A BIOINDICATOR PROTOCOL FOR SUSTAINABLE AGRIBUSINESS IN SOUTH AFRICA, USING NEW CROPS AS CASE STUDIES

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DECLARATION

"I declare that the thesis hereby submitted by me for the degree *Philosophiae Doctor* in Environmental Management at the University of the Free State is my own independent work and has not previously been submitted by me at another university/faculty. I furthermore concede copyright of the dissertation to the University of the Free State."

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Vaughn R. Swart

"A human being is a part of a whole, called by us 'universe', a part limited in time and space. He experiences himself, his thoughts and feelings as something separated from the rest... a kind of optical delusion of his consciousness. This delusion is a kind of prison for us, restricting us to our personal desires and to affection for a few persons nearest to us. Our task must be to free ourselves from this prison by widening our circle of compassion to embrace all living creatures and the whole of nature in its beauty."

Albert Einstein (1879 – 1955)

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CHAPTER 1
GENERAL INTRODUCTION

1.1 Overview

The future of successful and profitable agriculture and global food security depends on the sustainability of agriculture and the preservation of biodiversity. Sustainability is dependent on maintaining a high level of species richness and abundance. Approximately 40% of the Earth's land surface area is cultivated land (Hooke *et al.* 2012); subsequently biodiversity should be viewed equally as important in agroecosystems, as it may in any other habitat. When natural resources are diminished at a faster rate than they can be replenished, then the farming system is unsustainable.

With challenges, such as climate change becoming increasingly evident, new crops (or "alternative crops") are becoming more desirable to cultivate by the farming community as a whole. These new crops would need to be better-suited to apparent environmental changes. Assuming the challenges associated with sustainable management in an agribusiness context, managing new crops presents the additional challenge of preventing certain potential hazards *e.g.* the establishment of key pests in a new area, some of which are considered risks when climate change is viewed in real terms.

Sustainability of an agroecosystem is largely dependent on biological diversity. If we are to examine an agroecosystem, biodiversity must to be correctly defined. Noss (1990) and later Grumbine (1994) examined the composition, structure and functional components of biodiversity. Noss's (1990) definition is more applicable in the context of this study, as it is potentially more responsive to real-life management. Noss (1990) recognized three attributes of biodiversity; composition, structure and function which can be approached on different scales *viz*. genetic, populations, communities or landscape level.

A crop, together with the natural environment, must be considered as part of the agroecosystem and both must also be regarded as different habitats or biotopes. The cultivated crop may be managed, consequently affecting the arthropod biodiversity of the crop and possibly the biodiversity of the natural vegetation in turn. Collectively the natural environment represents a specific habitat, influencing the arthropod biodiversity of a crop. Any disturbances that may occur in the natural environment could potentially affect the arthropod community associated with a crop, or *vice versa*. The numerous ways in which arthropod species are able to migrate, or perhaps prevent migration from one habitat to another, is explored.

Certain criteria must be identified as indicators that may potentially constitute the bio-indicator protocol. Given that this case study is based principally on new crops, attention must be focussed on criteria that have implications on new crops. Edge effect is regarded as a potential physical indicator that may serve as a model for habitat quality. Various studies (Ferguson & Joly 2002, Ferguson 2004) have indicated that predator-prey ratio may serve as an effective criterion in determining the extent of various perturbations in relation to the edge. Biodiversity indices that deal with species richness, abundance and evenness are also taken into consideration, in order to indicate if certain disturbances have occurred. This thesis represents a case study, focusing specifically on the effects of climate on arthropod biodiversity, together with the effects of agricultural management practices, the application of pesticides and fertilisers, tillage, mowing and cover crops.

Once the final bio-indicator protocol for a sustainable agroecosystem is composed, several other important factors are also discussed that further complement the case study. This thesis will also investigate factors that potentially determine how aspects of arthropod biodiversity can contribute to an indicator protocol.

Rather than utilizing a specific taxonomic group, focus is framed upon sampling methodology, *i.e.* the sampling of a specific community within a habitat and subsequently applying this sampling technique as to complement the indicator.

In this thesis an attempt is further made to assign an economic value (ecosystem service index) to the arthropod communities. This value is based on a set of predetermined characteristics as assigned to each species occurring in a particular habitat. Such a final value may have potential, not just to promote biodiversity in agricultural function, but also to provide a functional component of biodiversity. The ecosystem evaluation system would then serve as a model to predict the establishment of pest species. Basic guild structures, coupled with ecosystem services, determine, and may further reveal, the integrity of a habitat.

Once all the indicators are combined, a final bio-indicator protocol would be the final outcome. This bio-indicator protocol based on arthropod assemblages would then be incorporated into an EMS (Environmental Management System) as indicators. Environmental Management Systems have been used to manage agriculture, especially in Australia where they have proven to be effective in improving the performance of an agribusiness overall, whilst simultaneously reducing environmental impacts (Carruthers 2007).

1.2 The sustainability of an agribusiness

For the purpose of this thesis, sustainability particularly includes the maintenance of the productive capacity of the agroecosystem, with the ability of the agroecosystem to maintain itself by preserving sustainable ecosystem services and functional biodiversity. Fig. 1.1 illustrates the effect of agricultural intensification on agroecosystem biodiversity and consequently the effect on sustainability and productivity. The direct effects of agricultural management are those associated with the reduction of plant richness and abundance in the ecosystem (Gliessman 2001). The indirect effects such as resource utilisation, pesticide use and other management practices, combined with low plant diversity (monoculture effect) significantly reduce the total biodiversity (Swift & Anderson 1993). The nexus of arthropod biodiversity, in the context of crop production systems, forms the basis of this thesis. It is thus utilised as an indicator of sustainability and productivity and how these may be affected.

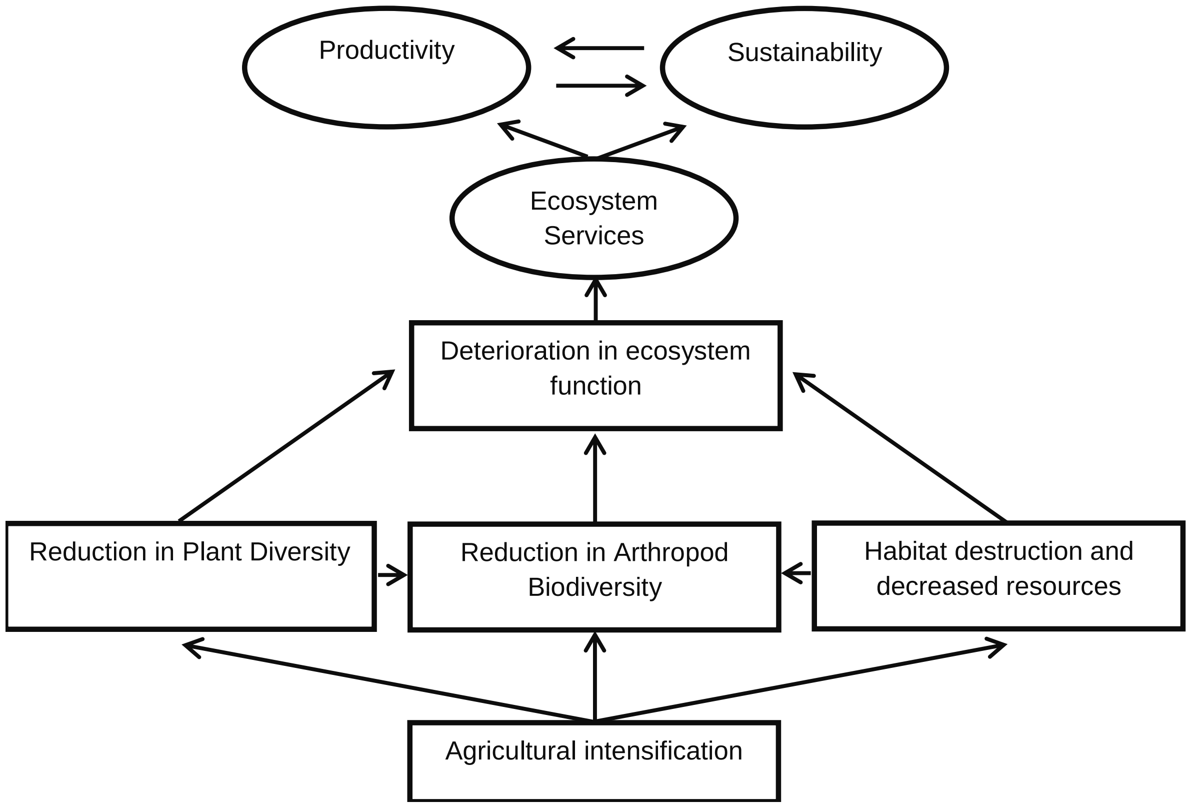

Fig. 1.1. Ultimate effect of agricultural intensification on agroecosystem biodiversity, sustainability and productivity (modified from Swift & Anderson 1993).

Diversity should be viewed as equally as important in agroecosystems as it may in any other habitat. When natural resources are diminished at a faster rate than they can be replenished, consequently affecting the quality of the land and functional ecosystem services, this leads to the farming system becoming unsustainable. Conservation of natural patches in combination with the promotion of flowering plants within the agroecosystem can maximize productivity and, therefore, contribute towards sustainable agriculture (Carvalheiro *et al.* 2011). Obviously, therefore, sustainability is dependent on maintaining a high level of organismic diversity, including arthropod biodiversity.

Currently, it is important that the conversion to sustainable agroecosystems becomes a priority regarding land management. To achieve sustainable agriculture we must deal with issues involving both environmental impacts and productivity of the land. To develop a system of sustainable agriculture successfully, such a program must have farmer involvement at all stages of its development and it must also focus on the farming system as a whole, not just on individual elements. More research, however, should be focused on the contribution of agricultural biodiversity towards sustainable agriculture, as well as defining acceptable indicators for agricultural biodiversity assessments.

1.3 New crops

Global trends exist for the development of new crops based on novel and indigenous biodiversity. Novel products and chemicals are also produced by another set of crops which supply pulp, fibres, polysaccharides, flavours, oils and health products such as antioxidants (Taylor 2009). With challenges, such as climate change becoming increasingly evident, new crops (alternative crops) are becoming more popular to cultivate. Many opportunities exist for developing new crops and new products for local and international markets. According to Van Wyk (2011), South Africa has more than 120 plant species that have the potential to be produced as new food or beverage products and this includes several indigenous fruits and vegetables. There also exists a growing awareness regarding the importance of these indigenous plants in new product development.

In this attempt to develop an indicator protocol it is important to remember that this protocol will specifically focus on new crops. The function of the indicator protocol, which is based on arthropod biodiversity, is to maintain a sustainable ecosystem. With the usual challenge of managing an agribusiness sustainably, managing new crops alone have additional challenges of preventing certain potential hazards, although certain of these hazards are considered risks when climate change is considered as well. Although these alternative crops are better suited to recent trends in the changing biotic and abiotic environment, hazards posed by the cultivation of new crops have the potential to cause serious disturbance, either as a result of the hazard itself or through control of the hazard. This may have serious implications in the sustainability of an agribusiness. Indicators are necessary to detect these changes in order to decide upon preventative measures which can be applied by utilizing appropriate agricultural practices (*e.g*. ecological management).

1.3.1 Potential hazards of new crops

The cultivation of new crops may have serious implications for pest and disease management. A thorough knowledge of pest, pathogen & host ecology and interactions between biotic and abiotic entities involved in new crop agroecosystems is therefore essential. Information must be utilized to create optimal conditions for the sustainable cultivation of specific new crops. Ecological principles and management practices that apply to new crops may not be applicable to more traditional crops and may have to be addressed differently by management tools such as Integrated Pest Management (IPM).

A new crop may be a previously known wild species of plant that has been domesticated for cultivation purposes. A cultivated wild species may be challenging to assess in terms of potential risks, such as the effect of insect pests (Holderness & Waller 1997). A poor knowledge base and a weak assessment of associated arthropods and diseases of wild plant species occurring as co-evolved potential pest species can have detrimental effects on plant phenology and production. Under agricultural circumstances conditions may be more favourable and the wild plant species may be more vulnerable to naturally associated pests. When insects eventually do establish themselves the effects may be severe, due to the genetic base of crops reduced by selection (the crop may be more susceptible than the wild species variant) and the potential insect pest species inevitably may have no natural enemies in the new geographic area. A similar situation may occur with the translocation and introduction of an exotic insect species in association with a specific crop (Holderness & Waller 1997). In addition, a lack of natural enemies within an undisturbed situation, and a more suitable environment, may result in the exotic insect species reaching pest status.

Biotechnology allows us to develop new genotypes in the form of hybrids, varieties and cultivars. These new genotypes may have been developed to improve yields, but may now be more susceptible to attacks by known pests (Holderness & Waller 1997). Furthermore, specific characteristics of the crops that are selected and breeding programmes may reduce genetic variability even further. Consequently, this may lead to the loss of natural resistance mechanisms or an increase in selection pressure of pests, resulting in an increase in susceptibility of insect attack.

Traditional crops that are relocated to new geographic areas (*i.e.* regions, countries and climatic zones) may also be considered to be new crops (Holderness & Waller 1997). In a new geographic area, factors such as daylight duration, minimum and maximum temperature, rainfall (season and amount) and relative humidity may be different to the region of origin, resulting in the plant suffering physiological stress and consequently becoming more susceptible to insect attack.

Newly-encountered pests or insects that migrate from native host plants onto an introduced crop may also pose a threat. In an agroecosystem that lacks resistance, for instance where predators and parasitoids are absent, the situation may be aggravated (Médiène *et al.* 2011). The Introduction of exotic pest species in association with a specific crop and a favourable new environment may lead to a known minor pest also attacking the crop. The environment might be less resistant to this pest species and may even not be resilient enough.

The implementation of new or different agronomic systems or practices regarding traditional crops, such as fertilization, monoculture and mono-succession may indirectly also constitute a new crop. The predisposition to known pests, such as the cultivation of a crop in sub or super-optimal conditions may lead to a less resistant ecosystem, thus a greater susceptibility of crops to insect pest attack (Médiène *et al.* 2011). Selection pressure for pests may occur as a result of the monoculture that leads to a reduction in the floral biodiversity and consequently a reduction in arthropod biodiversity. In other words, less resilience of the agroecosystem as a result of no natural enemies or competition leading to certain insects reaching pest status is the outcome and consequently high input production costs (intensive agronomic practices) have to be deployed which result in an even less resilient ecosystem.

It is important to pre-empt the possible risks of a specific new crop. It may be a single risk or even a combination of the above mentioned hazards that may pose a threat on your new crop. Identification of these risks will ensure focus on the events that are more likely to occur. These risks need to be taken into consideration when developing a bio-indicator protocol for new crops that may effectively be incorporated into an EMS for agriculture.

1.3.2 Implications for the development of indicators

Certain criteria related to arthropod biodiversity will be considered in the development of the proposed indicators. These criteria need to show sensitivity towards hazardous circumstances that are created by the cultivation of new crops. The intended indicators also need to be sensitive towards the establishment of insects as pests; pests that are more likely to occur and most likely to cause unacceptable damage to the crop (dependant on the suitability of the landscape). The extent to which these hazards have an effect on the ecosystem is determined by the resistance and resilience of the ecosystem. Resistance and resilience are important components in any ecosystem and in an agroecosystem they can be viewed as important elements of sustainability. The measurement of species richness, abundance and evenness are in themselves an effective indicator of ecosystem health and these variables form important components in the foundation for resistance and resilience. The potential for biodiversity to provide ecological resilience, i.e., the capacity to recover from functional disruption, and the mitigation of risks caused by disturbance (Holling 1996, Swift *et al*. 2004) is compelling, but poorly documented.

The resistance and resilience of an agroecosystem towards a potential pest needs to be viewed as “measurement units”. Criteria that support and affect these two aspects will be focused on in this investigation. Options that are available to manage pests, by means that will not lead to negative economic or ecological implications and doing so in the long term, will be suggested.

1.4 Biodiversity of an agroecosystem

Biodiversity within an agroecosystem needs to be properly defined within the context of this study. Franklin (1988), Noss (1990) and Grumbine (1994) all recognise that biodiversity consists of composition, structure and functional components. Composition deals with the identity and variety of elements in a collection and includes species lists and measures of species diversity and genetic diversity. Structure entails the physical organization or layout of a system, from habitat complexity as measured within communities to the pattern of patches and other elements at a landscape scale. Function involves ecological and evolutionary processes, including parasitism, disturbances and nutrient cycling.

According to Cromwell (1999), agrobiodiversity is essential for various reasons. It, firstly, provides the sustainable production of food and other agricultural products, including the building blocks for the evolution or deliberate breeding of useful new crop varieties. Secondly, it provides biological support to production, via, *e.g.* soil biota, pollinators pest natural enemies. Thirdly, it forms the basis for ecological services provided by agroecosystems, such as landscape protection, soil structure and health, water cycling and quality, and air quality.

Cromwell (1999) also identified several distinctive features with specific reference to agrobiodiversity compared to biodiversity in other situations. Such features are actively managed by farmers and many agrobiodiversity components would not survive without this human interference. Also, in many cases, indigenous knowledge systems and specific cultural applications form integral parts of agrobiodiversity management. Economically viable farming systems, such as those based on new crops, including exotic crop species create interdependence between countries for the genetic resources and diversity on which our food systems are based. In crop diversity, diversity within species (cultivars) is at least as important as diversity between species.

Finding a definition for biodiversity, that is completely responsive to real-life management and regulatory questions, is almost impossible. Noss (1990), however, characterizes it more appropriately for application in this study. Noss (1990) expands the primary attributes, *i.e.* composition, structure and functional components, into a hierarchy incorporating elements of each attribute at four levels of organization: regional landscape, community-ecosystem, population-species and genetic level; this provides both a conceptual framework for identifying specific and measurable indicators to monitor change and assess the overall status of biodiversity. As it is important to maintain a balance between the stability and biodiversity of an agroecosystem, it is notable that the stability of a community within such a system is an indication of its degree of disturbance and resultant succession (Begon *et al.* 2006). Moreover, since agricultural biodiversity is the focus of this study, the term agrobiodiversity will be adopted. Furthermore, since this thesis intends to utilize arthropods associated with the relevant landscape as indicators, it is also noteworthy to mention that agrobiodiverstiy refers to the arthropod biota on a landscape scale. Moonen & Bàrberi (2008) suggested that by assuming that biodiversity plays an important role in the regulation of ecosystem functioning and affect the quality of human society, directly or indirectly, biodiversity within agroecosystems can be justified. An element of biodiversity, both in natural and in agricultural ecosystems, provides services known as the ecosystem services, which is related to the ‘functional biodiversity’. This term is derived from the ‘functional groups’ and ‘diversity’ which are related to ecosystem functioning and to agroecosystem services.

An attempt will also be made to determine which attribute and at what level agricultural management practices may affect the biodiversity of the agroecosystem.

1.4.1 What affects arthropod agrobiodiversity?

Various biotic and abiotic factors influence the stature of an agroecosystem. Decisions that are made to manage some of these factors may influence other components, such as the biodiversity, within the agroecosystem. Arthropod biodiversity is known to be affected by certain agricultural practices, which inevitably influences the sustainability of the agroecosystem. This thesis specifically investigates how arthropod biodiversity is affected by certain biotic and abiotic factors, vegetation and agricultural management practices such as the application of pesticides and fertilisers, tillage, mowing and cover crops. When the final bio-indicator protocol is composed several other biotic and abiotic factors, not included in the case study, are also discussed. Overall, certain aspects of biodiversity are affected, depending on the type of disturbance. The study will investigate these aspects and determine how they contribute to an indicator protocol.

1.4.1.1 Agricultural management practices

Agricultural management practices are considered in the development of the indicator protocol. Dramatic land-use changes such as the conversion of complex natural ecosystems to simplified managed ecosystems and the intensification of resource use, including application of more chemicals and a generally higher input and output, is typical for agroecosystems as relatively open systems. In Table 1.1, Paoletti *et al.,* (1996) summarise the various farming practices that may sustain or decrease biodiversity in agroecosystems. Practices such as the application of insecticides affect the arthropod biodiversity to various degrees, depending on the type of insecticide. Generally, these agricultural practices are mentioned to highlight the range of practices that may affect the biodiversity and some may not be used in context of the specific new crops mentioned in this thesis. For instance, rotation with legumes is not possible with pistachio orchards as it is a perennial crop and so monosuccession is the only option, although cover crops may be rotated between the primary crops.

Other agrochemicals, such as herbicides, fungicides and nematocides, have also been found to affect biodiversity in various ways. These chemicals are also taken into consideration as potential drivers of perturbation. Physical disturbance of the agro-environment is another important factor to consider in planning agricultural management. For instance, groups of invertebrates are differentially affected by tillage operations because of their vertical distribution through the soil, their motility and powers of dispersal, as well as their susceptibility to soil compaction, pesticides and disturbance (McLaughlin & Minneau 1995).

Evans *et al.* (2010) showed that exposure of terrestrial arthropods to glyphosate-based herbicides affects their behaviour and long-term survival. Furthermore, they found that herbicides can disturb arthropod community dynamics irrespective of their impact on the plant community and may influence biological control in agroecosystems. Fields that received higher herbicide inputs showed reduced arthropod counts (Douglas *et al.* 2010). According to Griesinger *et al.* (2011), glyphosate-based herbicides are “info-disruptors” that alter the ability of males to detect and react fully to female signals. The use of agricultural fungicides, on the other hand, has been shown to have minor eco-toxicological consequences for insects (Johansen *et al.* 2007).

Table 1.1. Farming practices that can sustain or decrease invertebrate biodiversity in agroecosystems (modified from Paoletti 1999).

SUSTAINED INVERTEBRATE BIODIVERSITY	REFERENCES	DECREASED BIODIVERSITY
Hedgerows	Paoletti et al., 1989	Wild vegetation removal
Dikes with wild herbage	Paoletti et al., 1989	Tubular drainage or dike removal
Polyculture	Altieri et al., 1987; Paoletti, 1988	Monoculture
Agroforestry	Altieri et al., 1987; Paoletti, 1988	Monoculture
Rotation with legumes	Werner & Dindal, 1990	Monosuccession
Dead mulch, living mulch	Stinner & House, 1990; Werner & Dindal, 1990	Bare soil
Herbal strip inside crops	Joenie et al., 1997; Lys & Nentwig, 1992, 1994	Homogeneous fields
Appropriate field margins	Paoletti et al., 1997a	Large fields
Small fields surrounded by woodland	Paoletti et al., 1989	Large fields
Hedgerow surrounded fields	Nazzi et al., 1989	Open fields
Ribbon cropping	Unpublished assessments (Paoletti 1987—1990)	Conventional cropping
Alley cropping	Unpublished assessments (Paoletti 1987—1990)	Monoculture
Living trees sustaining grapes	Unpublished assessments (Paoletti 1987—1990)	Artificial stakes
Minimum, no tillage, ridge tillage	Stinner & House, 1990; Exner et al., 1990	Conventional plowing
Mosaic landscape structure	Paoletti, 1988; Noss, 1990; Karg, 1989	Landscape simplification, woodland clearance
Organic sustainable farming	Matthey et al., 1990; Werner & Dindal., 1990	Intensive input farming
On farm research	Stinner et al., 1991; Lockeretz, 1987	Conventional plot research
Organic fertilizer	Matthey et al., 1990; Werner & Dindal, 1990	Chemical fertilizer
Biological pest control	Pimentel et al., 1991; Paoletti et al., 1993	Conventional chemical pest control
Plant resistance	Pimientel et al., 1991	Plant susceptibility
Germplasm diversity	Altieri et al., 1987; Lal, 1989	Standardization

1.4.1.2 Abiotic conditions

Since this thesis will develop indicators using arthropod biodiversity, sampling needs to be conducted over the most suitable time period during a season. Abiotic factors such as temperature, rainfall and relative humidity are known to affect the arthropod activity and in turn the efficacy of the sampling technique. Certain species prefer specific climatic conditions, making it difficult to collect all species at one moment in time. In contrast, sampling at different time periods should increase the chances of collecting most of the species, as with Obrist & Duelli (2010) whom managed to find a certain time period of four weeks within which they could sample most effectively within a range of agricultural habitats. They also found that average alpha diversity is more strongly influenced by climate and weather conditions than considerable management changes in agriculture, although pesticides would obviously influence alpha diversity more drastically.

1.4.2 The effect of the natural environment on the crop, and vice versa

The crop and the natural environment are considered to be part of the agroecosystem as a whole, although they are each considered to be different habitats or biotopes. The cultivated crop, managed to various degrees, consequently affects the arthropod biodiversity of the crop and potentially affects the biodiversity of the natural vegetation. The natural environment consists of a specific biotope, whereas a specific community determines the arthropod biodiversity of the crop. Any perturbations that might occur in the natural environment may also affect the arthropod community within the crop. The various ways in which arthropod species may migrate or perhaps prevent migration from one habitat to another is explored.

1.5 Potential arthropod indicators (focusing upon potential hazards of new crops)

A definition for indicators in assessing states and trends was proposed by Heink & Kowarik (2010) who state that "An indicator in ecology and environmental planning is a component or a measure of environmentally relevant phenomena used to depict or evaluate environmental conditions or changes or to set environmental goals". Much research has been carried out on the potential of invertebrates as dependable bio-indicators of disturbance or degradation of ecosystems (Blair & Launer 1997, Rodriguez *et al.* 1998). Arthropods are prevalent in almost all environments and they have a high species richness and abundance, are easy to sample and are essential in ecosystem function (Rosenberg *et al.* 1986). They react to environmental changes more rapidly than vertebrates and can provide early detection of ecological changes (Kremen *et al.* 1993). They also fulfil various trophic functions in the ecosystem, such as detrivory, predation, parasitism, herbivory and pollination and these functions are affected by various perturbations. The effect of disturbance, such as agricultural practices, on this species diversity can be determined by evaluating appropriate species assemblages above the single species level, such as communities, functional groups and guilds (Belaoussoff *et al.* 2003). In general arthropods have potential as bioindicators as they are relatively small and mobile, have short generation times and are sensitive to local conditions such as temperature and moisture changes (Samways *et al.* 2010).

Certain criteria need to be identified as indicators which would constitute the bio-indicator protocol. As this thesis investigates case studies which are based on new crops, it is essential to focus attention on the criteria that have implications in terms of new crops. These could be:

- Edge effect which may serve as a model for ecosystem quality.
- Predator-prey ratio which has been shown to be an effective criterion in determining the extent of various perturbations.

- Biodiversity indices that deal with species richness, abundance and evenness can also indicate whether certain perturbations have occurred.

In this study an attempt was made to assign an economic value (index) to the appropriate arthropod community. The value is based on several predetermined criteria assigned to each species present. The final value may have potential not only to promote biodiversity in terms of agricultural function, but also to give the functional component of biodiversity a value, which serves as a model to predict the establishment of a pest species. Basic guild structures and ecosystem services can be determined and which can reveal the integrity of the habitat and whether the ecosystem within the habitat is functioning optimally.

Species diversity is an important component of an ecosystem, so ecologists often use change in species diversity to determine the effects of disturbance (May 1975, Hutchinson 1978, Magurran 2004) and it is therefore deemed important to determine species richness and abundance as a foundation for further analysis. For the purpose of assessment of cultivated areas criteria are required that are not based only on the maximizing of “biodiversity”, but should preferably include structural and functional qualities of the biocoenoses, according to the definition of Noss (1990). That said, however, it is important to derive indicators of ecological relevance besides focusing on species richness, abundance and evenness. To determine the integrity of an ecosystem, often not only a single indicator is needed, but a set of indicators which have to be carefully selected (van Oudenhoven *et al.* 2012). Therefore this study should be seen as a step in a path of developing a set of indicators within a comprehensive protocol.

1.5.1 Edge effect

Edge responses / effects between two adjoining patches, habitats or biotopes (Dauber & Wolters 2004) are vital components in the understanding of how spatial patterning of landscapes influences the abundance and distribution of organisms. Generally edges are boundaries between distinct patch types. The recognition of an edge depends on how the patches are defined within a landscape. Abiotic conditions, *e.g*., light, moisture and temperature near habitat edges are often very different than conditions far from edges. These differences can determine the availability of resources and the abundance of organisms as a function of distance from the edges (Collinge 2009). Some arthropod species migrate and consequently edges may to a certain extent fluctuate in biodiversity on either side of the line between two adjacent habitats, while maintaining the unique characteristics of each of these habitats. Migrations may take place as a result of differing conditions and it may be that certain species inhabit fragment edges due to more favourable changes in microclimate (temperature, humidity, wind velocity etc.) in comparison to the rest of the habitats. Edge effect therefore could imply a general increase in species richness and abundance near the edge of a habitat. However, in contrast to these positive effects, many species avoid edges and small habitats below a certain size threshold have been devalued for conservation purposes because of their high proportion of edges (Strayer *et al.* 2003).

Dauber & Wolters (2004) stated that the movement of arthropods across boundaries depends on the permeability of the edge. This has important implications concerning the possibilities of potential pest species migrating into a cultivated field from a neighboring habitat. Since these edge boundaries also add to the overall biodiversity of an area, they do play a role in the ecology of the respective systems, irrespective of the conservation value statement above. Impact of chemicals (insecticides, herbicides) that are applied in crop fields obviously affects edges of natural habitats. Furthermore, in transition to habitat edges different conditions often reduce the survival of species typical for the original habitat, while opportunistic species from the outside may successfully invade, causing either the interruption or enhancement of biotic interactions such as predation and parasitism rates (Tscharntke *et al.* 2002). Interruption may be expected from specialized host–parasitoid interactions and the potential control of herbivorous insects (Kruess & Tscharntke 2000), preferably primary pests.

Ries *et al.* (2004) state that understanding how ecological patterns change near edges is vital in order to comprehend landscape-level dynamics such as the impacts of fragmentation. Agricultural landscape patch size and fragmentation will be considered as a potential management option in this study, since Ries & Fagan (2003) stated that as fragmentation increases (which is typical of agricultural landscapes) the proportion of edge habitat also increases. Boundaries may favour ‘turning around’ behaviour (deflection of movement) and reduce the permeability of edges to dispersing animals (Stamps *et al.* 1987). The implicit hostility of habitat boundaries would increase the chance that a species may remain within a patch and consequently increases the probability that it encounters a corridor (Tischendorf & Wissel 1997). Likewise, deflection of movement at an edge of a corridor would direct movement along a corridor. Schtickzelle & Baguette (2003), suggest that the lower survival of dispersing individuals in a fragmented habitat patch network plays a vital role in the evolutionary development of edge avoidance behaviour. According to the hypothesis, this behaviour induces different dispersal rate patterns when comparing fragmented and continuous patch networks.

Ries *et al.* (2004) conducted an extensive review on habitat edges. Their first model is a mechanistic one which illustrates four mechanisms underlying edge responses, *i.e.* ecological flows, access to spatially separated resources, resource mapping and species interactions.

The mechanisms mentioned form the basis of a second model, which is more generalised and predictive (Fig. 1.2) and which can be used for most species in any landscape. Literature shows that edge responses, when observed, are generally predictable and consistent when the participating species and edge type are held constant (Ries & Sisk 2004). The model shows that when a habitat borders lower-quality habitat, where available resources are (a) the same to those in the higher-quality patch, a transitional response is predicted. If there are resources in the lower-quality patch that are (b) similar leading to a predicted neutral response (c), different, then a positive edge response is predicted. Finally, when both patches contain resources, edge response predictions are based on whether the resources are (d) different in each patch, which leads to a positive prediction. Finally, when resources are (e) concentrated along the edge, a positive response is predicted (Ries & Sisk 2004).

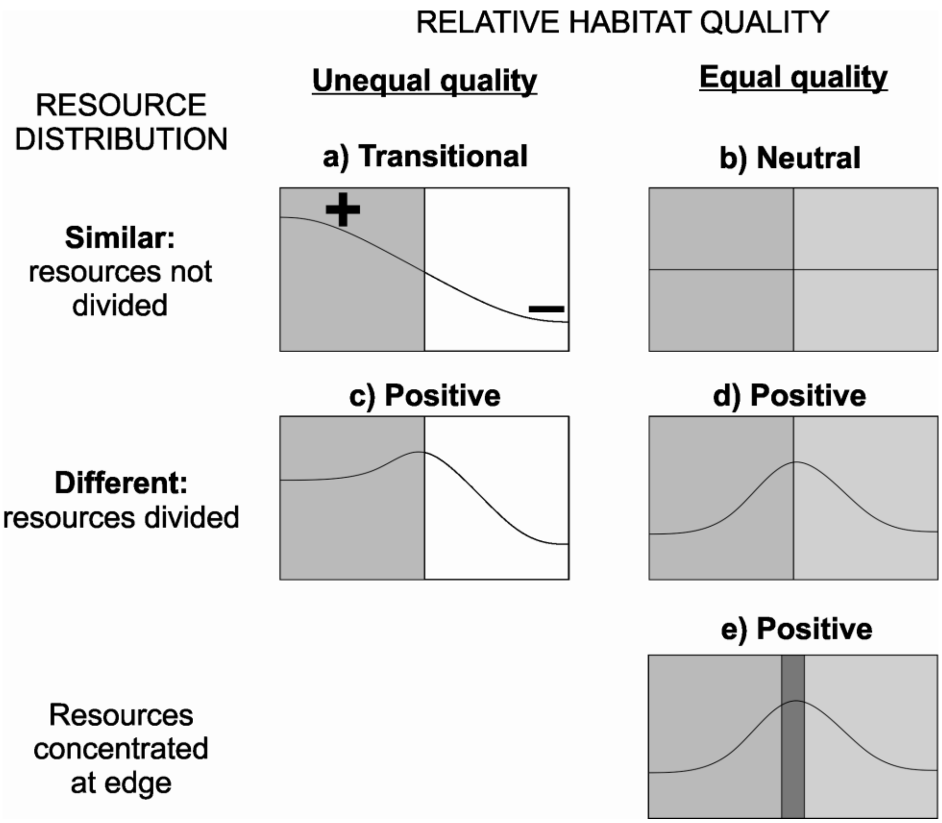

Fig. 1.2. A predictive model of edge responses that are (a) transitional (b) neutral or (c, d, e) positive based on relative habitat quality and resource distribution. Lower habitat quality is indicated by a white box, while habitats of higher or equal quality are shaded (adapted from Ries & Sisk 2004).

