# Implications of changes in land cover and landscape structure for the biocontrol potential of stemborers in Ethiopia

Kebede, Y., Bianchi, F., Baudron, F., Abraham, K., de Valença, A., & Tittonell, P.

# Implications of changes in land cover and landscape structure for the biocontrol potential of stemborers in Ethiopia

Yodit Kebede[a,*], Felix Bianchi[a], Frédéric Baudron[b], Kristin Abraham[c,d], Anne de Valenca[a], Pablo Tittonell[a,e]

*[a]Farming Systems Ecology, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands; [b]International Maize and Wheat Improvement Center (CIMMYT), 12.5 km Peg Mazowe Road, Harare, Zimbabwe; [c]Laboratory of Geo-information Science and Remote Sensing, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands; [d]Eleaf, Hesselink van Suchtelenweg 6, 6703CT Wageningen, The Netherlands; [e]Instituto Nacional de Tecnología Agropecuaria (INTA), Modesta Victoria 4450 - CC 277(8400), San Carlos de Bariloche, Río Negro, Argentina.*

Corresponding author: Yodit Kebede, Farming Systems Ecology, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands; Tel: +31 (0)317 481191; Fax: +31 (0)317 418094 ; E-mail: yodit.kebede@wur.nl

## Abstract

The land cover and structure of agricultural landscapes may influence the abundance and diversity of natural enemies of crop pests. However, these landscapes are continuously evolving due to changing land uses and agricultural practices. Here we assess changes in land use and landscape structure in a landscape in the Rift Valley region of Ethiopia, and explore the impact these changes are likely to have on the capacity of the landscape to support communities of natural enemies of maize stemborers *Busseola fusca* (Fuller). Land use and landscape structure were assessed in three periods over the last 30 years using focus group discussions with farmers and land use analysis through remote sensing. Natural enemies were sampled in maize fields adjacent to simple hedgerows, complex hedgerows, enset fields and khat fields at 1, 10 and 30 m using pitfalls and yellow pan traps in 2014 and 2015. The landscape analysis indicated that landscapes in the study area changed from maize dominated to more diverse small-scale and fragmented agroecosystems with a higher proportion of perennial crops. Maize fields adjacent to enset and complex hedgerows hosted significantly more predators (15.1 ± 9.8 and 22.3 ± 5.1 per trap at 1 m from the border, respectively) than maize fields adjacent to khat and simple hedgerows (7.2 ± 1.1 and 7.3 ± 1.7 per trap at 1 m from the border), and the effects of border type decreased with distance from the border. The abundance of parasitoids and parasitic flies were not influenced by border type. Our findings suggest that the changes in land use and landscape structure may have influenced the capacity of the landscape to support populations of natural enemies of stemborers in different ways. On the one hand smaller field sizes have resulted in more field borders that may support relatively high predator densities, on the other hand the area of khat increased and the area of enset

decreased, which may have a negative effect on predator densities. The overall outcome will depend on the interplay of these opposing effects.

**Keywords**: land use, maize, agroecosystem, *Busseola fusca* (Fuller), natural enemies, landscape ecology

## Introduction

Agriculture benefits from biocontrol services provided by natural enemies of crop pests (Losey & Vaughan, 2006). Natural enemies require resources, such as food and shelter, which may be scattered in space and time across the landscape. The composition and spatial arrangement of crop and non-crop habitats in the landscape mosaic may therefore influence abundance and diversity of natural enemies and the biocontrol function they provide (Bianchi et al., 2006; Landis et al., 2008; O'Rourke et al., 2011; Woltz et al., 2012). However, agricultural landscapes are not static, but subject to continuous changes. For instance, land use dynamics and changing agricultural practices may lead to changes in land cover (the biophysical cover of the earth's surface) and landscape structure (the spatial pattern of landscape elements and the connections between them). Such changes may influence resource availability for natural enemies and the disturbance levels they are subjected to (Rand et al., 2006; Tscharntke et al., 2005). Yet, little is known about the consequences of land cover changes for the natural enemy complex across agricultural landscapes and their potential to suppress crop pests (Werling et al., 2014). Such information is even scarcer in sub-Saharan Africa than in Europe or North America (Lemessa et al., 2015b; Shackelford et al., 2013).

African agroecosystems are complex socio-ecological systems that are managed for multiple outcomes, including food, nutritional security and income generation. They can also be diverse; for example in the Rift Valley region of Ethiopia, agroecosystems are generally fine-grained landscape mosaics composed of hedgerows (e.g. *Euphorbia spp*, *Lantana spp*), agricultural fields, grasslands, forest patches and scattered trees. Dominant crops include maize (*Zea mays* L.), enset (*Enset ventrocosum (*Welw.) Cheesman, a perennial tuber crop), khat (*Catha Edulis* (Vahl) Forssk, a perennial stimulant crop), coffee (*Coffea arabica* L.), common beans (*Phaseolus vulgaris* L.) and teff (*Eragrostis tef* (Zucc.) Trotter, a small grain cereal). These crops are generally produced in small fields of usually less than one hectare, and combined with livestock rearing and multipurpose trees (Abate et al., 2000; Abebe 2006, Lemessa et al., 2013).

In the Hawassa area, in the Rift Valley region of Ethiopia, there has been a trend of decreasing maize production and increasing cash crop production, in particular of khat and sugar cane (Abebe, 2013, Abebe, 2009). Because of the doubling of the population in the last 30 years (Dira and Hewlett, 2016) and lack of off-farm employment opportunities, farms have been subdivided into ever smaller farms and parcels, and non-cropped land has been converted to agriculture. These changes may impact the population of natural enemies of crop pest through two concomitant effects: (i) different crop and crop border vegetation types may provide different resources, microclimates and disturbance levels for natural enemies, and (ii) field size may affect the crop colonization process by natural enemies.

Maize is a major food crop in the Rift Valley region of Ethiopia, where yields are often low (average of 2.4 t $ha^{-1}$ in 2013; Kassie et al., 2014) because of low input use, erratic rainfall patterns, degraded soils and pest infestations (Worku et al., 2011). The stemborer *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) is a major pest of maize in the region (Gebre-Amlak, 1989; Getu, 2001), where crop losses may be as high as 26% by the first generation and up to 100% by the second (Gebre-Amlak, 1989). Typically, farmers in the Rift Valley do not control *B. fusca* with insecticides because they often cannot afford them, and because insecticides are not very efficient against larvae that tunnel into maize stems and cobs (Kfir et al., 2002). There is a suite of natural enemies that attack different stages of *B. fusca*, and that may provide top-down control (Bonhof et al., 1997; Gounou et al., 2009). However, little is known on the impact of the above-mentioned changes in land use and landscape structure on the natural enemy complex and on the biocontrol potential of *B. fusca*.

This paper aims to fill this knowledge gap (i) by analyzing how agroecosystems have changed in the last three decades in terms of land cover and landscape structure in a study landscape of the Rift Valley region of Ethiopia, and (ii) by assessing how adjacent crops and habitats influence the abundance of important natural enemy groups of *B. fusca* in maize fields in the same landscape. We hypothesize that (i) changes in social, economic and political drivers have resulted in changes in land use and landscape structure between 1980's and 2014, and that (ii) maize fields adjacent to relatively stable habitats (hedgerows and enset fields) host a larger community of natural enemies than maize field adjacent to more disturbed land uses (maize and khat fields).

## Material and methods

### *Study area*

The study area is located in the district of Tula near lake Hawassa in the Ethiopian Rift Valley (latitude 7˚0'25'' - 6˚56'35'' North and longitude 38˚27'58'' - 38˚29'47'' East; Figure 1). The area has a moist to sub-humid warm subtropical climate with annual precipitation ranging from 750 to 1200 mm in a bimodal distribution pattern from March to April and June to August (Dessie and Kleman, 2007). The landscape is heterogeneous and the average farm size is below one hectare of arable land (Dessie and Kinlund, 2008; Dessie and Kleman, 2007). Farms are dominated by mixed crop-livestock systems with maize, bean, enset, and khat as main crops (maize and bean are often intercropped in the same field).

## *Focus group discussions*

To assess farmers' knowledge and perceptions about important historical periods of land cover change and the nature of these changes, a focus group discussion was conducted with 20 key informants from Tula. Participants were asked to draw a time line to identify periods of major changes in land cover, and to estimate the proportion of each land cover type and major crops. The discussions revealed that the years 1984, the start of the communist Derg regime, and 1998, the end of the same regime, represented key transitions for land cover change. These milestones years were used for selecting satellite images for land cover analysis.

