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# Participatory development of agroecosystem network models for agricultural pest management in smallholder communities

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**Abstract**

Guatemala is a country characterised by extreme spatial variability, combining an enormous diversity of climates, geographies, and agroecosystems within a very small geographical scale, which complicates the development of sustainable agroecosystem design. Adding to this complexity has been the promotion of two very different rural agricultural development paradigms for smallholder farming communities: market-based commercialisation versus low-input subsistence-based approaches. In the case of the former, communities have turned to high-input, high-output agricultural systems based on a cash economy, while, in that of the latter, other communities have adopted a low-input, organic-style management system. The opposing nature of the two approaches, combined with increasing pest pressures as well as climate extremes and climate changes, makes the development of methods for the analysis and design of these agroecosystems' sustainability of paramount urgency.

Unfortunately, methods for assessing the ecological sustainability of agroecosystems have centered either on indicator-based approaches or large-scope qualitative ecosystem network (pest and beneficial organism) evaluations and have been lacking in mechanistic rigour and quantifiability, respectively. In this research we present a method for the participatory development of agroecosystem network models with stakeholder communities, which allows us to simplify these complex networks and compare agroecological networks in both a high-input a low-input setting. The participatory method was designed for effective and rapid application in low-resource settings where time and resource-intensive identification of all insects present is not feasible. The results suggest that the low-input agroecosystem has structural trophic characteristics promoting a more resilient and stable agroecological system.

***Keywords.*** *agroecological network (AEN), participatory methodology, food web, integrated pest management (IPM).*

# Introduction

Research on agricultural sustainability has fallen short in understanding the effects of different management techniques on the natural ecosystem, especially with regards to smallholder farming communities. In fact, there is a critical need for information comparing the relative performance of conventional with low-input or organic agriculture in the subsistence farmer setting, both in the short and long term. Unfortunately, the question of which agricultural system is more resistant or resilient, that is, which is best-suited to perform acceptably under shocks and longer-term trends, has generally been ignored (e.g. Zimmerer, 2013).Methods for assessing the ecological sustainability of agroecosystems have centered on indicator-based approaches or larger-scope qualitative ecosystem network evaluations and have been lacking in mechanistic rigor and quantifiably. Moreover, the vast majority of agricultural (crop growth, soil and nutrient, water balance) models ignore the role of ecological communities and pest management in the agricultural system (Tixier *et al.*, 2013), possibly due to the complexity of ecological networks or to the belief that pesticide applications effectively remove these from immediate concern. Reflecting this, decision support systems developed for integrated pest management rely mostly on mathematical models of only the immediate pest of concern for whose control the decision support system was designed (e.g., Barclay & Vreysen, 2011; Naranjo & Ellsworth, 2009). This is problematic, as the exclusion of other and likely relevant trophic relationships adds error and uncertainty to the model predictions (potentially jeopardising effective control and control strategy sustainability) and obstructs the possibility of the user adopting control policies that actively take advantage of these relationships to achieve the desired pest control.

Consequently, there is an urgent need to develop methodologies that will address the problem of how agricultural management decisions by smallholder farming communities impact the biophysical components of the agroecosystem. Here a new two-step methodological framework for the participatory and qualitative modelling of pest dynamics in complex agroecosystems is proposed. First, initial scope targeting and qualitative modelling of crop and pest dynamics through local and expert stakeholders' interviews is used to construct an agroecological network (AEN) model showing the trophic relationships in the agroecosystem. Secondly, collection of observational field data is used to verify uncertain relationships in the initial AEN models. This methodology was developed and applied to two case study regions in Guatemala. The first, in the municipality of Concepción, department of Tz'olöj Ya' (Sololá in Spanish), is characterised by a market-based commercialised agricultural system (high-input, high-output horticultural agricultural systems based on a cash economy). The second case study region, in the municipality of Chiche', department of K'iche' (El Quiché in Spanish), has adopted a low-input subsistence-based agriculture (low-input, organic-style management system based on corn, beans, and several *Curcubita* species).