In addition, several crucial factors were identified that could affect edge responses, *i.e.* edge orientation, intrinsic sensitivity to edges, edge contrast, fragmentation effects, temporal shifts in resource distribution or use and study design (Peyras *et al.* 2013). Little research focuses on tools necessary to extrapolate these responses to larger landscapes or to use them to understand population dynamics and community patterns. Subsequently, this limits the ability for this information to inform conservation and management decisions in real and dynamic landscapes.

1.5.2 Biodiversity indices

The clearing of land for agricultural purposes has consequently led to a decline of biodiversity (Benton *et al.* 2002, Green *et al.* 2005). Following the signing of the Convention on Biological Diversity, the European Commission published a Biodiversity Action Plan (BAP) for Agriculture [COM (2001)162 vol. III] as part of a strategy to halt the global decline in biodiversity by 2010. Whilst this aspiring aim has not been realised, the necessity to halt biodiversity loss remains (Butchart *et al.* 2010). Biodiversity indices that deal with species richness, abundance and evenness are also taken into consideration to indicate whether certain perturbations have occurred and fulfil a meaningful role. For instance applying the evenness index can expose a sporadically dominant insect species that might establish itself as a pest. Other ways in which biodiversity indices can contribute to an indicator protocol will be discussed on a more detailed level in chapters four and five.

Species richness alone is not a suitable indicator for assessment of the effects of farming systems on the various attributes of biodiversity (Büchs 2003). However, abundance and evenness in combination with species richness forms the basis of a biodiversity assessment and may contribute enormously to elucidate the integrity of an ecosystem. The evenness variable is especially meaningful as a predictor of certain pest species with high thresholds and species that might dominate a noteworthy environmental event, such as disturbance. Although indices provide valuable information regarding species richness and abundance, they simultaneously tend to strip much valuable information regarding composition, structure and function from a sample.

1.5.3 Guilds and ecosystem services analysis

For the purpose of assessing cultivated areas, criteria are required that are not based on a maximizing of "biodiversity" only, but include stronger structural and functional qualities of the biocoenoses according to the definition of Noss (1990). One of the main intentions of this thesis is to derive indicators of ecological relevance. This can only be done by analysing guild structure and to determine how communities support ecological services. Obrist & Duelli (2010) found that the ratio between guilds are affected when considering agricultural habitats, managed forests, and unmanaged habitats, indicating that the environment / landscape play an important role in this regard. This thesis will also look at how the ratios are affected in relation to the study design. In the context of ecosystem services, Haines-Young *et al.* (2012) describe 'functions' as indicators of "capacity or capability of the ecosystem to do something that is potentially useful to people", while De Groot *et al.* (2010) relates the term 'function' to the potential of a system to deliver a service.

1.5.4 Predator-prey ratio

Predator-prey ratio in various studies has also proved to be an effective criterion in determining the extent of various perturbations. The trophic-level hypothesis of island biogeography highlights the relative importance of natural enemies which increase with habitat area. Predator-prey ratios have been shown to be higher on older fallows in comparison with younger ones. Larger fallows also had a greater predator-prey ratio than small field margin strips (Denys & Tscharntke 2002).

1.5.5 Economic value of biodiversity and ecosystem services

The more diverse an ecosystem the more ecosystem services are available depending on species richness. The value of these ecosystem services are irreplaceable and essential for survival of mankind (consider, for example, crop pollination), are expendable, but at a high economic and environmental cost (*e.g.* pest control and add economic value to human enterprises (*e.g.* natural enemies) (Kremen & Chaplin-Kramer 2005). In this thesis an attempt is made to assign an Agrecosystem Function Index (AFI), which enhance the economic value (index) of the arthropod community. This economic value is derived from Losey & Vaughn (2006) who assigned estimated values to certain ecosystem services in agriculture.

1.6. Incorporating arthropod biodiversity indicators into an environmental management strategy

The bio-indicator protocol will be available for incorporation into an environmental management strategy. The foundation upon which the indicator protocol will be based will follow that of the Environmental Management System (EMS) as a guideline. An EMS protocol has been used to manage agriculture, especially in Australia, where it has proven to be successful in improving the performance of an agribusiness overall, simultaneously reducing environmental impacts (Carruthers & Tinning 2003). The EMS endeavours to stabilize the balance between ecological stability and agricultural biodiversity and to provide an indication when the balance or the stability of the agroecosystem is in danger of collapsing. Ecological tools are essential to predict current or future threats to the stability of a specific agroecosystem.

1.7. Aims and objectives of this thesis

The aim of this thesis is to investigate arthropod biodiversity in the context of ecological function and agroecosystem resilience capability that may be used in indicators as a robust method for sustainability of ecosystem services on new crops.

These indicators would be combined and subsequently integrated into an EMS for agriculture. Four objectives have been determined, which will each be posed as a hypothesis:

- The first objective is to determine the relationship between arthropod diversity indices (species richness, abundance and evenness) and arthropod assemblages.
    - *Hypothesis 1*: If the arthropod species richness differs between a new crop and the natural environment, changes in species richness indices will be dependent on the arthropod assemblages within the habitats.

- The second objective is to determine the relationship between the edge effect reaction of arthropods and the resistance and resilience of an agroecosystem.
    - *Hypothesis 2*: If the resistance and/or resilience of an agroecosystem towards incoming pests is dependent on the arthropod response to the edge effect, then a positive edge effect response will have greater resistance and/or resilience towards incoming potential pests.

- The third objective is to determine the relationship between agricultural practices (such as pesticides, fertilizers and surrounding vegetation) and arthropod richness and abundance.
    - *Hypothesis 3:* If arthropod richness and abundance are dependent and affected by agricultural practices (pesticides, fertilizers, patch size, cover crops and surrounding vegetation), then the selection of correct agricultural management practices will improve arthropod species richness and abundance.

- The final objective is to determine the relationship between the arthropod species richness and abundance, and the proposed AFI (Agroecosystem Function Index), which is based upon the economic value of ecosystem services.
    - *Hypothesis* 4: If the AFI is dependent on the economic value of ecosystem services, then an increase in the AFI should be effective in indicating an economic gain as a result of an increase in arthropod species diversity.

CHAPTER 2

SITE DESCRIPTION AND SAMPLING METHODS

2.1 Selection of sites

The two field sites that were selected were vastly different new crop cultivations. The two sites also differed quite dramatically from each other regarding abiotic and biotic variability, as well as in geographic location. Pistachio nuts (*Pistacia vera*) (Anacardiaceae) (Fig. 2.1) were cultivated at Green Valley Nuts (GVN) (S29° 34.927; E22° 54.642) in the Prieska district, Northern Cape Province (Fig. 2.3), whilst kenaf (*Hibiscus cannabinus*) (Malvaceae) (Fig. 2.2) was cultivated at Constantia (CON) (S28° 47.969; E29° 38.197) in the Winterton district, KwaZulu-Natal (Fig. 2.3). Both are regarded as new crops, since they have never been cultivated in the respective areas before.

Fig. 2.1. Rows of pistachio trees, with cover crop or ground vegetation in-between rows, comprising a pistachio orchard.

Fig. 2.2. A stand of kenaf on the right that is surrounded by natural vegetation on the left.

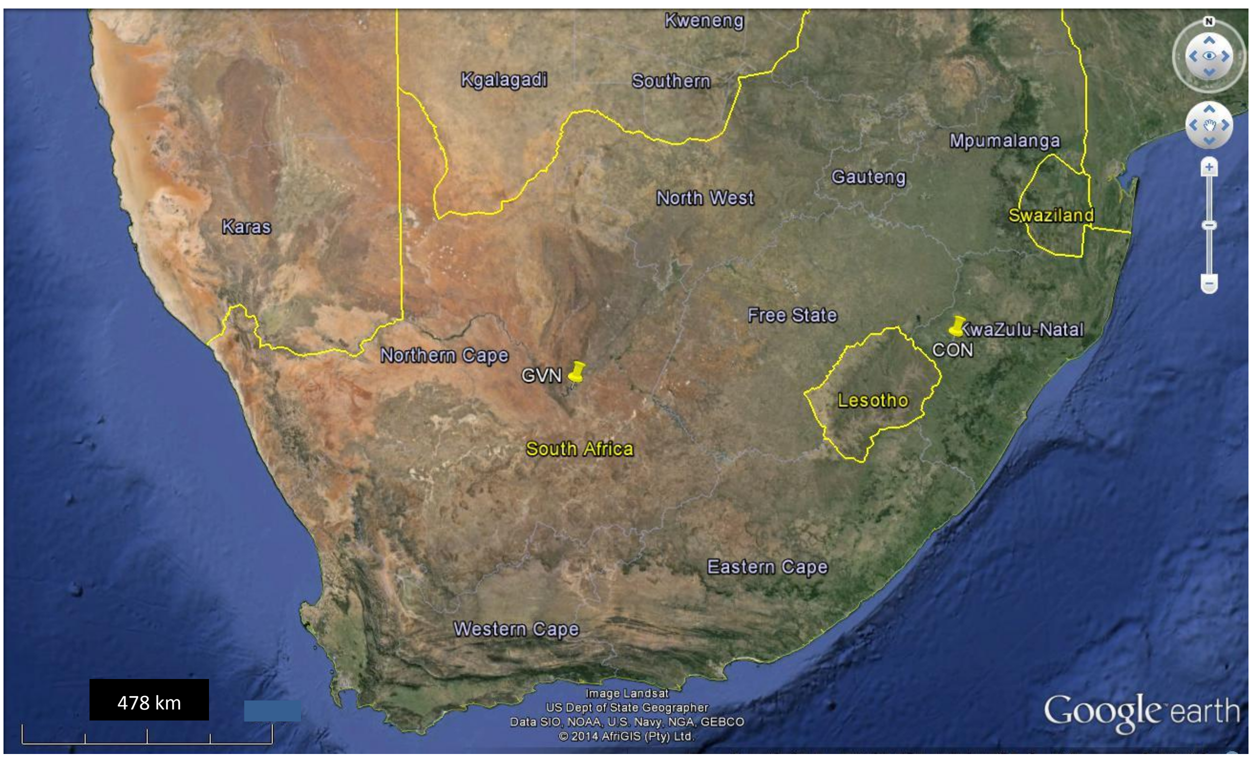

Fig. 2.3. The location of sites at Green Valley Nuts (GVN) in Northern Cape Province and Constantia (CON) in KwaZulu-Natal, South Africa.

2.1.1 Green Valley Nuts (Prieska, Northern Cape)

The Green Valley Nuts (GVN) landscape (Fig. 2.4) mainly consists of Orange River Nama Karoo type habitat and has a low annual rainfall (300 mm). The soil types on the farm are Augrabies silt, Namib Prieska Mispah and Namib ecotype. Ground cover vegetation was present within the orchards which consisted of a variety of weed and grass species (see Chapter 5). Agricultural activity (*e.g.* pesticides and mowing of ground cover vegetation and proximate natural vegetation) was intensively practiced at this site. Irrigation of the orchards is supplied mainly from the Orange River by means of drip spray. Pistachio nuts are a perennial crop.

The orchards consist of 16ha of trees. The sampling conducted from November 2005 to April 2006 or GVN1 (in Blocks 36, 42, 51 and 64) was done at a different sub-site than sampling conducted from November 2006 – April 2007 or GVN2 (in Blocks 46, 51, 59 and 62). The rearrangement of orchards was because the kenaf at Constantia during the first season was moved by the farmer from one sub-site to another (first season: CON1; second season: CON2) and therefore the sub-sites at GVN were also rearranged.

The sampling which was conducted from 2005 to 2007 is used as case study data and is applied to compose a model which is applicable to any new or even conventional crop.

2.1.2 Constantia (Winterton, KwaZulu-Natal)

Constantia (CON) consists mainly of Natal Central Savanna / Lowveld Bushveld type habitat (Fig. 2.5) and has a high annual rainfall (1000 mm). The soil type on the farm is mainly Avalon. No cover crops or ground cover was present since the kenaf was planted on a centre pivot system, albeit that most of the ‘irrigation’ was supplied by rainfall. Low intensity agricultural activity (no tillage, no mowing of proximate natural vegetation) was practiced on this farm. Kenaf is an annual crop.

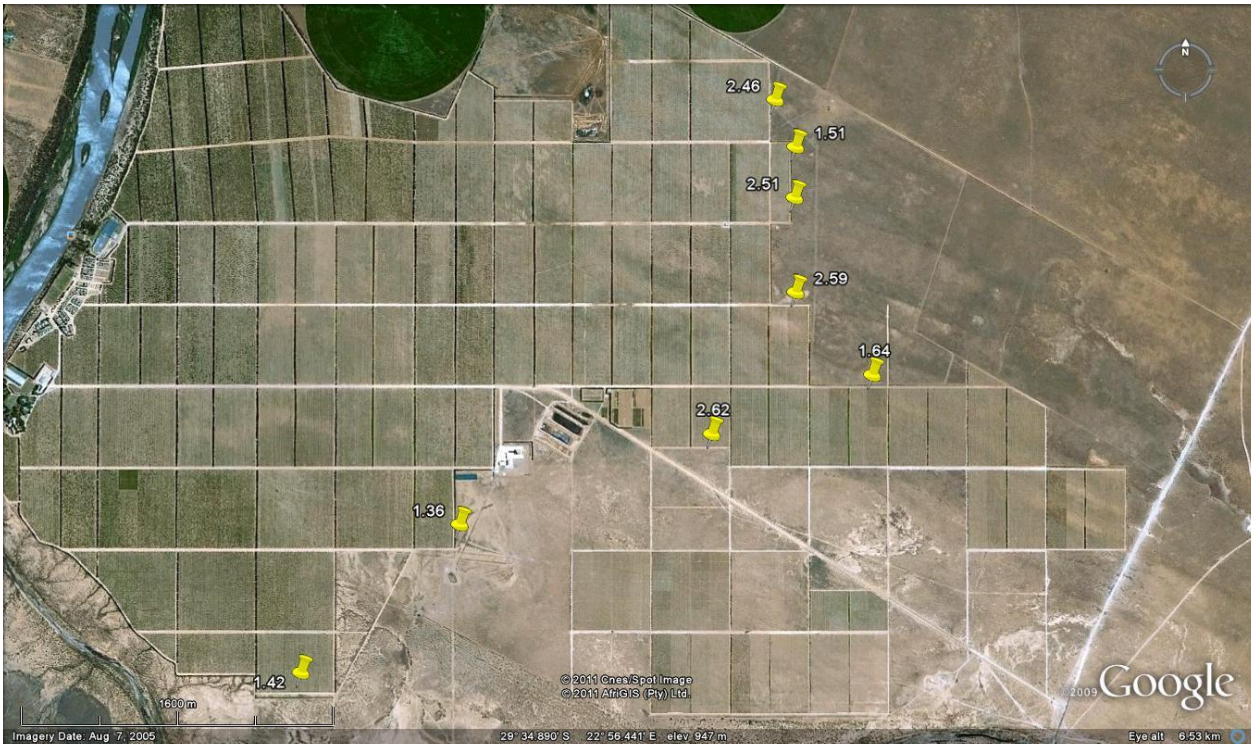

Fig. 2.4. Location of sampling points at Green Valley Nuts study site in Northern Cape Province, South Africa.

The sampling conducted from November 2005 to April 2006 (or CON1) (Pivot: S28°47'58.11, E29°38'11.84) was done at a different sub-site than sampling conducted from November 2006 – April 2007 (or CON2) (Pivot: S28°47'35.04, E29°37'45.05). This was due to fields being rotated with other crops. As mentioned previously the rearrangement of orchards was because the kenaf at Constantia during the first season was moved by the farmer from one sub-site to another.

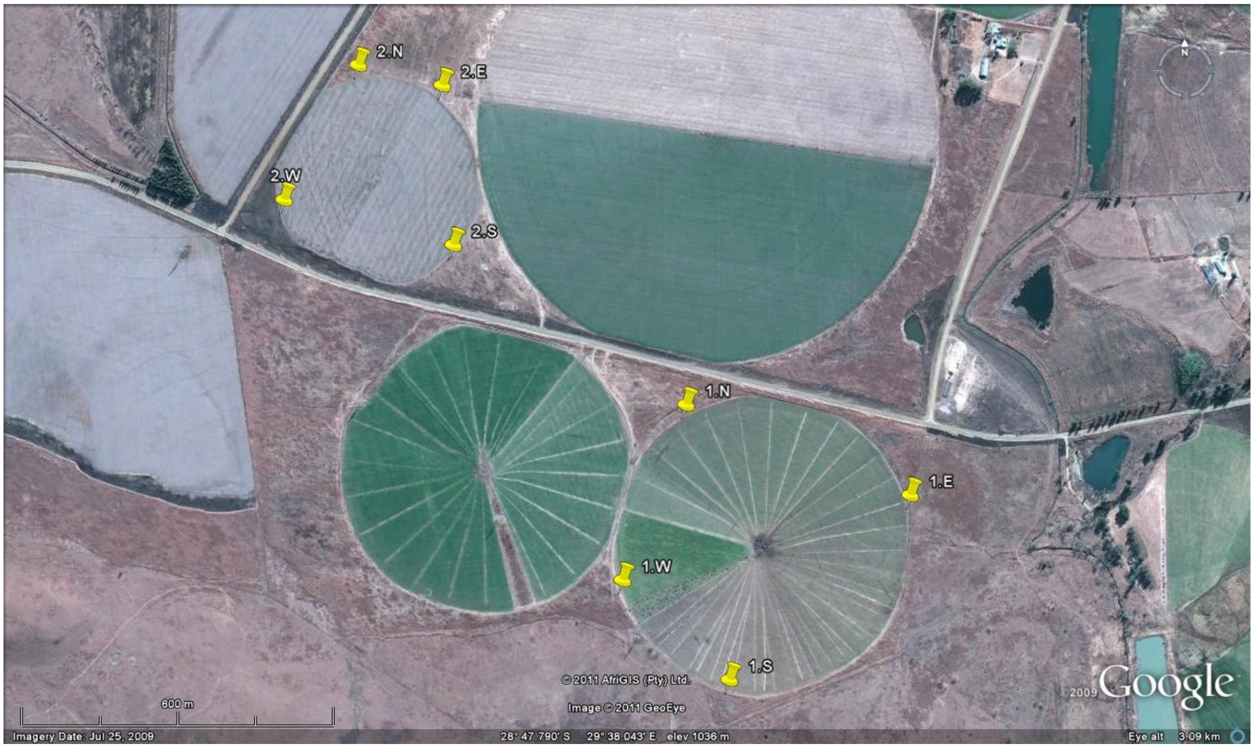

Fig. 2.5. Location of sampling points at Constantia study site in Kwa-Zulu Natal, South Africa.

2.2 Sampling methodology

Sampling was carried out at four different locations at each site over two summer seasons (GVN1 & CON1 = 2005 – 2006, and GVN2 & CON2 = 2006 – 2007) across all phonological stages of the crop. Arthropods and vegetation were sampled at different distances from the edge within the crop and the surrounding natural vegetation (Fig. 2.6 & Fig. 2.7). At GVN four different orchards were used, while at CON, points at N, S, W and E within the pivot. At each location three transects in the relevant crop and three in the surrounding environment were set 2, 10 and 50 meters from the crop border (transect 1, 2 and 3 were located 50m, 10m and 2m from the edge within the crop, and transect 4, 5, and 6 at 2m, 10m and 50m from the edge in the natural environment). Linear transects were measured and marked off at 20m intervals per transect and were then subsequently transversely sampled for arthropods and vegetation. A single sampling technique was used to collect arthropods within transects and comprised of sweeping the crop and the natural vegetation with a round sweep net (120cm circumference) with an arc of approximately 90˚ covering approximately a length of 1m. A total of 25 sweeps were carried out within each 20m transect.

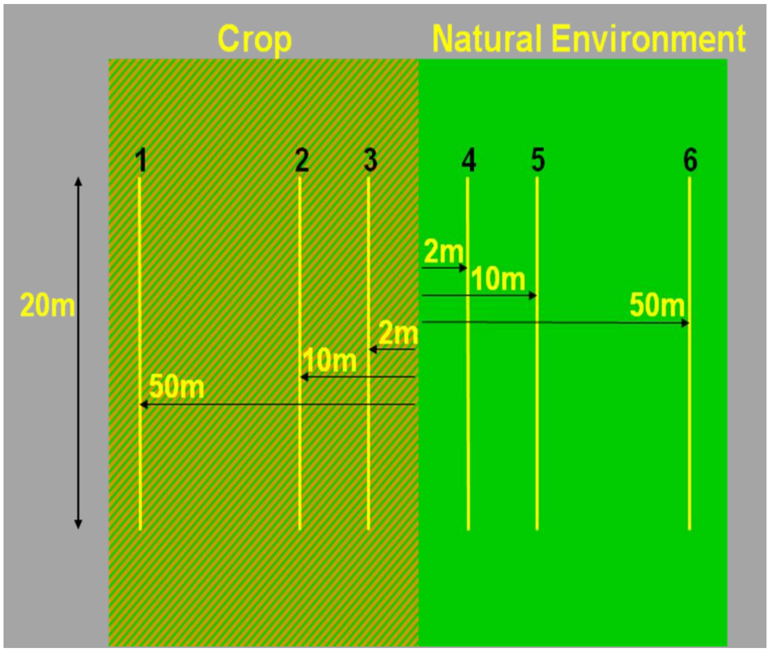

Fig. 2.6. The layout of transects for sampling in an orchard at Green Valley Nuts.

Sweeping was the preferred and most sufficient and efficient sampling method as mentioned in Chapter 1. This method is inexpensive and does not have any delay period. Pitfall traps were considered but they have a considerable delay between setting traps and obtaining material. The sweep net method allows samples to be immediately available to the researcher. One of the main objectives of the proposed indicator would be to use a quick, efficient method to sample arthopods, since the indicator is based on a robust methodology. Although sweep sampling does miss part of the arthropod community, it has been shown that sweeps alone do show analogous responses to those of multiple sampling techniques (Knops *et al*. 1999, Haddad *et al*. 2009). Similar arthropod surveys have been used in South Africa (five replicates of five sweeps to survey a 50ha area (Jonsson *et al.* 2010)), in North America ((25 sweeps for a 9 x 9 m plot in an experimental grassland (Haddad *et al*. 2009) and in Europe (10 sweeps in a 8 x 2 m plot of grassland (Koricheva *et al*. 2000)). All these studies also utilised other sampling techniques, but it is reasonable to question how informative these additional samplings were of the assemblage as a whole. Spafford & Lortie (2013) suggested that sweep netting and pan trapping be used concurrently for community-level arthropod surveys in grassland systems. However, since this study focuses on a robust methodology which is situated in an agricultural landscape, pan trapping would not be suitable under the conditions (especially when taking irrigation into consideration). As a general ecological principle, criteria such as consistency, reliability and precision are necessary for the applicability of a given method for arthropod surveys.

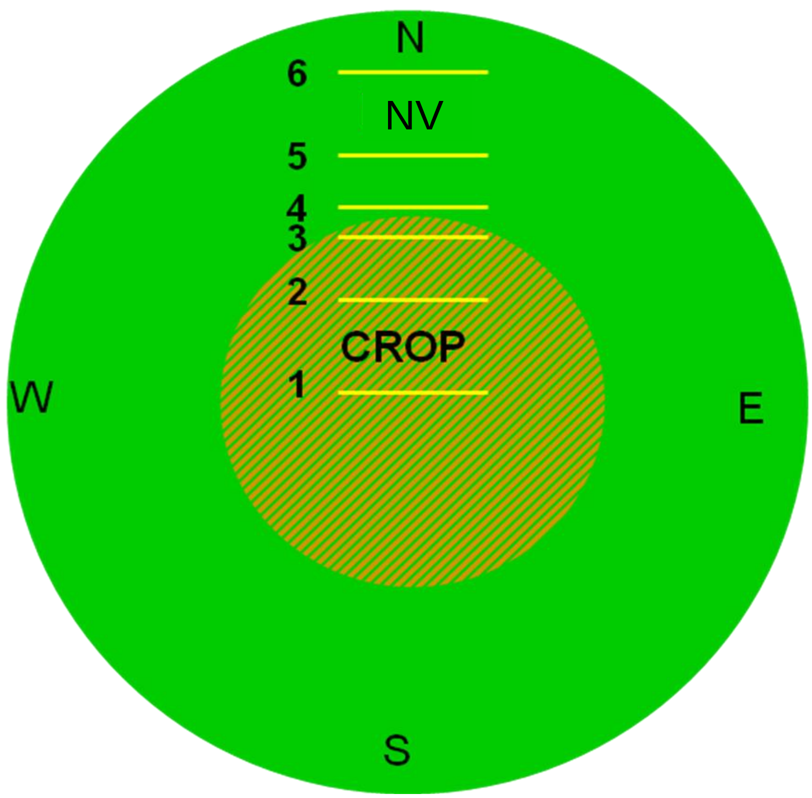

Fig. 2.7. The layout of transects for sampling at in a pivot at Constantia. Transects were transversely sampled for North, South, West and East. Similar to GVN, transects 1, 2 and 3 were set at 2, 10 and 50 m from the edge towards the interior of the crop, and 4, 5 and 6 were set at 2, 10 and 50 m from the edge within the natural vegetation (NV).

Specimens were transferred to a transparent plastic bag and then euthanized using an appropriate dose of ethyl acetate. The arthropod sampling was conducted once a month over a period of 6 months from November 2005 to April 2006 and repeated the following year from November 2006 to April 2007. All arthropods collected were sorted, identified to morphospecies and quantified. Morphospecies were selected as the preferred taxonomic level, since it has been shown that family names can be used as surrogates for species for a wide range of organisms without the necessity of specialized taxonomy (Balmford *et al.* 1996 *a*, *b*; Báldi 2003).

Plant species were sampled in each linear transect (including cover crops where applicable). Each transect was marked off at 20 metres and a plant was counted if part of the plant crossed the transect. The number of individuals plants per species (frequency) per transect were quantified.

2.3 Statistical analysis

Chapters 3, 4, 5 and 6 each deal with a different hypothesis concerning these sampling sites and the data used to argue the hypotheses will be statistically analysed. Each chapter will separately justify and provide sufficient explanations of the statistic equations applied. Material was pooled in different ways in the chapters that follow.

CHAPTER 3

THE LINK BETWEEN ARTHROPOD DIVERSITY IN A NEW CROP AND BORDERING NATURAL ENVIRONMENT LANDSCAPE

3.1 INTRODUCTION

The cultivation of crops involves potential risks posed by arthropods as pests. If the crops are new crops in an area, there exists an added financial risk. The cultivation of new crops in a new geographic location always poses risks of unknown nature, since a cultivated unknown ('wild') species may be challenging to assess in terms of these risks, of which associated insect pests is one (Holderness & Waller 1997). In such scenarios additional risks include insects migrating from the surrounding natural environment to the new crop. This migration relates to a new geographic location and opportunism, triggering a pest outbreak as a result of niche displacement.

Pest outbreaks may be triggered by a variety or a combination of biotic or abiotic factors, whether as a result of new crop hazards or intense agricultural practices. The migration of arthropod species between the crop and the natural environment may vary as a result of temporal (seasonal) resource availability. Ideally, the potential risks of pest threats need to be forecasted and prevented by making responsible management decisions.

There is a difference between the temporary presence of a pest in an agroecosystem and the establishment of a pest in an agroecosystem. Crucially the latter has far-reaching implications and needs to be mitigated by proper management practices. The distribution of species is influenced by the structure and composition of the landscape and therefore it is important to consider structural, functional and compositional biodiversity when dealing with ecosystem management. Species richness is an important indicator when addressing biodiversity and is, amongst others, necessary to maintain high connectance amongst organisms within a food web (Sánchez-Moreno *et al.* 2011). As such species richness can be affected by various disturbance factors.

This chapter deals with the link between arthropod communities in new crop cultivation and the surrounding natural vegetation, which applies and highlights the importance of species richness as a simplistic analysis. Species richness has the potential to be a simple and efficient way of determining the stability, variation and/or the integrity of an ecosystem. Understanding the differences in species richness dynamics between a crop and the immediate natural vegetation and their underlying impacts on one another is necessary for responsible decision making. The structure and composition of a newly established new crop agroecosystem may have even more profound interactions and influences within the two habitats.

The use of diversity indices has increased due to the necessity of testing different methodologies to develop the ecological status of a region. Responsive pest management by means of the reactive approach has its limits since it focuses on the control of a single pest species which may not solve a pest problem in the long run. As such responsive pest control may lead to resistance and resurgence of the current pest species and the establishment of additional pest species (Hardin *et al.* 1995).

The integrity of an agroecosystem partially depends on the biodiversity and only the average local species richness (alpha-diversity) is generally not considered to be a valuable and applicable aspect of biodiversity. Species richness within an agroecosystem originates from the surrounding natural habitat and ecological resilience (Peterson *et al*. 1998) and sustainability of ecosystem services (Hooper *et al*. 2005, Kremen 2005, Loreau 2000) may depend greatly on this local species richness. This dependency may be intensified when major global environmental changes such as global warming and management changes (crops that undergo changes in management practices are regarded as new crops) (Loreau *et al*. 2003, Allison 2004, Kassar & Lasserre 2004) are considered. Pollination (Kremen *et al*. 2007), pest control (Moonen & Barberi 2008) and prevention of alien biological invasions are important ecosystem system services that all depend on local species richness in one way or another.

Ecosystem resistance and resilience, and ecosystem services are important for an agroecosystem to expose certain beneficial ecological pulses. Biodiversity and landscape ecology are mutually dependent within an overriding ecological paradigm (van Hook 1994). In this regard French & Elliott (1999) observed that the structure of the landscape is an important component in determining the spatial distribution of ground beetles and Landis *et al*. (2000) found that the diversification of a habitat has the potential to increase predator density and diversity by providing alternative food and enhanced habitat resources. The latter is supported by Lundgren (2009) who reported that these alternative nutritional inputs all potentially increase the efficacy of predators in biological control (Lundgren 2009). Albeit that several indicator scenarios depend on a single group or taxon, the loss of local species richness is overall more significant and pertinent than the loss of a red list species, based solely on the multiple ecological functions provided by the different species.

A downside of this argument is that arthropod diversity indices have their limitations in that large volumes of information cannot be incorporated into one value. Furthermore, the main requirements mentioned by McGeoch (1998) for demarcating biodiversity indicators cannot be combined, since there is always the challenge of finding a compromise between the inherent complexity of biodiversity and the simplicity of what is affordably measurable (Schmeller 2008). However, an upside to all this is that potential arthropod pest species may be identified by simply comparing the evenness of arthropod communities between two habitats.

The relative sensitivity of a species richness index should be sufficient in determining its effectiveness as an index. Thus the community structure within an agroecosystem landscape expressed as arthropod species diversity indices (species richness + abundance + evenness) should demonstrate the ecological functional differences between the crop and the natural vegetation.

Sampling rarefaction as a measure of species richness may be effective as an indicator of biodiversity and from this potential arthropod pest species may be identified by comparing the evenness of arthropod communities between two habitats. Ideally, forecasting the hazards of a new crop and simultaneously minimising the use of intensive agricultural practices such as pesticides, there should be justification that species richness alone be used as an indicator. If local species richness indices are sensitive regarding differences between a crop and the natural vegetation, then species richness should give an indication of ecological integrity. Therefore based on the above background argument the first objective of this study is to determine the relationship of biodiversity indices (species richness + abundance + evenness) between a new crop and the natural environment (which together comprise an agroecosystem landscape).

Hypothesis 1: If the arthropod species richness differs between a new crop and the natural environment, changes in species richness indices will be dependent on the arthropod assemblages within the habitats.

3.2 METHODOLOGY

3.2.1 Analysis of variance

An analysis of variance (ANOVA) was performed for the mean number of species and the mean number of individuals (± confidence interval of 95%) for the crop and natural vegetation at the different sampling locations. The purpose of this was to test for differences between the means. A post-hoc Tukey test was performed to determine which groups among the sample have significant differences. This method calculates the difference between the means of all the groups and Tukey's HSD (Honest Significant Difference) test values are numbers which act as a distance between the groups.