## *Land cover classification*

A quantitative land cover analysis of Hawassa area was conducted for 1984, 1998 and 2014 using Landsat 8 OLI/TIRS data for 2014 and Landsat 5 TM data for 1984 and 1998. All images had a 30 x 30m resolution. The analysis focused on an area of 5 x 6 km area around Tula, referred to as the study area in the rest of the paper (Figure 1). After radiometric correction, the different bands of each image were stacked into a single image. An object-based classification was conducted for 1984, 1998 and 2014 in which related pixels were grouped in objects using eCognition (Blaschke, 2010) and cropped and non-cropped areas could be distinguished. Using a phenology based classification approach, cropland was further subdivided into the following classes: annual, perennial, perennial dominated mixed crops, and annual dominated mixed crops (Wang et al., 2011). Fields were classified as mixed crops when their size was smaller than the resolution of the image (30 x 30m) and could not be classified as annual or perennial crops. The accuracy of the classification was assessed for 1984 using aerial images from 1972 and a topographic map from 1988, and was 77.1%. For 2014 the accuracy was assessed by ground truthing with 30 GPS points per class and was 75.8%. These accuracy levels fall within the 67 - 87% range that has been reported in other pixel-based classification analyses in Ethiopia (Meshesha, 2013). Changes in land cover were assessed as the difference in the land cover class (in ha and percentage) through pixel-by-pixel comparisons between 1984 and 1998, and between 1998 and 2014 using Erdas software (Lu et al., 2004).

***Landscape metrics***

To assess changes in landscape structure between 1984, 1998 and 2014, we selected landscape sectors of 1 km radius centred around each of the 16 focal maize fields selected for the natural enemies density assessment (see below; Figure 1). The area of perennial crops, mixed crops and annual crops were assessed within each sector for 1984, 1998 and 2014. The proximity index between annual and perennial crops, patch density and edge density of each land cover type were calculated using Fragstats (McGarigal et al., 2002). The proximity index (without dimension) is a measure of the closeness of patches and is derived by dividing the summed patch area by the nearest patch to patch distance between annual and perennial crops. High values of the proximity index indicate small distances between annual and perennial crops, and can be considered as a proxy for the potential insect population exchange between annual and perennial crops. Patch density is calculated as the number of patches of each land cover class per unit area (3.14 $km^2$). Edge density (m/ha) is a measure of the perimeter-to-area ratio of patches, calculated for each land cover class by dividing the total edge length of patches by the area of the landscape sector (3.14 $km^2$).

### *Arthropod sampling and identification*

The abundance and diversity of arthropods were assessed in maize fields in Tula in 2014 and 2015. Farmer's maize fields that bordered an enset field, a khat field, a 'simple' hedgerow and a 'complex' hedgerow were selected. Four fields were selected for each maize field-border combination, for a total of 16 maize fields. All enset crops were at least 3 m high, while khat crops (also perennial) were at least 0.5 m high. Hedgerow-maize interfaces were at least 30 m long and hedgerows were classified as 'simple' or 'complex' based on a visual assessment of vegetation density and diversity (Bayley, 2001). Hedgerows with less than 50% vegetation cover and less than 8 plant species were considered 'simple', while hedgerows with vegetation cover of 75% or higher, more than 8 plant species and at least 2 m wide were considered 'complex' (Appendix 1). The maize fields were at least 40 x 30 m, and had a minimum density of 4 plants per $m^2$. Maize was intercropped with bean in 15 fields, and with enset in one field. Tilling and weeding are common cultivation practices in maize and khat fields, but not in enset.

Yellow pan traps and pitfall traps were placed in the maize fields at 1, 10 and 30 m from the maize field-border interface. Each field had two transects of traps, separated by 10 m, hence each field had 6 yellow pan traps and 6 pitfall traps. The pitfall and pan traps were placed at 1 m distance from each other, and referred to as sampling station. Pitfall traps consisted of a 10 cm diameter plastic cup, filled with 30 ml water and a droplet of detergent to break the surface tension. A cover was placed over the trap at

5-10 cm height to prevent rainwater infiltration, without inhibiting arthropod movement. The yellow pan traps consisted of 20 cm diameter yellow plastic dishes, filled with 30 ml water and a droplet of detergent, placed at 80 cm height on a pole. The traps were emptied after 3 days and arthropod samples were transferred to plastic tubes with 70% ethanol. In 2014, two samplings were conducted in the first week of October when maize plants were mature, while in 2015 one sampling was conducted in the first week of October when maize plants were mature and a second one in the first week of November when maize plants were senescent.

Arthropod samples were sorted and natural enemies of stemborers were identified at the family level using identification keys of Polaszek et al. (1998) and Getu (2001), and sorted by morphospecies. All other specimens were identified at the order level. All specimens were counted and classified as parasitoid wasps, parasitic flies, ants, rove beetles, spiders and other predators (Appendix 3).

### ***Data analysis***

The relationship between the abundance of five stemborer natural enemy groups (parasitoids and parasitic flies combined, ants, rove beetles, spiders and other predators), and border types were analyzed using generalized linear mixed models. Border type (enset, khat, simple hedgerow and complex hedgerow), distance from border (1, 10, and 30 m), year (2014 and 2015) and maize stage (mature and senescing) were fixed factors, and the variable “field” was taken as a random factor. The data from the traps in the two transects (pseudo-replicates) were pooled. The data from the pitfalls and yellow pans were analyzed separately and also as pooled samples per sampling station. Here we report the results of the analysis with the pooled pitfall and yellow pan samples.

In all the models, four discrete stochastic distributions were considered for the error distribution of the data: Poisson, negative binominal, zero-inflated Poisson and zero-inflated negative binominal. The models, with farm as random factor, were fitted using glm (for Poisson distribution), glm.nb (for negative binominal distribution) and zeroinfl functions (for zero inflated Poisson and negative binominal distributions) using the R packages MASS (Venables and Ripley, 2002) and PSCL. Akaike's Information Criterion corrected for finite sample sizes (AICc) was used to rank and select models (Burnham and Anderson, 2003). The negative binomial error distribution had the lowest AICc in all analyses. Model selection of explanatory variables was conducted using the dredge procedure in R package MuMIN. This procedure generates a complete set of sub-models with combinations of the terms of the full model, and sorts the sub-models on the basis of AICc values and associated Akaike weights.

## Results

### ***Land cover change***

The land cover analysis indicated major changes in the study area between 1984 and 2014. The area of perennial crops increased by 173%, while the area of annual crops, grassland, bare soil and mixed crops decreased by 98, 90, 53, 44%, respectively (Figure 2; Appendix 2). The focus group discussion in Tula confirmed these trends, and indicated that maize was the dominant crop in the 1980's with an estimated cover of 55%, which decreased to 40% in 2014 (Figure 3). Khat increased from less than 5%

to 30%, homegarden from 5 to 10% and enset decreased from 30 to 20% (Figure 3). Maize is mostly intercropped with bean.

The changes in land cover are also reflected in the structure of the landscape. The mean area of perennial crops in the sectors around focal maize fields increased (Figure 4A), while the patch density decreased slightly from 1984 to 2014 (Figure 4B). This indicates that perennial crops cover a larger proportion of the landscape and are arranged in larger or more interconnected patches. The area, patch density and edge density of mixed crops remained more or less stable (Figure 4A, B and C). In parallel there has been a strong decrease of the area, patch density and edge density of annual crops (Figure 4A B and C), indicating that maize is grown in smaller fields, which are included in the mixed crop category. The proximity index increase three-fold between 1984 to 2014, indicating shorter distances between annual and perennial crops. This suggests that the Tula landscape has become increasingly dominated by small-scale mosaics of mixed and perennial crops.

### ***Abundance of natural enemies of maize stemborers***

In 2014 and 2015 a total of 690 samples were collected, yielding 25,360 specimens belonging to 146 morphospecies from nine orders (Diptera, Hymenoptera, Coleoptera, Hemiptera, Arachnida, Orthoptera, Neuroptera, Phthiraptera and Lepidoptera; Appendix 3). Out of the total specimens 35.6% were considered to be potential natural enemies of *Busseola fusca*, which consisted of Formicidae (56%), Staphylinidae (25%), parasitoid wasps (14%), spiders (14%) and parasitic flies (10%).

The outputs of the generalized linear mixed models indicated that (i) maize fields adjacent to enset and complex hedgerows had significantly higher abundances of predators as compared to maize fields adjacent to khat and simple hedgerows, and (ii) there were significant interactions between border type and distance, and border type and year (Table 1; Figure 5). These interactions indicate that the effect of border type on predator abundance in maize vary in different years and at different locations within the field, and can therefore not be generalized. The positive effect of enset and complex hedgerow on predator abundance was most pronounced at the crop interface, 1 m within the maize field (Figure 5A). By contrast, border types did not influence the abundance of parasitoids and parasitic flies in maize fields, and their abundance was only significantly affected by maize stage, with lower abundances in senescing maize (Table 2; Figure 5D). When focusing on the main predator groups, regression analysis indicated that ants were most abundant near complex hedgerow-maize interfaces (Figure 6A), rove beetles were most abundant near enset-maize interfaces and complex hedgerow-maize interfaces (Figure 6B), and spiders were not influenced by border type and distance from the field edge (Figure 6C).