The overall objective of this research was to develop a methodological framework for the participatory building of qualitative AEN models. The participatory approach of the development of the methodology allowed for the simplification of complex networks of pest-beneficial insect-crop relationships to those species of agronomic importance, which will be the base for building quantified models in future research (for comparison, Pocock *et al* (2012) identified over 500 species and 1500 interspecific interactions in a study of a 125-ha farm in the UK). This line of research, by allowing for the analysis of the effects of the choice of agricultural management technique, has potential applications in developing solutions to the growing resistance to pesticides, in increasing awareness of pesticide effects on human health, and in understanding the unexploited benefits of the strong pest-suppression potential of ecological regulatory processes.

### Case study regions

Guatemala offers an interesting opportunity to compare alternative agricultural development approaches since some villages have opted for intensive, export-based production of horticultural crops, while others have opted for production of traditional crops for self-sufficiency, with only surplus product being brought to the market. The close geographical proximity of these very different development approaches offers an exceptional opportunity to compare their effectiveness and sustainability. In the case of the municipality of Concepción (Tz'olöj Ya', 14º46'44"N 91º08'48"W), the Canadian IDRC-funded PROSOL Project has aimed to increase farmers' incomes in the region through aid in the formation of cooperatives and the commercialisation of high-value crops, in particular export vegetables. At the same time, CARITAS (a branch of the Catholic Church) has promoted a low-input development approach centred on traditional subsistence crops in the nearby municipality of Chiche'(K'iche', 15º00'38"N 91º03'54"W). The close geographical proximity (see Figure 1) yet very different agricultural systems in Concepción and Chiche' offers an exceptional opportunity to develop and test the proposed methodology.

Both case study regions are part of the same ecoregion: the Central American pine-oak forest. This ecoregion is characterised by a temperate climate with limestone highlands, northern limestone lowlands, metamorphic lands and piedmont volcanic lands. It is an important migratory route offering a habitat to birds and insects that migrate between high and low altitudes (Tolisano & Mercedes Lopez, 2010). On the other hand, the socioeconomic and agronomic situation in each region differs significantly. In Concepción, the high-input conventional agriculture adopted by some farmers has boosted their incomes, though at the expense of environmental degradation. On the other side, the low-input subsistence agriculture approach adopted in Chiche' has shielded farmers from the vagaries of market prices as well as from most of the more severe environmental degradation issues affecting Concepción; however, concerns have been raised regarding its socioeconomic sustainability, especially as non-agricultural economic needs (such as education or health care) begin to highlight the vulnerabilities of a low-cash system. It is important to note that this low-cash system has also encouraged the communities in K'iche' to find local home-made solutions to pest management.


**Figure 1.Geographic location of the two site study regions: Concepción (Tz'olöj Ya', 15º00'38"N 91º03'54"W) and Chiche' (K'iche', 15º00'38"N 91º03'54"W) (Google Earth Pro, 2015).**

# Methodology

We propose the following four-step approach to identifying trophic relationships in low-resource smallholder farming settings:

1. Use of stakeholder interviews to identify species of agronomic importance to include in AEN model.
2. Use of general field traps to capture and identify beneficial insects.
3. Comparison of collected beneficial with the literature to identify potential hosts.
4. Analysis of population data to further elucidate trophic relationships.

As mentioned above, the methodology used in this study is innovative as it develops a framework for the participatory building of qualitative AEN models. While, in most cases, it does not allow for the identification of each organism to the species level, it does allow, with minimal resources, for the identification of the major trophic interactions of importance in the agroecological system.

### Stakeholder interviews

First, initial scope targeting and qualitative modelling of crop and pest dynamics through local and expert stakeholders' interviews were used to form the base of the agroecological network (AEN) model. Indeed, it combined the practical knowledge of farmers and experts in entomology and agronomy. Semi-structured interviews with local farmers, agronomists, and entomological experts were conducted in order to identify the crops, pests, and beneficial insects of importance in the region. In each case, the interviewee was asked to identify crops of importance, followed by the pests and then beneficial insects of importance. The interviewee wrote each one on a piece of paper, using lines to connect predator and prey and identify trophic interactions.