3.2.2 Sample rarefaction

Rarefaction is used to assess species richness from sampling results and therefore sampling rarefaction serves as a tool to describe biodiversity. Rarefaction based on rarefaction curves allows the calculation of species richness for a given number of individual samples. It is simultaneously an indication of whether sufficient sampling has been conducted.

Sample rarefaction curves represent the number of species as a function of the number of samples. A steep slope indicates that a large fraction of the species diversity remains to be discovered and more samples have to be taken to boost confidence levels. If the curve flattens out to the right, an asymptote has been reached, indicating that a sufficient number of samples have been taken. It is usually assumed that more intensive sampling is likely to yield only few additional species and theoretically, the larger the number of individuals sampled the more species that will be recorded

Sampling curves generally rise very quickly at first and then level off towards an asymptote as fewer new species are found per unit of individuals sampled. Rarefaction generates the expected number of species in a small sample of *n* individuals (or *n* samples) drawn at random from the large pool of *N* samples (Heck *et al*. 1975). Rarefaction curves generally grow rapidly at first, as the most common species are recorded, but the curves plateau as only the rarest species remain to be sampled.

The cumulative richness as a function of transects was determined for each of the sampling months. Transects were then grouped according the crop and the natural environment and their species richness relative to the number of samples compared with each other by using sample rarefaction at 95% confidence.

3.2.3 Detrended correspondence analysis (DECORANA)

Detrended correspondence analysis (DECORANA) is frequently and best used on quantitative data and gives good results with classed abundance data. This method is also effective when it is suspected that the sites are arranged along an environmental gradient. This method has the ability to associate species with particular clusters of sites by plotting the site and species ordination on the same graph, which allows the influence of the species in determining the ordination of the sites to be uncovered. DECORANA allows group differences to be visualized and individual differences can be used to show outliers. This ability of this method to associate certain arthropod species with specific clusters of sites is an important part of revealing complexities within the ecosystem. The material of the various sampling dates were pooled in each transect.

3.2.4 Guild structure analysis

After the arthropod taxa were identified to morphospecies, they were broadly grouped according to trophic structure (*i.e.* herbivores, predators, parasitoids, saprivores and omnivores). The variation of both absolute and relative trophic composition was analysed per season for the crop and the natural habitat at GVN and CON. The crop and the natural habitat were then compared with each other over a temporal scale.

3.2.5 Biodiversity indices

The *Margalef index* is a very simple index to apply that measures species richness (community diversity). It is very sensitive to sample size and is known to compensate for sampling effects (Magurran 2004). In terms of biodiversity measurement it incorporates both species richness and abundance. The equation is as follows: $d = S - 1/\ln N$, where S is the number of species and N is the total number of individuals in the sample.

Chao-1 is an estimate of true species richness of a sample. Chao-1 = S + F1 (F1 - 1) / (2 (F2 +1)), with the bias corrected where F1 is the number of singleton species and F2 the number of doubleton species. The estimator reveals that if a community is being sampled, and rare species (singletons) are still being discovered, it is likely that there are still more rare species that have not been sampled. As soon as all species have been recovered at least twice (doubletons), there is likely no more species to be found. This may have benefits for sampling over short periods of time. Tests of the estimator have shown that it does provide reasonable estimates for modern data sets (Chao 1984, Chazdon *et al.* 1998).

Extensive review of diversity indexes performed by Hayek & Buzas (2010) show *Buzas and Gibson's evenness* to be effective and this was used to calculate for this aspect of biodiversity for the crop and the associated natural vegetation per sampling date. Buzas and Gibson's evenness is expressed as $E = e^H/S$, where e is the natural logarithm base, H is the Shannon Weaver index and S is the number of species. These two measures are particularly effective in encapsulating many aspects of diversity into a single value and are the least biased by differences in species richness and sampling efforts (Hayek & Buzas 2010).

3.3 RESULTS AND DISCUSSION

3.3.1 Species list

A morphospecies list was compiled for GVN1, GVN2, CON1 and CON2 (Appendix A). A total of 3130, 3486, 3041 and 3974 individuals were collected at GVN1, GVN2, CON1 and CON2, respectively, and a total of 73, 173, 102 and 250 morphospecies of arthropods were collected at GVN1, GVN2, CON1 and CON2, respectively.

The number of individuals and the number of species increased at both sites from season 1 to season 2. This increase may be due to the change in location of the orchard sites at GVN and the pivot site at CON. However, the number of individuals only slightly increased relative to the number of species, which more than doubled. This suggests that during the first season, because of the similar number of individuals, niches were occupied, but with a fewer number of species, or as a result of an increase in plant diversity (data not shown) more niches were available during the second season. At CON the increase in the number of species and the slight increase in the number of individuals could alternatively be attributed to the difference in surface area. The surface area of CON1 was larger than CON2. It is known that small plots which are intensively managed are likely to be invaded by arthropods from surrounding, less intensively managed areas and consequently a negative effect of intensive management might be masked (Sattler *et al.* 2010). Therefore the results suggest that the size of the patch had an influence on the number of species.

Since the crop and the natural vegetation are different habitats it would be of more value to compare the number of species and the number of individuals between the crop and the natural vegetation at the different sites and during the different seasons.

3.3.2 Analysis of variance between the crop and the natural vegetation

An analysis of variance (ANOVA) with 95% confidence intervals (Fig. 3.1) on the mean number of arthropod species, showed the natural vegetation side at CON to be significantly higher, the crop side to be significantly higher at GVN2, and no significant difference between crop and natural vegetation side at GVN1. A post-hoc Tukey test showed that the mean number of species differed significantly between crop and natural vegetation at all the sites.

The mean number of species were found to be higher on the natural vegetation side at GVN1, however, the mean number of species were higher on the crop side at GVN2. Generally, the high number of species incidence on the crop side is as a result of the ground cover vegetation or cover crop which is present within the crop side because herbivore and predator species richness are strongly positively correlated to plant species richness (Haddad *et al*. 2009).

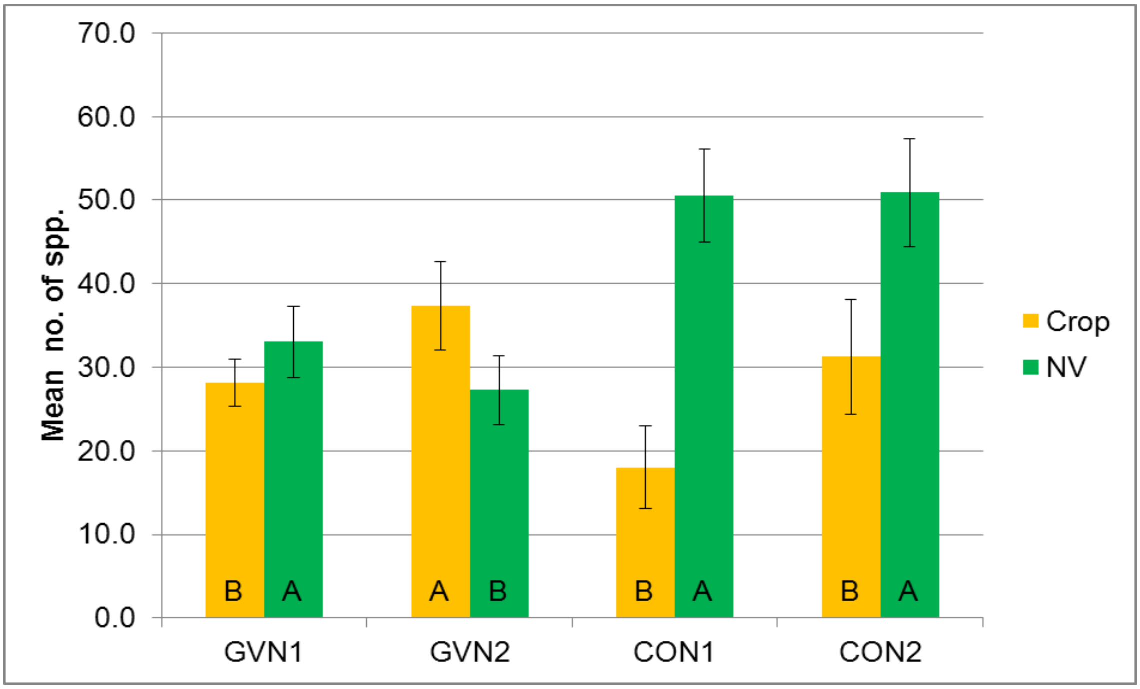

Fig. 3.1. Analysis of variance (ANOVA) for the mean number of species (± confidence interval of 95%) for crop and natural vegetation (NV) at the different sampling locations. The bars with different subscript (A or B) are significantly different applied by the Tukey test: $p < 0.05$, df = 46, Q-value = 2.84, HSD = 5.01.

Relative to the number of species, which more than doubled, the total number of individuals (Appendix A) only slightly increased, but this was not significant. The similar number of individuals suggests that all niches were occupied during the first season, however, they were occupied with fewer species. Knops *et al*. (1999) showed that the invasibility of a site depends on the availability of the resources that limit the growth of the invading species.

The difference between GVN1 and GVN2 implies that an increase in resources occurred because of the change in the intensification of agricultural practices which eventually favoured the number of species positively. Relative to the crop the natural vegetation decreased in the number of species at GVN2, which implies that resources here decreased, resulting in a decrease in the number of species.

An analysis of variance (ANOVA) with 95% confidence intervals (Fig. 3.2) on the mean number of individuals showed the natural vegetation side at CON to be significantly higher, the crop side to be significantly higher at GVN2, and no significant difference between crop and natural vegetation at GVN1. A post-hoc Tukey test showed that the mean number of species differed significantly between crop and natural vegetation at all the sites, except for GVN1 where they were similar. Similar patterns at the sites regarding the number of species and the number of individuals suggest that they are related.

Regardless of incredible arthropod diversity worldwide, evidence suggests the existence of repeatable, self-similar patterns across spatial scales for diversity-related patterns, such as rank-abundance distributions, species-area curves, and size-frequency distributions (Finlay *et al*. 2006). Because arthropod species are quite responsive to changing environments, including those resulting from human management practices (Morris 2000), densities and diversity can be highly variable within and among years and sites, which is the case between the first and second season surveys in this study.

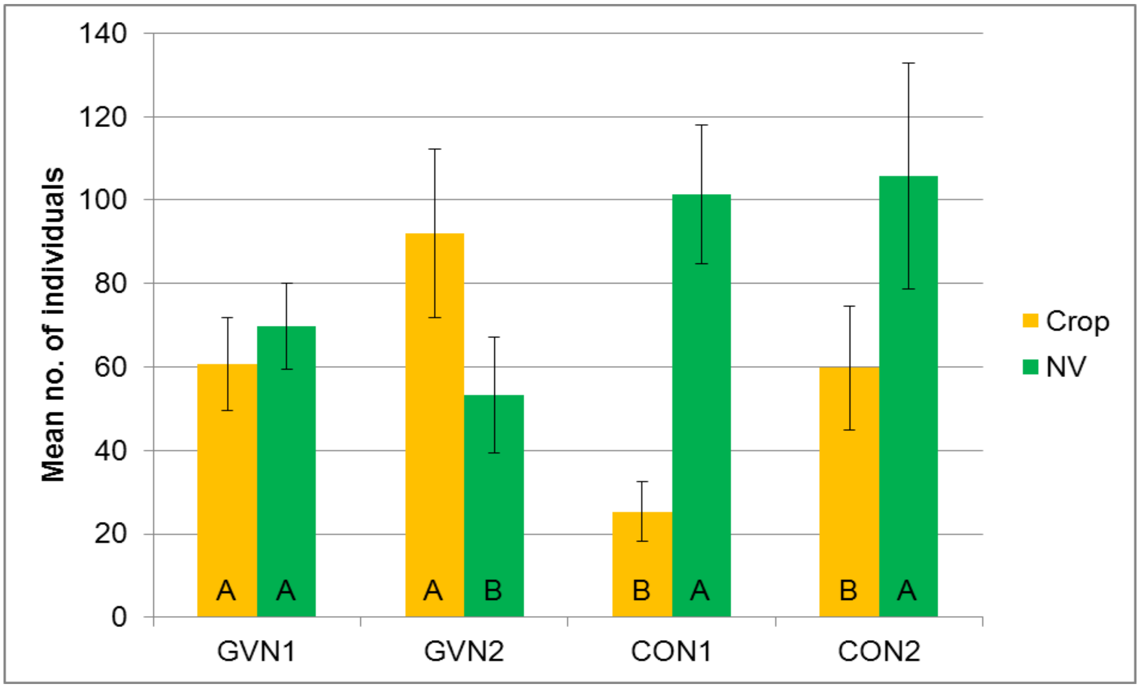

Fig. 3.2. Analysis of variance (ANOVA) for the mean number of individuals (± confidence interval of 95%) for crop and natural vegetation (NV) at the different sampling locations. The bars with different subscript (A or B) are significantly different applied by the Tukey test: $p < 0.05$, df = 46, Q-value = 2.84, HSD = 14.76.

3.3.3 Sample rarefaction

Figs. 3.3 to 3.6 show the rarefaction curves for the accumulated number of arthropod morphospecies collected during the first (2005 – 2006) and the second season (2006 – 2007) at GVN and CON within the crop and the natural vegetation. The solid (+) and stripped red lines (-) represent the standard deviation at 95% confidence level.

At GVN and CON the species richness at both sites (Figs. 3.3 & 3.5) eventually levels off completely in the first sampling; it also levels off in the second season for GVN in the second sampling, but not for CON. The second season at both sites (Figs. 3.4 & 3.6), however, has higher species richness than the first and tends not to level off; indicating that species richness is still increasing slightly towards the end of the sampling period. These results show that at both sites the second season needed more sampling effort to increase efficiency, although, as results show later, the sampling repetitions used proved to be sufficient to make clear deductions. During CON1 the natural vegetation reached an asymptote relatively sooner than the crop (Fig. 3.5), whilst Fig. 3.6 shows that that neither the curve of the crop or the natural vegetation reaches an asymptote. A robust method for biodiversity measurement and the development of biodiversity indices which are less sensitive to sample size will need to be considered.

Figs. 3.3 & 3.4 show the rarefaction curves at GVN for the accumulated number of arthropod morphospecies collected during the first (GVN1) and second samplings (GVN2), respectively. In Fig. 3.3 it can be observed that the species richness within the crop (n = 72) and within the natural vegetation (n = 73) are the same. In Fig. 3.4 it is seen that species richness is double that of the previous season within the crop (n = 166) and the natural vegetation (n = 157). Also, the sample rarefaction curve at GVN1 is observed to reach an asymptote relatively sooner than the curve of GVN2 for both the crop and the natural vegetation. The final species richness seems to differ significantly between the crop and the natural vegetation at GVN2 compared to GVN1 with almost similar species richness between the crop and the natural vegetation. The sample rarefaction curve of the natural vegetation is higher than that of the crop throughout GVN1, whereas the curve of the crop is higher than that of the natural vegetation during GVN2. As previously mentioned in Chapter 2, GVN is situated in a semi-arid region, with intensive agricultural practices within the orchards providing ideal conditions for arthropods from the natural environment to colonise the additional niches within the cover crop vegetation on floor of the orchards. Necessary to consider here would be that ideal conditions (such as sporadic rainfall) in the natural environment may provide temporary complementary resources for arthropods, whilst conditions in this regard within in orchards remain homogeneous due to irrigation practices. The rarefaction curves at CON for the accumulated number of arthropod morphospecies collected during the first (CON1) and second sampling (CON2), Figs. 3.5 & 3.6 respectively, show that the sample rarefaction curve of the natural environment is overall higher than that of the crop. Since the crop habitat has no other vegetation, such as cover crops, supplementary niche availability is low explaining the lower therefore less species richness occurs within the crop setup.

The rarefaction curves at CON for the accumulated number of arthropod morphospecies collected during the first (CON1) and second sampling (CON2), Figs. 3.5 & 3.6 respectively, show that the sample rarefaction curve of the natural environment is overall higher than that of the crop. Since the crop habitat has no other vegetation, such as cover crops, supplementary niche availability is low explaining the lower therefore less species richness occurs within the crop setup.

All in all therefore, it seems to be an advantage to have natural vegetation within and outside cropping systems which, in both isolation from one another and in combination, supports higher species richness within an agricultural landscape.

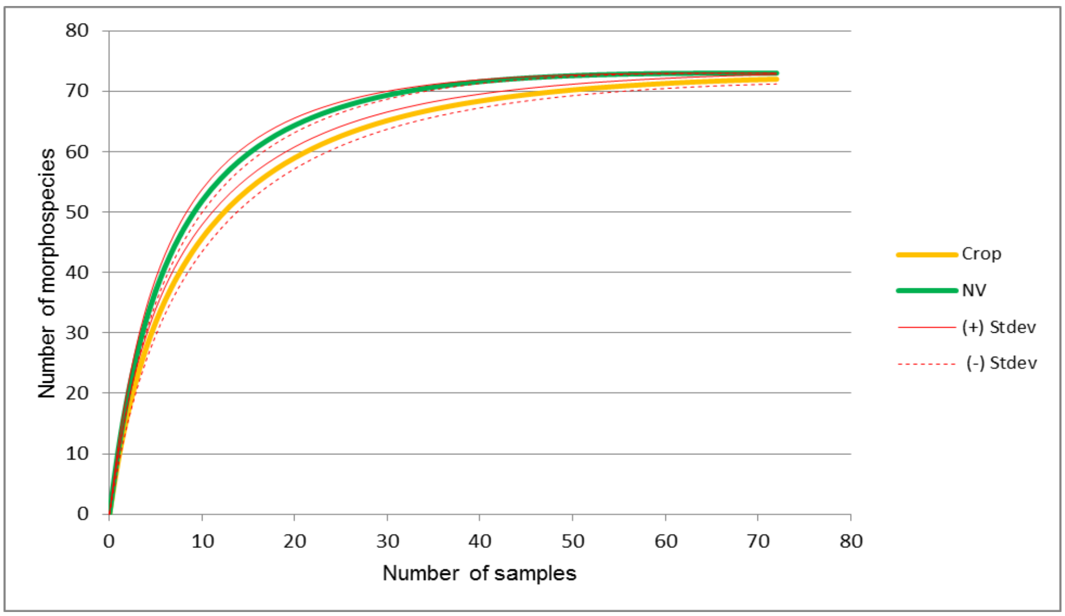

Fig. 3.3. Sampling rarefaction for transects within the crop and the natural vegetation for GVN1 (the first sampling season, 2005 – 2006, at Green Valley Nuts; NV = natural vegetation, Stdev = standard deviation).

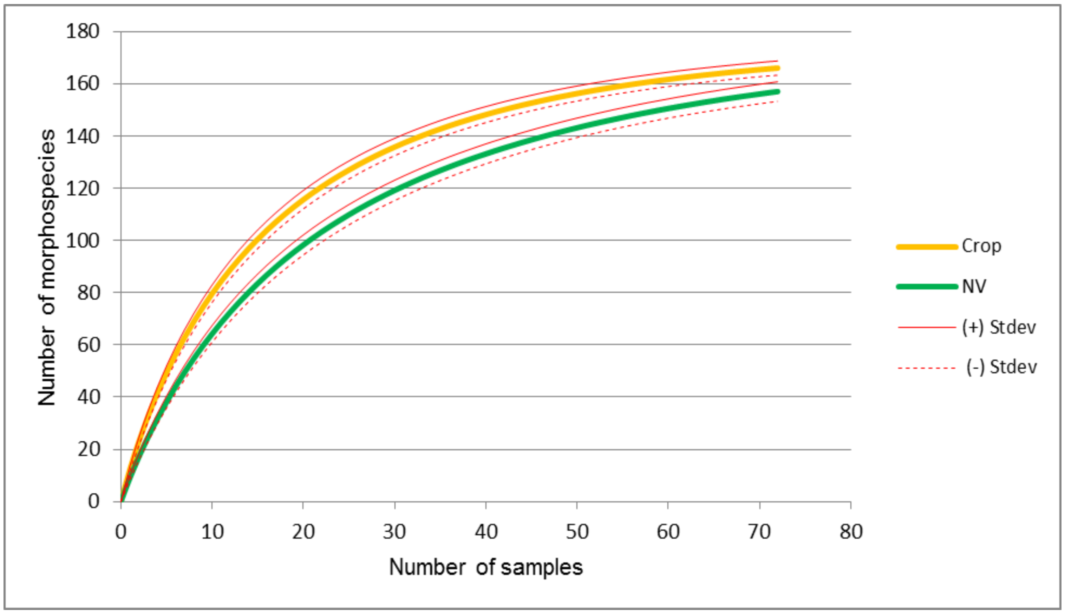

Fig. 3.4. Sampling rarefaction for transects within the crop and the natural vegetation for GVN2 (the second sampling season, 2006 – 2007, at Green Valley Nuts; NV = natural vegetation, Stdev = standard deviation).

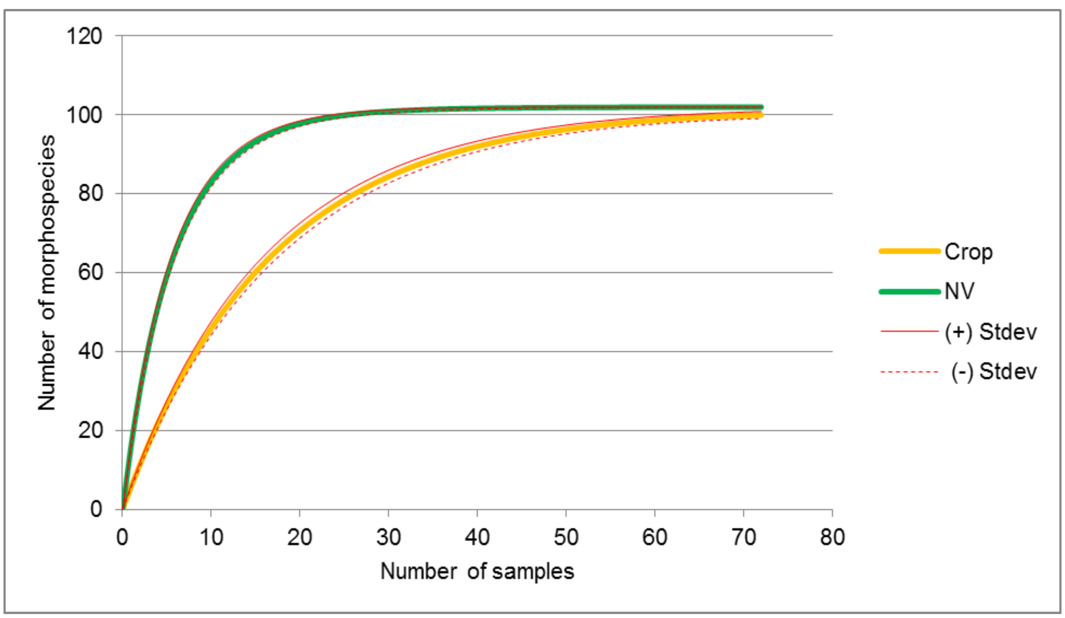

Fig. 3.5. Sampling rarefaction for transects within the crop and the natural vegetation for CON1 (the first sampling season, 2005 – 2006, at Constantia; NV = natural vegetation, Stdev = standard deviation).

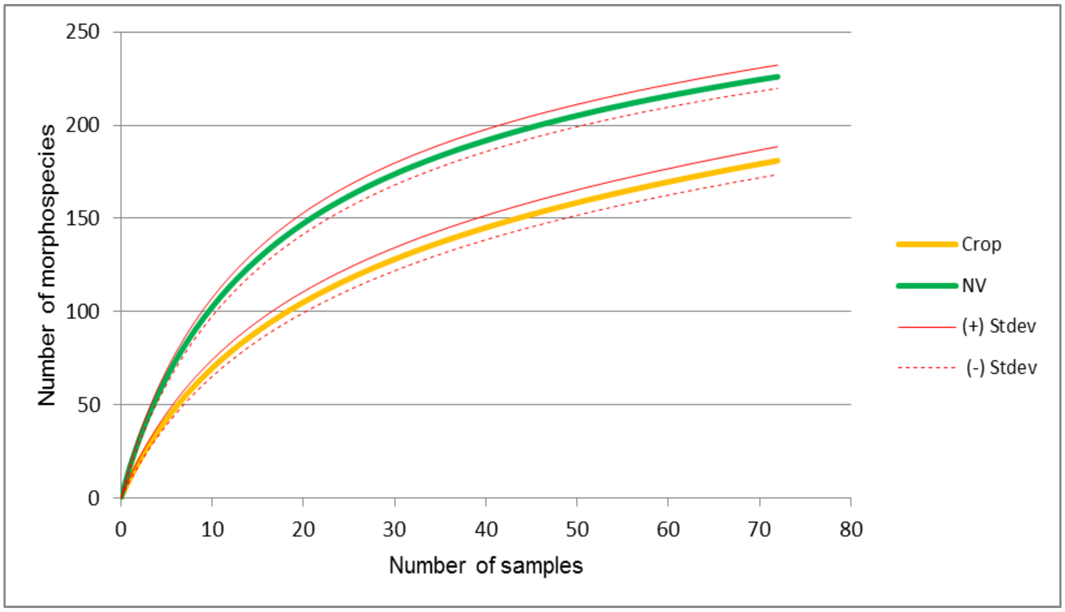

Fig. 3.6. Sampling rarefaction for transects within the crop and the natural vegetation for CON2 (the second sampling season, 2006 – 2007, at Constantia; NV = natural vegetation, Stdev = standard deviation).

It was mentioned in Chapter 2 that at GVN and CON the sampling localities differ from the first season to the second season. During the second season the difference in landscape structure between the sites may demonstrate the higher species richness within the crop. As mentioned in Chapter 2 GVN has natural vegetation present within the orchards which may result in higher species richness, compared to CON which has no natural vegetation within the kenaf stand and therefore exhibiting lower species richness within the crop.

Green Valley Nuts is situated in a semi-arid region, with intensive agricultural practices and high resource availability within the orchards, providing ideal conditions for arthropods from the natural environment to colonise the additional niches within the cover crop vegetation on the floor of the orchards.

Generally, the high number of species incidence on the crop side is as a result of the ground cover vegetation or cover crop which is present within the crop side because herbivore and predator species richness are strongly positively related to plant species richness (Haddad *et al*. 2009). Intercropping is effective in providing a favourable habitat for a diverse range of arthropods that would not be present in a single crop environment (Kanaga *et al.* 2009, Maeto 2009). Resource availability may also influence foraging behaviour and interactions amongst arthropods (Lach 2008). Here it would be necessary to consider that ideal conditions (such as sporadic rainfall) in the natural environment may provide temporary complementary resources for arthropods, whilst conditions in this regard within orchards remain homogeneous due to irrigation practices.

3.3.4 DECORANA (Detrended correspondence analysis)

An environmental gradient is evident at all the sites. It should be noted that since the distances between transects in the figures are far from each other they are represented by a different assemblage of morphospecies while points that are close to each other have a similar species assemblages.

Fig. 3.7a & b shows differences between transects lumped as the crop and the natural vegetation which lie to the left and right, respectively. This could indicate arthropod host specificity to both the cover crops and pistachio within the orchards on the one hand and the natural vegetation in the area surrounding the crop on the other. Clearly therefore, the species assemblages differ between the orchard vegetation and the surrounding natural vegetation. In all likelihood this is due to different plant species inhabiting the two habitats.

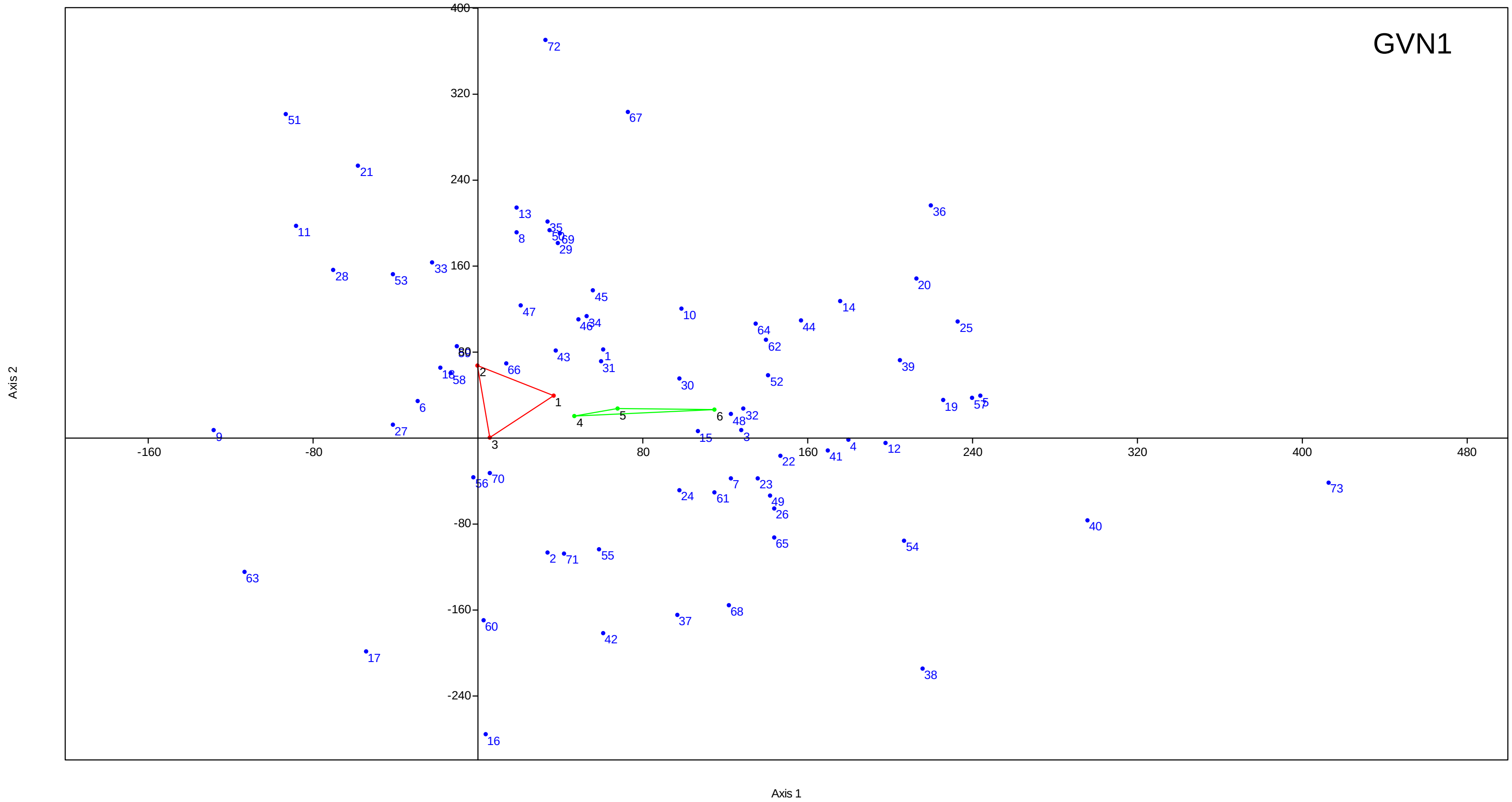

Fig. 3.7a. DECORANA representing three grouped transects within the crop (—) and three grouped transects within the natural vegetation (—) at GVN1. The blue dots with numbers represent morphospecies (refer to Appendix 1).