## Discussion

While there is increasing recognition that landscape context can influence natural enemy communities, little is known about the influence of changes in landscape context on natural enemy populations and the associated potential for biocontrol (Chaplin-Kramer et al., 2011). We show that our study area in the Rift Valley region of Ethiopia has become more fine-grained due to farm subdivisions, resulting in smaller field sizes evidenced by the disappearance of the annual crop class, which includes annual crop fields larger than 30 x 30 m, and a strong increase in the proximity index for annual and perennial crops (Figure 4). In addition, the focus group discussion revealed that maize monocrops have been progressively replaced by khat. We also show that the abundance of some, but not all, stemborer natural enemy groups in maize crops are positively influenced by adjoining complex hedgerows and enset fields. This effect was more prominent at the border of the maize fields for predators but not for parasitoids and parasitic flies.

Ethiopian agricultural landscapes are continually changing because of social and economic drivers, such as population growth (Dira and Hewlett, 2016) and changes in farmer livelihood strategies, often resulting in a shift from food crops to cash crops (Assefa and Bork, 2014; Meshesha et al., 2013), and the subdivision of fields into smaller units. The changes in landscape composition of Tula confirm this trend, exemplified by the reduction in the proportion of enset and maize (food crops), an increase in the proportion of khat (cash crop) and homegardens (Figure 3), and a strong increase of the proximity index (Figure 4D). Therefore, the remaining maize fields tend to have a higher perimeter-area ratio (because of reduced field sizes) and are more likely to be bordered by a perennial element (because the increase of the area perennial crops).

Our findings indicate that maize fields bordered by an enset field or a complex hedgerow are associated with higher predator densities than maize fields bordered by a khat field or a simple hedgerows (Figure 5). Enset vegetation is structurally complex and provides a more humid microclimate than maize fields, while complex hedgerows are relatively undisturbed habitats that may provide floral resources for natural enemies (e.g. *Lantana camara* L.). While khat is a perennial crop, it has a relatively simple vegetation structure and often treated with chemical insecticides, which may explain the relatively low predator density at khat-maize interfaces (Figure 5). In addition, there has been increasing number of homegardens in Tula because of the increase of the population density. Homegardens can be very diverse in composition and structure (Abebe et al., 2006), providing high quality resources for nesting and foraging for a diverse natural enemy community (Lemessa et al., 2015b). The common practice of maize-legume intercropping can result in increased parasitism rates (Skovgard and Päts, 1996; Chabi-Olaye, 2005) and lower stemborer densities than under maize monocropping (Songa et al., 2007; Midega, 2014). Thus, the changes in crop types in Tula during the last three decades have likely influenced predator densities in maize agroecosystems, which can be positive (e.g. enset-maize and complex hedgerow-maize interfaces) or negative (e.g. khat-maize interfaces).

While predators have been associated with suppression of stemborers, there is little quantitative information available on the stemborer life stages they attack (Bonhof, 2000, Getu, 2001). In our study, ants and rove beetles were the two most abundant predator groups, which have been reported to feed on stemborer eggs and larvae (Bonhof, 2000). The association of ants with enset fields and complex hedgerows is in line with results of Lemessa et al. (2015a), who found that ant abundance was positively related to tree cover. Enset fields may also offer favorable conditions for rove beetles through the provision of a litter layer of fallen leaves, and the presence of animal manure which is used as amendment (Amede and Taboge, 2007). The influence of neighboring habitat on spider abundance was not clear, and there was no apparent spatial pattern in the fields. This suggests that spiders may have colonized these habitats by ballooning, which may involve dispersal at a scale of several kilometers (Schmidt and Tscharntke, 2005; Bianchi et al., 2017).

Parasitoid abundance was relatively low and could be related to the fact that we sampled during the maturity and senescence stages of maize when resource levels in maize are low (Getu, 2001; Yitaferu and Walker, 1997). However, our findings are in line with other studies reporting typical parasitism rates in stemborer larvae below 10%

(Kebede, unpublished data; Mailafiya et al., 2011). The abundance of parasitoids and parasitic flies was not related to the distance from bordering habitats, which is in line with data from mark-recapture studies showing that parasitoids can easily cross distances in the order of tens of meters (Schellhorn et al., 2014).

## Conclusion

Overall, our study shows that the agricultural landscape of Tula is highly dynamic and has become more fine-grained with a higher proportion of khat. These findings suggest that the changes in land use and landscape structure may have influenced the capacity of the landscape to support populations of natural enemies of stemborers in different ways. The smaller field sizes have resulted in more field borders that can support relatively high predator densities in the case of maize-enset and maize-complex hedgerow interfaces. The small maize fields may also foster an effective colonization by predators from adjoining crops and habitats, as the distance from the field edge to the field interior is often less than 30 m, well below the colonization distance of most natural enemies (Bianchi and van der Werf, 2003; Tscharntke et al., 2007). On the other hand the area of khat increased and the area of enset decreased, which may have a negative effect on predator abundance. The overall outcome of the landscape changes for natural enemy abundance and the associated potential for stemborer control will depend on the interplay of these opposing effects, and merits further research.

## Acknowledgments

This work was implemented by CIMMYT and Wageningen University as part of the projects ATTIC (Trajectories and Trade-offs for Intensification of Cereal-based systems) and SIMLESA (Sustainable Intensification of Maize-Legume Cropping systems for Food Security in Eastern and Southern Africa), made possible by the generous support of CRP MAIZE (www.maize.org) and the Australian Centre for International Agricultural Research (ACIAR) . Any opinions, findings, conclusion, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of CRP MAIZE and ACIAR.

## References


Abate, T., van Huis, A., Ampofo, J.K., 2000. Pest management strategies in traditional agriculture: an African perspective. Annu. Rev. Entomol. 45, 631-659.

Abebe, T., 2013. Determinants of crop diversity and composition in Enset-coffee agroforestry homegardens of Southern Ethiopia. Journal of Agriculture and Rural Development in the Tropics and Subtropics 114, 29-38.

Abebe, T., Wiersum, K., Bongers, F., Sterck, F., 2006. Diversity and dynamics in homegardens of southern Ethiopia. Tropical Homegardens. Springer, pp. 123-142.

Abebe, T., Wiersum, K.F., Bongers, F., 2009. Spatial and temporal variation in crop diversity in agroforestry homegardens of southern Ethiopia. Agroforestry Systems 78, 309-322.

Amede, T., Taboge, E., 2007. Optimizing soil fertility gradients in the enset (*Ensete ventricosum*) systems of the Ethiopian highlands: trade-offs and local innovations. Advances in integrated soil fertility management in Sub-Saharan Africa: challenges and opportunities. Springer, pp. 289-297.

Assefa, E., Bork, H.R., 2014. Deforestation and forest management in southern Ethiopia: investigations in the Chencha and Arbaminch areas. Environ. Manage. 53, 284-299.

Bayley, D., 2001. Efficient weed management. NSW Agriculture, Paterson.

Bianchi, F.J.J.A., Van der Werf, W., 2003. The effect of the area and configuration of hibernation sites on the control of aphids by *Coccinella septempunctata* (Coleoptera: Coccinellidae) in agricultural landscapes: a simulation study. Environ. Entomol. 32, 1290-1304.

Bianchi, F.J.J.A., Booij, C.J., Tscharntke, T., 2006. Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proc. Biol. Sci. 273**,** 1715-1727.

Bianchi, F.J.J.A., Walters, B.J., Cunningham, S.A., Hemerik, L., Schellhorn, N.A., 2017. Landscape-scale mass-action of spiders explains early-season immigration rates in crops. Landscape Ecology 32, 1257-1267

Bonhof, M., 2000. The impact of predators on maize stem borers in coastal Kenya.PhD thesis. Wageningen University, The Netherlands, 181 pp.

Bonhof, M.J., Overholt, W.A., Van Huis, A., Polaszek, A., 1997. Natural enemies of cereal stemborers in East Africa: a review. Insect Science and Its Application 17**,** 19-35.

Chabi-Olaye, A., Borgemeister, C., Nolte, C., Schulthess, F., Gounou, S., Ndemah, R., Sétamou, M., 2005. Role of habitat management technologies in the control of cereal stem and cob borers in sub-Saharan Africa. Proceedings of the Second International Symposium on the Biological Control of Arthropods, pp. 12-16.

Chaplin-Kramer, R., O'Rourke, M.E., Blitzer, E.J., Kremen, C., 2011. A meta-analysis of crop pest and natural enemy response to landscape complexity. Ecol. Lett. 14**,** 922-932.

Dessie, G., Kinlund, P., 2008. Khat expansion and forest decline in Wondo Genet, Ethiopia. Geografiska Annaler Series B-Human Geography 90B**,** 187-203.

Dessie, G., Kleman, J., 2007. Pattern and magnitude of deforestation in the south central rift valley region of Ethiopia. Mountain Research and Development 27**,** 162-168.

Dira, S. J., & Hewlett, B. S. 2016. Learning to Survive Ecological Risks among the Sidama of Southwestern Ethiopia. Journal of Ecological Anthropology, 18, 1.