Farmer-built models were used as the model backbone to identify the crops and pests of importance to include in the model, while the input of agronomists was used for species identification and disambiguation of common names. Since the large majority of farmer and extension worker-built models did not include beneficial organisms, input from entomologists was used to add higher trophic levels to the model.

### Field data collection

Collection of observational field data was then used to identify which beneficial insects were present in the area (as the majority of them had not been identified in the previous step). The field data was collected by monitoring the plots of six farmers form Concepción (total of 31 plots of sizes varying from 722 $m^2$ to 2166 $m^2$, encompassing carrots, cabbages, tomatoes, beans, onions, and potatoes), and 14 plots in Chiche' (of sizes varying from 676 $m^2$to 722 $m^2$ and encompassing corn, beans, and *Curcubita sp*). The methodology presented by Arévalo-Rodríguez and Schuster (2014) was followed to capture insects in the field. In every plot, two to three yellow plastic plates 15 cm in diameter were dispersed throughout the plot. Each plate was filled with a solution of soapy water and left at the surface of the soil for a period of 24 h. To reduce logistics demand, only insects of interest (pests, generalist predators, and frequently appearing parasitoids) were studied. The presence and abundance of these insects was then recorded, and unknown insects (mostly beneficial) were stored in 80% alcohol solution for later identification.

### Comparison with the literature

In general, parasitoid host identification proved the most challenging part of the research. A literature review was conducted to identify the known parasitoids of each pest present in the field, and pictures of these parasitoids were then compared with the collected field samples. Using this method, several tentative identifications and host-parasitoid relationships were identified.

### Population data analysis

In order to strengthen the conclusions arrived to from literature data, the correlations between the populations of parasitoids and presumed hosts across different sites and dates was used to increase the level of certainty in the AEN network. Strong positive correlations, especially between adults of both species, were considered supportive of a parasitoid-host relationship.

## Results

The two AEN models developed in Concepción and Chiche' are shown in Figure 2 and 3. In each model, crops are shown in the lower row, followed pest and diseases in the middle row and the beneficial insects in the top row. As identification to the species level was often not attainable, and concidering that the most important aspect for this research was the consistency of the identification of each insect in the field (rather than its precise nomenclature), several species were identified by number.

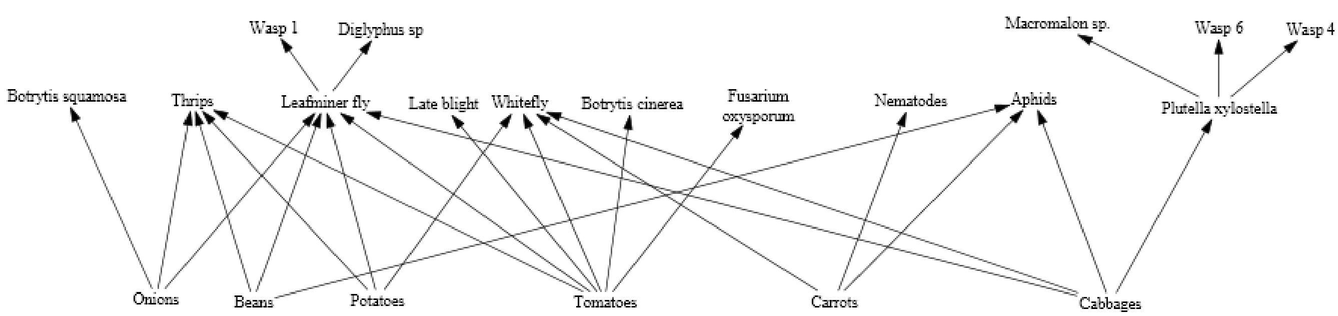


**Figure 2. Results of AEN analysis in Concepción, Tz'olöj Ya'. The network was built with farmers, agronomists, and entomologists along with field data taken during the months of February to April. The lower row includes crops, the middle row insects and diseases, and the upper row beneficial insects.**