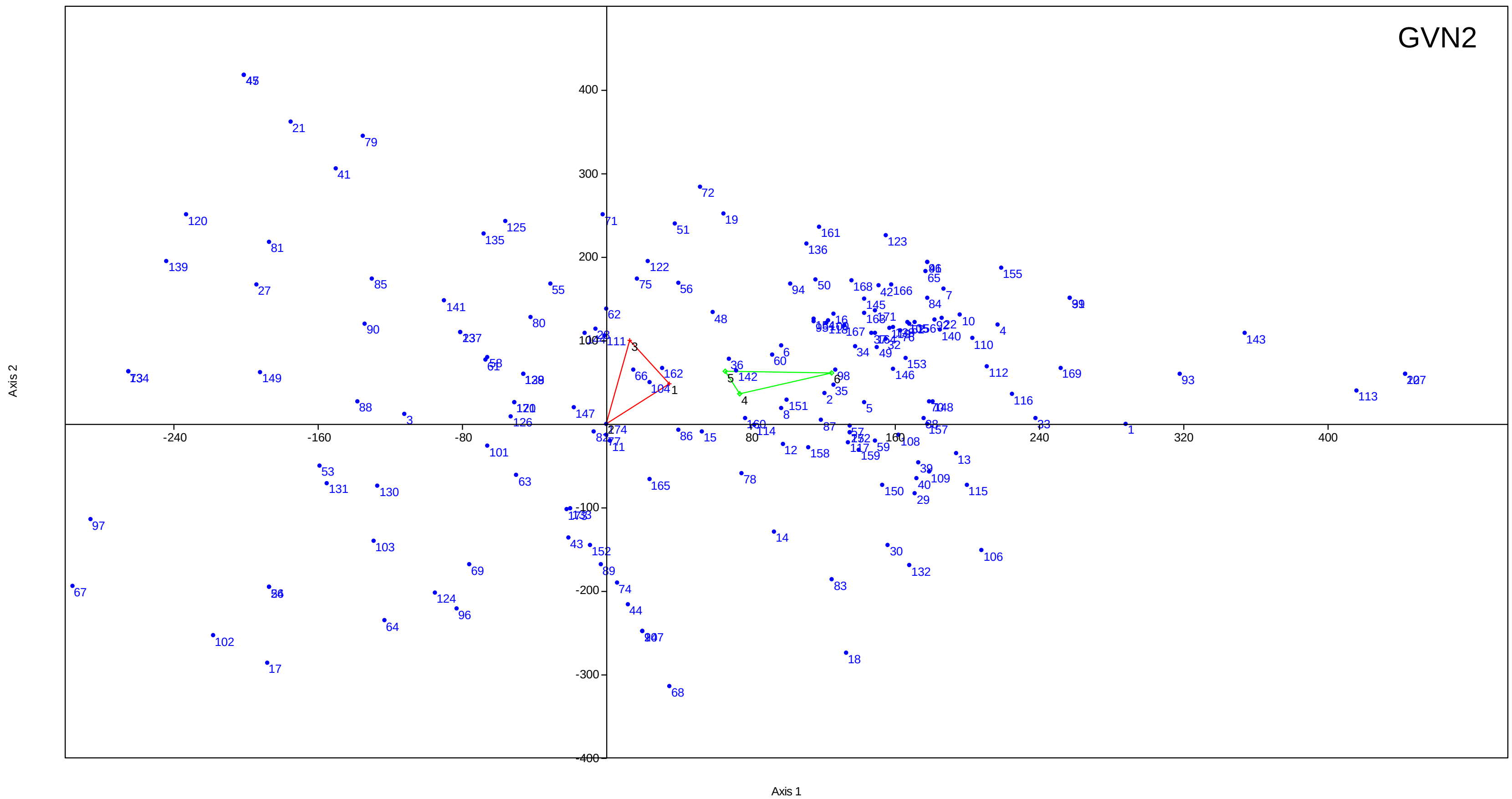

Fig. 3.7b. DECORANA representing three grouped transects within the crop (—) and three grouped transects within the natural vegetation (—) at GVN2. The blue dots with numbers represent morphospecies (refer to Appendix 1).

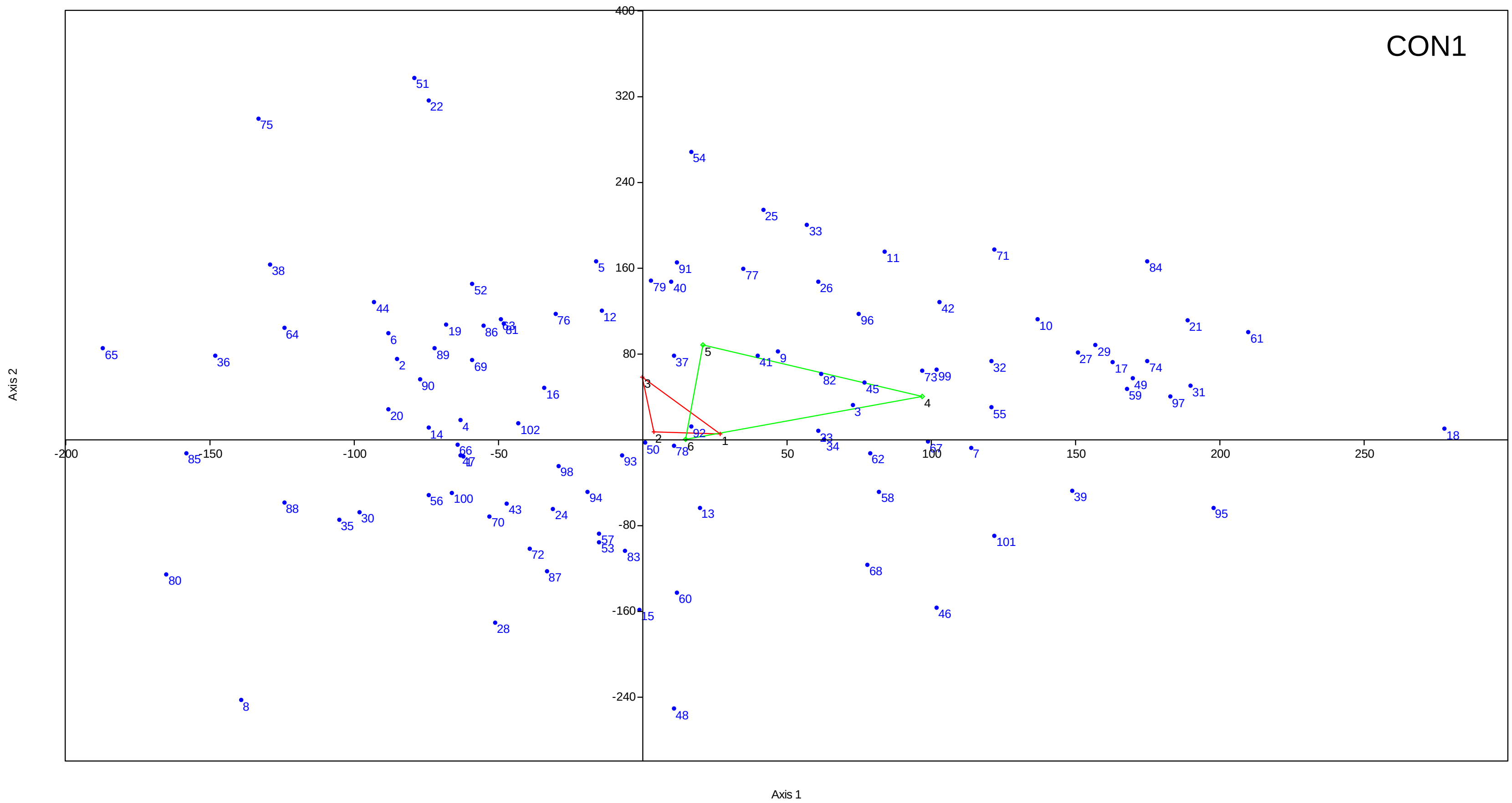

Fig. 3.8a. DECORANA representing three grouped transects within the crop (—) and three grouped transects within the natural vegetation (—) at CON1. The blue dots with numbers represent morphospecies (refer to Appendix 1).

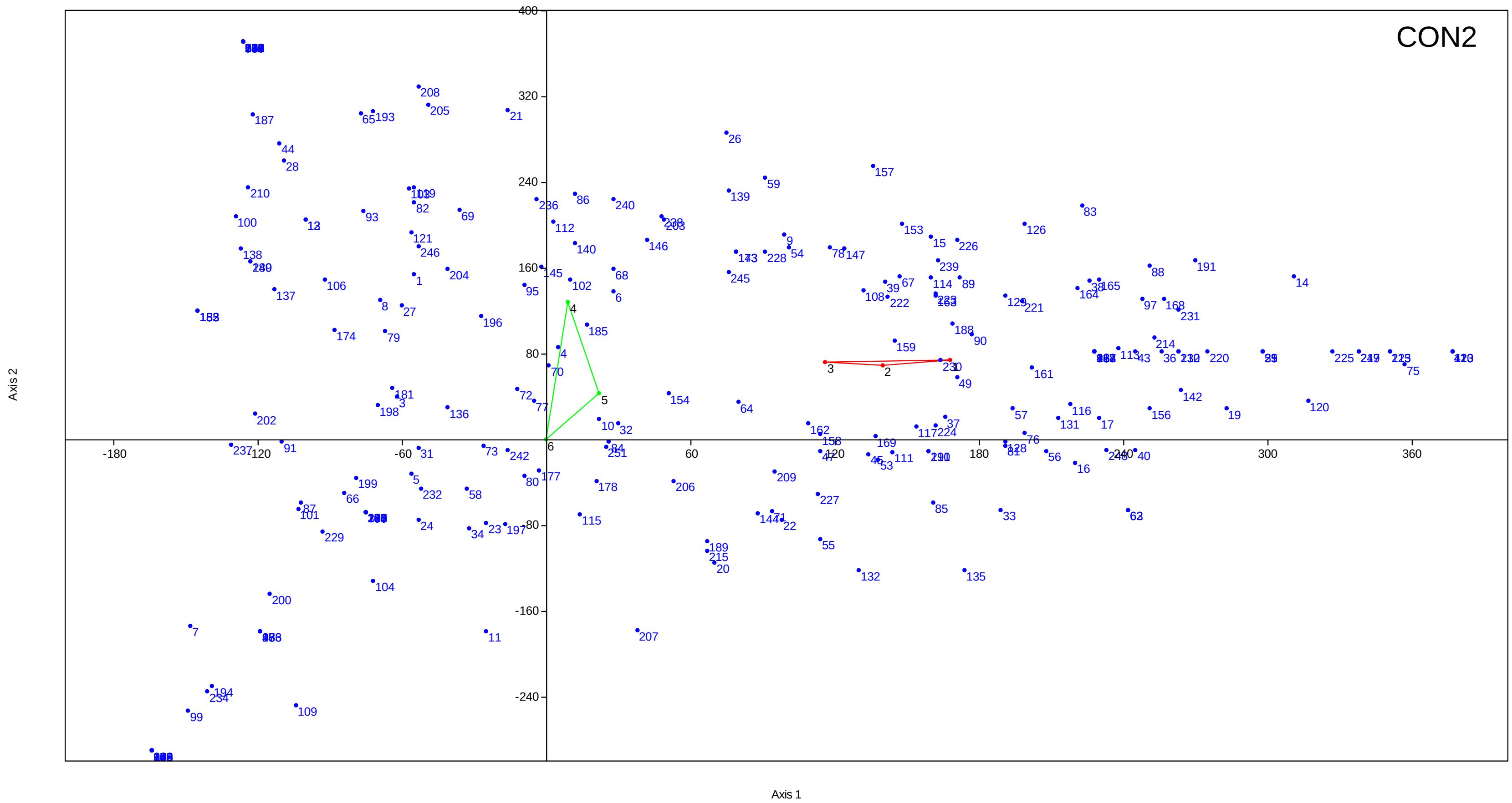

Fig. 3.8b. DECORANA representing three grouped transects within the crop (—) and three grouped transects within the natural vegetation (—) at CON2. The blue dots with numbers represent morphospecies (refer to Appendix 1).

Fig. 3.8a, shows that transects 5 and 6 in the natural vegetation are grouped closer to transects in the crop. However, transect 4 (an edge transect) of the natural vegetation on the right side of Axis-1 is much further away. From this pattern one may notice that even transects could be different within a habitat. The species assemblages, especially the phytophagous species are dependent on the specific plant species present within each transect and therefore the above situation becomes more meaningful.

The natural vegetation and the crop are on the right side of Axis-2 with CON2 (Fig. 3.8 b) and are well isolated from one another and the exact opposite of CON1. This could be attributed to the difference in plant species composition (data not shown) between the two samplings which was evident with sample rarefaction (Fig. 3.6), since sampling of CON1 and CON2 were carried out on different locations/pivots. CON1 and CON2 differ vastly, almost revealing a more unstable ecosystem compared to the GVN samples. This raises the question whether this could be due to the more stable climax natural vegetation composition in the harsh GVN environment or are there other parameters that may play a role?

It is evident that the species compositions are different and that this can possibly be attributed to several factors. Characteristics of vegetation that may influence arthropod diversity include primary production, degree and heterogeneity of landscape structure, plant species richness, species composition of vegetation, chemical attributes of foliage from both defensive and nutritional viewpoints, and factors affecting mutualistic relationships between plants and insects (*e.g.* flower density/diversity, pollinator diversity, and plant-microbe interactions) or competitive and/or exploitive interactions among species from multiple trophic levels (Joern & Laws 2013). Additionally this analysis was repeated over six months and this may also reduce the response towards the spatial factor.

3.3.5 Guild structure analysis

Figs. 3.9 to 3.12 show the absolute and relative abundance for arthropod trophic groups for each sampling date of the study (a - relative abundance of guilds, b - absolute abundance of guilds).

Fig. 3.9 shows that the relative abundance of predators to other guilds increases over time on both sides of the edge at GVN1. During the fifth sampling date (8 April 2006) a significant increase in herbivores in the crop and natural vegetation, leading to a relative decrease in predator to herbivore ratio, is recorded. It is important to note that these changes occur simultaneously within the crop and the natural vegetation. These simultaneous occurrences accentuate the possibility of connectedness between the crop and the natural vegetation. During the first four sampling dates arthropod abundance is higher within the natural vegetation, whereas at sampling date 5 and 6 arthropod abundance within the crop is higher.

GVN2 (Fig. 3.10a) exhibits different patterns, with an episotic (occurring sporadically or incidentally) population of omnivores on the second sampling date (20 January 2007) steadily decreasing on the third sampling date and returning to its original proportion on the fourth sampling date. Once again this phenomenon occurs simultaneously within the crop and the natural vegetation. Although signs of this occurrence are observed on both chart (*i.e*. a & b) it can be observed more clearly in the relative abundance guild chart.

With reference to (Fig. 3.10b) there also seems to be an episotic population of herbivores within the crop on the fourth fourth and fifth sampling date (11 March 2007 and 4 April 2007). In contrast to the previous, in Fig. 3.10a, this incident is better observed on the absolute guild chart. During the rapid increase in herbivores within the crop there is a slight increase in herbivores in the natural vegetation, the same applies the following month. It is possible that herbivores which increased within the crop migrated to the natural vegetation, meaning that arthropod communities may eventually migrate to the natural vegetation once the crop resources are not sufficient.

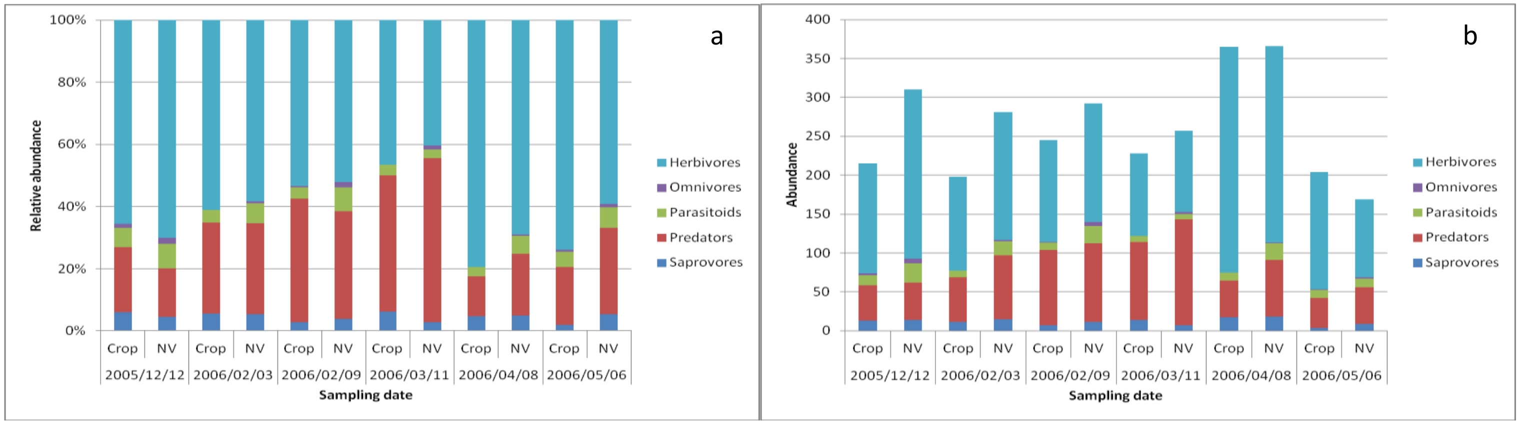

Fig. 3.9. The relative (a) and absolute (b) abundance of the arthropod trophic groups at GVN1 highlighting the difference between the crop and the natural vegetation (NV).

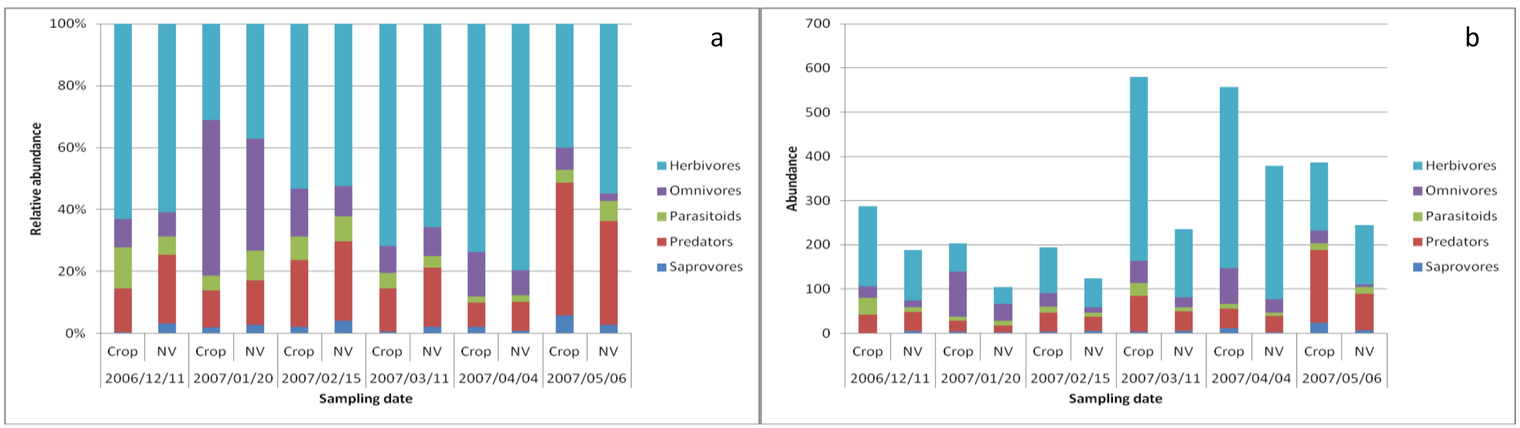

Fig. 3.10. The relative (a) and absolute (b) abundance of the arthropod trophic groups at GVN2 highlighting the difference between the crop and the natural vegetation (NV).

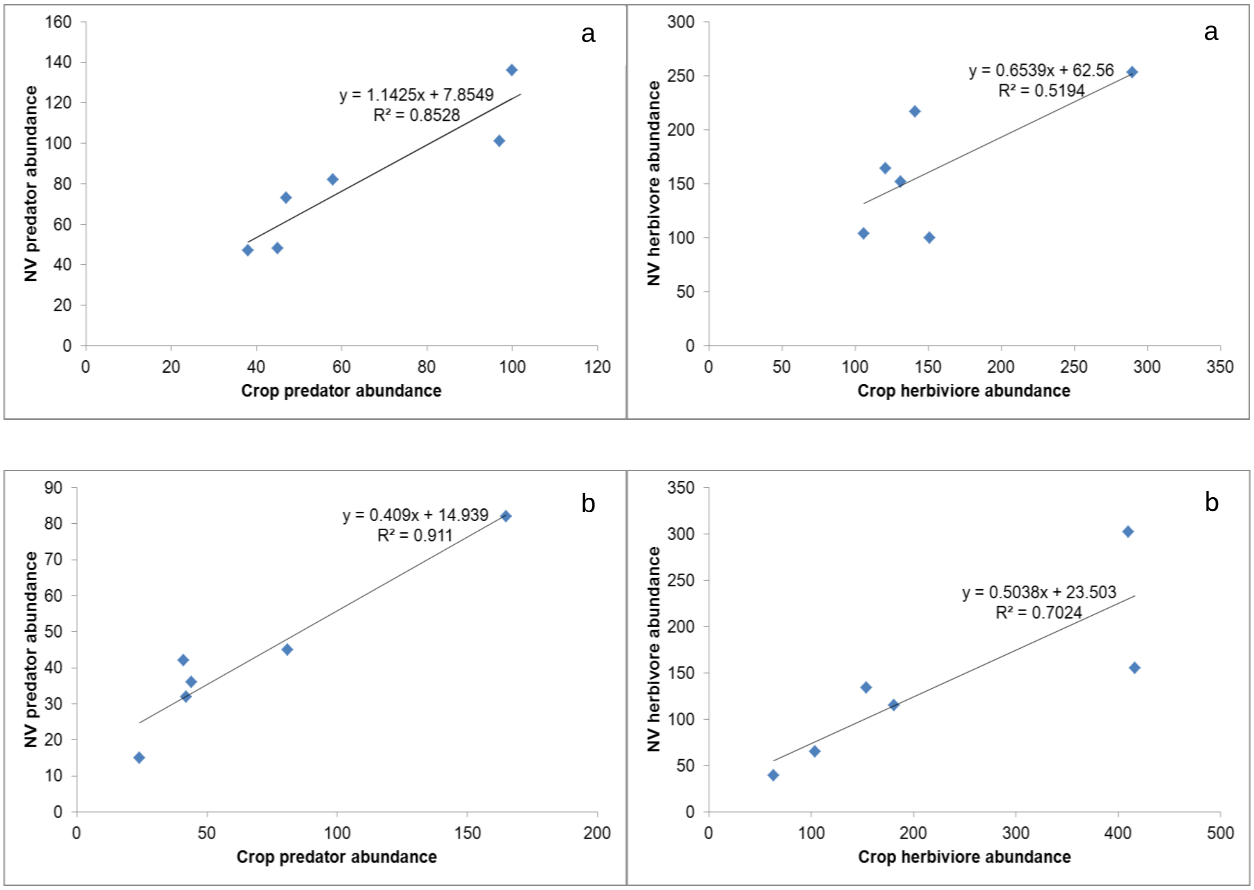

Fig. 3.11. Regression analyses showing how dependant predators and herbivores at a) GVN1 and b) GVN2 are between the crop and the natural vegetation (NV).

As observed, an increase in predators and herbivores on the crop side leads to an increase on the natural vegetation side and a decrease in predators and herbivores on the crop side would lead to a decrease on the natural vegetation side. Regression analyses revealed (Fig. 3.11) that the abundance of predators and the herbivores on the crop and natural vegetation side were positively related and significantly related to one another (At GVN1 predators in the crop and the natural vegetation, R^2=0.85; herbivores in the crop and the natural vegetation, R^2=0.51 and at GVN2 predators in the crop and the natural vegetation, R^2=.91; herbivores in the crop and the natural vegetation, R^2=0.70). The abundance of predators on the crop and natural vegetation are more closely related than the herbivores. Furthermore, it has been shown that herbivore and predator species richness are strongly positively related to plant species richness and these relationships are caused by different mechanisms at herbivore and predator trophic levels. As mentioned before, cover crops were present at GVN and evidence shows that intercropping can offer pest management benefits by increasing the abundance, diversity and richness of natural enemies (Theunissen 1994). More importantly, it has been shown that a threefold increase occurs, from low to high plant species richness, in abundances of predatory and parasitoid arthropods relative to their herbivorous prey. Over a long term, the loss of plant species proliferates through food webs, decreasing arthropod species richness, shifting a predator-dominated trophic structure to being herbivore dominated, and importantly more likely impacting on ecosystem functioning and services (Haddad *et al*. 2009).

Plant diversity relates to predator and parasitoid richness as strongly as it does to herbivore richness (Dinnage *et al.* 2012). Besides the creation of more arthropod feeding or habitat niches, phylogenetic diversity might affect arthropod diversity indirectly through its effects on plant productivity ('abundance hypothesis'). Such an increase in plant productivity will provide a larger resource base for herbivores and more habitat volume for predators. This could increase the overall abundance of arthropods, and consequently increase species richness through abundance-based 'sampling' (Gotelli & Colwell 2011).

Figs. 3.12 & 3.13 display the relative abundance of the trophic guilds for CON1 and CON2 on the crop and the natural vegetation side remain relatively constant over time. The zero abundance on the final sampling date represents the crop that has been harvested. With regard to the absolute abundance, the natural vegetation side is dominant most of the time, except for the final sampling date at CON1 and CON2 which cannot be compared. No significant changes are observed with the relative abundance, with only the absolute abundance revealing noticeable changes. This occurrence may be affected by the less intense agricultural practices at CON. The peaks within the absolute abundance may be due to climatic factors, which will be addressed in Chapter 5.

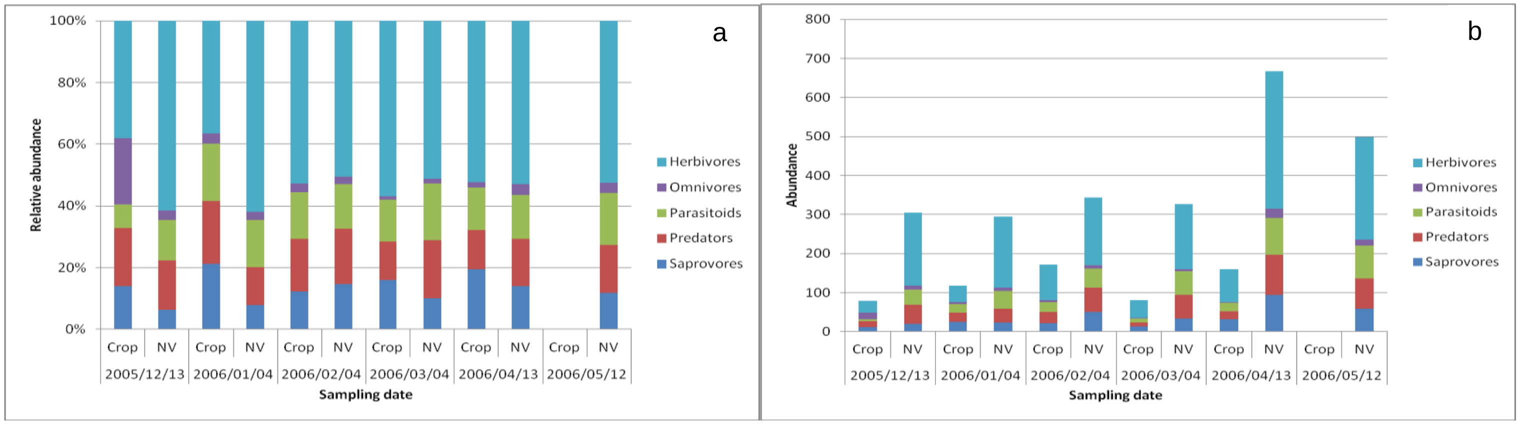

Fig. 3.12. The relative (a) and absolute (b) abundance of the arthropod trophic groups overtime at CON1 highlighting the difference between the crop and the natural vegetation (NV).

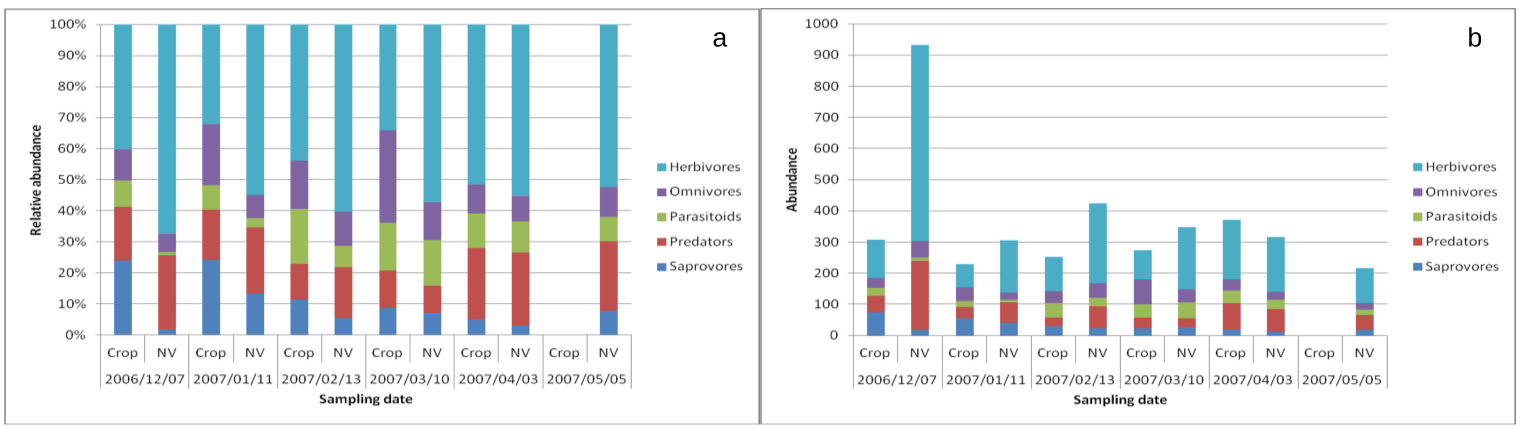

Fig. 3.13. The relative (a) and absolute (b) abundance of the arthropod trophic groups at CON2 highlighting the difference between the crop and the natural vegetation (NV).

Regression analysis revealed (Fig. 3.14) that no relationship exists between the abundance of predators and herbivores on the crop and the natural vegetation (CON1 predators R^2=0.05, herbivores R^2=0.02; CON2 predators R^2=0.12 and herbivores R^2=0.10). It seems that ground cover vegetation enables a certain degree of connectivity between the crop and the natural vegetation, whilst the absence of ground cover results in a loss of connectivity. The overall guild proportions of CON seem to show less fluctuation compared to that of GVN.

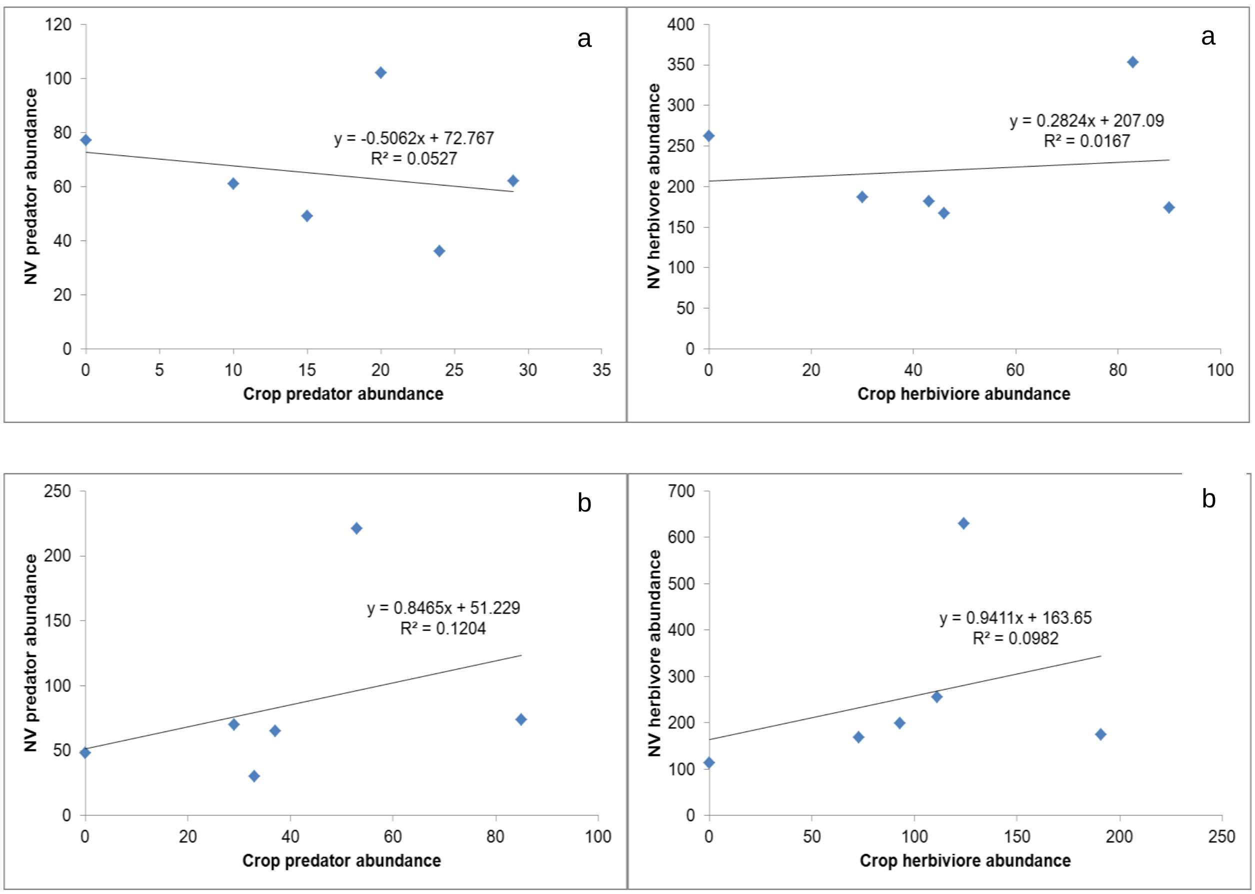

Fig. 3.14. Regression analyses showing how dependant predators and herbivores at a) CON1 and b) CON2 are between the crop and the natural vegetation (NV).

3.3.6 A comparison of crop and natural vegetation diversity over time

3.3.6.1 Margalef Index

At GVN the arthropod community diversity of the crop and the natural vegetation fluctuate overall and in relation to each other, whereas at CON arthropod community diversity fluctuates in a synchronised manner relative to each other.

