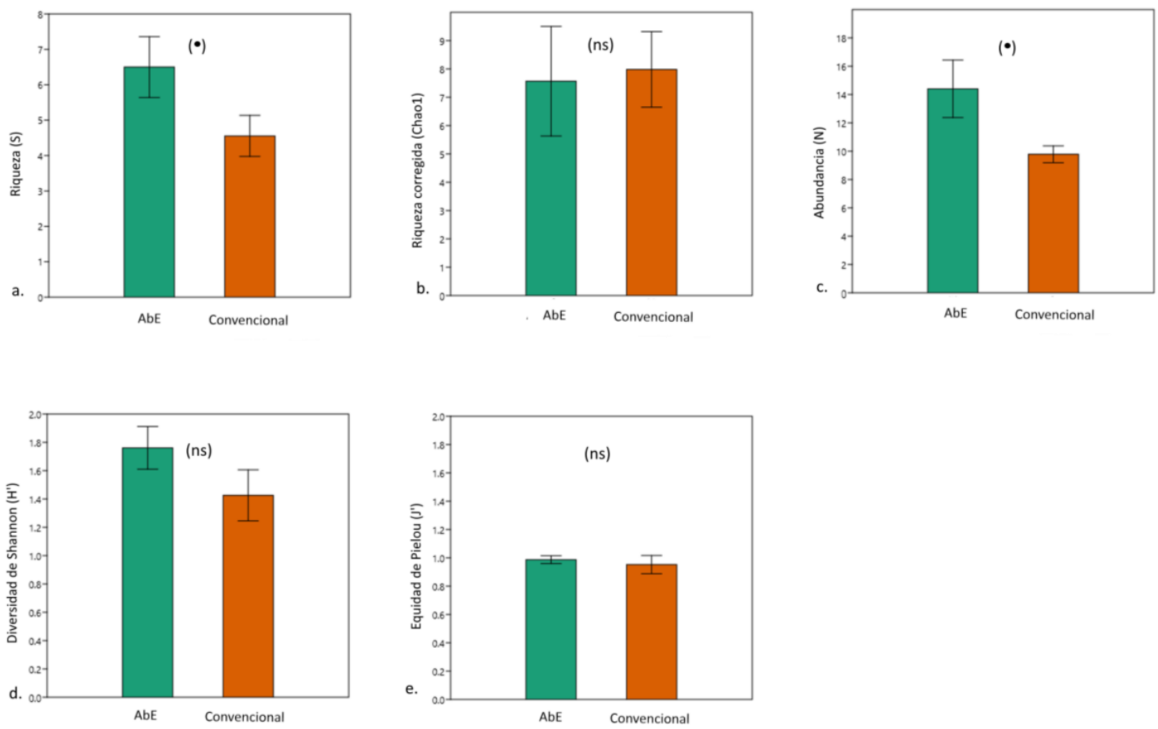


Figure 4. Diversity metrics of plants involved in interactions with insects, by type of management: a) species richness (number of species recorded per plot); b) richness corrected by rarefaction using the

Chao1 estimator; c) individual abundance; d) Shannon diversity; e) Pielou evenness. The bars represent the mean plus/minus the standard error.

Evenness and Similarity between Species Communities

The non-metric multidimensional scaling analysis shows that it is **not possible to discriminate between plots based on the composition of insect species** present, except for one of the EbA management plots (EbA A1, represented in the upper left, Figure 5). It also shows that most of the conventional management plots are very close in terms of their composition, according to Euclidean distance measurements.