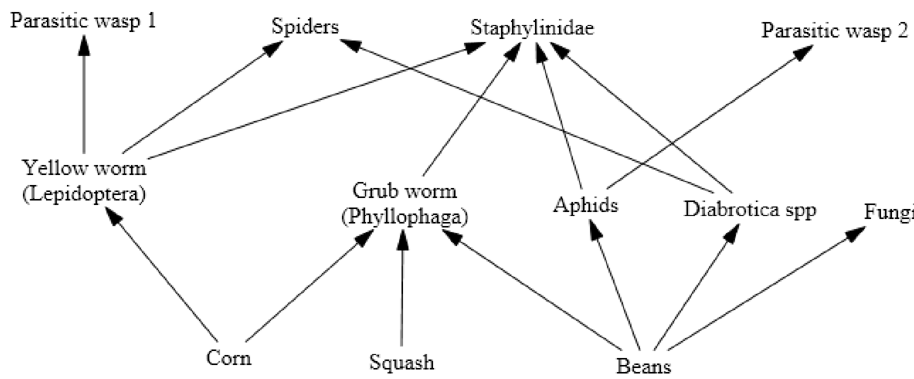


**Figure 3.Results of AEN analysis in Chiche', K'iche'. The network was built with farmers, agronomists, and entomologists along with field data taken during the month of April. The lower row includes crops, the middle row insects and diseases, and the upper row beneficial insects.**

For instance, wasp 1 (see Figure 4a) was described as 2-3 mm long wasp with long and curved antenas as well as a red abdemen; wasp 4 (see Figure 4b) was identified as a 7 mm long black wasp with short antenas; finally, wasp 6 (see Figure 4c) was described as a thin wasp with 2mm-long antenas and orange abdomen.In Chiche', seeding started in April, reducing the amount of days for data collection. As such, photos and specific identification of the organisms mentioned in the stakeholder interviews was not possible for all organisms, in particular parasitic wasps.

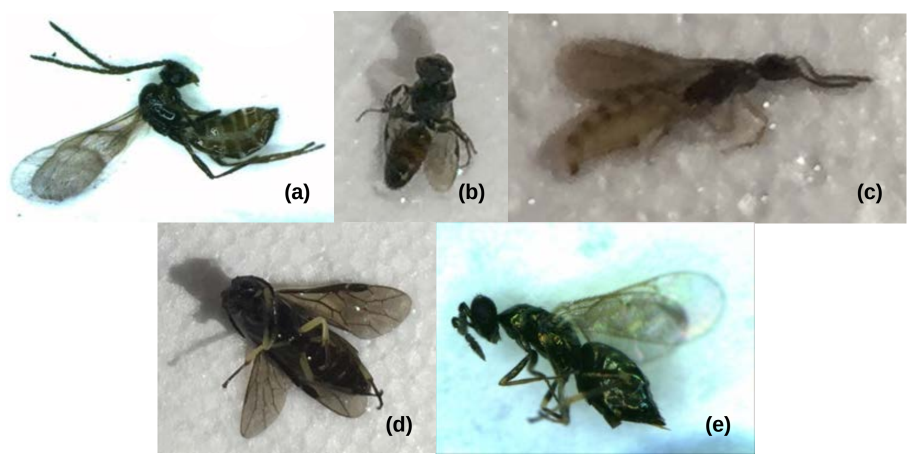


**Figure 4.Wasps identified on the field of Concepción, Tz'olöjYa': named accordingly as (a) wasp 1, (b) wasp 4, (c) wasp 6, (d) *Macromalon sp*, and (e) *Diglyphus sp*.**

By comparing the two AEN models developed for the different study regions, it is possible to draw conclusion on the state of the local ecosystems. For instance, in the in case of Concepción, there was an average of 3.67 different pests and diseases attacking a single crop, whereas in Chiche' this number was reduced to 2.33 pests and diseases per crop. On the other hand, only 2/6 pest have a predator in the Concepción AEN, as compared to 4/4 pests in Chiche'. This was reflective of the general level of farmer concern regarding pests in each region. Interestingly, the Concepción AEN consists entirely of "food chains," where predators are generally host-specific and only attack one prey. Contrarily, the Chiche' AEN shows a more complex, "food web" structure, with several generalist species competing for the same prey and, at the same time, relying on different prey for survival.