The first and second seasons of GVN (Fig. 3.15) differ from each other regarding arthropod community diversity. In the first season (Fig. 3.15a) the natural vegetation has a higher diversity than the crop, by the fourth and fifth sampling date it is similar to the crop and towards the end of the season it is lower than the crop. These differences in diversity throughout the season may be due to a variety of factors, especially since agricultural practices are intense at GVN and due to the fact that ground cover vegetation is present. Especially irrigation regimes within the orchards could be a significant parameter here.

Both seasons have lower diversities towards the end of the sampling period. One possibility could be the onset of winter irrespective of continued irrigation of the crop, where the natural vegetation is exposed to normal natural conditions and a subsequent downward trend in species richness.

The only possible indication of migration between the crop and natural vegetation would be where the diversity trends cross over each other. For instance, at GVN1 on the third sampling date the natural vegetation is higher than the crop, following the estimated line towards the fourth sampling date one can observe that they cross-over leading to slightly higher crop diversity (Fig. 3.15). A similar pattern is seen between the third and the fourth sampling date of GVN2, except the crop initially has a higher diversity, then crossing over leading to a lower diversity over two sampling periods and crossing over again ending in a higher diversity than the natural vegetation towards the end of the sampling period. There is also the possibility that the cross-over trends may imply arthropod communities migrating from one habitat to another.

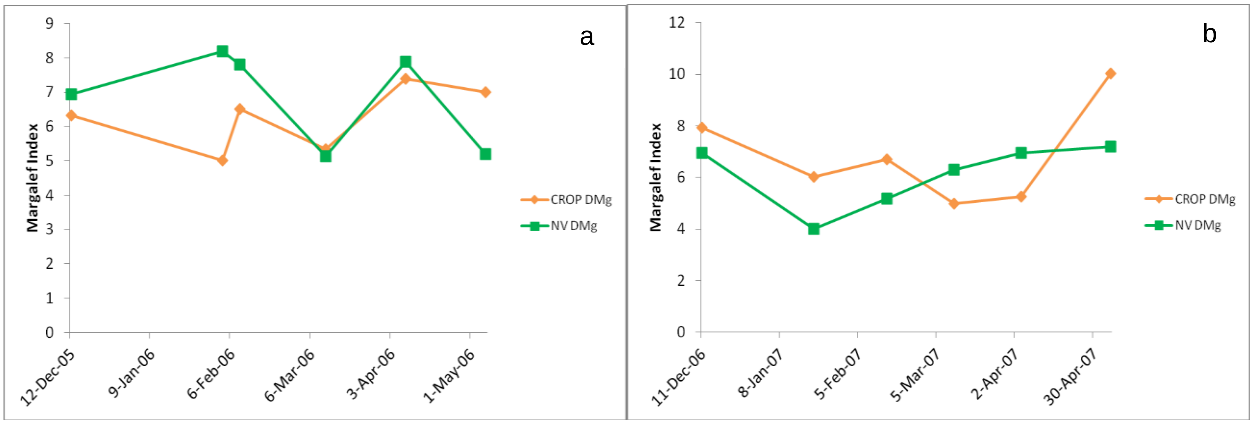

Fig. 3.15. The Margalef indices of arthropod diversity over time for the crop and the natural vegetation (NV) of GVN1 (a) and GVN2 (b).

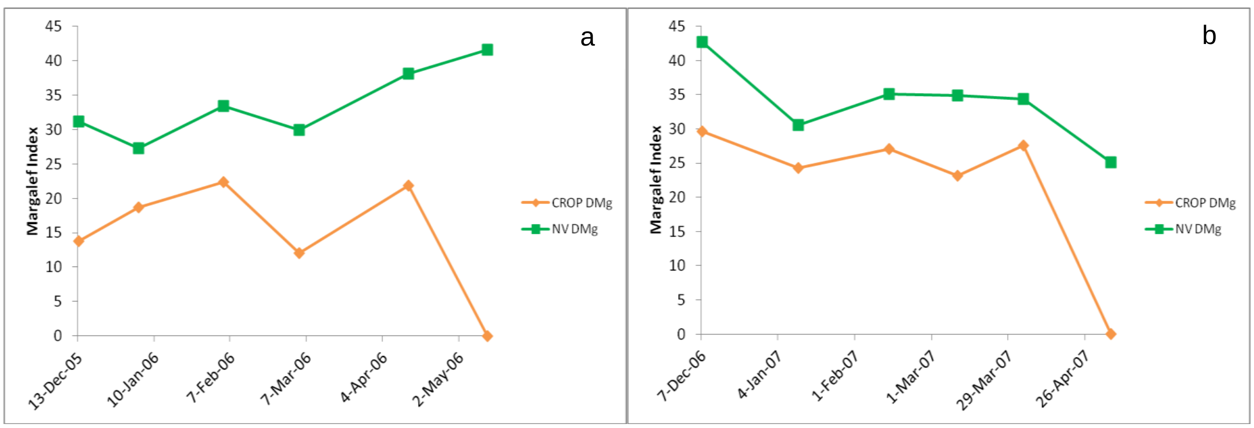

Fig. 3.16. The Margalef indices of arthropod diversity over time for the crop (Crop) and the natural vegetation (NV) of CON1 (a) and CON2 (b).

The diversity of the crop and the natural vegetation at CON (Fig. 3.16) are more or less synchronised as they fluctuate over the samplings, with the natural vegetation diversity always being higher than the crop diversity. The dramatic decrease in diversity towards the end of the seasons at CON is as a result of the crop being harvested. After harvesting the crop area is desolate and has no vegetation to support any above-ground arthropod species since no ground cover is present and most of the irrigation is dependent on rainfall, very few differences in resource availability is evident. This allows for both habitats, the crop and the natural vegetation, to demonstrate synchronised trends relative to one another.

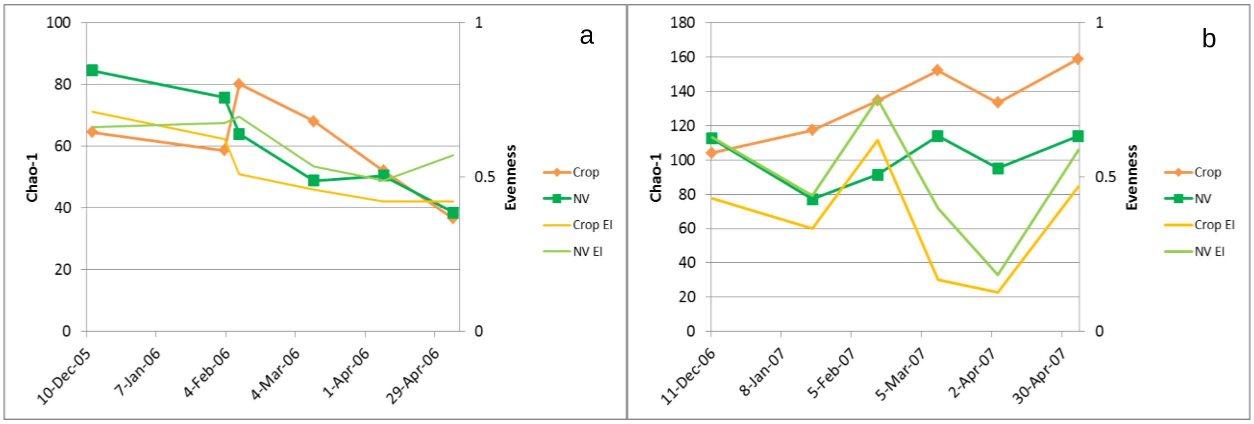

Fig. 3.17. The arthropod diversity on the primary axis and evenness on the secondary axis over time for the crop (Crop) and the natural vegetation (NV) of GVN1 (a) and GVN2 (b).

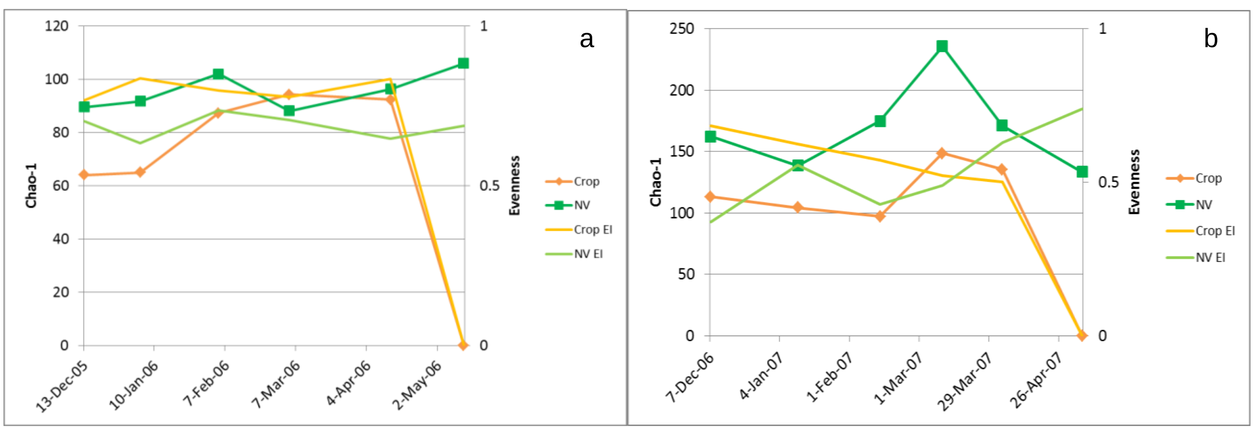

Fig. 3.18. The arthropod diversity on the primary axis and evenness on the secondary axis over time for the crop (Crop) and the natural vegetation (NV) of CON1 (a) and CON2 (b).

3.3.6.2 Chao-1 and Buzas and Gibson's evenness

In comparison to the above figures, different trends are observed when using the Chao-1 estimator. Chao-1 incorporates the singletons and doubletons making it less sensitive to sampling as such. Chao-1, in combination with Buzas and Gibson's evenness, reveals more about the structure of the community as opposed to the species richness indicator above.

At GVN1 (Fig. 3.17a) similar cross-over patterns are observed, although the cross-over occurs between sampling period 2 and 3 and not 3 and 4 as observed with the Margalef index. The cross-overs seem to be particularly more intense at GVN1. Evenness remains constant at about 0.7 for the first three samples and then decreases to 0.5 after the sampling 3. This denotes an increase of a particular species or group of species. A similar pattern for the evenness on the crop side is observed, however, the Chao-1 index increases. If one looks at the guild analysis (Fig. 3.9), one can clearly see an increase in predators at sample four. However, from there onwards a clear increase in herbivores occurs. The evenness factor may therefore forewarn a crop grower of unusual increases in certain guilds. This would indicate an increase in either predatory or herbivorous species populations, the latter depicting potential pests and necessitating proactive management protocols. A more synchronised variation occurs in both crop and natural vegetation diversity in the second season at GVN (Fig. 3.17b). More intense changes are observed regarding evenness. Synchronised occurrences like this can also be an indication that changes within the two habitats (crop and natural vegetation) are related, albeit that the evenness of the crop is lower than the evenness of the natural vegetation. This may reflect that certain communities within the crop are abnormally high compared to the natural vegetation. This, in turn, may be a good indicator of pre-established pests.

At CON (Fig. 3.18) the diversity of the natural vegetation remains higher than that of the crop, except for one exception in CON1, where crop diversity is higher than natural vegetation diversity. In comparison with the Margalef index crop diversity crosses over natural vegetation diversity at sampling 4. The crop evenness at CON remains higher overall than natural vegetation, except for the last two sampling dates at CON2. As mentioned before the overall decline at the end of the season in the crop is as a result of the crop being harvested. The decline towards the fifth sampling period, which is autumn, is likely to be arthropods preparing for the overwintering period or depart from the crop.

In annual cropping systems, maximizing the overwinter survival of natural enemies may be critical in ensuring adequate biological control in the following growing season. In contrast the advantage of annuals, in the case of kenaf, however, is that there is no persistence of the vegetation into the next growing season. Given sufficient alternative prey, populations of generalist predators may establish within a crop before the arrival and seasonal increase of pests (Landis *et al.* 2000).

3.4 CONCLUSION

With reference to the first hypothesis (*viz. Hypothesis 1*: If the arthropod species richness differs between a new crop and the natural environment, changes in species richness indices will be dependent on the arthropod assemblages within the habitats), the arthropod species richness differs between a new crop and the natural environment, thus changes in diversity indices are dependent on the arthropod assemblages within the habitats. The number of individuals remained constant, however, the number of species increased dramatically at GVN and CON from the first to the second season. The number of species and the number of individuals fluctuate relative to one another from one season to another. These differences may especially be attributed to the change in resource availability and patch size within the separate habitats. Species-area relationships may predict scale-dependent patterns of arthropod diversity. Arthropod diversity increases together with productivity, in support of the “more individuals hypothesis,” in which greater population size leads to lower extinction rates of coexisting species in higher productivity systems (Joern & Laws 2013). When comparing the two, the diversity within the crop at GVN has a variation of trends relative to the natural vegetation, while the diversity at CON within the crop is synchronised relative to the natural vegetation. Margalef provides a simplistic analysis, whilst the combination of Chao-1 (being less sensitive to sample size) and Buzas's & Gibson's evenness reveals more about community structure. Just using plain abundance analysis is not sufficient enough to detect any changes in community structures. Diversity indices are limited to reveal only richness, abundance and evenness, and demonstrate limited information regarding the value of the species present. Investigation into the variables which have an effect on the dynamics of arthropod diversity within the crop and the natural vegetation will be dealt with in Chapter 5. Vegetation manipulation in agroecosystems and their surroundings is one integrated pest management (IPM) tactic used to enhance beneficial arthropod numbers in crops (Bugg & Waddington 1994).

CHAPTER 4

THE SPATIAL AND TEMPORAL RELATIONSHIP OF THE EDGE BETWEEN CROP AND NATURAL VEGETATION

4.1 INTRODUCTION

The obvious notion is that the junction between two adjacent habitats forms a discrete edge. Less clear is the effect of such edges on assemblages of arthropods that operate at the edges at relatively small spatial scales. Generally an increase in the presence of ecological edges takes place with habitat fragmentation and consequently the role of arthropod diversity within these edges will change, *e.g.* migration of potential pests into an agroecosystem and resistance against increasing agricultural disturbances. Edges create habitat heterogeneity and this is important in maintaining biodiversity within these landscapes by providing resources throughout the year for species-rich arthropods communities (Benton *et al*. 2003). Considering this across a range of spatial scales, habitat heterogeneity was reduced wherever agricultural intensification has been introduced to the landscapes.

Generally, research suggests that natural habitats can be important sources of natural enemies occurring in crop fields, and proximity to natural habitats may result in the prevention or reduction of agricultural pests (Landis *et al*. 2000). Agricultural landscapes are known to be a mosaic of suitable habitat patches interspersed with non-suitable habitats, depending on the species complexes in question (Vandermeer *et al*. 2010). For certain species this simplified version of the landscape and the connectivity of habitat patches form a continuum that may be crucial to their survival; whilst, for other species, the patchiness of the landscape provides a habitat ranging across the spectrum of suitable to unsuitable. In this context it is important to realise that arthropods can utilise resources from both crop and non-crop patches (Duelli *et al*. 1990) and the choice to migrate from one patch to another depends on the risks associated with a particular habitat.

Any change in species assemblages and their distribution within a particular landscape may lead to cascading effects throughout the community. For example, changes in abiotic conditions near a habitat edge may lead to the establishment of new plant species of attracting previously absent arthropods that may now utilise these new resources, potentially leading to new interactions that affect a multiple of taxa and, ultimately, change overall community structure (Ries & Sisk 2004).

If the edge between a crop and the natural habitat has a high species richness and abundance, the probability of a potential pest colonizing the crop may potentially be decreased. In this regard the movement of arthropods across edges depends on the edge permeability (Dauber & Wolters 2004), and this, amongst others, may be due to increased predatory pressure on the edge (Rand *et al.* 2006).

In order for an edge to prevent colonization by a pest or an invasive species that may establish itself as a pest, an edge needs to meet certain criteria. One of these is reversing the decline in agricultural biodiversity that requires enhancing heterogeneity of the agroecosystem from within individual fields to whole landscapes (Benton *et al*. 2003). Movement across particular edges is influenced by the shape of the edge (perimeter- to area ratios) and their contrast (the degree to which habitat types on each side of the edge differ from one another) (Prado 2000, Collinge & Palmer 2002). A study by Collinge & Palmer (2002) supports the hypothesis that edges with a high degree of contrast (‘‘hard’’ edges) are relatively impermeable to movement, and those with a low degree of contrast (‘‘soft’’ edges) are more permeable as suggested by Stamps *et al*. (1987), and therefore edges with low contrast boundaries exhibit net immigration.

To understand ecological processes, including edge effects, knowledge of the spatial and temporal distributions of species, as well as the causes and consequences of these patterns, are essential (Levin 1992a). Arthropod species may encounter a range of edges varying in contrast, and this degree of contrast changes across the season as the crops develop. For example, spatial dynamics between predator and prey populations in agricultural landscapes can affect the strength of trophic connections, altering a natural enemy's potential as a biological control agent (Yasuda & Ishikawa 1999, Pearce & Zalucki 2006).

In this chapter it is necessary to investigate manners in which the edge effect can be applied as an indicator of agroecosystem integrity and to assess the range of possible interactions that might occur.

Therefore the second objective of this thesis is to determine the relationship between the distance from the edge of the crop and the natural vegetation and the effect the distance has on the diversity of arthropods over time.

Hypothesis 2: If arthropod diversity is dependent on the distance from the edge (between crop and natural vegetation), then variable adjacent distances should differ in arthropod diversity.

4.2 METHODOLOGY

Since the edge effect is the adaptation of ecological trends that occur around the edge of two adjacent habitats, edge effect studies have adopted one of the following methodological approaches: (1) the one-sided approach that focus on ecological trends from an edge to the interior of just a single habitat and (2) the two-sided approach that focus on ecological trends across the whole gradient from the interior of one habitat to the interior of the other habitat, crossing through the edge. Two-sided studies have, however, become more frequent, and the two-sided edge effect approach can produce a broader understanding of the ecological processes associated with edges (Fonseca & Joner 2007). In this thesis the two-sided approach is more suitable, since emphasis is placed upon the relatedness between crop and natural vegetation.

4.2.1 Analysis of variance between transects

An analysis of variance (ANOVA) was performed for the mean number of species and the mean number of individuals (± confidence interval of 95%) for each transect for the crop and natural vegetation at the different sampling locations. The purpose of this was to test for differences between the means for each transect and to investigate whether the edge transects are transitional or not. A post-hoc Tukey test was performed to determine which transects can be grouped among the sample and which transects have significant differences. This method calculates the difference between the means of all the transects and Tukey's HSD (Honest Significant Difference) test values are numbers which act as a distance between the groups; it defines a value known as Honest Significant Difference.

4.2.2 Cluster analysis

To accentuate the differences in species communities between transects a dendrogram was used, which demonstrates the Sørensen-Dice similarity measure of adjacent transects within the crop and the natural vegetation. The hierarchical clustering routine produces a dendrogram, which indicates how data points can be clustered. The algorithm that was used is the unweighted pair-group average. Clusters are joined based on the average distance between all members between two groups.

4.2.3 Guild structure analysis

After the arthropod taxa were identified to morphospecies, they were grouped according to their feeding attributes as herbivores, predators, parasitoids, saprivores and omnivores. The variation of both absolute and relative trophic composition was analysed per season for all transects within the crop and the natural habitat at Green

Valley Nuts (GVN) and Constantia (CON). Guild composition within the different transects were then compared with each other.

4.2.4 Spatial species diversity and evenness for each site and transect

These statistics apply to association data, where the number of individuals are tabulated in rows (depicting taxa) and columns (depicting adjacent transects). The morsphospecies for each sampling date was pooled as per transect. This would focus analysis on the differences between the transects. Paleontological Statistics Software (PAST) was used to analyse the spatial species diversity. The statistics applied for each association are as follows:

Dominance: Dominance = 1 – Simpsons Index *i.e.* $D = \sum_i (n_i/n)^2$, which ranges from 0 (all taxa are equally present) to 1 (one taxon dominates the community completely), where *ni* is number of individuals of taxon *i*.

Buzas & Gibson evenness: Extensive review of diversity indexes performed by Hayek & Buzas (2010) show Buzas & Gibson's evenness to be optimally informative and was thus calculated for the crop and the natural vegetation per sampling date. Buzas & Gibson's evenness is expressed as $E = e^H / S$ where e is the natural logarithm base, H is the Shannon Weaver index and S is the number of species. These two measures are particularly effective in encapsulating many aspects of diversity into a single value and are the least biased by differences in species richness and sampling efforts (Hayek & Buzas 2010).

Margalef's richness index: The Margalef index is a very simple index to apply. It measures species richness (community diversity), is very sensitive to sample size and is known to compensate for sampling effects (Magurran, 2004). It also incorporates both species richness and abundance and is calculated as follows: $D=(S-1) / \ln(n)$ where S is the number of species, and *n* is the total number of individuals in the sample.

Fisher's alpha: Fisher's alpha is a diversity index which is defined implicitly by the formula $S = \alpha \ln(1+n/\alpha)$, where S is number of taxa, n is number of individuals and α is the Fisher's alpha. It measures the diversity within a population. It is a parametric diversity index assuming that species abundance follows log distribution. It is a scale independent indicator of diversity, but can be underestimated in communities where clustered distribution of species is found.

4.2.5 Temporal species diversity and evenness

Chao-1: Chao-1 was used to estimate true species richness for each adjacent transect. Chao-1 = S + F1(F1 - 1) / (2 (F2 +1)), with the bias corrected where F1 is the number of singleton species and F2 the number of doubleton species. The estimator reveals that if a community is being sampled, and rare species (singletons) are still being discovered, it is likely that there are still more rare species that have not been sampled. As soon as all species have been recovered at least twice (doubletons), there is a likelihood that no more species are to be found. This may have benefits when sampling only occurred over short periods of time. Tests of the estimator have shown that it does provide reasonable estimates for modern data sets (Chao 1984, Chazdon *et al*. 1998).

Buzas & Gibson evenness was calculated for each transect, per sampling date and is the least biased by differences in species richness and sampling efforts (Hayek & Buzas 2010).

4.3 RESULTS AND DISCUSSION

4.3.1 Analysis of variance (ANOVA) between transects

An analysis of variance for the number of species and the number of individuals at GVN1 (Figs. 4.1a & b) showed a significant difference between transect 4 (an edge transect on the natural vegetation side) and transect 1. The number of species and the number of individuals were more prevalent in transect 4 compared to the other transects. A post-hoc Tukey test also revealed a significantly higher number of species and number of individuals within transect 4. Transect 1, within the crop, was found to have the significantly lower number of species and number of individuals. All the other transects (2, 3, 5 & 6) were relatively similar to each other.

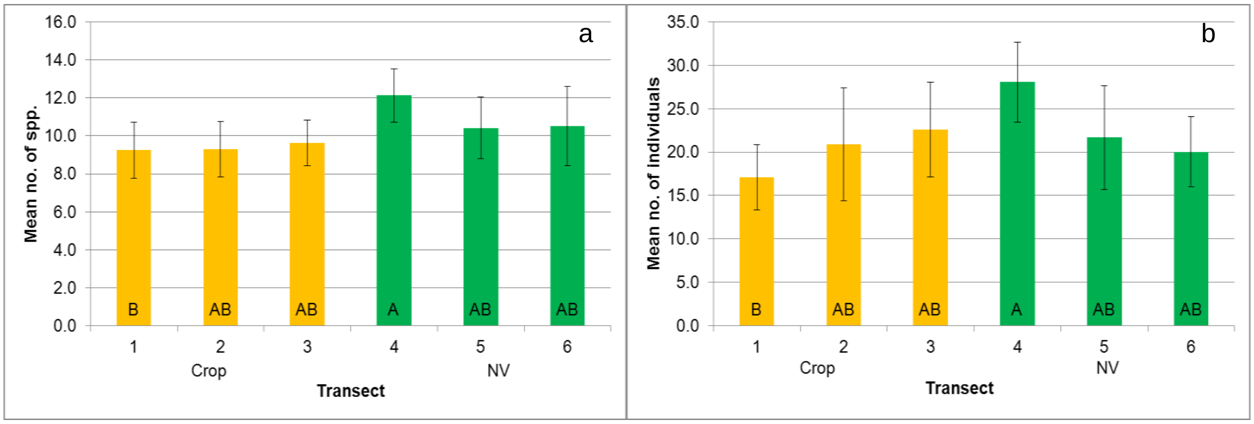

Fig. 4.1. Analysis of variance (ANOVA) (± confidence interval of 95%) at GVN1 for the a) mean number of species and b) mean number of individuals for transects across crop and natural vegetation. The bars with different subscript (A or B) are significantly different applied by the post-hoc Tukey test for mean number of species: $p < 0.05$, df = 138, Q-value = 4.09, HSD = 3.1, and for the mean number of individuals: $p < 0.05$, df = 138, Q-value = 4.09, HSD = 10.18.

An analysis of variance for the number of species and the number of individuals at GVN2 (Figs. 4.2a & b) showed a significant difference between transects 1 and 6. The number of species were most prevalent in transect 1 within the crop and the least within transect 6 within the natural vegetation. The number of individuals were prevalent on transect 1, 2 & 3 within the crop and the least with transect 6 within the natural vegetation. A post-hoc Tukey test also revealed similar results, which were significant.

Transect 1, within the crop, was found to have the significantly higher number of species and number of individuals. Transects 2, 3, 4 and 5 were similar regarding the mean number of species and extended between the range of transect 1 and 6.

Regarding the mean number of individuals, transects 1, 2, 3 were similar and significantly different to transect 6, while transects 4 and 5 ranged between the highest and lowest extremes.

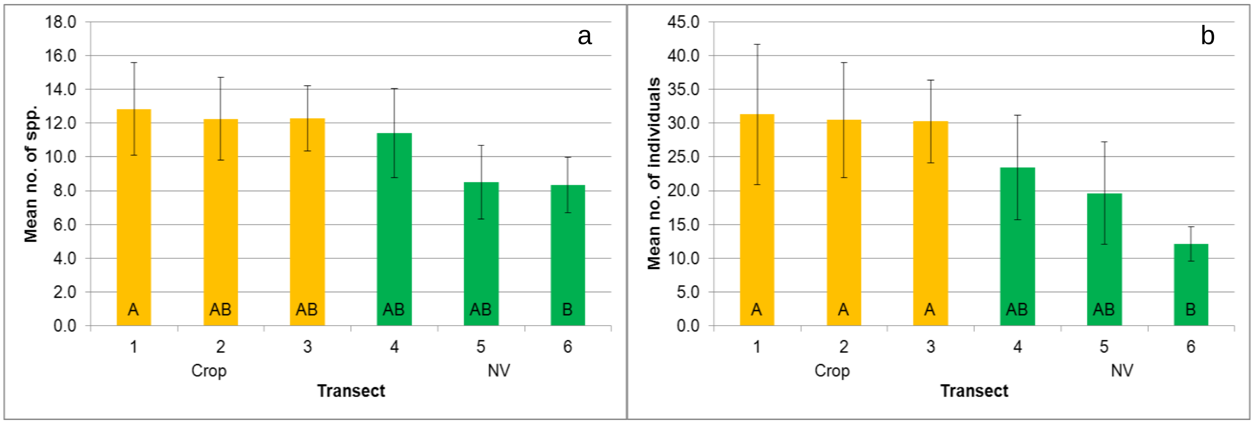

Fig. 4.2. Analysis of variance (ANOVA) (± confidence interval of 95%) at GVN2 for the a) mean number of species and b) mean number of individuals for transects across crop and natural vegetation. The bars with different subscript (A or B) are significantly different applied by the post-hoc Tukey test for mean number of species: $p < 0.05$, df = 138, Q-value = 4.09, HSD = 4.48, and for the mean number of individuals: $p < 0.05$, df = 138, Q-value = 4.09, HSD = 14.81.

An analysis of variance during CON1 and CON2 for the number of species and the number of individuals at CON1 (Figs. 4.3a & b, 4.4a & b) showed a significant difference between transects on the crop and natural vegetation side. During CON1 and CON2 the number of species and the number of individuals were more prevalent at transects 4, 5 and 6 on the natural vegetation side. A post-hoc Tukey test also revealed a significantly higher number of species and number of individuals at CON1 and CON2 within transect 4, 5 and 6 on the natural vegetation side. The results therefore suggest that the edge, between transects 3 and 4 is a meaningful transitional area between the two crop and natural vegetation habitats.

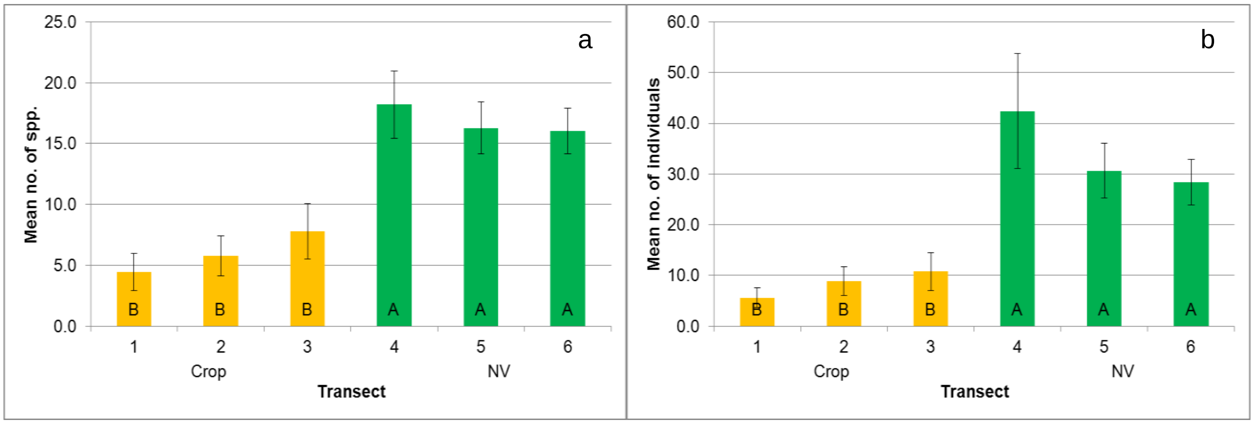

Fig. 4.3 Analysis of variance (ANOVA) (± confidence interval of 95%) at CON1 for the a) mean number of species and b) mean number of individuals for transects across crop and natural vegetation. The bars with different subscript (A or B) are significantly different applied by the post-hoc Tukey test for mean number of species: $p < 0.05$, df = 138, Q-value = 4.09, HSD = 4.11, and for the mean number of individuals: $p < 0.05$, df = 138, Q-value = 4.09, HSD = 11.52.

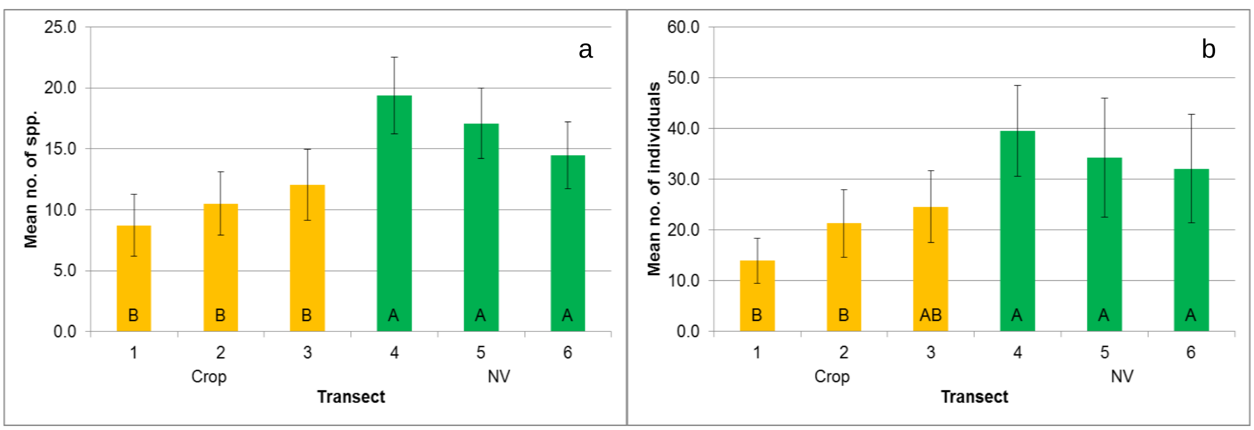

Fig. 4.4 Analysis of variance (ANOVA) (± confidence interval of 95%) at CON2 for the a) mean number of species and b) mean number of individuals for transects across crop and natural vegetation. The bars with different subscript (A or B) are significantly different applied by the post-hoc Tukey test for mean number of species: $p < 0.05$, df = 138, Q-value = 4.09, HSD = 5.53, and for the mean number of individuals: $p < 0.05$, df = 138, Q-value = 4.09, HSD = 17.32.