Gebre-Amlak, A., 1989. Phenology and fecundity of maize stalk borer *Busseola Fusca* (Fuller) in Awassa, Southern Ethiopia. Insect Science and Its Application 10**,** 131-137.

Getu, E., Overholt, W., Kairu, E., 2001. Distribution and species composition of stemborers and their natural enemies in maize and sorghum in Ethiopia. International Journal of Tropical Insect Science 21, 353-359.

Gounou, S., Jiang, N.Q., Schulthess, F., 2009. Long-term seasonal fluctuations of lepidopteran cereal stemborers and their natural enemies on maize and wild host plants in southern Benin. Insect Science 16**,** 329-341.

Kassie, B.T., Van Ittersum, M.K., Hengsdijk, H., Asseng, S., Wolf, J., Rötter, R.P., 2014. Climate-induced yield variability and yield gaps of maize (*Zea mays* L.) in the Central Rift Valley of Ethiopia. Field Crops Research 160, 41-53.

Kfir, R., Overholt, W.A., Khan, Z.R., Polaszek, A., 2002. Biology and management of economically important lepidopteran cereal stem borers in Africa. Annu. Rev. Entomol. 47**,** 701-731.

Landis, D.A., Gardiner, M.M., van der Werf, W., Swinton, S.M., 2008. Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes. Proceedings of the National Academy of Sciences 105**,** 20552-20557.

Lemessa, D., Hamback, P.A., Hylander, K., 2015a. Arthropod but not bird predation in Ethiopian homegardens is higher in tree-poor than in tree-rich landscapes. PLoS One 10**,** e0126639.

Lemessa, D., Hambäck, P.A., Hylander, K., 2015b. The effect of local and landscape level land-use composition on predatory arthropods in a tropical agricultural landscape. Landscape Ecology 30**,** 167-180.

Lemessa, D., Hylander, K., Hambäck, P., 2013. Composition of crops and land-use types in relation to crop raiding pattern at different distances from forests. Agriculture, Ecosystems & Environment 167**,** 71-78.

Losey, J.E., Vaughan, M., 2006. The Economic Value of Ecological Services Provided by Insects. Bioscience 56, 311-323.

Mailafiya, D.M., Le Ru, B.P., Kairu, E.W., Dupas, S., Calatayud, P.A., 2011. Parasitism of lepidopterous stem borers in cultivated and natural habitats. Journal of Insect Science 11**,** 15.

McGarigal, K., S.A. Cushman, M.C. Neel, and E. Ene. 2002. FRAGSTATS v3: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html

Meshesha, D.T., Tsunekawa, A., Tsubo, M., Ali, S.A., Haregeweyn, N., 2013. Land-use change and its socio-environmental impact in Eastern Ethiopia's highland. Regional Environmental Change 14**,** 757-768.

Midega, C.A.O., Jonsson, M., Khan, Z.R., Ekbom, B., 2014. Effects of landscape complexity and habitat management on stemborer colonisation, parasitism and damage to maize. Agriculture Ecosystems & Environment 188, 289-293.

Olango, T. M., Tesfaye, B., Catellani, M., & Pè, M. E. 2014. Indigenous knowledge, use and on-farm management of enset (*Ensete ventricosum* (Welw.) Cheesman) diversity in Wolaita, Southern Ethiopia. Journal of Ethnobiology and Ethnomedicine, 10, 41. http://doi.org/10.1186/1746-4269-10-41

O'Rourke, M.E., Rienzo-Stack, K., Power, A.G., 2011. A multi-scale, landscape approach to predicting insect populations in agroecosystems. Ecological Applications 21**,** 1782-1791.

Polaszek, A., 1998. African cereal stem borers: Economic importance, taxonomy, natural enemies and control. CAB International., London, Royaume-Uni.

Rand, T.A., Tylianakis, J.M., Tscharntke, T., 2006. Spillover edge effects: the dispersal of agriculturally subsidized insect natural enemies into adjacent natural habitats. Ecol. Lett. 9**,** 603-614.

Schellhorn, N.A., Bianchi, F.J.J.A, Hsu, C.L., 2014. Movement of entomophagous arthropods in agricultural landscapes: links to pest suppression. Annu. Rev. Entomol. 59**,** 559-581.

Schmidt, M.H., Tscharntke, T., 2005. Landscape context of sheetweb spider (Araneae: Linyphiidae) abundance in cereal fields. Journal of Biogeography 32**,** 467-473.

Shackelford, G., Steward, P.R., Benton, T.G., Kunin, W.E., Potts, S.G., Biesmeijer, J.C., Sait, S.M., 2013. Comparison of pollinators and natural enemies: a meta-analysis of landscape and local effects on abundance and richness in crops. Biol. Rev. Camb. Philos. Soc. 88**,** 1002-1021.

Skovgard, H., Päts, P., 1996. Effects of intercropping on maize stemborers and their natural enemies. Bulletin of Entomological Research 86**,** 599-607.

Songa, J.M., Jiang, N., Schulthess, F., Omwega, C., 2007. The role of intercropping different cereal species in controlling lepidopteran stemborers on maize in Kenya. Journal of Applied Entomology 131**,** 40-49.

Tscharntke, T., Bommarco, R., Clough, Y., Crist, T.O., Kleijn, D., Rand, T.A., Tylianakis, J.M., van Nouhuys, S., Vidal, S., 2007. Conservation biological control and enemy diversity on a landscape scale. Biological Control 43, 294-309.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity - ecosystem service management. Ecol. Lett. 8, 857-874.

Venables, W.N., Ripley, B.D., 2002. Random and mixed effects. Modern Applied Statistics with S. Springer, pp. 271-300.

Wang, C.Z., Fritschi, F.B., Stacey, G., Yang, Z.W., 2011. Phenology-based assessment of perennial energy crops in North American Tallgrass Prairie. Annals of the Association of American Geographers 101, 742-751.

Werling, B.P., Dickson, T.L., Isaacs, R., Gaines, H., Gratton, C., Gross, K.L., Liere, H., Malmstrom, C.M., Meehan, T.D., Ruan, L., Robertson, B.A., Robertson, G.P., Schmidt, T.M., Schrotenboer, A.C., Teal, T.K., Wilson, J.K., Landis, D.A., 2014. Perennial grasslands enhance biodiversity and multiple ecosystem services in bioenergy landscapes. Proc. Natl. Acad. Sci. USA 111, 1652-1657.

Woltz, J.M., Isaacs, R., Landis, D.A., 2012. Landscape structure and habitat management differentially influence insect natural enemies in an agricultural landscape. Agriculture, Ecosystems & Environment 152, 40-49.

Worku, M., Twumasi Afriyie, S., Wolde, L., Tadesse, B., Demisie, G., Bogale, G., Wegary, D., Prasanna, B., 2011. Meeting the challenges of global climate change and food security through innovative maize research. Proceedings of the National Maize Workshop of Ethiopia, 3; Addis Ababa, Ethiopia; 18-20 April, 2011. In: Worku, M., Twumasi Afriyie, S., Wolde, L., Tadesse, B., Demisie, G., Bogale, G., Wegary, D., Prasanna, B., (Eds.), National Maize Workshop of Ethiopia. CIMMYT, Addis Abeba, Ethiopia.

Yitaferu, K., Walker, A.K., 1997. Studies on the maize stem borer, *Busseola fusca* (Lepidoptera:Noctuidae) and its major parasitoid, *Dolichogenidea fuscivora* (Hymenoptera:Braconidae), in eastern Ethiopia. Bulletin of Entomological Research 87**,** 319-324.

## Table captions

Table 1: Estimates of the most parsimonious model for the abundance of predators with a negative binomial error distribution. The variables are border type (enset, khat, simple hedgerow and complex hedgerow), distance from border (1, 10, and 30 m), and year (2014 and 2015). “Field” was taken as a random variable, BorderKhat, Distance1m and Year2014 are reference variables.

Table 2: Estimates of the most parsimonious model for the abundance of parasitoids and parasitic flies with a negative binomial error distribution. “Field” was taken as a random variable. MaizeStageM1 (mature maize) is reference variable, MaizeStageM2 is senescent maize.