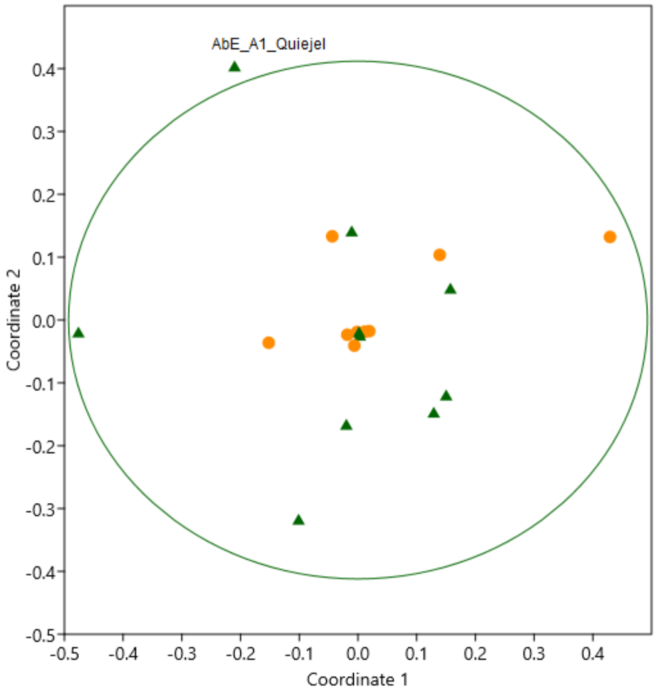


Figure 5. Non-metric multidimensional scaling (NMDS) analysis based on Euclidean distances between insect communities found at different evaluated points. Green triangles represent EbA management plots, and orange points represent conventional management plots. The green ellipse indicates the 95% confidence interval.

The cluster analysis based on Jaccard similarity shows very little similarity (less than 0.45) between the communities of different plots, based on the insect species present. In general, it is not possible to identify groups based on management or the basin to which the plots belong (Figure 6).