The difference in response for the mean number of arthropod species and individuals of the transects between the different sites, can firstly be explained by the difference in the landscape structure. Relative to GVN, CON has lower mean number of species and individuals on the crop side and this may be attributed to the fact that GVN had well established ground cover vegetation, while CON had none. Ground cover (cover crops) leads to an increase of plant diversity within orchards, which enhances the abundance of beneficial arthropods in the tree canopy, in comparison to bare soil (Silva *et al*. 2010). Besides direct effects on natural enemies, cover crops may have indirect impact on pests, such as over-wintering sites, and crop productivity, such as through the competition for water, soil nitrogen and soil organic matter content (Wright *et al*. 2003).

With reference to the difference in response of GVN1 and GVN2, besides the overall higher number of arthropod species during GVN2, the number of species and individuals on the crop side were also higher than the natural vegetation side, when compared to GVN1, where the number of species and individuals on the crop side were lower than the natural vegetation side. Arthropod species are known to be quite responsive to changing environments, including those resulting from human management practices (Morris 2000) and densities and diversity can be highly variable within and among years and sites, which is the case here. Definite edge responses were observed with the ANOVA analyses. To reiterate what was mentioned in Chapter 1, edge responses, when observed, are generally predictable and consistent when the participating species and edge type are held constant (Ries & Sisk 2004). At GVN1 (Fig. 4.1) edge responses were similar to the model and where both patches contain resources, edge response predictions are based on whether the resources are different in each patch, which leads to a positive prediction. With reference to GVN2 (Fig. 4.2) edge responses were similar to the model where a habitat borders lower-quality habitat and where available resources are the same to those in the higher-quality patch, a transitional response is predicted. The transitional response was higher on the crop side and lower on the natural vegetation side. At CON1 and CON2 the transitional response was higher on the natural vegetation side and lower on the crop side and thus edge responses were similar to the model where a habitat borders lower-quality habitat and where available resources are the same to those in the higher-quality patch, a transitional response is predicted.

Species richness may also be increased in high-edge patches if organisms are able to gain access to important resources by exploiting edge habitats (Fletcher *et al*. 2007). Edges act *via* two mechanisms, *i.e.* changing abiotic and biotic flows, and by providing organisms with access to different resources (Fletcher *et al*. 2007). Abiotic flows consist of changes in temperature, moisture, and other environmental characteristics associated with edges (Chen *et al*. 1999). Biotic flows include the movement or dispersal of species across habitat edges, potentially giving rise to ‘‘spillover’’ across habitat boundaries (Brudvig *et al*. 2009).

4.3.2 Cluster analysis

Various clusters can be observed, either with transects in the crop or natural vegetation side, although there are a few exceptions (Figs. 4.5 & 4.6). Fig. 4.5 shows that GVN1 transects 3 and 5, and 4 and 6 are more similar to each other in turn than to the other transects. Species communities within crop transect 1 and 2 differ dramatically compared to the previously mentioned transects. The similarity of transect 3 with the natural vegetation transects could be as a result of species from the natural vegetation temporarily crossing over the edge onto the crop side, creating the impression it has a community structure similar to the natural vegetation. The dendrogram at GVN2 (Fig. 4.5) shows that transect 4 is more similar to transects 1, 2 and 3 than to natural vegetation transects 5 and 6. This phenomenon can probably be explained in a manner similar to that of GVN1, whereby species from the natural vegetation tend to cross over to the crop side. Although there were obvious differences in the habitats regarding management and plant community composition, the results suggest that arthropods diversity differed between the different transects during both sampling periods.

At CON1 and CON2 slightly similar patterns can be observed (Fig. 4.6). At both sites transects 4, 5 and 6 are more similar than transects 1, 2 and 3, albeit that this is more so at CON1 than at CON2. Furthermore, crop transects at CON2 seem to be more similar to each other, compared to the crop transects at CON1. These differences might be attributed to lower diversity indices of arthropod communities at CON1 (Refer to Chapter 3, Figs. 3.5 & 3.6 or Addendum A). This shows that samples with a lower richness can differ more dramatically than samples with a higher richness.

Differences between GVN and CON can be attributed to the presence of ground cover at GVN and the absence of it at CON. The ground cover on the crop side at GVN allows for a more gradual transition for arthropod communities across the edges, while the edges at CON are considerably more stark and abrupt and therefore edge transitions at CON are affected relative to that. These differences show the contrasting movement or dispersal of species across different habitat edges, potentially giving rise to ‘‘spillover’’ across habitat boundaries (Brudvig *et al*. 2009).

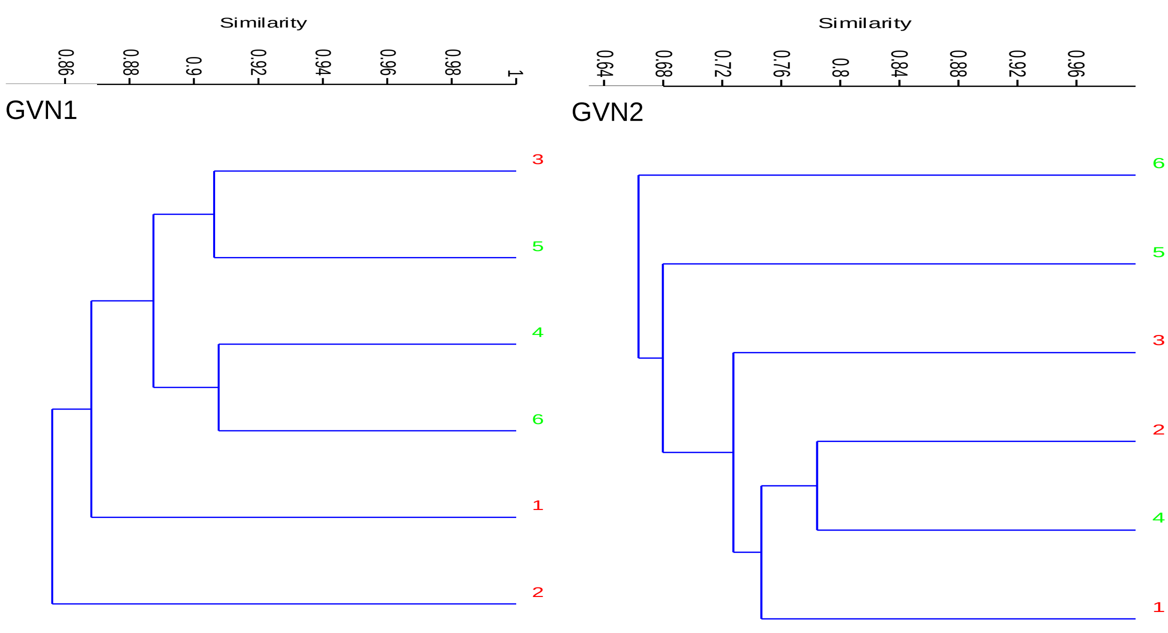

Fig. 4.5. Dendrogram showing cluster analysis of species communities of transects within the crop (1, 2 & 3) and the natural vegetation (4, 5 & 6) at GVN1 and GVN2. The Sørensen-Dice similarity measure was used.

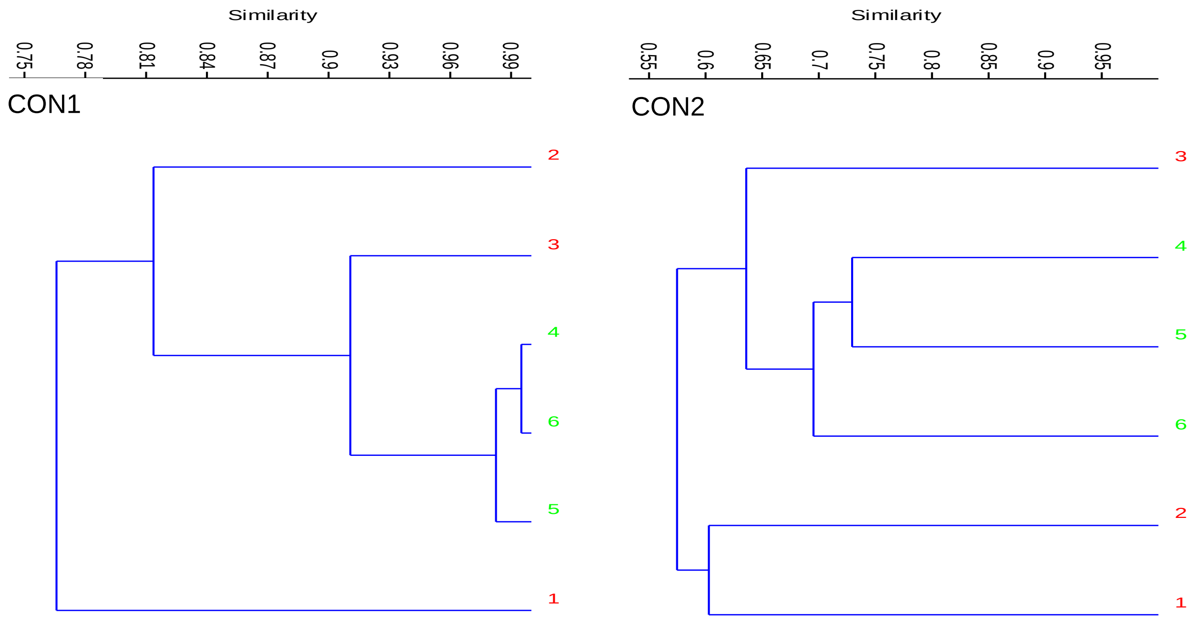

Fig. 4.6. Dendrogram showing cluster analysis of species communities of transects within the crop (1, 2 & 3) and the natural vegetation (4, 5 & 6) at CON1 and CON2. The Sørensen-Dice similarity measure clustering method was used.

4.3.3 *Guild structure analysis*

An obvious difference in total arthropod abundance can be observed at the edge between the crop and natural vegetation (Figs. 4.7, 4.8, 4.9 & 4.10). At all the sites, except GVN2, transect 4 has a higher absolute abundance (slightly higher in proportion to the other guilds) in predator- parasite combination. Species are known to be quite responsive to changing environments, including those resulting from human management practices (Morris 2000) and densities and diversity can be highly variable within and among years and sites. Predominantly, the various guilds remain in relative proportion to one another, even though slight spatial differences in absolute abundance are observed. At GVN1 the overall arthropod abundance seems to increase gradually from transect 1 as it approaches the edge at transects 3 and 4 (Fig. 4.7), after which it decreases at transects 5 and 6.

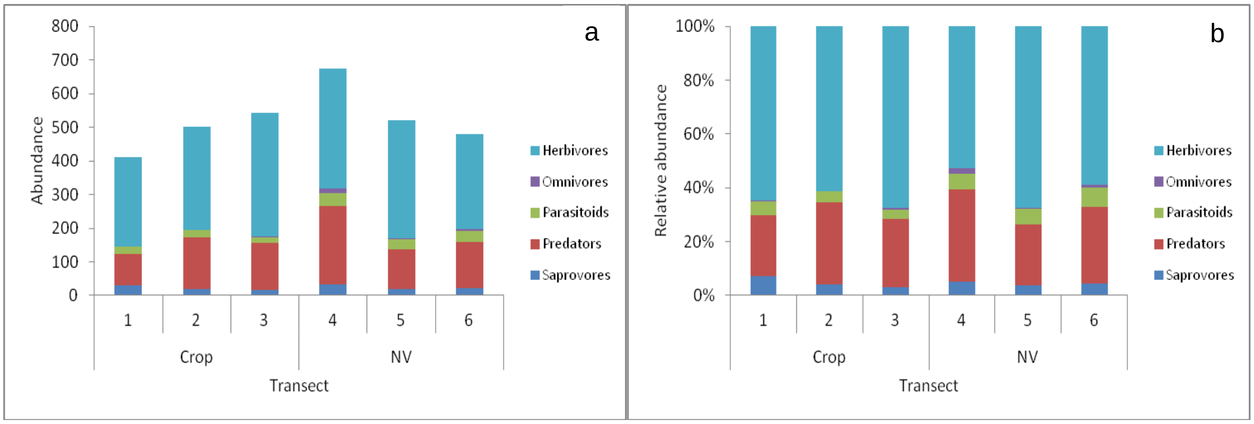

Fig. 4.7. The overall absolute (a) and relative (b) abundance of the arthropod trophic groups at GVN1, highlighting the difference between transects within the crop and the natural vegetation (NV).

At GVN2 there is an even abundance within the crop transects and then a steady decline from transects 4 to 6, revealing, as mentioned above, an opposite scenario than the other sites (Fig. 4.8). Overall the abundance of omnivores, mostly ant species, were higher at GVN2 compared to GVN1, with a slight increase in transects closer to the edge. This probably reflects temporal invasion and establishment over the two sampling periods. The relative proportion of guilds seems to be more or less similar to each other for each transect, and the omnivores show a similar pattern compared to that of absolute abundance.

The overall abundance at CON1 and CON2 is observed to be lower on the crop side and higher on the natural vegetation side (Figs. 4.9 & 4.10). Once again there is a slight increase in abundance from transects 1 to 3 at CON1 and there is an increase in predators and parasitoids on the edge transects. At CON1 a five-fold overall abundance occurs at transect 4 and then a there is a decrease from transect 4 to transect 6 (Fig. 4.9a). At CON2 a 40% increase in abundance occurs at transect 4 and then a decrease from transect 4 to transect 6 takes place (Fig. 4.10a). A clear edge effect can be observed at CON with an intense increase in abundance in transect 4 in comparison to transect 3. The relative abundance between the guilds is very similar to one another.

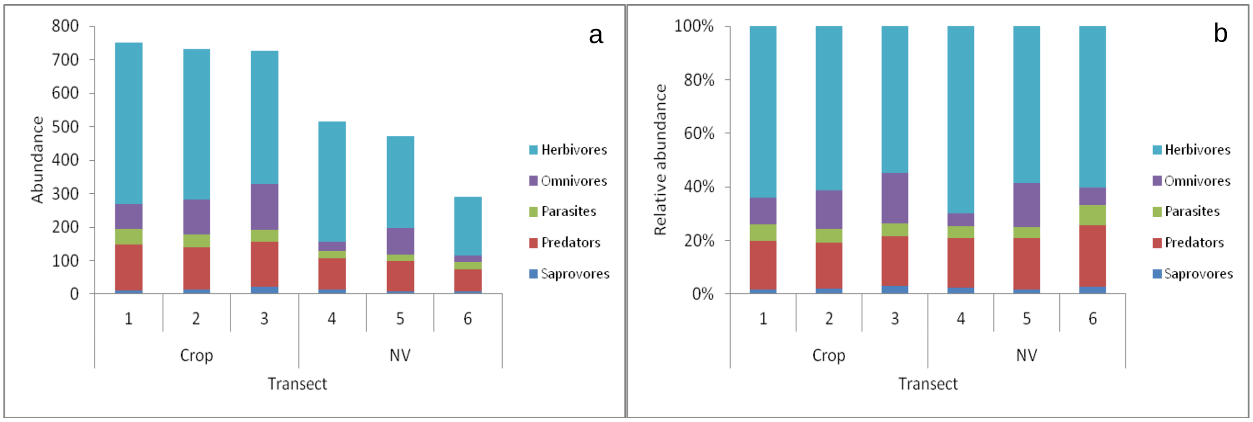

Fig. 4.8. The overall absolute (a) and relative (b) abundance of the arthropod trophic groups at GVN2, highlighting the difference between transects within the crop and the natural vegetation (NV).

Regarding spatial food web ecology, generalist predators have been confirmed to often utilise (or couple) spatially separated prey resources (McCann & Rooney 2009). Organisms at lower trophic levels may respond to resources at a microhabitat scale (especially when their resources are spatially static over time). Predators often utilise resources on a larger macrohabitat scale in order to meet their energy demands (McCann & Rooney 2009). Organisms at higher trophic levels, like generalist predators and parasitoids, spatially pursue multiple prey resources (Eveleigh *et al.* 2007) and often couple spatially distinct resources. Such resource coupling by generalist predators explains one of the common patterns found in edge studies, *i.e.* higher abundance of generalist predators (Martinson 2009) and higher predation rates (Batary & Baldi 2004) along habitat edges.

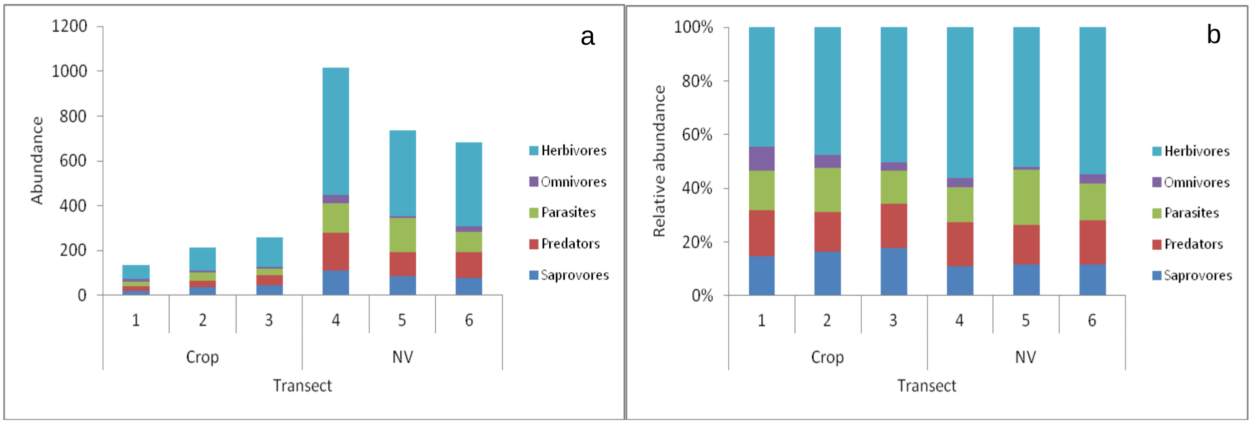

Fig. 4.9. The overall absolute (a) and relative (b) abundance of the arthropod trophic groups at CON1, highlighting the difference between transects within the crop and the natural vegetation (NV).

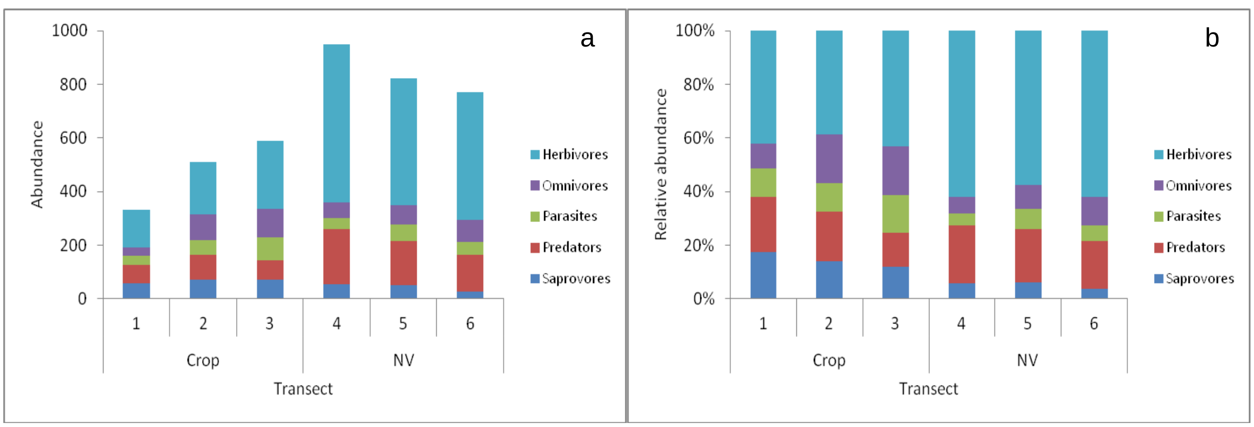

Fig. 4.10. The overall absolute (a) and relative (b) abundance of the arthropod trophic groups at CON2, highlighting the difference between transects within the crop and the natural vegetation (NV).

The increase in absolute abundance in predators and parasites on the edge transects seem to agree with previous studies that have shown either an increase in predation or parasitism rates, (Paton 1994, Lahti 2001) or no effect with no decreases in predation and parasitism near edges (Chalfoun *et al.* 2002). In general, therefore, the role of edges within an agricultural landscape can be very important and to be able to analyse the response of resident arthropods to edges within an agroecosystem landscape contributes valuable information towards using bioindicators as a management tactic.

4.3.4 Spatial species diversity and evenness for each site and transect

In all orchards at GVN1 (Fig. 4.11) the strongest contrast in indices seem to occur between transect 3 and 4. The Margalef index shows a decrease in species richness from transect 1 and 2 up to transect 3 and then a steady incline up to transect 6, except for orchard 42. The diversity has a similar trend shown by the Fisher alpha diversity index, again except for orchard 42. The application value of this is that edges between habitat patches are often (mostly) ecologically distinct from patch interiors, and understanding how ecological patterns change near edges is key to understanding landscape-level biological dynamics (Ries & Sisk 2004).

In most of the orchards at GVN2 (Fig. 4.12), the most contrast in certain indices again seem to occur between transect 3 and 4. However, this time the contrast seems to be more spread out between transect 2 and 5. Diversity has a similar trend, as observed by the Fisher alpha diversity index, except for orchard 62. Dominance is higher in transects within the crop than transects within the natural vegetation, except in transect 51. When observing this in combination with evenness this suggests that within the crop there are certain species that are prevalent when compared to others, thus increasing the dominance and decreasing evenness. Evenness is evidently higher on the edge transects (either transect 4 or transect 3 and 4) except for orchard 59, although the edge transects (3 and 4) are higher than the transect 1 within the crop. Another common trend is that evenness seems to increase when dominance decreases, and vice versa. Therefore dominance and evenness may serve as important tools to determine an increase in arthropod species which might be favoured by certain environmental conditions, allowing such species to eventually reach pest status.

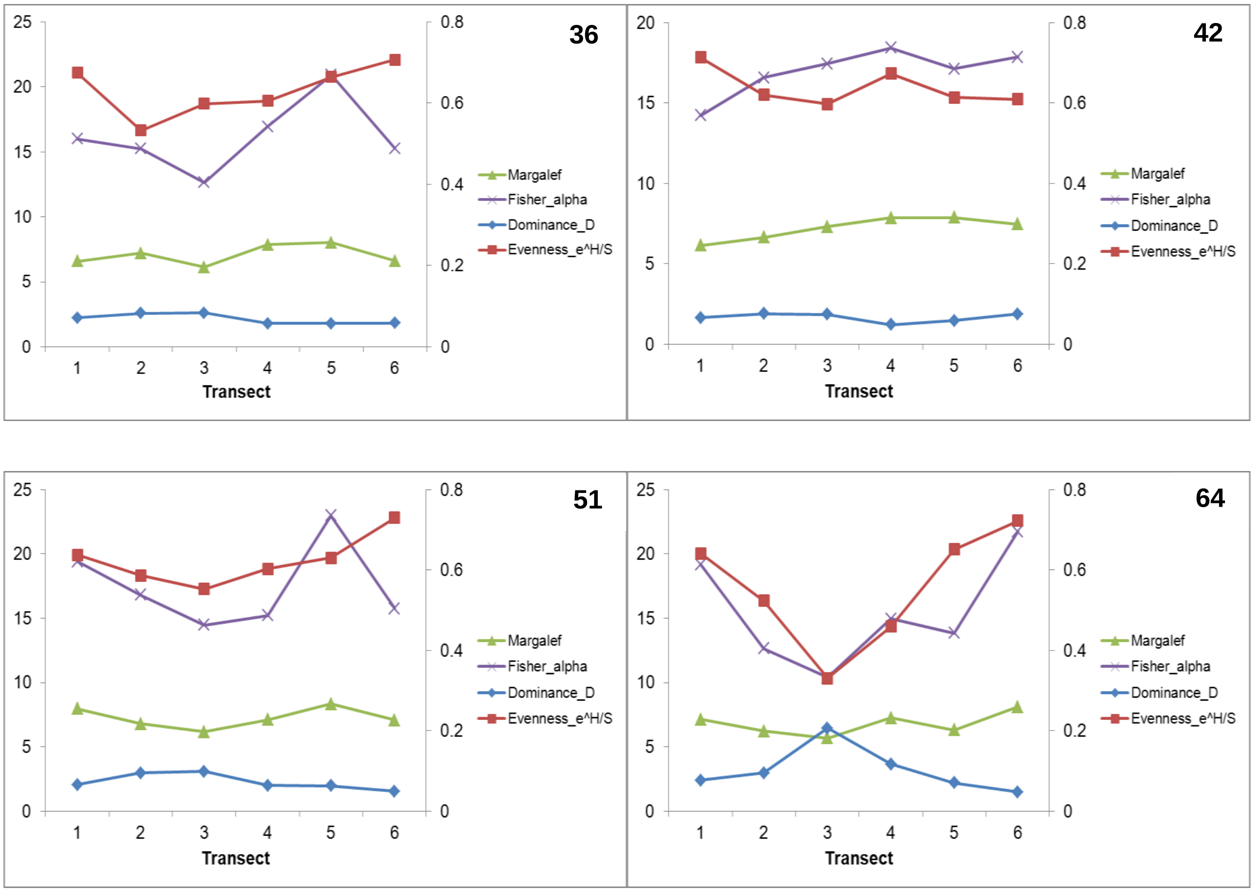

Fig. 4.11. A comparison of transect diversity and evenness for each individual orchard using a variety of indices (GVN1, orchards 36, 42, 51 and 64). The Y-axis represents Margalef and the Fisher_alpha indices while the secondary Y-axis represents Dominance and Evenness.

Similar trends of contrasting changes are also seen at the edges of the CON sites (Figs. 4.13 & 4.14). Species richness shown by the Margalef index is lower in the crop transects than in the natural vegetation transects, with differences occurring on the edges. Diversity shown by the Fisher alpha index shows overall decline from transect 1 up to transect 6. Dominance is slightly higher within crop side transects compared to transects on the natural vegetation side, especially in CON1. In CON1, but not in CON2, evenness follows a similar trend compared to the dominance. This pattern suggests that the homogenenous structure of the crop results in certain arthropod species being more abundant within the crop. During CON2, the richness was higher and this contributes to the volatile fluctuation in the evenness over time. In CON1 the similarity of north, south, west and east to each other are obviously attributed to the fact that all samples were taken within the same pivot.

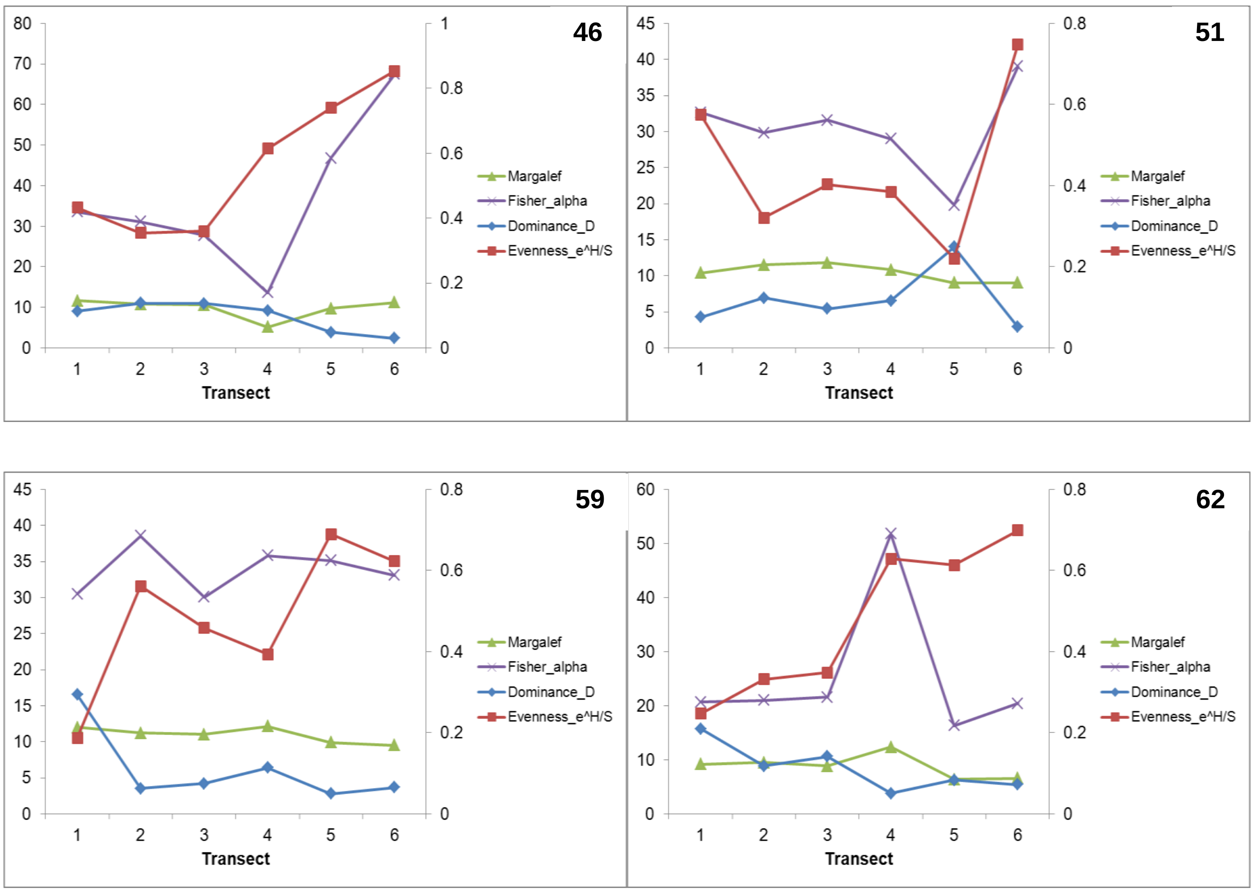

Fig. 4.12. A comparison of transect diversity and evenness for each individual orchard using a variety of indices (GVN2, orchard 46, 51, 59 and 62). The Y-axis represents Margalef and the Fisher_alpha indices while the secondary Y-axis represents Dominance and Evenness.

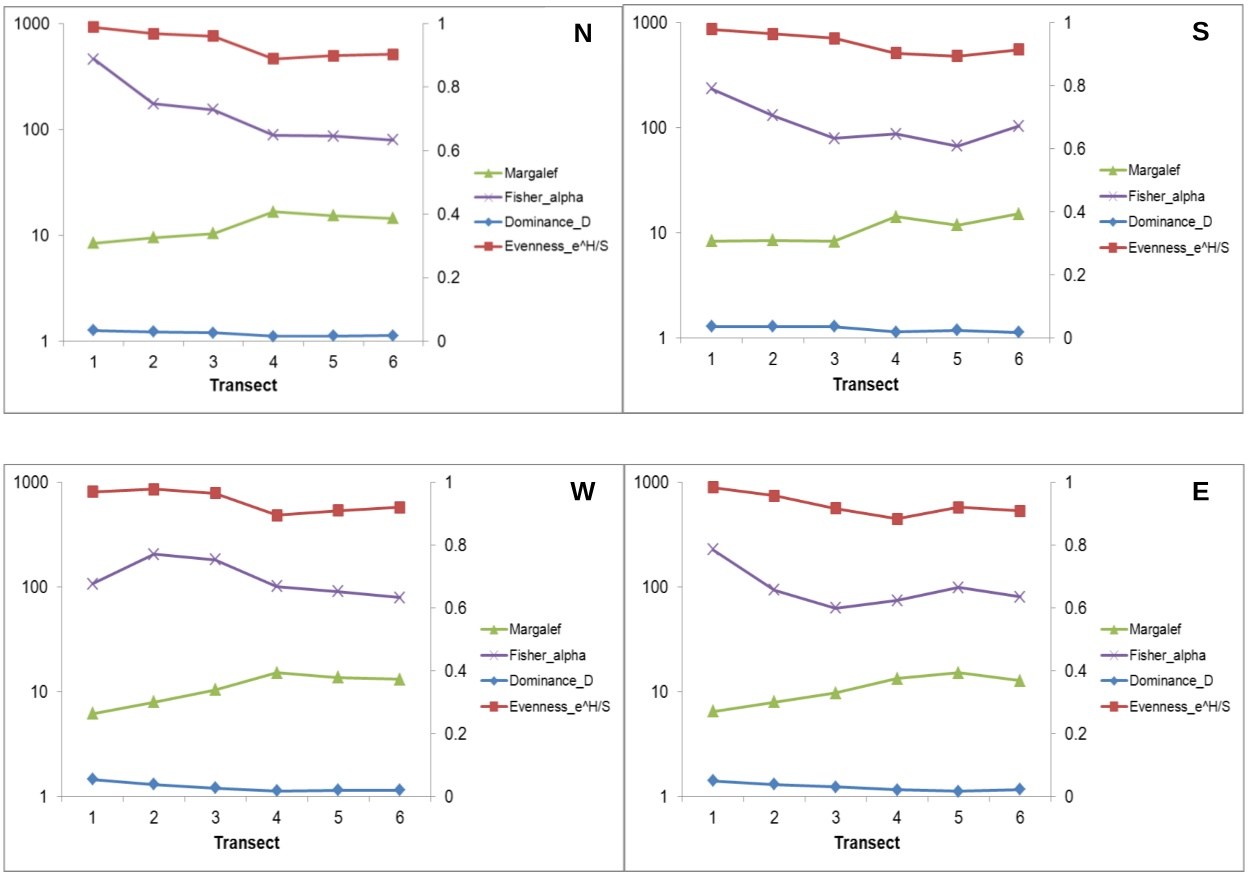

Fig. 4.13. A comparison of transect diversity and evenness for each individual orchard using a variety of indices (CON1 north, south, west and east). The Y-axis represents Margalef and the Fisher_alpha indices while the secondary Y-axis represents Dominance and Evenness.