# Discussion

The results of the two AEN models provide a simplified illustration two agroecosystems, one with high input (horticultural) agriculture and one with low-input (subsistence crop) agriculture was performed. The results suggest that the latter system contains a lower amount of pests and diseases diversity per crop, which could be due to either the cropping system choice or, potentially, to the higher amount of pesticides applied in the former. Similar observations were found by Pontius *et al.* (2002), who report that, in an experiment with one insecticide-treated and one untreated rice paddy plot, the untreated plot, ironically, escaped a pest population outbreak suffered by the treated one. This was explained by the higher presence of predators untreated plot early on in the season, which reached levels high enough to prevent a pest outbreak later in the season.

At the same time, the higher-level trophic interactions in the high-input agricultural system (Figure 2) consisted mainly of specific parasitic interactions between beneficial insects and their pests, whereas the low-input agriculture system (Figure 3) included two generalist predators alongside specialist parasitoids. As also reported in Pontius *et al.* (2002), generalist predators offer strong pest control potential, as they are able to alternate preys and feed on a variety of insects present in the field, thus freeing the predator population from limitation by any single pest population. This allows predators to build up their populations before the pest populations also built up to significant levels, reducing the chances that pest populations can escape control by natural enemies. This could be an explanation for the reduced number of pests identified in the food web diagram by the farmers in Chiche', where no insecticides are used. It is important to note that other pests may exist in Chiche' but that, due to successful natural control and low populations, these and their damage would not have been observed by farmers and would therefore not have been identified in the AEN diagram.

The presence of generalists in the Chiche' AEN creates diamond-like food web structures, where two species compete for a common crop and are the prey of a common generalist predator. Krivan (2013) studied species interactions in di- and tri-trophic food web modules and concluded that generalist flexible predators in diamond-like food web can enhance species richness and the resilience of the system. This provides further support to the hypothesis that the low-input agricultural management conserves the natural tendency of native agroecological systems to reduce pest appearances.

Overall, the unique participative approach by which the AEN qualitative models where developed will allow for the quantitative monitoring and understanding of pest management intervention impacts on the local AEN (unlike most integrated pest management interventions). It uses local knowledge to narrow down the range of species of interest to a manageable number (unlike most AEN research) while combining traditional and researcher knowledge to increase communities' sense of ownership in the model and its results and recommendations through the participatory process. As compared to other ecological modelling approached, such as agent-based models, this methodology is limited in its ability to precisely identify and model the behaviour of each species (while agent-based models can explicitly model the exact location and behaviour of each individual, this approach is restricted to a coarser grain of resolution and cannot analyse the impacts of intra-field plant spatial arrangement). However, for the analysis of landscape-level dynamics and more complex food web interactions, a coarser modeling scale may be more appropriate, given logistic and data limitations.

# Conclusion

This study developed and applied a methodology for participatory, qualitative agroecological network (AEN) modelling in two study regions in the highlands of Guatemala. The results show that the methodology functions reasonably well for the simplification of the agroecological system into its major species of agronomic importance, as well as the identification of the main relationships and dynamics within the system, in a limited-resource setting. The AEN models developed in the case studies also suggest that high-input ("conventional") management techniques enhance linear chain-like AEN structures that most likely reduce the agroecosystem's potential for resilience and long-term pest suppression. On the other hand, low-input (subsistence) management techniques may help to conserve the agroecosystem complexity through the presence of generalist predators that keep pest populations at a low stable level. Future research will consist of field observations of parasitism in order to verify the parasitoid-host interactions identified here, followed by quantification of the model using field population data in order to allow for quantitative predictions and model testing and validation.

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