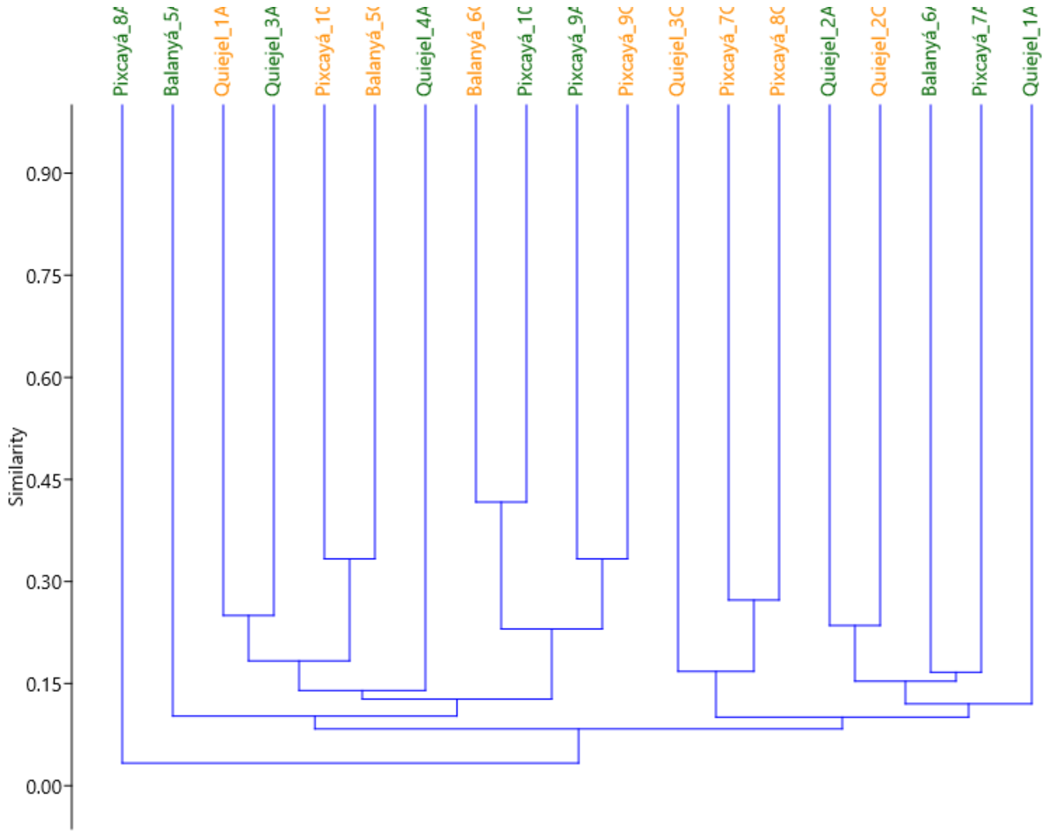


Figure 6. Cluster dendrogram based on the Jaccard similarity index using a hierarchical clustering algorithm. It shows the similarity between the evaluated plots in terms of the presence of identified morphospecies of insects. The green color represents EbA management plots, the orange color represents conventional management plots. It also indicates the basin to which the evaluated plot belongs (Quiejel, Pixcayá, or Balanyá).

"IPAB and Farm Diversity."

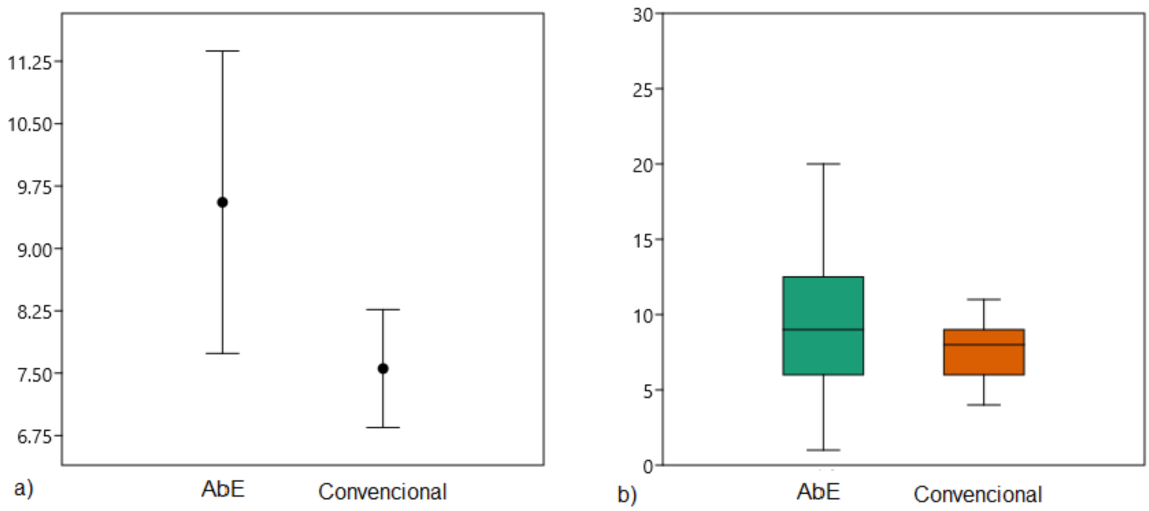
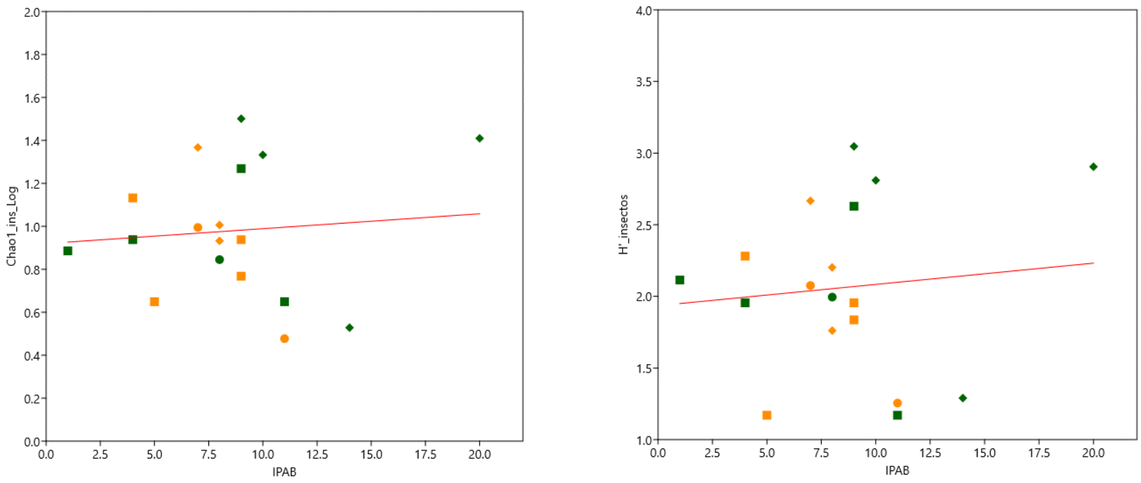