Considering CON1 (Fig. 4.13) species richness shown by the Margalef index lower in crop transects than in natural vegetation transects. Evenness is slightly higher within the transects on the crop side compared to the transects on the natural vegetation side, except for the western section, where it shows an increase over the edge. Considering CON2 (Fig. 4.14) diversity shown by the Fisher alpha index seems to increase from transect 3 up to transect 4, with a variety of outcomes in different directions thereafter.

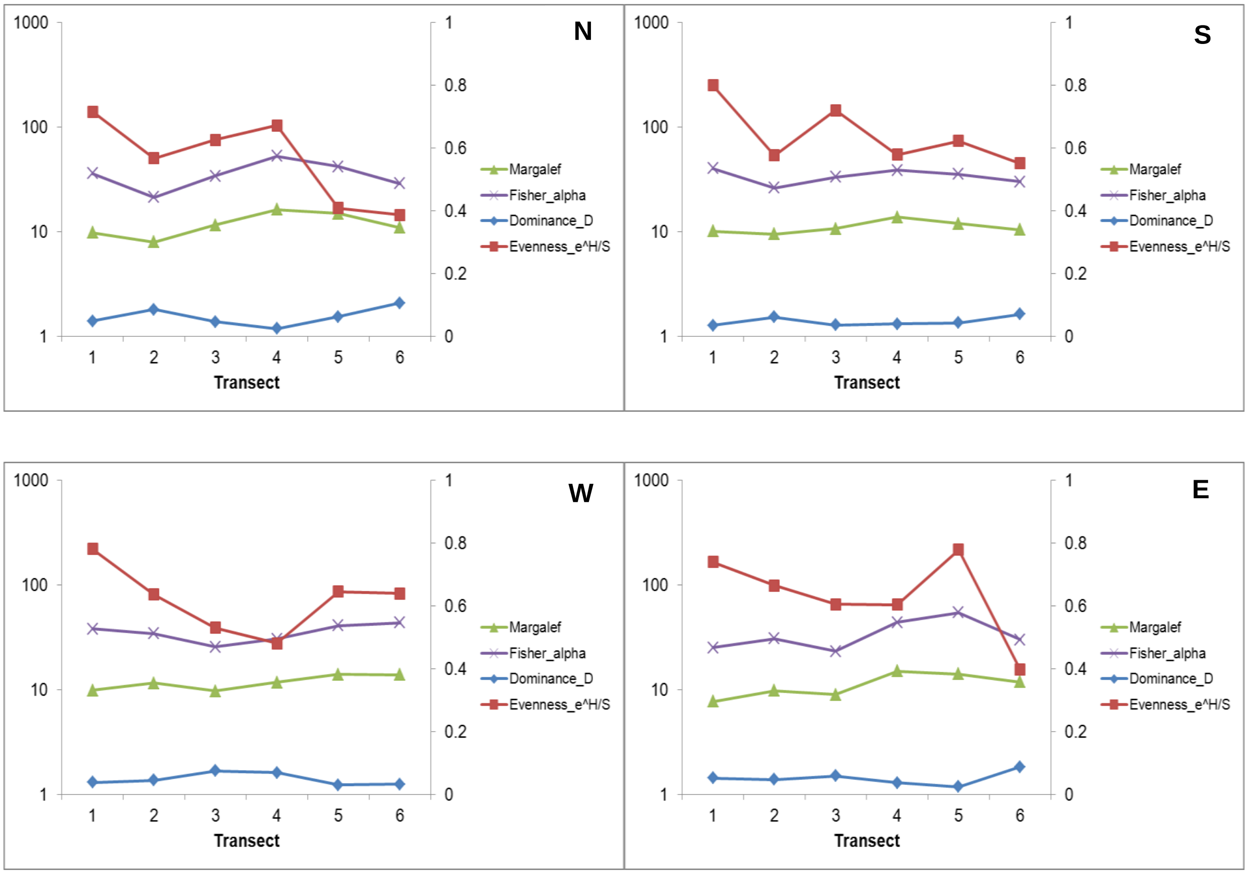

Fig. 4.14. A comparison of transect diversity and evenness for each individual orchard using a variety of indices (CON2 north, south, west and east). The Y-axis represents Margalef and the Fisher_alpha indices while the secondary Y-axis represents Dominance and Evenness.

Based on abundance indices, it is well known that edges more or less contain the species that one would expect in adjacent habitats. As such unexpected ecological patterns are often produced by complex interactions triggered by the mixture of different resources, natural enemies and abiotic conditions (Leopold 1933).

Edge effects result from several factors, including varied birth and survival tempos, the relative quality of the habitats, in addition to the movement behaviour of organisms (Kareiva 1987). Edge effects can influence the intrinsic population densities of the edge, as illustrated by the null model and the attracting-edge model. Insect population densities can be higher or lower at edges depending on these factors, (Fagan *et al*.

1999). This has been illustrated for insects where differential distribution patterns at habitat edges affects species interactions and influences the composition and dynamics of ecological communities.

4.3.5 Temporal species diversity and evenness

During the first season of GVN1 (Fig. 4.15) it is evident from the clustered columns that the diversity of transect 3 within the crop is relatively high in most cases compared to the rest of the transects. The evenness, however, is relatively low compared to the other transects. This indicates an increase in abundance of particular species lowering the evenness, seemingly, however, increasing the species richness.

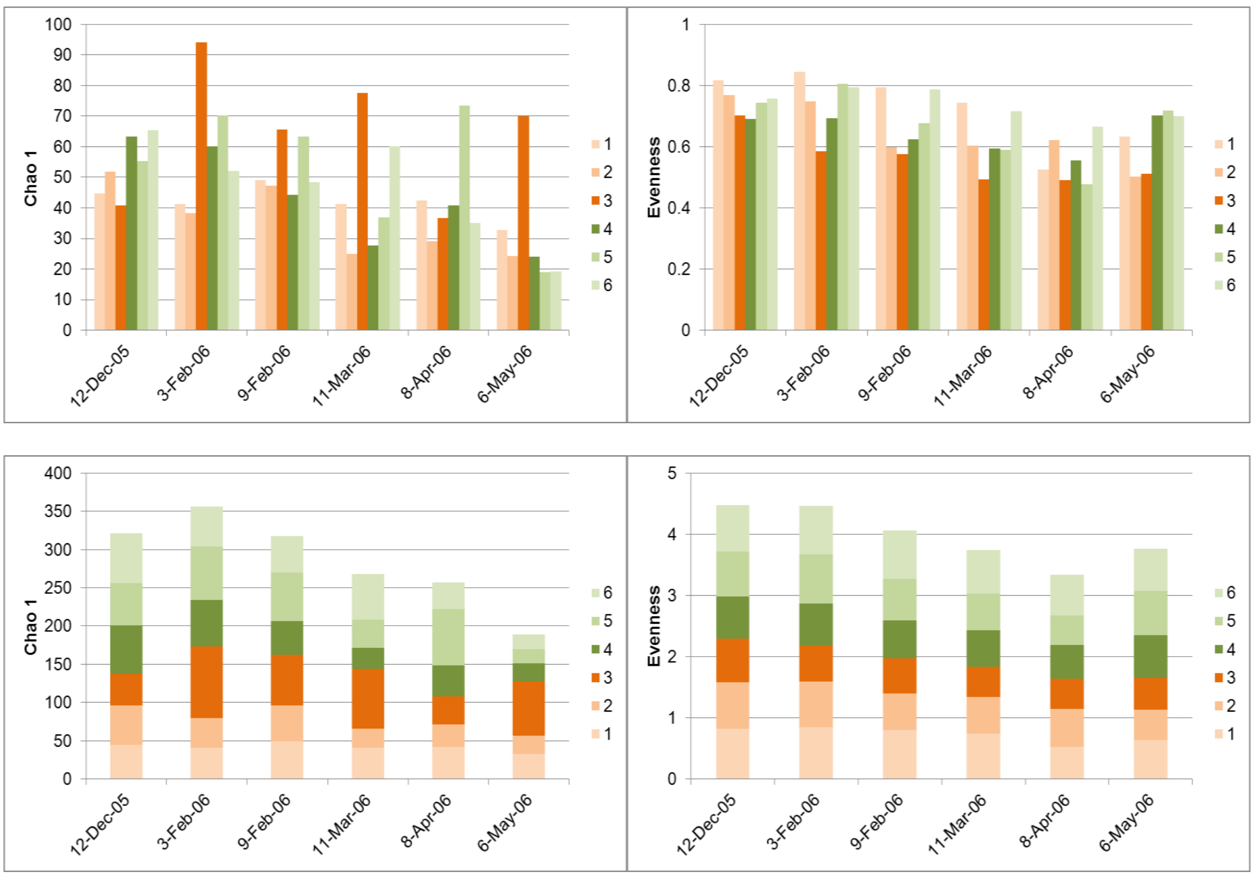

Fig. 4.15. A comparison of transect diversity and evenness for all orchards using Chao 1 and Buzas & Gibson's evenness analysis over time at GVN1. Diversity and evenness of transects are illustrated by clustered columns (above) and stacked columns (below). Numbers 1–3 represent the crop transects, and 4-6 represent the natural vegetation transects.

The dynamics are meaningful in an agroecosystem with changes in diversity not affecting changes in evenness and vice versa. These changes can be attributed to the movement of species within the agroecosystem and can be observed by comparing the stacked columns of Chao 1 and Buzas & Gibson's evenness. A possible explanation is that communities may need to search for a suitable specialised food sources within the particular habitat causing changes in diversity over time. Transects on the edge between the crop and the natural vegetation seems to react similarly in most instances in relation to the surrounding transects and the overall diversity. There are, however, a few exceptions, *e.g.* during the final sampling date on the stacked columns the overall richness decreases from the previous sampling date, while the evenness increases. This may be due to species communities showing succession responses after a disturbance and in this case the disturbance event may be harvesting. In most instances, when species richness increases on the edge (*i.e.* transect 3 and 4), the overall richness seems to increase.

Similar occurences with relatively high richness values on the edge and relatively lower evenness values can be observed during the second season at GVN2 (Fig. 4.16). During this season it is evident that higher evenness occurs in the natural vegetation, but with relatively lower richness values. These instances could be occuring as a result of abiotic factors, especially climatic conditions. Results suggest a relative equilibrium shift between overall richness and evenness in the stacked columns after the third sampling date. During the first three sampling dates the results show low richness with high evenness, after which richness increases and evenness decreases, following a similar trend for the final three sampling dates. Once again the edge transects seem to remain relatively stable compared to the other transects.

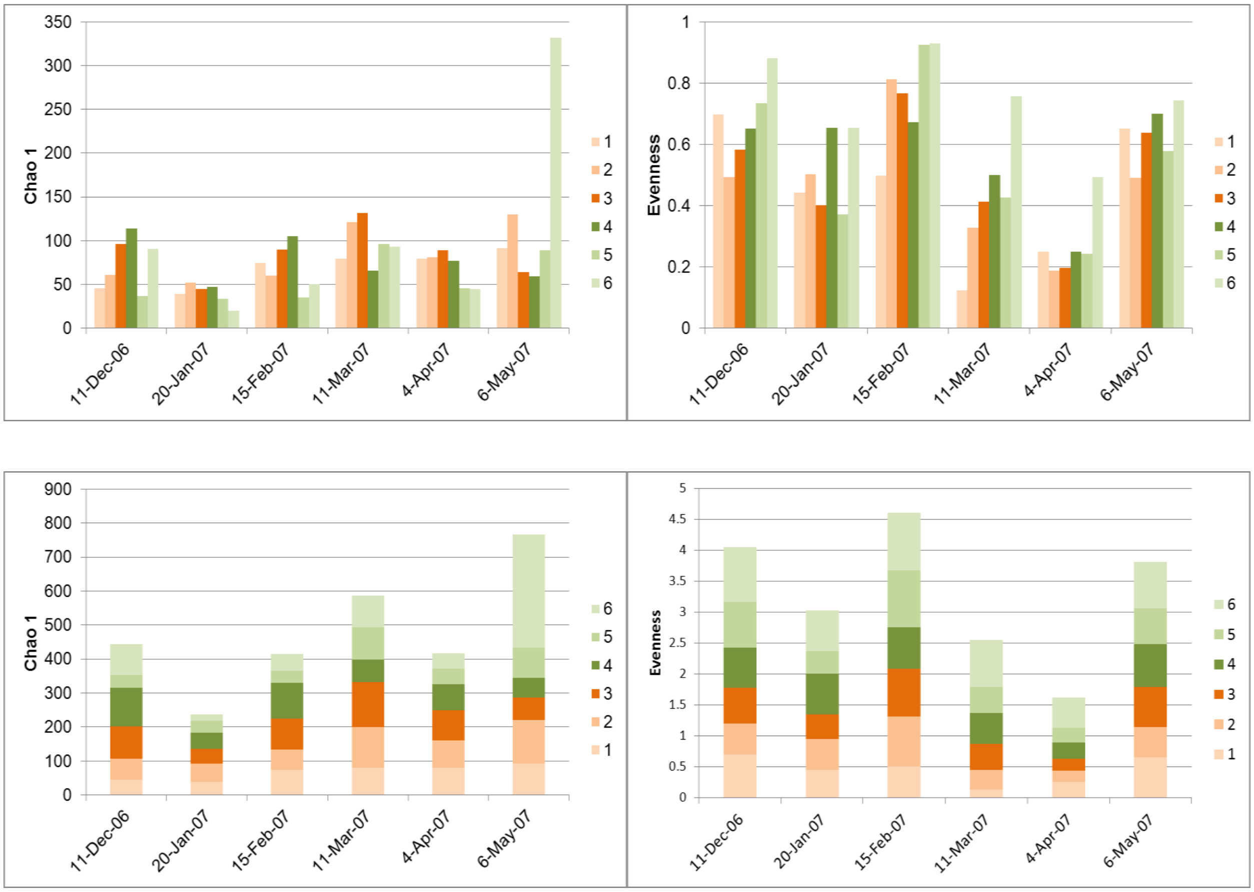

Fig. 4.16. A comparison of transect diversity and evenness for all orchards using Chao 1 and Buzas & Gibson's evenness analysis over time at GVN2. Diversity and evenness of transects are illustrated by clustered columns (above) and stacked columns (below). Numbers 1–3 represent the crop transects, and 4-6 represents the natural vegetation transects.

The richness of the edge transect at CON1 (Fig. 4.17) on the natural vegetation side seems to be higher than the crop edge transect, although crop edge evenness seems to be higher. This may be an indication that certain species communities use the natural vegetation as a refuge. Evenness is higher overall on the crop side than the natural vegetation transects, however, lower richness is observed. The low richness or evenness on the final sampling date is due to the harvesting of the crop. The overall richness seems to compensate for the harvesting, giving the impression that species communities migrate to the natural vegetation after harvesting, since no resources are available after such a major disturbance. During this specific sampling, the edge transect on the natural vegetation side seems to increase dramatically, confirming the refuge theory for habitat edges.

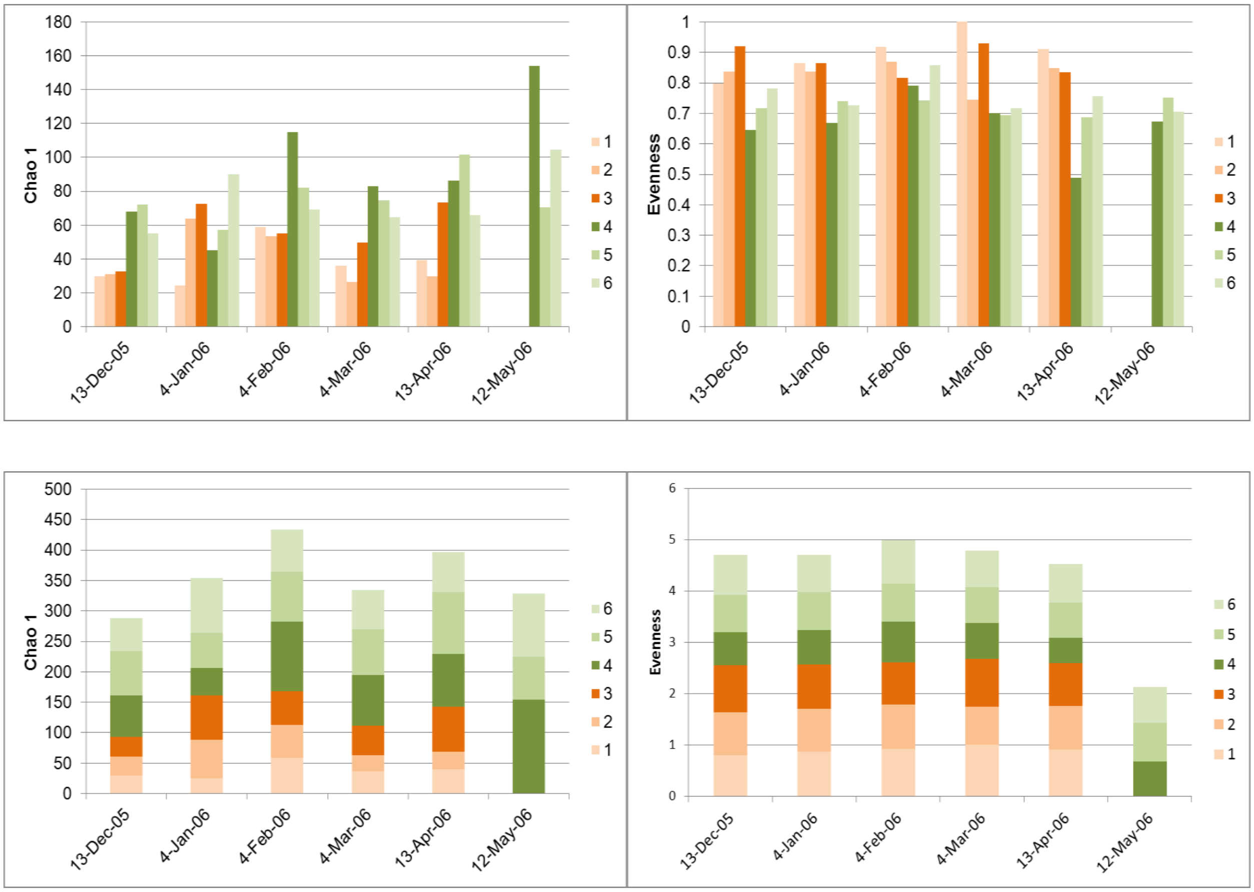

Fig. 4.17. A comparison of transect diversity and evenness for all orchards using Chao 1 and Buzas & Gibson's evenness analysis over time at CON1. Diversity and evenness of transects are illustrated by clustered columns (above) and stacked columns (below). Numbers 1–3 represent the crop transects, and 4-6 represents the natural vegetation transects.

Results of the clustered columns show a relatively low richness within the crop transects at CON2 (Fig. 4.18) and especially the edge transect which is observed to be lower in comparison to the natural vegetation edge transect. However, evenness is similar for most sampling dates. Again high richness with low evenness seems be a trend in the natural vegetation edge transect. This may be due to the fact that this CON2 crop was still young and small (only a few centimetres in height) if it were to be compared to a fully grown kenaf plant. Generally, the clustered columns regarding richness and evenness show very few peaks and depressions during the season, except for the final sampling date after harvesting. This may be due to less intense agricultural practices carried out at CON.

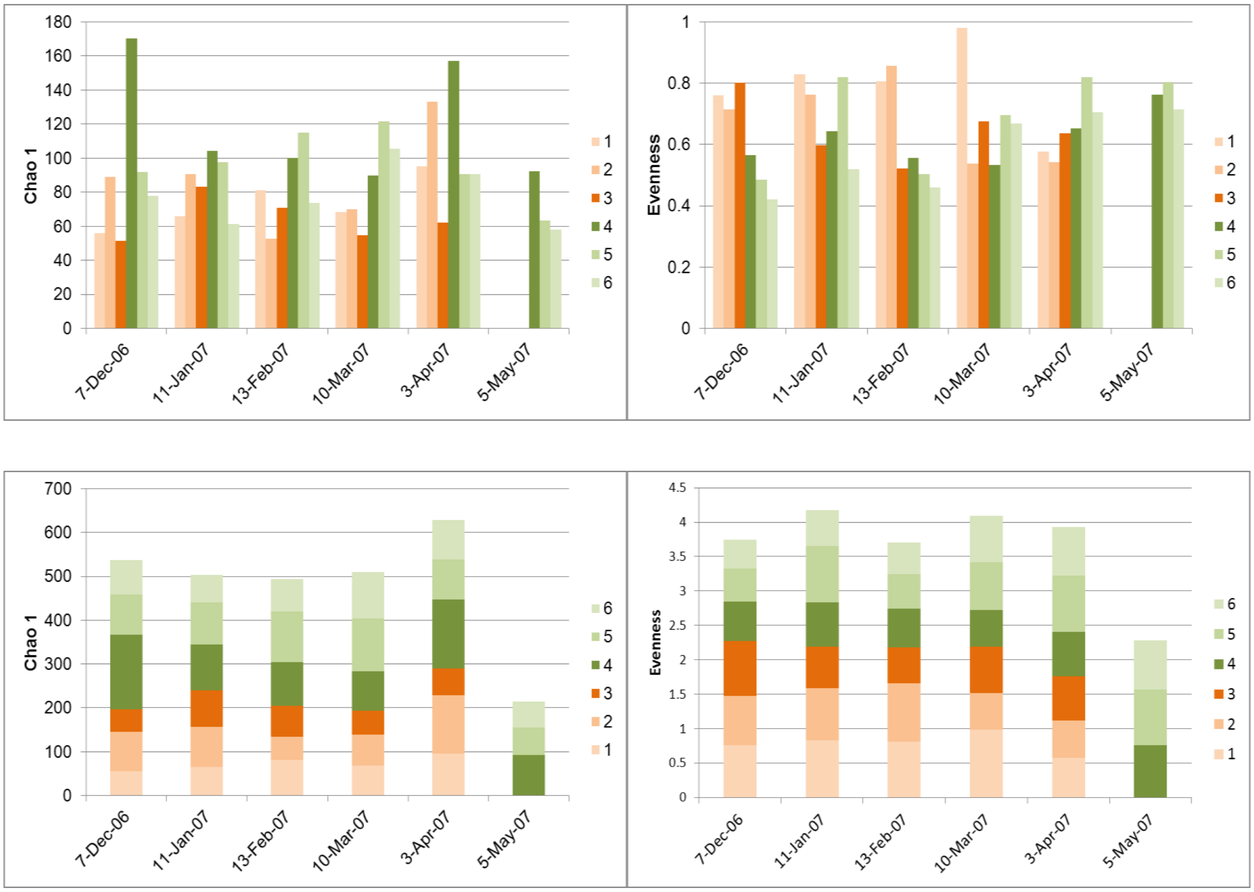

Fig. 4.18. A comparison of transect diversity and evenness for all orchards using Chao 1 and Buzas & Gibson's evenness analysis over time at CON2. Diversity and evenness of transects are illustrated by clustered columns (above) and stacked columns (below). Numbers 1–3 represent the crop transects, and 4-6 represents the natural vegetation transects.

An overall observation, which seems to be the norm, is that in most cases there is an inverse relationship between richness and evenness. In instances where richness increases and evenness decreases it may be a “red light” warning that certain species are increasing due to favourable conditons. Such occurences may reflect the establishment of unwanted herbivores as primary pests. Edges are known to increase populations of herbivores, because they provide additional food sources, offer refuges after harvest, provide hibernation sites and provide escape shelter from pesticide pressure (Lys *et al.*1994, Baines *et al.* 1998, Salvete 1998). Results suggest that the efficacy of edges for use in possible biological control practises greatly depends on ecological successional age coupled to unkown environmental variables.

In the above context the following scenario might be detrimental to the ecosystem - high evenness with low richness or low evenness with high richness. Both these circumstances represent separate situations, with the first scenario representing a situation where low diversity causes a particular species to easily influence the evenness and emanating in an outbreak of the species.

Empirically, few studies have analysed the edge over time to track its changes (Oliveira & Pillar 2004). In artificially created edges, such as present in agroecosystems, numerous manipulated events influence the redistribution of the natural community and contribute to shrinkage of the natural habitat area. Obviously this influences the optimal functioning of such an edge.

4.4 CONCLUSION

With reference to the hypothesis (viz. *Hypothesis 2*: If the resistance and/or resilience of an agroecosystem towards incoming pests is dependent on the arthropod response to the edge effect, then a positive edge effect response will have greater resistance and/or resilience towards incoming potential pests), arthropod richness, abundance and evenness is dependent on the distance from the edge (between crop and natural vegetation), as a result of different arthropod species assemblages spatially. Definite edge responses were observed and they were generally predictable relative to the resources available and the habitat quality (Ries & Sisk 2004). In this study edge clusters are evident between crop and natural vegetation transects. Although these edge clusters are not similar *per se*, they expose similar tendencies in the changes they undergo regarding the arthropod assemblages and communities. Analysis of guilds emphasizes that the function of edges may possibly be to act as refugia for predators and parasitoids and herbivores. Dominance and evenness are important in the identification of pest species progressing towards primary pest status. It is evident that two-sided edge effect studies have the potential to not only contribute towards restoration and expansion of endangered ecosystems (Fonseca & Joner 2007), but also to serve as a tool in agroecosystem management. The theoretical framework of edge effect and structure proposed by Ries and Sisk (2004), based on resource distribution and use and assessment of the abundance of particular target species and communities is an important avenue to be explored. This model recognizes four mechanisms that change the abundance of species communities across habitat edges, *i.e.* ecological flow, access to spatially separated resources, resource mapping, and species interaction. According to the model, knowledge of edge effect interactions and availability of restoration resources on both sides of the edge (and at the edge itself) and the nature of the resources (whether complementary or supplementary), enable the prediction of organism response to edges. By understanding the causes controlling organism abundance at the edge zone, one would be able to speed up restoration, conservation and, in the case of agroecosystems, management processes, successfully.

CHAPTER 5

THE SENSITIVITY OF ARTHROPOD DIVERSITY TOWARDS ABIOTIC FACTORS IN NEW CROP AND SURROUNDING NATURAL VEGETATION ENVIRONMENTS

5.1 INTRODUCTION

Often the alteration of species packing in ecosystems as a result of species invasions and extinctions caused by human activities has altered ecosystems and several of these changes are difficult and expensive to undo (Hooper *et al.* 2005). Weather and climate affect arthropod diversity that is important to agriculture in a variety of ways. Temperature, rainfall, wind etc. all have the potential to influence arthropod pests and beneficial insects both directly and indirectly. Such influences may either be immediate or cumulative and can either affect the production site or more distant temporary refugia (Drake 1994).

The increased use of synthetic fertilisers and pesticides in agroecosystems has led to higher crop yields, but this is more often than not accompanied by a decline in biodiversity; biodiversity decline has also been driven by changes at landscape level, such as specialised regional farm practices, increase in field size, and removal of surrounding natural vegetation (Tilman *et al.* 2001). The loss of biodiversity in agroecosystems has increased the farmers need for external inputs, because beneficial agents such as natural enemies of crop pests and ecosystem engineers are no longer provided. This trend has led to the unfortunate strong reliance on petrochemicals in agroecosystems. However, many scientists have been arguing for more than two decades that this reliance on petrochemicals could be considerably reduced by better manipulation of biotic interactions (Médiène *et al*. 2011).

Weather and climate have the potential to not only influence the development rate, survival, and level of activity of single organisms, but also the phenology, distribution, size, and resilience of larger populations and therefore overall community structure.

Rainfall variability, for instance, is often of particular significance in determining the size and quality of insect populations, whilst low winter temperatures limit the survival and distribution of species. Following a disturbance such as pesticide application, the migration and the re-establishment of populations are often affected by weather and the climate regimes. Drake (1994) confirms this effect by stating that the initiation of pest outbreaks, the susceptibility of crops to insect attack and the capacity of producers to manage insect populations may all be affected by the weather and climate.

There is a great deal of evidence that shows how farming practices influence richness and abundance of taxa (Firbank *et al.* 2003, Fuller *et al.* 2005), how threats posed by agricultural change biodiversity dynamics (Krebs *et al*. 1999, Petit *et al*. 2001, Tilman *et al.* 2001), and how farming practices can be modified to mitigate these threats and generate benefits (McNeely & Scherr 2003). The biophysical processes linking agriculture and biodiversity to one another are so numerous and interacting so strongly that it is difficult to ascribe a particular biodiversity response to an individual agricultural cause. Rather, most biodiversity changes are responses to a suite of agricultural changes that can be grouped as agricultural intensification on the one hand, or habitat restoration or abandonment on the other (Chamberlain *et al*. 2000). This complexity means that we lack a clear conceptual model of how agricultural intensification (and by implication, de-intensification- though this is unlikely to be a straightforward reversal) affects biodiversity.

Current research on these topics is directed mainly at the development of pest-forecasting systems, and at estimating the impact of climate change. Indicators of circumstances in which pest populations thrive or are potentially most damaging, such as multiple regression models (Fielding & Brusven 1990) and model-based indices of environmental conditions (Wright *et al*. 1988) have been proved effective. Development rate of organisms is relatively straightforward to investigate in the laboratory and the results can be incorporated into a development model which can then be used to predict the phenologies of field populations from climatic averages or forecast temperatures (Tauber *et al*. 1986). Various options exist to increase beneficial biotic interactions in agroecosystems and to improve pest management and crop nutrition, whilst decreasing chemical use.

Firstly, it has been shown that the choice of cultivar, the sowing date and nitrogen fertilisation practices can be manipulated to prevent interactions between pests and crop, both temporally or spatially (Pickett *et al*. 1997, Meynard *et al*. 2003). However, the efficacy of these manipulations may be limited by pest adaptation. Secondly, beneficial biotic interactions may result from appropriate changes to the habitats of natural enemies, mediated by soil and weed management (Jones *et al*. 1994, Holland 2004). Knowledge is scarce regarding this topic, and indirect and complex effects are poorly understood. Thirdly, changes achieved by crop diversification (Tahvanainen & Root 1972, Root 1973, Roldan *et al*. 2003, Alvear *et al*. 2005, Diekow *et al*. 2005, Madari *et al*. 2005, Teasdale *et al*. 2007) and fourthly, ecosystem-based adaptation or community-based adaptation which includes managed systems such as agricultural landscapes (Rahim *et al*. 1991, Dunning *et al*. 1992, Rebek *et al*. 2005, Bianchi *et al*. 2006, Luka *et al*. 2006, Pontin *et al*. 2006) are promising. However, these practices also present drawbacks that may not necessarily be outweighed by beneficial effects. For instance, Ries & Fagan (2003) stated that as cropping system fragmentation increases the proportion of edge habitat will also increase. Disturbed areas (which are in effect fragmented patches) are inherent in agroecosystems due to operations such as harvest activities, pesticide application and tillage programmes and they can differ in intensity and shape (Büchs *et al.* 2003). Overall these management approaches provide a powerful framework within which to develop sustainable agronomic practices.

Within a particular habitat some degree of spatial variability of microclimate can be expected, and this may be a cause of organismal development rate variability, which has to be incorporated into more advanced models (Lysyk 1989). Most studies indicate that temperature and moisture are the key factors influencing insect numbers at a particular locality (*e.g.* McDonald & Smith 1988). There will generally be an optimum range for each parameter. However, the indirect nature of many of the environmental effects means that prediction of numbers from environmental conditions is not always straightforward. This suggests that for plant-feeding organisms the most important effect of environmental conditions is inclined to be host quality.

The third objective of this study is to determine the relationship between biotic (vegetation) and abiotic factors (climate, weather and agricultural practices, such as pesticides, fertilizers, patch size, cover crops and surrounding vegetation) and arthropod richness, abundance and evenness.

Hypothesis 3: If arthropod richness and abundance are dependent and affected by climate and weather conditions, and agricultural practices (pesticides, fertilizers, patch size, cover crops and surrounding vegetation), then the correct choice of agricultural management practices will improve arthropod species richness, abundance and evenness.

5.2 METHODOLOGY

5.2.1 Regression analysis of arthropod and vegetation species richness and abundance

A regression analysis was carried out to determine whether richness and abundance of plant species had an effect on richness and abundance of arthropods. These R^2-values were recorded and graphically represented for the GVN1, GVN2, CON1 and CON2 sites. Arthropod richness and abundance was grouped for all the sites per transect and regression was conducted with the plant species richness and abundance for all sites per transect.

5.2.2 Abiotic factors influencing species richness, abundance and evenness

Abiotic factors were recorded and are presented at the specific times that they occurred. Total rainfall ten days prior to the sampling date was recorded and plotted. The temperature range (minimum and maximum) was also recorded for 10 days prior to the actual sampling dates.