Table 1

| | Estimate | Std. Error | z value | Pr(>\|z\|) | |
|---|---|---|---|---|---|
| **Intercept** | **1.989** | **0.231** | **8.597** | **0.000** | ******* |
| **BorderEnset** | **0.923** | **0.327** | **2.820** | **0.005** | ****** |
| **BorderHedge complex** | **1.121** | **0.310** | **3.620** | **0.000** | ******* |
| BorderHedge simple | -0.081 | 0.314 | -0.258 | 0.796 | |
| Distance10m | 0.327 | 0.261 | 1.253 | 0.210 | |
| Distance30m | 0.172 | 0.265 | 0.650 | 0.516 | |
| Year2015 | 0.019 | 0.222 | 0.084 | 0.933 | |
| **BorderEnset:Distance10m** | **-0.782** | **0.365** | **-2.146** | **0.032** | ***** |
| **BorderHedge complex:Distance10m** | **-1.192** | **0.363** | **-3.281** | **0.001** | ****** |
| BorderHedge simple:Distance10m | -0.444 | 0.360 | -1.233 | 0.218 | |
| **BorderEnset:Distance30m** | **-0.818** | **0.368** | **-2.222** | **0.026** | ***** |
| **BorderHedge complex:Distance30m** | **-0.774** | **0.368** | **-2.106** | **0.035** | ***** |
| BorderHedge simple:Distance30m | -0.204 | 0.360 | -0.566 | 0.572 | |
| **BorderEnset:Year2015** | **-1.210** | **0.306** | **-3.960** | **0.000** | ******* |
| BorderHedge complex:Year2015 | -0.239 | 0.305 | -0.782 | 0.434 | |
| BorderHedge simple:Year2015 | 0.167 | 0.300 | 0.559 | 0.576 | |

Significance codes: '***' P<0.001; '**' P< 0.01 ; P< 0.05 '*'

Table 2

| | Estimate | Std. Error | z value | Pr(>\|z\|) | |
|---|---|---|---|---|---|
| Intercept | 1.228 | 0.071 | 17.422 | 0.000 | *** |
| **MaizeStageM2** | **-0.979** | **0.136** | **-7.223** | **0.000** | *** |

Significance codes: '***' P<0.001; '**' P< 0.01 ; P< 0.05 '*'

**Figure captions**

Figure 1: Location of the study area and focal maize fields for natural enemy sampling. The study area is located in Tula, south of Lake Hawassa in the Rift Valley of Ethiopia.

Figure 2: Land cover classification based on the analysis of Landsat images of Tula for the years 1984, 1998 and 2014.

Figure 3: Proportion of crop types in Tula during three time periods as stated by farmers during a focus group discussion.

Figure 4: Area (A), patch density (B), edge density (C) of perennial, mixed and annual crops, and proximity index between annual and perennial crops (D) in Tula in 1984, 1998 and 2014. Perennial crops include enset and khat, and annual crops are dominated by maize (and teff in the 1980's). Mixed crops represent adjoining perennial and annual crops with field sizes smaller than 30 x 30 m. Error bars indicate SEM, (-) stands for dimensionless.

Figure 5: Abundance of predators (A and B) and parasitoids and parasitic flies (C and D) of maize stemborers in maize fields by border type for 2014 and 2015 (A and B) and maize stage (C and D). Pooled pitfall and yellow pan samples are presented and error bars indicate SEM.

Figure 6: Abundance of Formicidae (A), Staphylinidae (B) and Arachnida (C) in maize fields in yellow pans and pitfall traps in 2014 and 2015. Error bars indicate SEM.

Figure 1

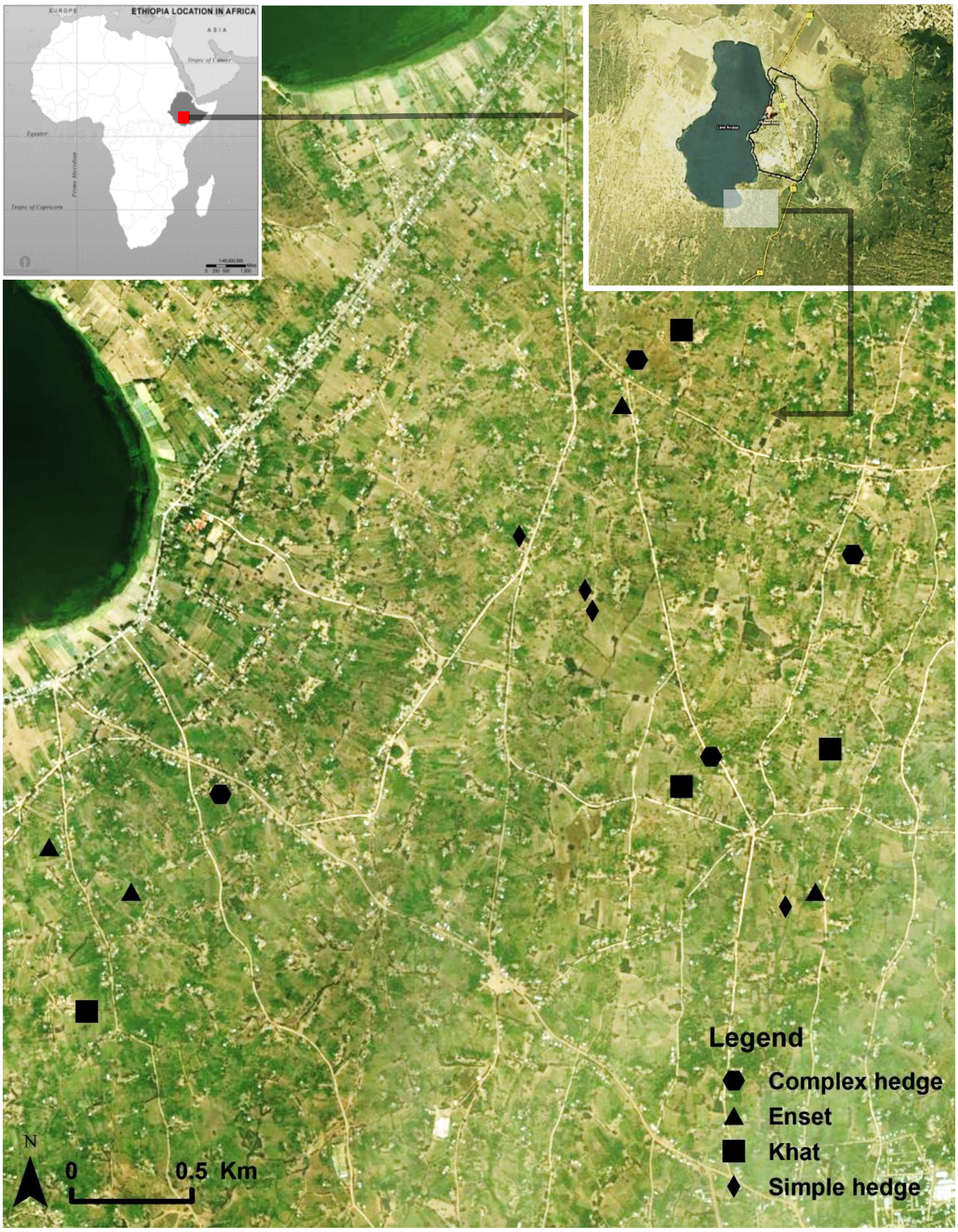

EUROPE
ETHIOPIA LOCATION IN AFRICA
ASIA
Legend
Complex hedge
Enset
Khat
Simple hedge
N
0
0.5 Km