Figure 7. IPAB Index Values for Each Management Type: a) a graph showing the average value with the standard error; b) a box plot showing the distribution of values obtained based on the calculated median.



a) b)

Figure 8. Least Squares Linear Models to Identify Responses of Alpha Diversity Values: a) Estimated richness Chao1 and b) Shannon diversity, to the values of the Practices Index (IPAB) calculated. Green markers represent EbA management plots, orange markers represent conventional management plots. Diamonds represent Quiejel basin plots, dots represent Balanyá basin plots, and squares represent Pixcayá basin plots. Slope (a): 0.007, P=0.71, r=0.09; Slope (b): 0.015, P=0.68, r=0.1.

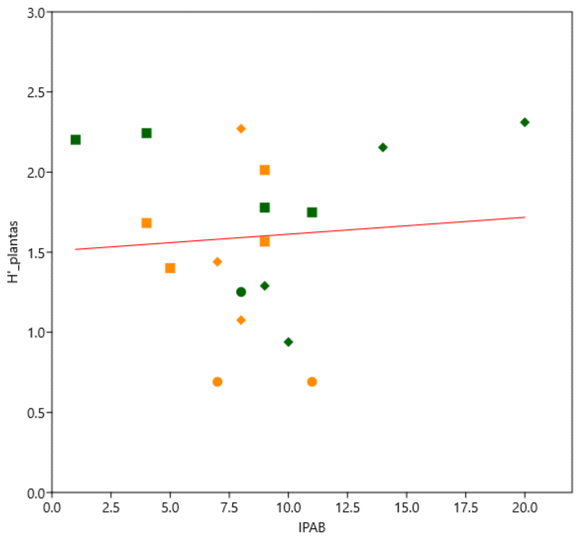


Figure 9. Least Squares Linear Model to Identify Responses of Shannon Diversity Values to the Calculated Practices Index (IPAB). Green markers represent EbA management plots, orange markers represent conventional management plots. Diamonds represent Quiejel basin plots, dots represent Balanyá basin plots, and squares represent Pixcayá basin plots. Slope: 0.010, P=0.75, r=0.08.

Interpretation of Results and Recommendations:

The results of this product provide an approximation of the performance of the EbA (Ecosystem-Based Adaptation) tool in **indicating biodiversity gains for the agricultural systems in the Quiejel, Pixcayá, and Balanyá basins at the farm level**. **Comparing agricultural plots with EbA (Ecosystem-Based Adaptation) management and conventional management allowed for the evaluation of differences in selected biological diversity indicators between management types.** This, in turn, tested quantitative tools for assessing biodiversity gains related to farm management. Additionally, the performance of different indicators to describe or explain such biodiversity gains was tested. Below is an interpretation of each aspect evaluated, along with corresponding recommendations.

Biological Diversity by Management Type:

Diversity metrics had, on average, higher values in EbA plots than in conventional management plots. For most indicators, especially those related to insect diversity, this difference was statistically significant. In this case, insects proved to be highly informative indicators when using a sampling methodology that can be standardized and represents moderate and affordable sampling efforts, provided that trained technical personnel are available to carry out the sampling. Furthermore, quantifying and characterizing the plant species with which insects interact, mainly pollinators visiting flowers, serves as an approximation of the degree of functionality of complex ecological processes within each plot.