Figure 2

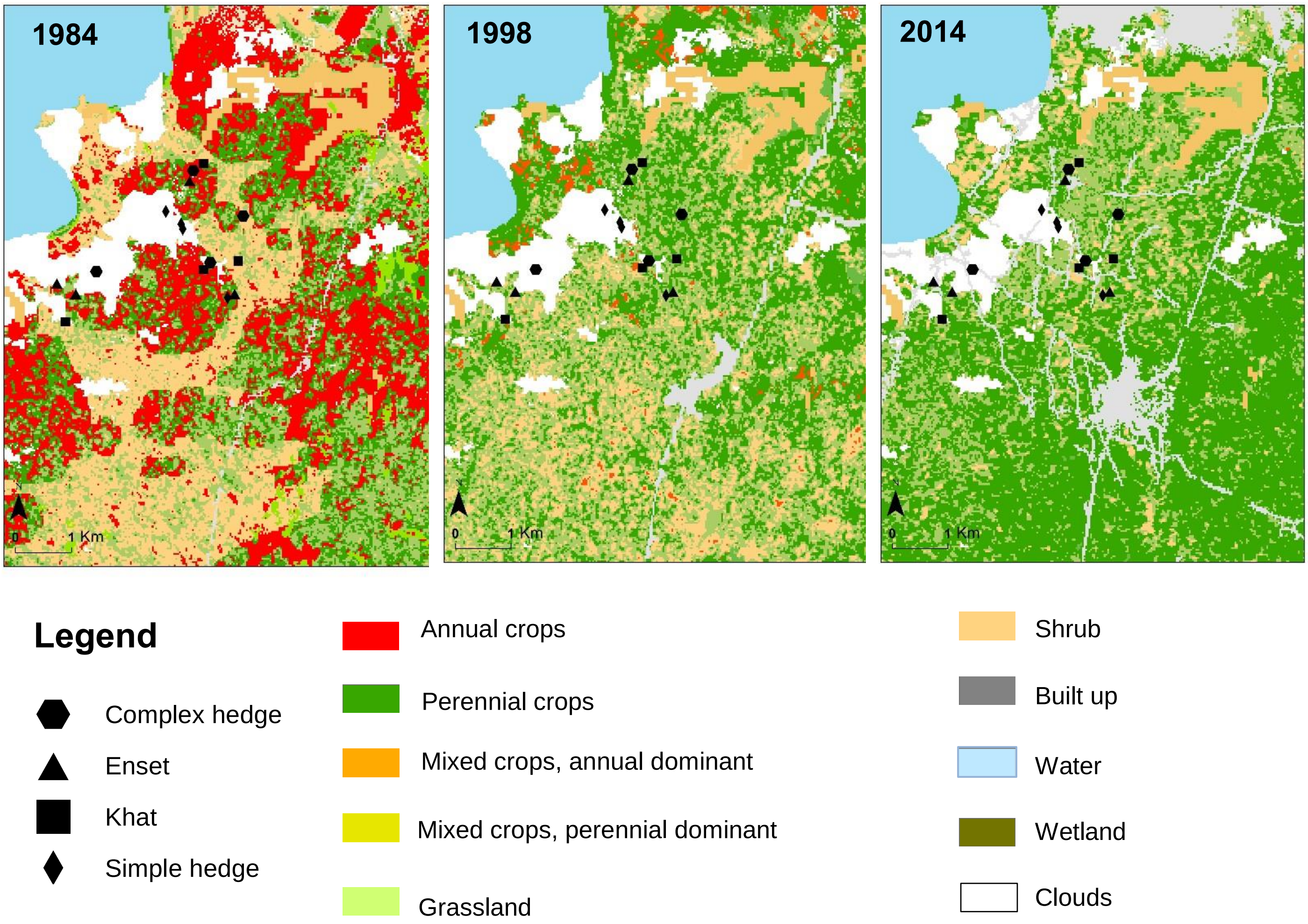
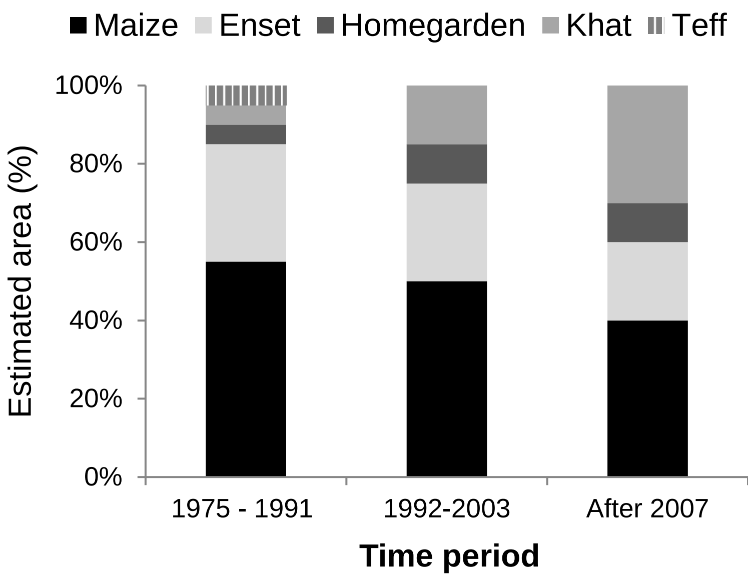
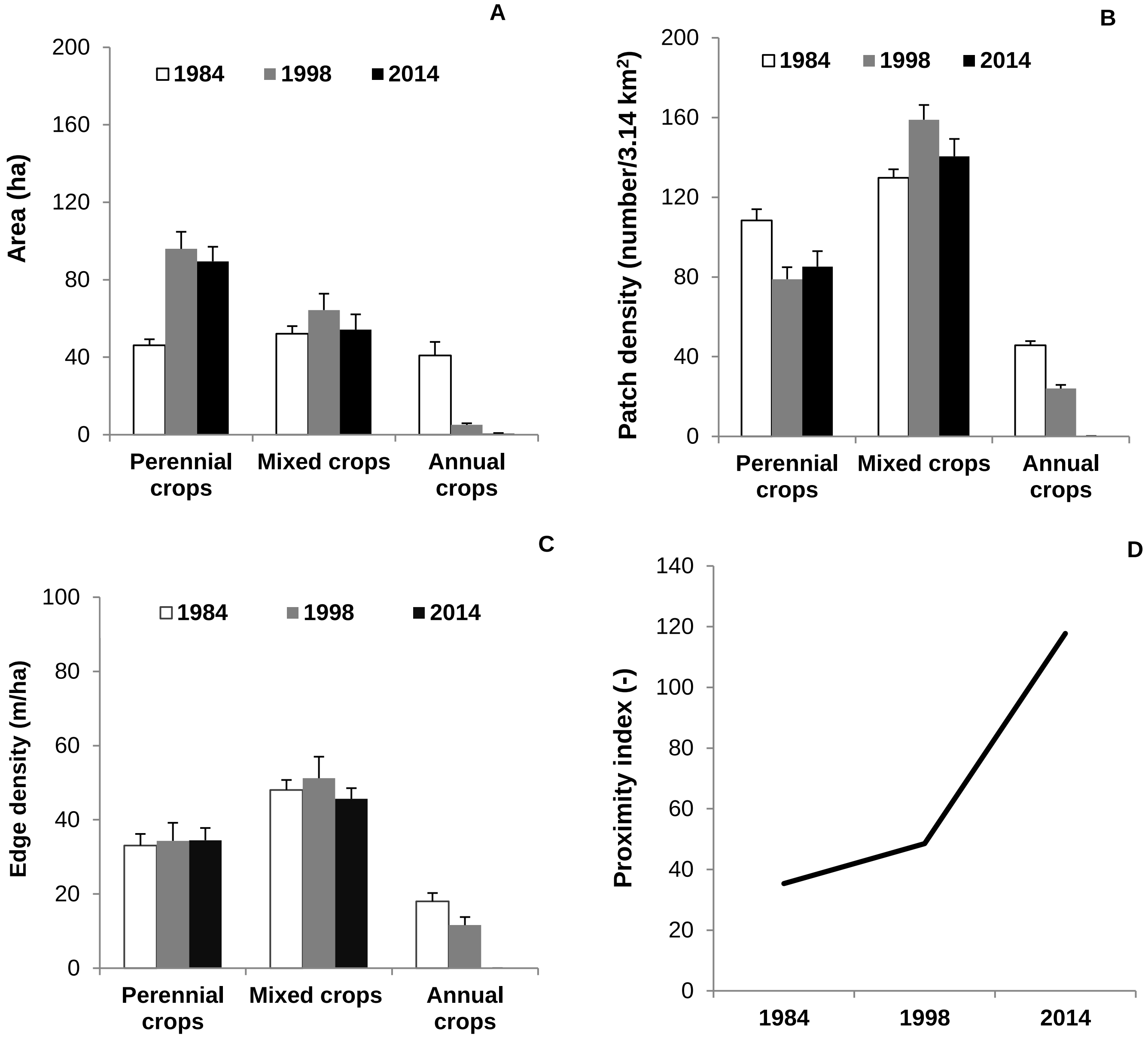

1984
1998
2014
0
1 Km
Legend
Complex hedge
Enset
Khat
Simple hedge
Annual crops
Perennial crops
Mixed crops, annual dominant
Mixed crops, perennial dominant
Grassland
Shrub
Built up
Water
Wetland
Clouds

Figure 3

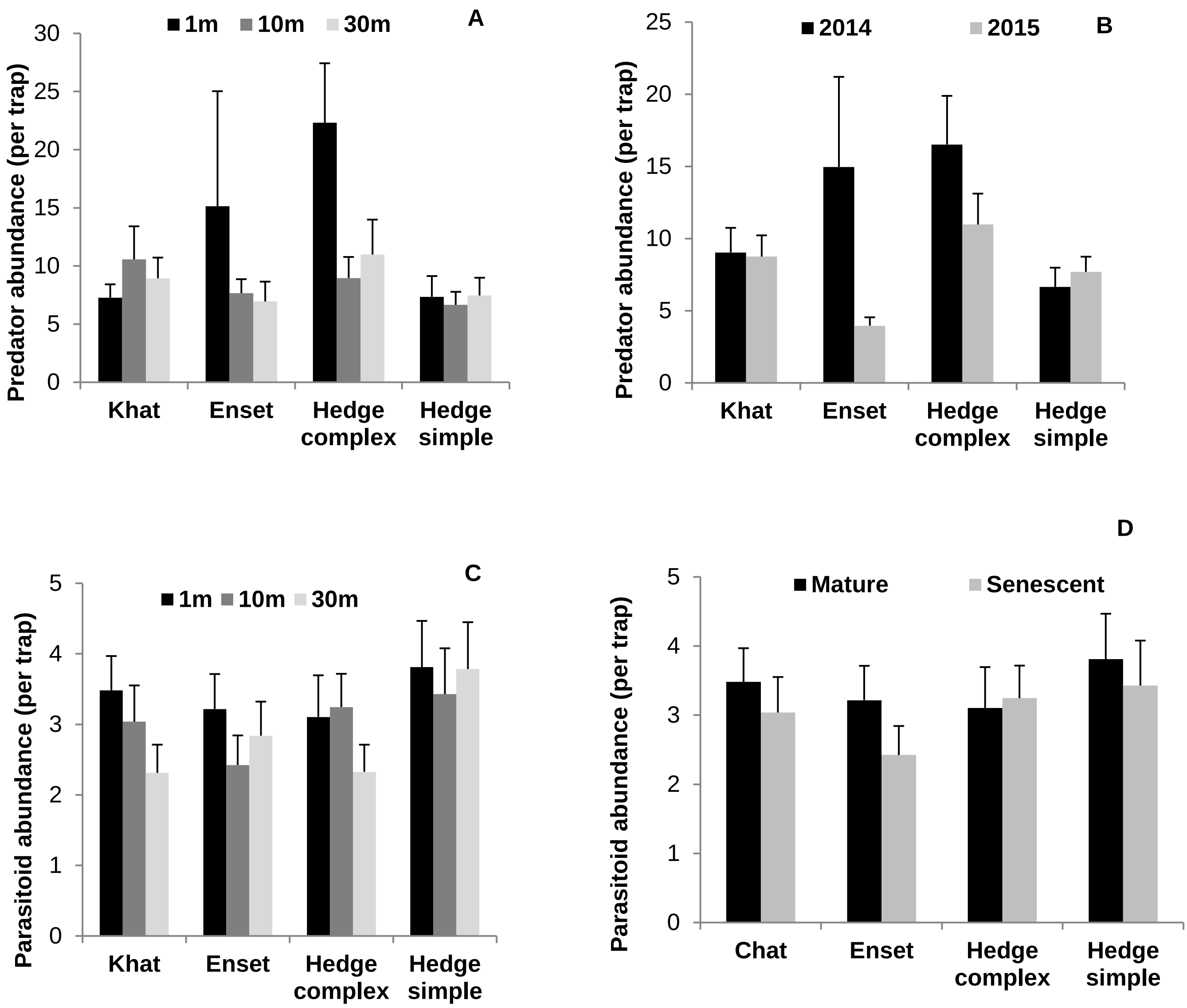


Maize
Enset
Homegarden
Khat
Teff
100%
80%
60%
40%
20%
0%
Estimated area (%)
1975 - 1991
1992-2003
After 2007
Time period

Figure 4

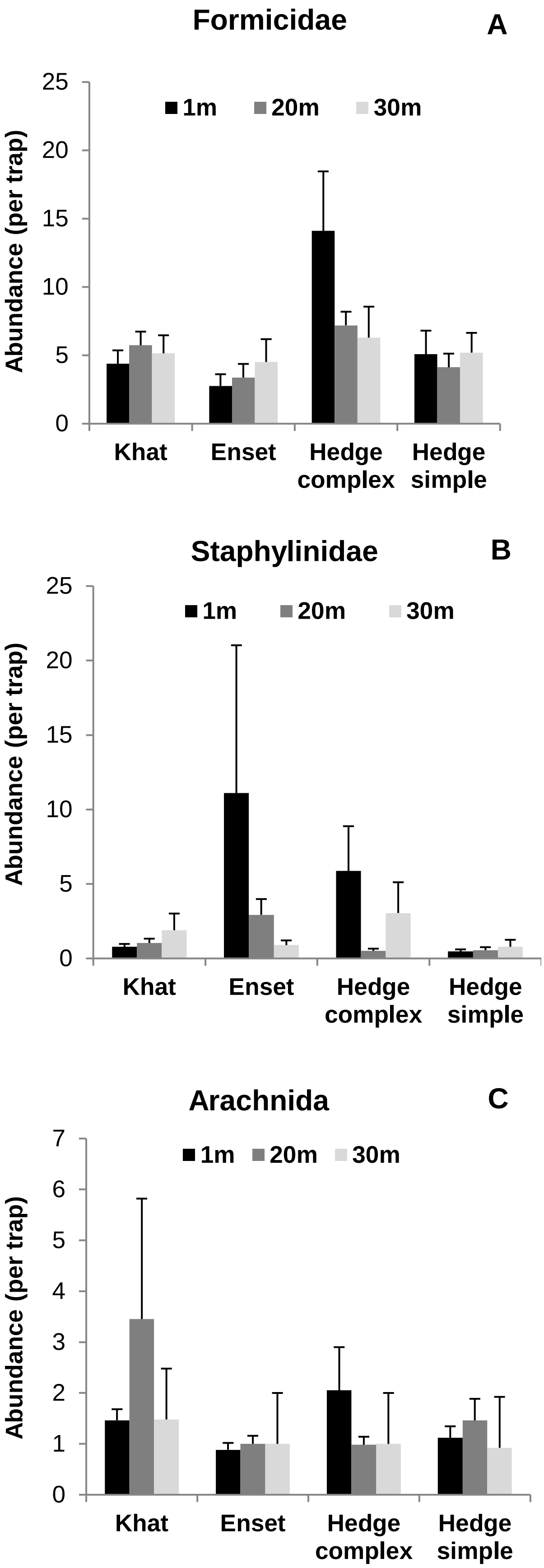

A
Area (ha)
1984
1998
2014
0
40
80
120
160
200
Perennial crops
Mixed crops
Annual crops
B
Patch density (number/3.14 km²)
1984
1998
2014
0
40
80
120
160
200
Perennial crops
Mixed crops
Annual crops
C
Edge density (m/ha)
1984
1998
2014
0
20
40
60
80
100
Perennial crops
Mixed crops
Annual crops
D
Proximity index (-)
0
20
40
60
80
100
120
140
1984
1998
2014

564 Figure 5

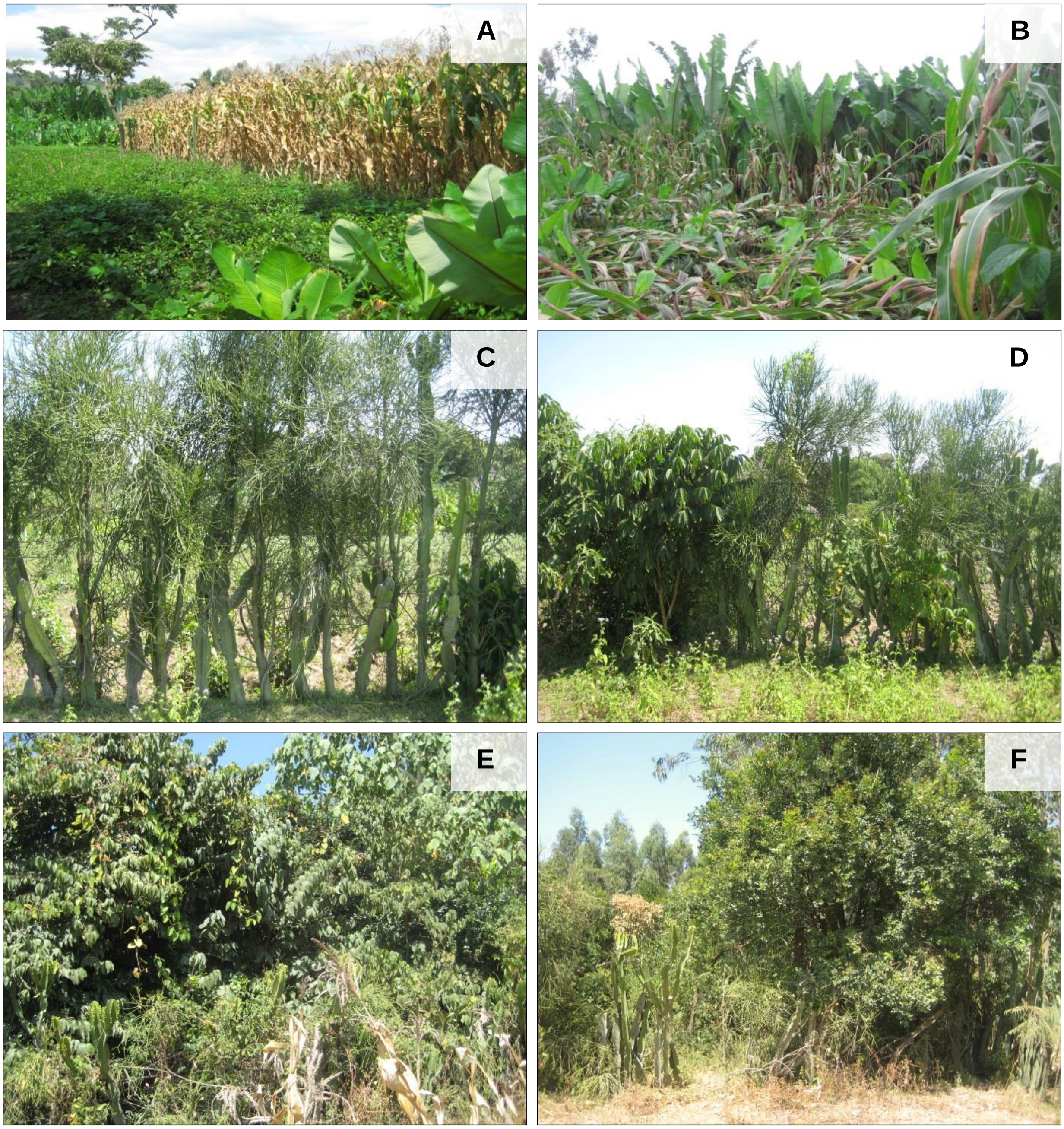


A
1m
10m
30m
Predator abundance (per trap)
30
25
20
15
10
5
0
Khat
Enset
Hedge complex
Hedge simple
B
2014
2015
Predator abundance (per trap)
25
20
15
10
5
0
Khat
Enset
Hedge complex
Hedge simple
C
1m
10m
30m
Parasitoid abundance (per trap)
5
4
3
2
1
0
Khat
Enset
Hedge complex
Hedge simple
D
Mature
Senescent
Parasitoid abundance (per trap)
5
4
3
2
1
0
Chat
Enset
Hedge complex
Hedge simple