Species Assemblages and Management:

Beta diversity analyses (NMDS with Euclidean distance and Jaccard similarity) did not allow for the identification of patterns suggesting grouping or similarity based on shared species, depending on the type of management. These results also do not align with previous studies in the agricultural highlands of Guatemala (see Escobedo-Kenefic et al. 2014), where it was found that similarity in species assemblages can be influenced by geographic proximity and shared environmental conditions in nearby sampling points. For the application of the indicators used in this consultancy to assess the implementation of EbA management, this can be an advantage, as it suggests that the response in diversity measures corresponds to local conditions determined by SBN management at the farm level and not to environmental conditions that cannot be controlled at that scale. Additionally, conventional management plots exhibited greater similarity in terms of their community composition, indicating that they may be characterized by less diverse assemblages dominated by generalist species.

Agricultural Practices Index Favourable for Biodiversity:

For this product, a test was conducted to evaluate the performance of an agricultural practices index that can be obtained from surveys conducted with farm owners or managers. Questions related to the management already applied to the plots, which can be easily weighted, were selected for inclusion in the index. On average, the index values were higher for EbA plots, but it could not be conclusively determined that it was significantly higher. This is because the index values were variable for EbA plots, whereas those calculated from surveys related to conventional management plots were more constant. This contrast may be attributed to the inherently variable nature of the EbA management approach, which is not the case with conventional management. This variability may also help explain the variability found in biological indicators, especially for EbA plots.

Relationship Between IPAB and Indicator Diversity:

The calculated index did not perform well as a predictor of insect or plant diversity metrics. However, it allowed for the identification of some interesting elements that can be considered in the evaluation of SBN management:

In all cases, the linear models showed positive but not statistically significant slopes, suggesting that a larger sample size and/or the inclusion of elements not considered in the survey could yield more informative results.

There was little variation in index values for conventional management plots, making them less informative for the models. In contrast, the variation in index values for EbA plots made it possible to test the relationship between the index and diversity metrics. This supports what was observed for alpha and beta diversity values, as the variation in EbA plots could reflect the heterogeneity resulting from the incorporation of traditional and/or alternative agricultural practices. In principle, diversity in agricultural practices is conducive to maintaining biodiversity and its interactions, unlike conventional practices, which are much more homogeneous.

General Considerations:

The results of this evaluation show that insects and their ecological metrics can be used as indicators of biodiversity gains at the farm level. Pollinating insects respond to local conditions related to management, such as the abundance and diversity of semi-natural vegetation. However, it is also advisable to include other types of ecological interactions as estimators of ecological functionality in farms. Therefore, it is recommended to include observations of ecological interactions other than floral visits to improve information about ecological processes in farms and test their performance as indicators.

Additionally, it is essential to emphasize that the success of using the indicators used in this work to describe and detect biodiversity gains based on farm management in the studied farms depends largely on the training of personnel responsible for data collection. Furthermore, the support of trained taxonomists is necessary, as the performance of the analyses used here depends to a large extent on the correct identification and classification of specimens.

References

1. Cely-Santos, M., Philpott, S. 2019. Local and landscape habitat influences on bee diversity in agricultural landscapes in Anolaima, Colombia. J. Insect Conserv. 23, 133 – 146. https://doi.org/10.1007/s10841-018-00122-w
2. Escobedo-Kenefic, N., Casiá-Ajché, Q.B., Cardona, E., Escobar-González, D., Mejía-Coroy, A., Enríquez, E., Landaverde-González, ¿P. (2022) Landscape or local? Distinct responses of flower visitor diversity and interaction networks to different land use scales in agricultural tropical highlands. Front Sustain Food Syst 6:974215. doi: 10.3389/fsufs.2022.974215. Escobedo, N.,
3. Dardón, M.J., López, J., Martínez, O., Cardona, E. (2014). Efecto de la configuración del paisaje en las comunidades de abejas (Apoidea) de un mosaico de bosque pino-encino y áreas agrícolas de Sacatepéquez y Chimaltenango, Guatemala. Ciencia, Tecnología y Salud, 1(1):15-22. doi: 10.36829/63CTS.v1i1.1 Hammer, Ø., Harper, D., Ryan, P. (2001) Past: Paleontological statistics software package for education and data analysis. Paleontol Electron, 4:1-9.
4. Chowdhury, S., Dubey, V.K., Choudhury, S., Das, A., Jeengar, D., Sujatha B., K.A., Kumar, N., Semwal, A., Kumar, V. (2023). Frontiers in Environmental Science, 11. DOI=10.3389/fenvs.2023.1146052 Taylor, D., Mohamed, Z., Shamsudin, M., Mohayidin, M.,
5. Chiew, E. (1993). Creating a farmer sustainability index: A Malaysian case study. American Journal of Alternative Agriculture, 8, 175 - 184. doi: 10.1017/S0889189300005403