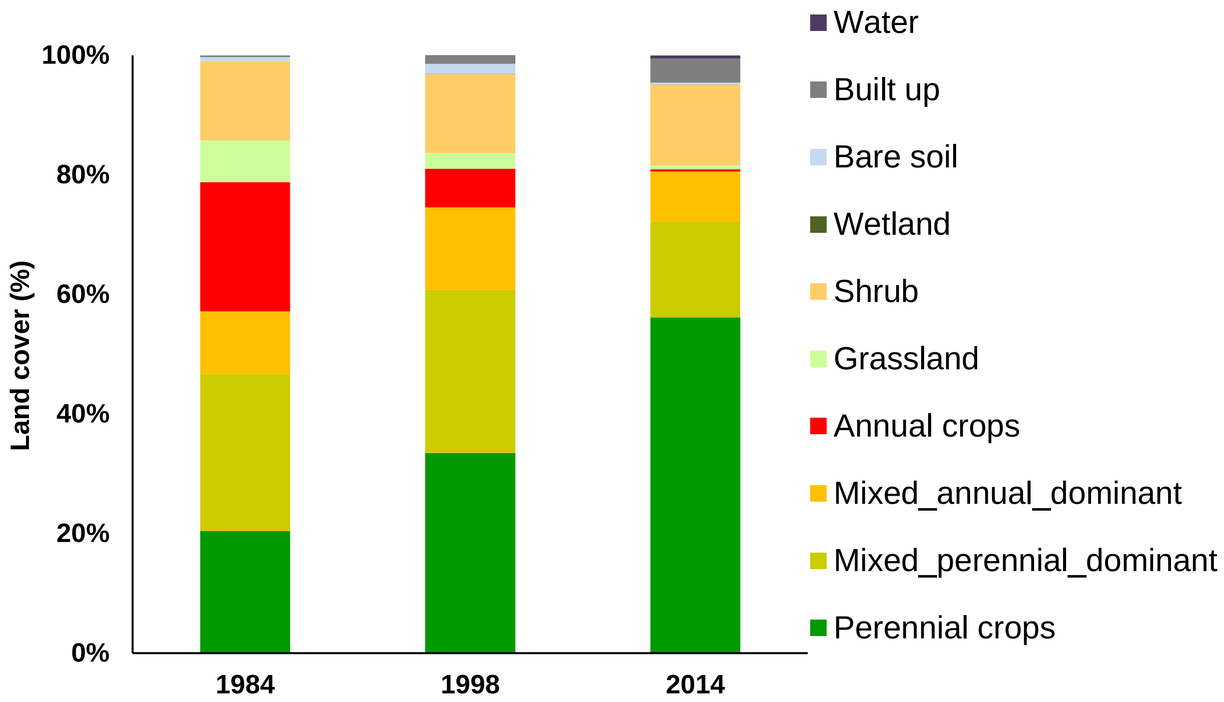
Figure 6


Formicidae
A
Abundance (per trap)
25
20
15
10
5
0
1m
20m
30m
Khat
Enset
Hedge complex
Hedge simple
Staphylinidae
B
Abundance (per trap)
25
20
15
10
5
0
1m
20m
30m
Khat
Enset
Hedge complex
Hedge simple
Arachnida
C
Abundance (per trap)
7
6
5
4
3
2
1
0
1m
20m
30m
Khat
Enset
Hedge complex
Hedge simple

Appendix 1: The four border types of maize fields: chat field (A), enset field (B), simple hedgerows (C and D) and complex hedgerows (E and F).



Appendix 2: Land cover composition (%) of Tula in 1984, 1998 and 2014 based on Landsat image analysis.



Appendix 3: Abundance (mean ± SE) and diversity of natural enemies of *Busseola fusca* by order, (sub) family, number of morphospecies and sampling method (pitfall and yellow pan) in Tula in 2014 and 2015.

| | | | | 2014 | | | 2015 | | |
|---|---|---|---|---|---|---|---|---|---|
| **Functional trait group** | **Order** | **(Sub)Family** | **Morpho species** | **N** | **pitfall** | **yellow pan** | **N** | **pitfall** | **yellow pan** |
| **Predators** | Hymenoptera | Formicidae | 5 | 2411 | 12.28±1.5 | 0.28±0.05 | 147 | 9.12±1.10 | 0.47±0.13 |
| | Coleoptera | Staphylinidae | 8 | 1360 | 0.48±0.06 | 6.60±3.29 | 380 | 1.62±0.45 | 0.86±0.35 |
| | Arachnida | Araneidae | 8 | 564 | 2.68±0.66 | 0.26±0.04 | 384 | 2.16±0.36 | 0.34±0.05 |
| | Hymenoptera | Vespidae | 1 | 184 | 0.02±0.01 | 0.94±0.10 | 118 | 0.05±0.02 | 0.73±0.11 |
| | Coleoptera | Coccinellidae | 2 | 8 | 0.04±0.02 | 0.01±0.01 | 7 | 0.04±0.03 | 0.01±0.01 |
| | Dermaptera | Forficulidae | 2 | 0 | 0 | 0 | 4 | 0.01±0.01 | 0.01±0.01 |
| **Total Predators** | | | 26 | 4527 | 15.48±1.7 | 13.01±3.2 | 237 | 8.09±1.23 | 2.43±0.40 |
| **Parasitoid flies** | Diptera | Tachnidae | 2 | 619 | 0.01±0.01 | 3.21±0.30 | 284 | 0.17±0.05 | 1.71±0.20 |
| **Parasitoids wasps** | Hymenoptera | Chalcidoidae | 15 | 540 | 0.91±0.10 | 1.90±0.17 | 220 | 0.56±0.08 | 0.88±0.10 |
| | Hymenoptera | Ichneumonida | 5 | 115 | 0.06±0.02 | 0.54±0.06 | 105 | 0.10±0.03 | 0.58±0.08 |
| | Hymenoptera | Unknown | 5 | 128 | 0.15±0.09 | 0.52±0.07 | 73 | 0.12±0.08 | 0.36±0.07 |
| | Hymenoptera | Braconidae | 2 | 20 | 0.01±0.01 | 0.09±0.03 | 31 | 0.02±0.01 | 0.18±0.05 |
| **Total Parasitoids** | | | 29 | 1422 | 1.14±0.11 | 6.26±0.38 | 713 | 0.98±0.12 | 3.71±0.28 |
| **Other** | Diptera | | 36 | 1111 | 10.48±0.7 | 47.42±2.9 | 216 | 3.51±0.39 | 10.74±0.62 |
| | Orthoptera | | 5 | 344 | 1.74±0.14 | 0.05±0.03 | 325 | 1.94±0.17 | 0.17±0.07 |
| | Coleoptera | | 17 | 295 | 1.10±0.10 | 0.43±0.05 | 415 | 2.03±0.19 | 0.68±0.12 |
| | Hemiptera | | 10 | 326 | 0.20±0.04 | 1.50±0.16 | 216 | 0.49±0.10 | 0.93±0.24 |
| | Hymenoptera | | 6 | 60 | 0.10±0.09 | 0.21±0.07 | 79 | 0.15±0.08 | 0.37±0.07 |
| | Phthiptera | | 4 | 79 | 0.35±0.07 | 0.06±0.02 | 35 | 0.14±0.03 | 0.09±0.03 |
| | Neuroptera | | 4 | 26 | 0.01±0.01 | 0.13±0.04 | 15 | 0.03±0.02 | 0.07±0.02 |
| | Lepidoptera | | 1 | 9 | 0 | 0.05±0.02 | 47 | 0.18±0.03 | 0.13±0.03 |
| | Other | | 9 | 99 | 0.49±0.07 | 0.03±0.01 | 560 | 3.05±0.88 | 0.13±0.07 |
| **Total Other** | | | 92 | 1235 | 14.49±0.8 | 50.81±2.9 | 385 | 11.51±1.09 | 13.33±1.0 |