Annex

Annex 1.

R Script

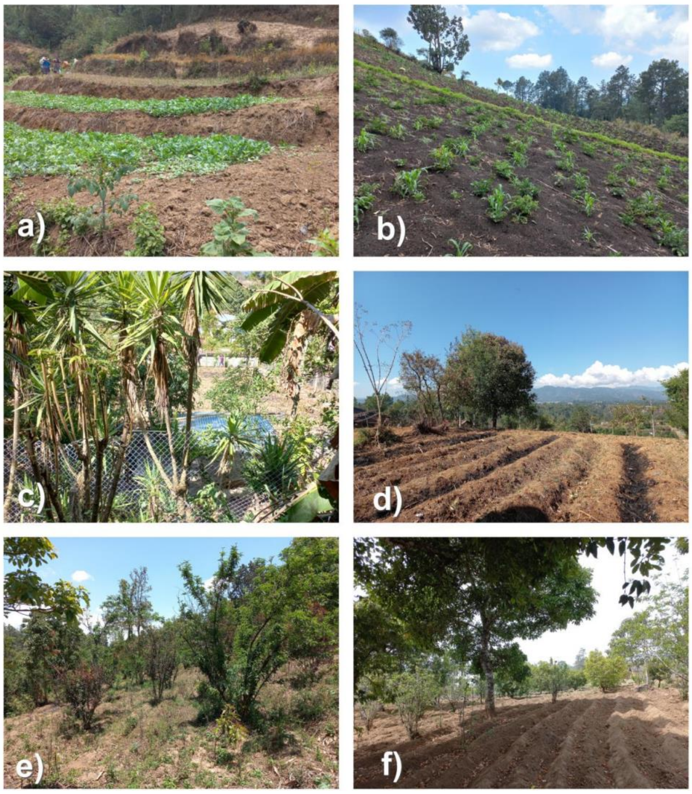
Script used for the selection of farms using a random stratified sampling.

```
#Random sampling code to select target farms
#Load packages and install if necessary with install.packages function
library(dplyr)
library(sampling)
 library(pwr)
library(tidyverse)
library(tidytext)
# Create a seedset
set.seed(1)
#Data from microwatershed Pixcaya Pampumay, available data. We enclose data and
separate them in EbA actions with coordinate. Within a Data frame.
```

```
data_PxPa <- read.csv("C:/Users/saraf/Documents/Farms_selec/Pixcayá-Papumay_R.csv")
data_PxPaEbA <- data. frame(data_PxPa$AccionesEbA, data_PxPa$X, data_PxPa$Y)
summary(data_PxPaEbA)
# There are 2,547 points of intervened farms limited in 38-unit data, considering annual and
#perennial agriculture and the minimum of farms resulting from all the microwatersheds.
The #number of interventions in farms is not uniform.
#With available data we get the samle size using the sampler package.
install.packages('sampler')
 library(sampler)

# Define random sample size
Rsamplac (N= universe,
e= tolerable margin error 5,
ci =95, p= 0.05 (default),
over=O)
rsampcalc (N = 38, e = 5, ci =95, p= 0.05, over = 0)

#Determine random sample size rsamplac we used 38 farms as a reference, reducing the p
value #significance to 0.05. To create stratified data:
 stratified <- data_PxPaEbA %>% group_by('target')
 %>% sample_n(size = 25)

#Do the same for the other 3 microwatersheds.
```

Annex 1.

Quiejel



Balanyá and Pixcayá Pampumay