The *Margalef Index* was calculated for the crop and the natural vegetation for each orchard and pivot direction over time. These values were then compared to each other and compared with the abiotic factors previously mentioned. The Margalef Index is a very simple index to apply and measures species richness (community diversity). The index is very sensitive to sample size and is known to compensate for sampling effects (Magurran 2004). In terms of biodiversity measurement it incorporates both species richness and abundance. The equation is as follows: $d = S – 1 / \mathit{ln}N$, where S is the number of species and N is the total number of individuals in the sample.

Extensive review of diversity indexes performed by Hayek & Buzas (2010) show *Buzas and Gibson Evenness* to be effective and this was used to calculate this aspect of biodiversity for the crop and the associated natural vegetation per sampling date. Buzas and Gibson Evenness is expressed as $E = eH / S$ where H is the Shannon index and S is the number of species. The above two measures are particularly effective in encapsulating many aspects of diversity into a single value and are the least biased by differences in species richness and sampling efforts (Hayek & Buzas 2010).

After the arthropod taxa were identified to morphospecies, they were broadly grouped according to trophic structure (*i.e.* herbivores, predators, parasitoids, saprivores and omnivores). The variation of both absolute and relative trophic composition was analysed per season for the crop and the natural habitat at Green valley Nuts (GVN) and Constantia (CON) sites. The crop and the natural habitat were compared over a temporal scale.

5.3 RESULTS AND DISCUSSION

5.3.1 Regression analysis of arthropod and vegetation species richness and abundance

The vegetation within the orchards/pivots and surrounding natural vegetation varies and this will affect arthropod species composition and assemblages. Fig. 5.1 suggests that the abundance and richness at GVN is positively correlated with the abundance and richness of vegetation. However, at CON, results (Fig. 5.2) suggest that only the richness of arthropods is positively correlated with the richness of the vegetation, and that arthropod abundance is independent of vegetation abundance. At CON the number of individuals on the crop side were quantified as fourty individual plants, which explains the grouping of some points at 40 (Fig. 5.2).

It is known that insect numbers generally respond to plant diversity, structure and density, as well as the size and spatial arrangement of the habitat (Tscharntke & Brandl 2004). Furthermore, herbivore and predator species richness are positively related to plant species richness and these relationships are caused by different mechanisms at herbivore and predator trophic levels. It has been shown that a threefold increase occurs, from low to high plant species richness, in abundances of predatory and parasitoid arthropods relative to their herbivorous prey.

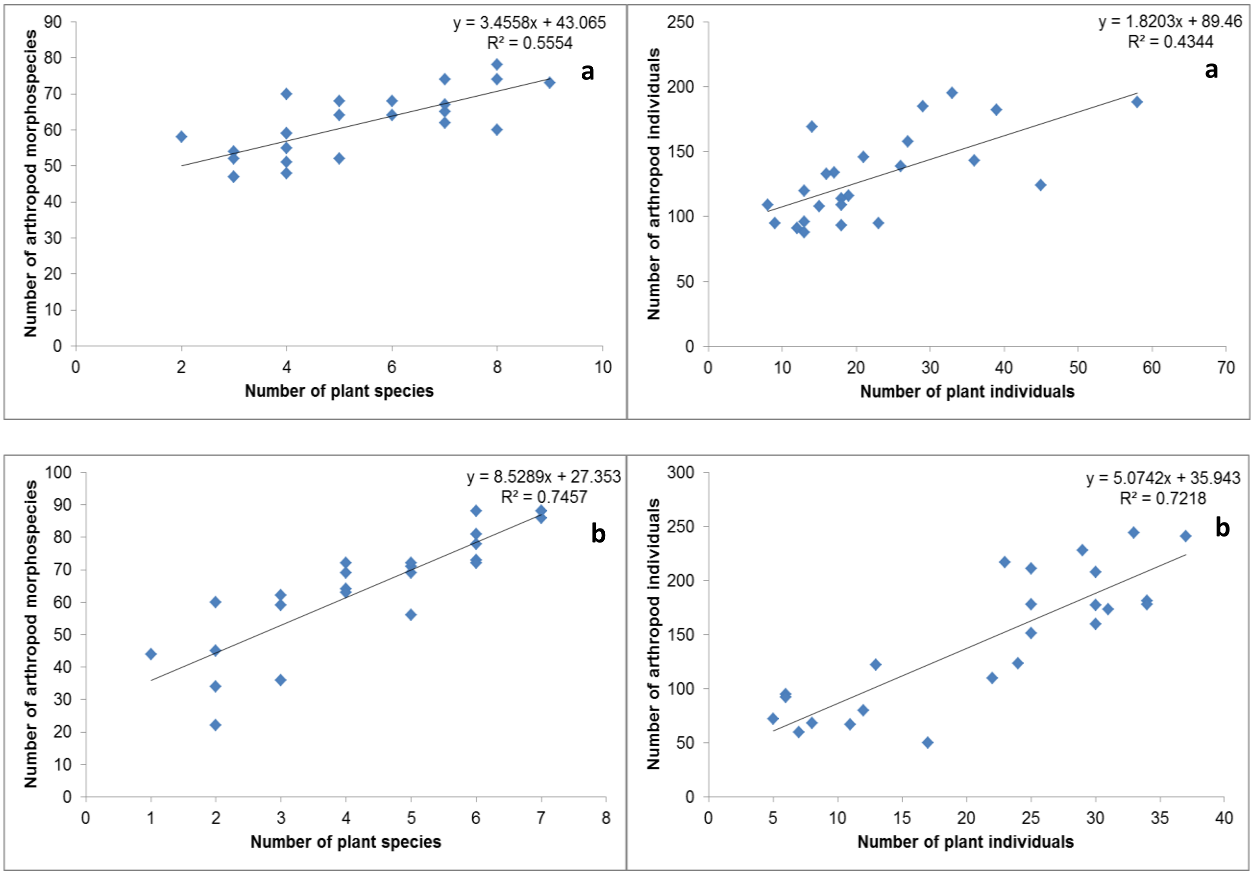

Fig. 5.1. Regression analyses for the dependence of arthropod richness and abundance on the richness and abundance of vegetation at a) GVN1 and b) GVN2 across all transects.

Over a long term, the loss of plant species proliferates through food webs, decreasing arthropod species richness, shifting a predator-dominated trophic structure to becoming herbivore dominated, and most likely impacting ecosystem functioning and services (Haddad et al. 2009). The combination of predator species traits and landscape features determines the functional connectivity of the landscape and may partially determine where biocontrol services may have to be provided. Therefore, pest suppression is likely to depend on predator species traits and the spatial, temporal, and disturbance contexts of the landscape.

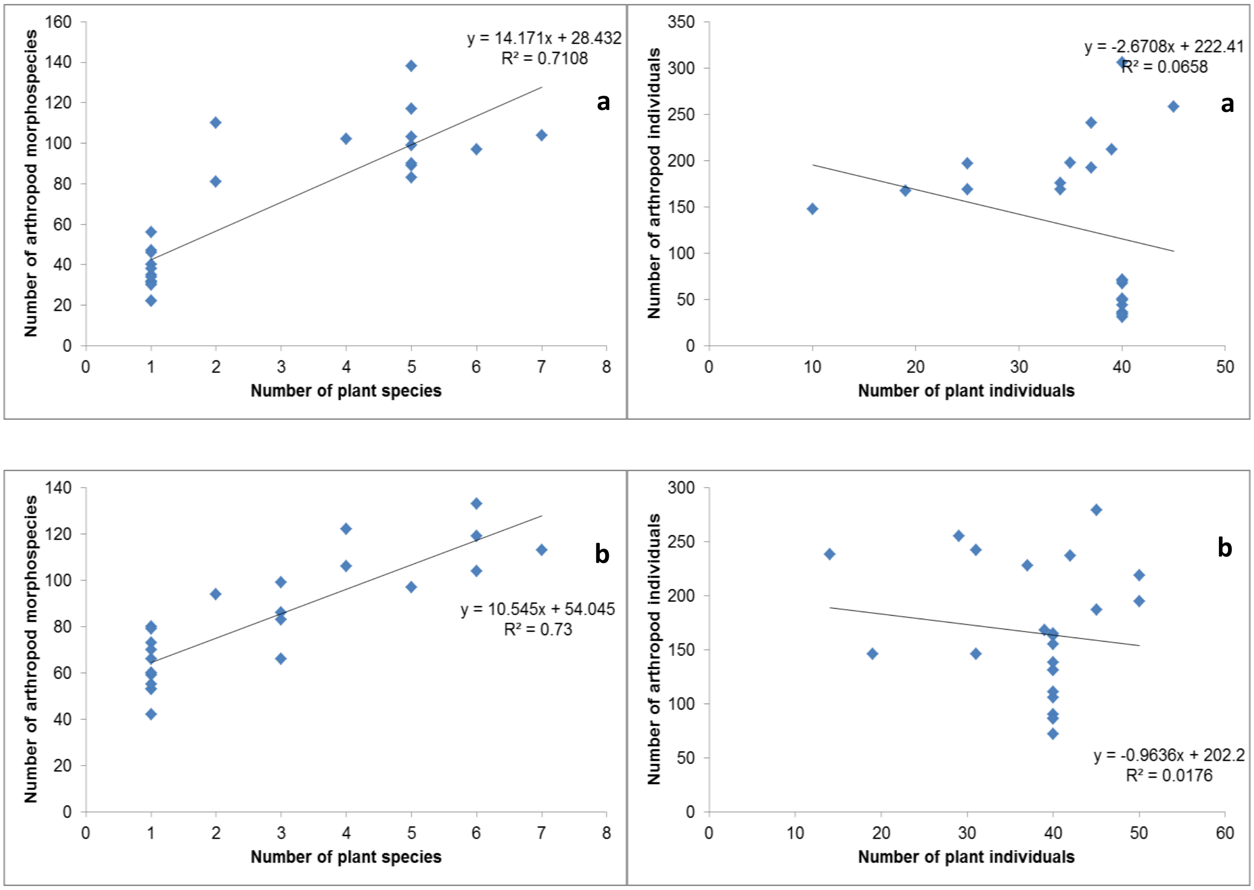

Fig. 5.2. Regression analyses for the dependence of arthropod richness and abundance on the richness and abundance of vegetation at a) CON1 and b) CON2 across all transects.

5.3.2 Abiotic factors influencing arthropod species richness, abundance and evenness

In orchard 36, GVN1, the natural vegetation is initially slightly more arthropod species rich than the crop (Fig. 5.3a). It is only on the fourth sampling date that the species richness indices are similar, thereafter it increases simultaneously. Finally, at the last sampling date there is species richness crossover, where the crop species richness is more abundant than the natural vegetation. During the second and third sampling date the evenness (Fig. 5.3b) increases, possibly as a result of high rainfall, although these results can be deceptive because the absolute abundance decreases. After the first rainfall, before the second sampling date, the natural vegetation increases in richness and the crop decreases in richness. During this period the relative (Fig. 5.3c) and absolute abundance (Fig. 5.3d) of the herbivores were observed to decrease as a result of vegetation and resource decline, which may be due to extensive agricultural activities before the second sampling date. These activities include application of insecticide, fungicide and growth supplement. It becomes evident that these activities could influence the arthropod species richness to such an extent that it eventually decreases. Before the third sampling date there was an increase in arthropod species richness of the crop. Considering the downward trend in evenness (Fig. 5.3b) for the crop, an unchanged evenness for the natural vegetation and total increase in arthropod assemblages (Fig. 5.3d), an increase in particular herbivore species within the crop is indicated. There was also a significant increase in predators within the crop and the natural vegetation during sampling period 4, although during this period the evenness decreased, indicating an increase in a particular species, especially on the natural vegetation side. Furthermore the relatively slight increase of predators on the crop side could be the result of spillover from the natural vegetation side. There is a significant decrease in predators and an increase in herbivores during the fifth sampling period on either side. After the third sampling period very few agricultural activities took place. The results suggest that this absence of disturbance may result in species richness recovery and consequently species assemblage succession taking place.

In orchard 42, fairly similar patterns occurred during the first two sampling periods, where natural vegetation initially recorded higher species richness, compared to that of the crop (Fig. 5.4a). From the third sampling date onwards species richness of the crop and the natural vegetation fluctuated synchronously up to the final sampling date. Furthermore, during second sample there is not as much decrease in arthropod species richness as in orchard 36, which supports the notion that intense agricultural activities have a negative influence on species richness in general, as only crop supplement was administered in this instance. Overall evenness decreased throughout the season and it is only during the second and third sampling dates that crop evenness increased slightly, whilst it decreased simultaneously within the natural vegetation (Fig. 5.4b). This increase in evenness may be due to the occurrence of rainfall, which contributed to the suitability of the natural vegetation, consequently leading to a more even distribution of arthropod species across the agricultural landscape. It is important to note that irrigation practices were continuous throughout the season within the crop, creating a more stable habitat than the natural vegetation.

During the second and especially the third sampling dates high rainfall seemed to boost arthropod richness within the crop habitat, irrespective of prior agricultural activities. High temperatures of close to 40°C during sampling might also have had an effect on sampling efficiency, because sampling was conducted during daylight hours.

Guild composition (Fig. 5.4c & d) remained relatively stable over time; the only change was a distinct increase in herbivores within the crop and the natural vegetation during the fifth sample. The results (Fig. 5.4a) indicate that the application of plant supplement occurred before this, suggesting that an improvement in plant quality leads to an increase in herbivore richness. After the third sampling date both natural vegetation and crop species richness decreased, with evenness (Fig. 5.4b) also decreasing in both habitats, possibly due to the effects of the growth supplement that was constantly administered to the crop during this time.

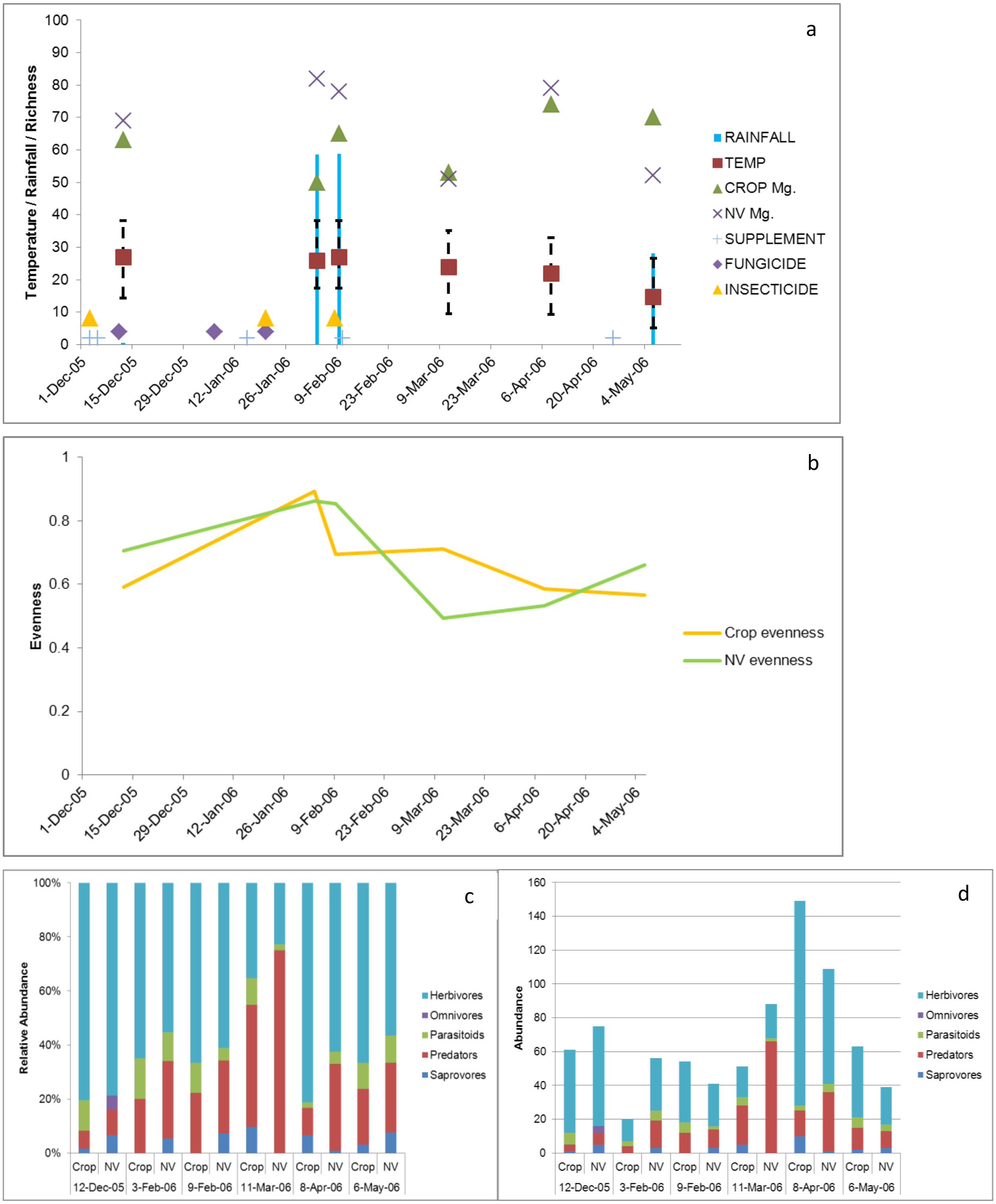

Fig. 5.3. The effect of temperature, rainfall and various agricultural practices on a) arthropod species richness (Margalef index; Crop Mg. and NV (natural vegetation) Mg.) within crop and NV and how it relates to b) evenness, c) relative abundance and d) absolute abundance at GVN1, orchard 36 (5.3a and 5.3b shows two-weekly interval timeline on x-axis; 5.3c and 5.3d show actual sampling dates on x-axis).

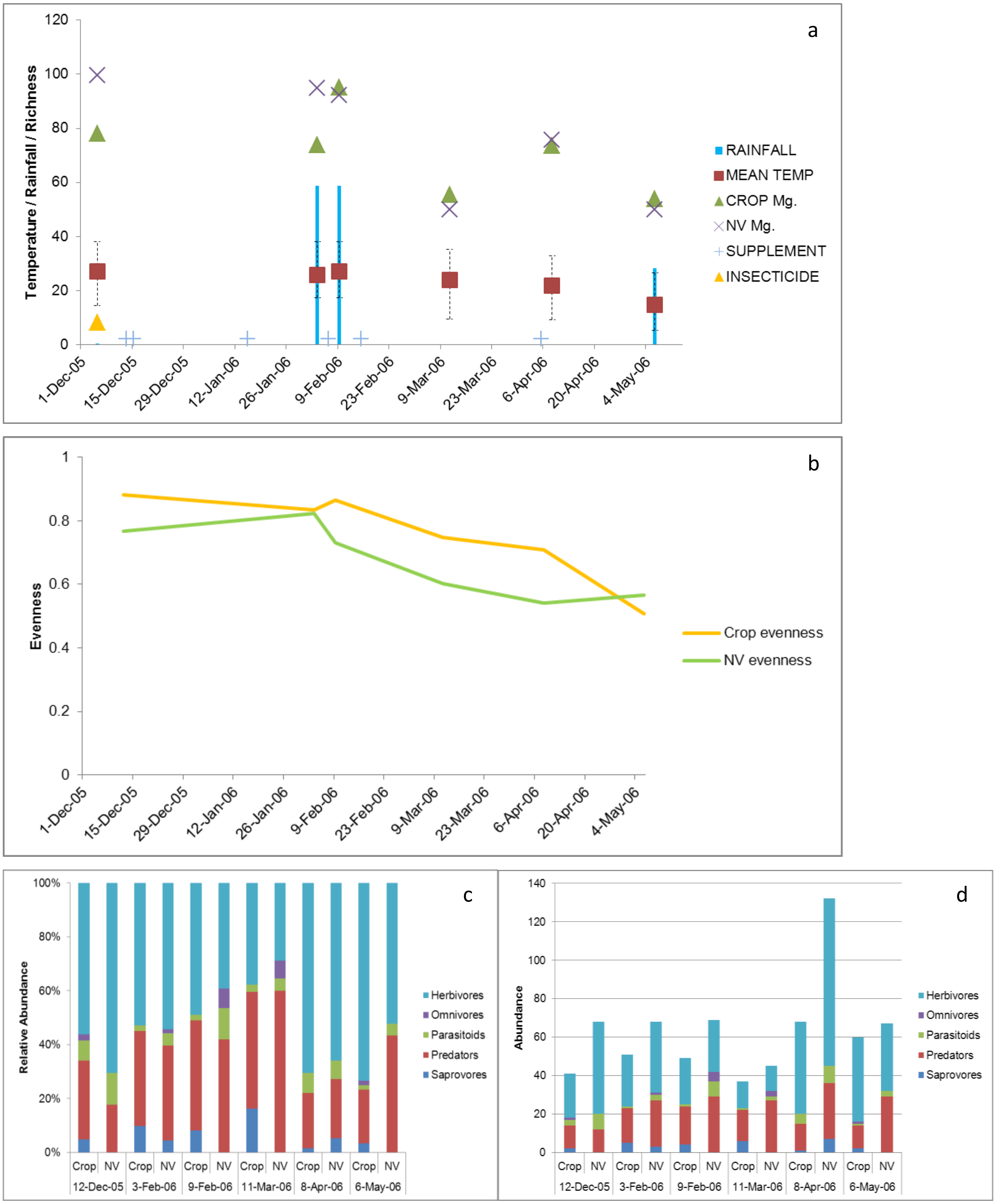

Fig. 5.4. The effect of temperature, rainfall and various agricultural practices on a) arthropod species richness (Margalef index; Crop Mg. and NV (natural vegetation) Mg.) within crop and NV and how it relates to b) evenness, c) relative abundance and d) absolute abundance at GVN1, orchard 42 (5.4a and 5.4b shows two-weekly interval timeline on x-axis; 5.4c and 5.4d show actual sampling dates on x-axis).

For the first four samples, and again at sample 6 of the natural vegetation in orchard 51, species richness was more than that of the crop (Fig. 5.5 a). It is only on the fifth sampling after the natural vegetation richness decreases that the crop and natural vegetation are similar, and additionally the evenness decreases on the crop side and remains relatively similar on the natural vegetation side. The similarity between the crop and the natural vegetation reveal the relatedness between the two habitats. An increase in herbivores between the fourth and the fifth sampling suggests that the decrease in evenness might indicate an increase in a potential pest species. The decrease in predators on the crop and natural vegetation side between the fourth and fifth sampling may be due to the cooler temperatures in the beginning of autumn. At the second and third sampling dates the evenness within the crop (Fig. 5.5b) decreased, possibly as a result of high rainfall, although these results can be deceptive, as shown in the absolute abundance that remains more or less the same. Before the first sample the ground cover within the orchard was mowed, which continued until the fourth sample. Herbicide was also sprayed at the crop habitat after the first sampling, but the next sample was only taken much later, giving the vegetation and the associated arthropod communities a chance to recover. Prior to the fourth sampling date herbicide was once again applied and a drastic decline in species richness, as well as in herbivore and parasitoid abundance, was recorded (Fig. 5.5c & d).

In orchard 64, the first three samples of the natural vegetation showed higher species richness compared to that of the crop (Fig. 5.6a); during the fourth and final sample the richness was similar and in sample 5, natural vegetation richness was again higher than crop richness. At the second and third sampling date the evenness within the natural vegetation (Fig. 5.6b) decreased clearly. During this time there was no increase in herbivores (Fig 5.6c & d), but there was an increase in predators. This might be a result of favourable conditions due to rainfall and the associated general increase of prey. At the fifth sampling date there was a drastic increase in herbivores, whilst the evenness decreased, suggesting a population increase of a particular species, perhaps a potential pest species.

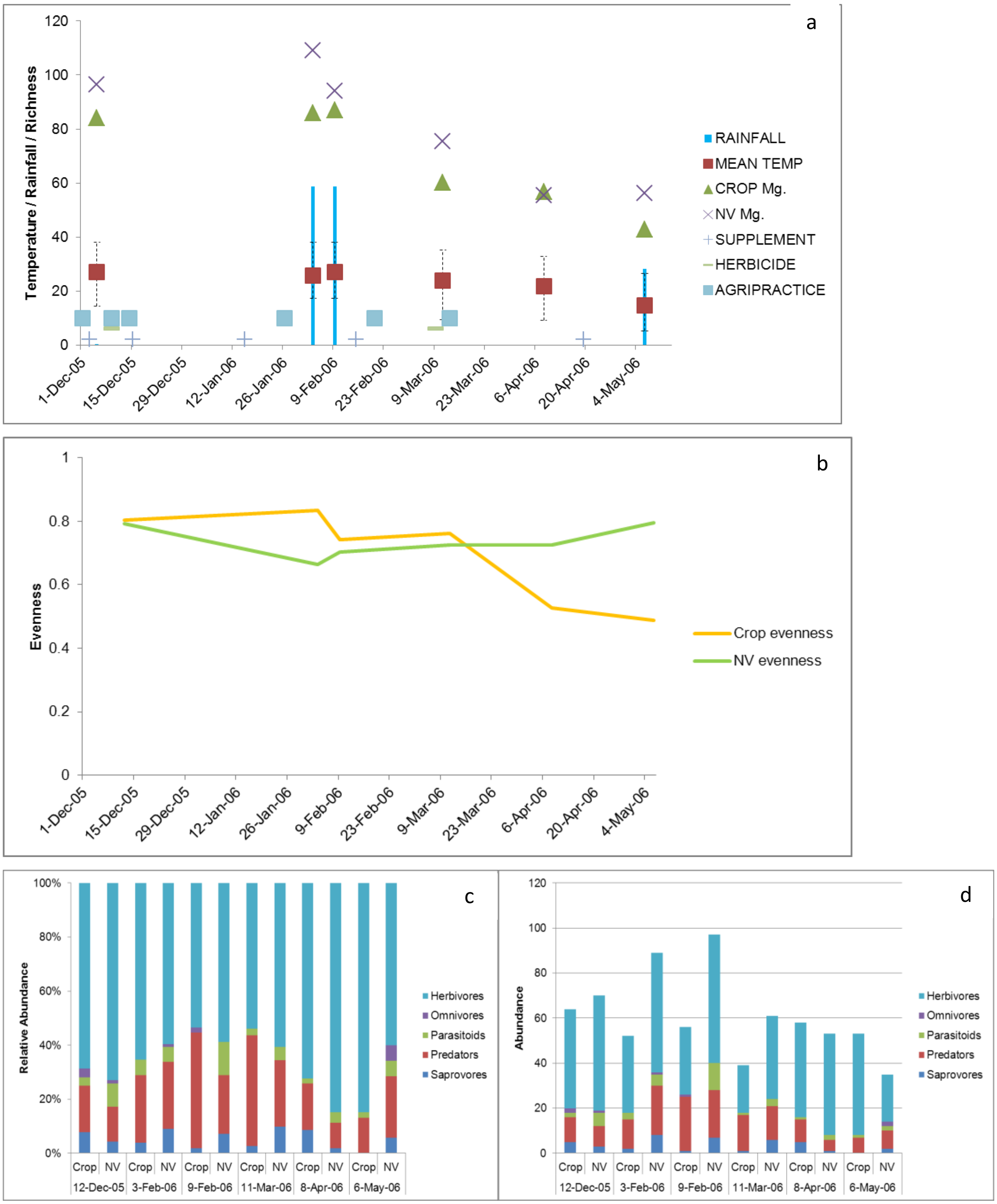

Fig. 5.5. The effect of temperature, rainfall and various agricultural practices on a) arthropod species richness (Margalef index; Crop Mg. and NV (natural vegetation) Mg.) within crop and NV and how it relates to b) evenness, c) relative abundance and d) absolute abundance at GVN1, orchard 51 (5.5a and 5.5b shows two-weekly interval timeline on x-axis; 5.5c and 5.5d show actual sampling dates on x-axis).

During the second season at GVN2 (Fig. 5.7 – 5.10) there was much less rainfall and this affected the species richness of the natural vegetation quite dramatically. The arthropod species richness was recorded to be higher within the crop most of the time. However when comparing the total occurrence of arthropods, GVN2 had higher richness and abundance than GVN1. This might be due to the immigration of arthropods from surrounding areas and natural vegetation into the cropping system and using it as a refugium against unfavourable drought conditions. Irrigation modifies the agroecosystem into a landscape patch of higher resource availability than the surrounding arid natural vegetation, which is low in resources.

In orchard 46, crop species richness remained higher than natural vegetation throughout the season and it fluctuated synchronously with the natural vegetation (Fig. 5.7a). During the second sampling it is evident that herbicide and/or crop supplement application have quite a dramatic effect on the crop and subsequently on the natural vegetation side. During the second sampling species evenness was observed to increase slightly (Fig. 5.7b); the abundance of predators (Figs. 5.7c & d) also decreased, possibly due to a decrease in prey, which, in turn, suggests that it is as a result of the decrease in vegetation, which had been affected by herbicide application. The discontinuation of any agricultural practices leads an increase in species richness, but a decrease in evenness, up until rainfall events. After rainfall, there is a decrease in evenness, although this may be too late in the season for any potential pest to establish itself, after which there is again an increase in evenness towards the end of the season.

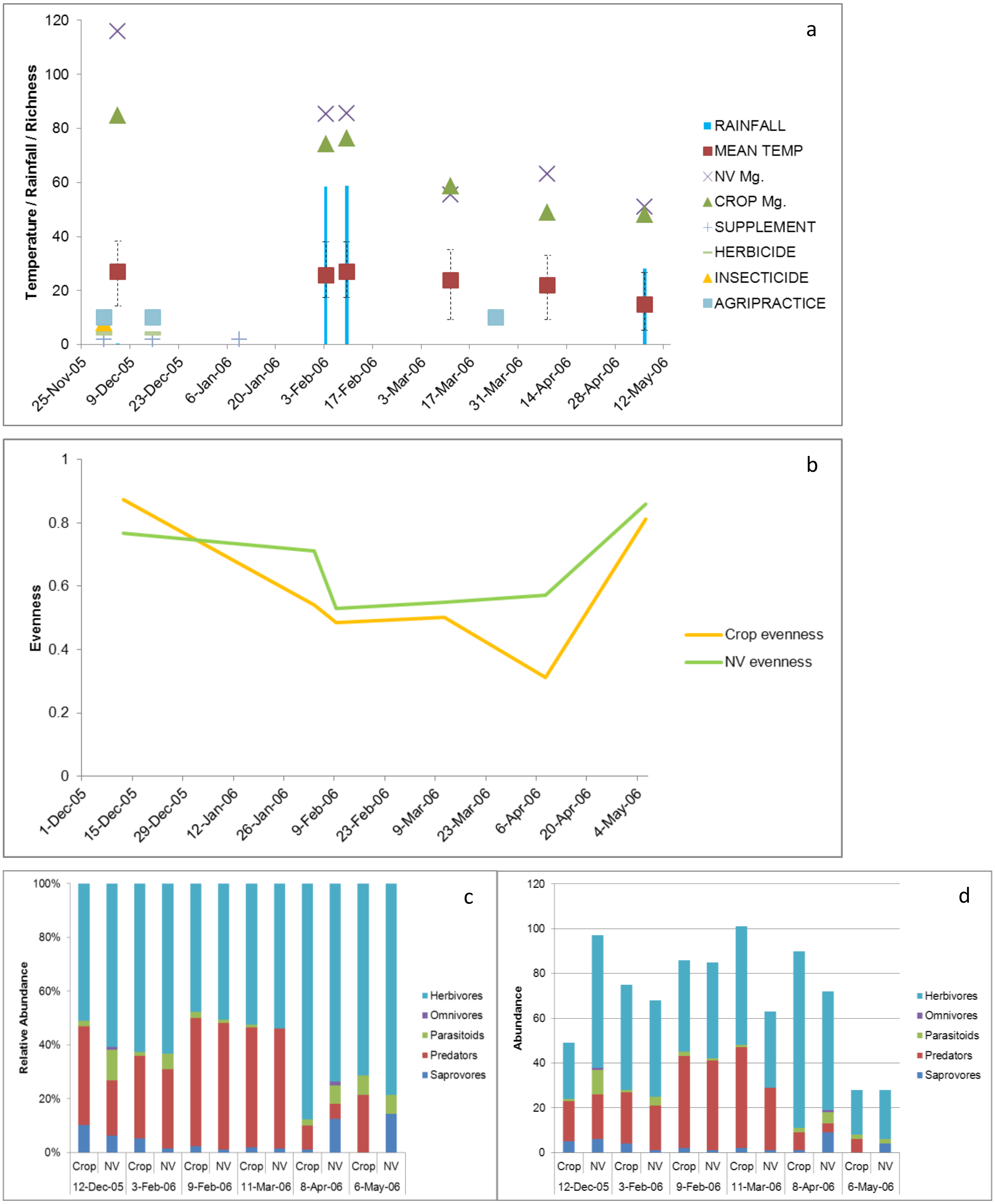

Fig. 5.6. The effect of temperature, rainfall and various agricultural practices on a) arthropod species richness (Margalef index; Crop Mg. and NV (natural vegetation) Mg.) within crop and NV and how it relates to b) evenness, c) relative abundance and d) absolute abundance at GVN1, orchard 64 (5.6a and 5.6b shows two-weekly interval timeline on x-axis; 5.6c and 5.6d show actual sampling dates on x-axis).

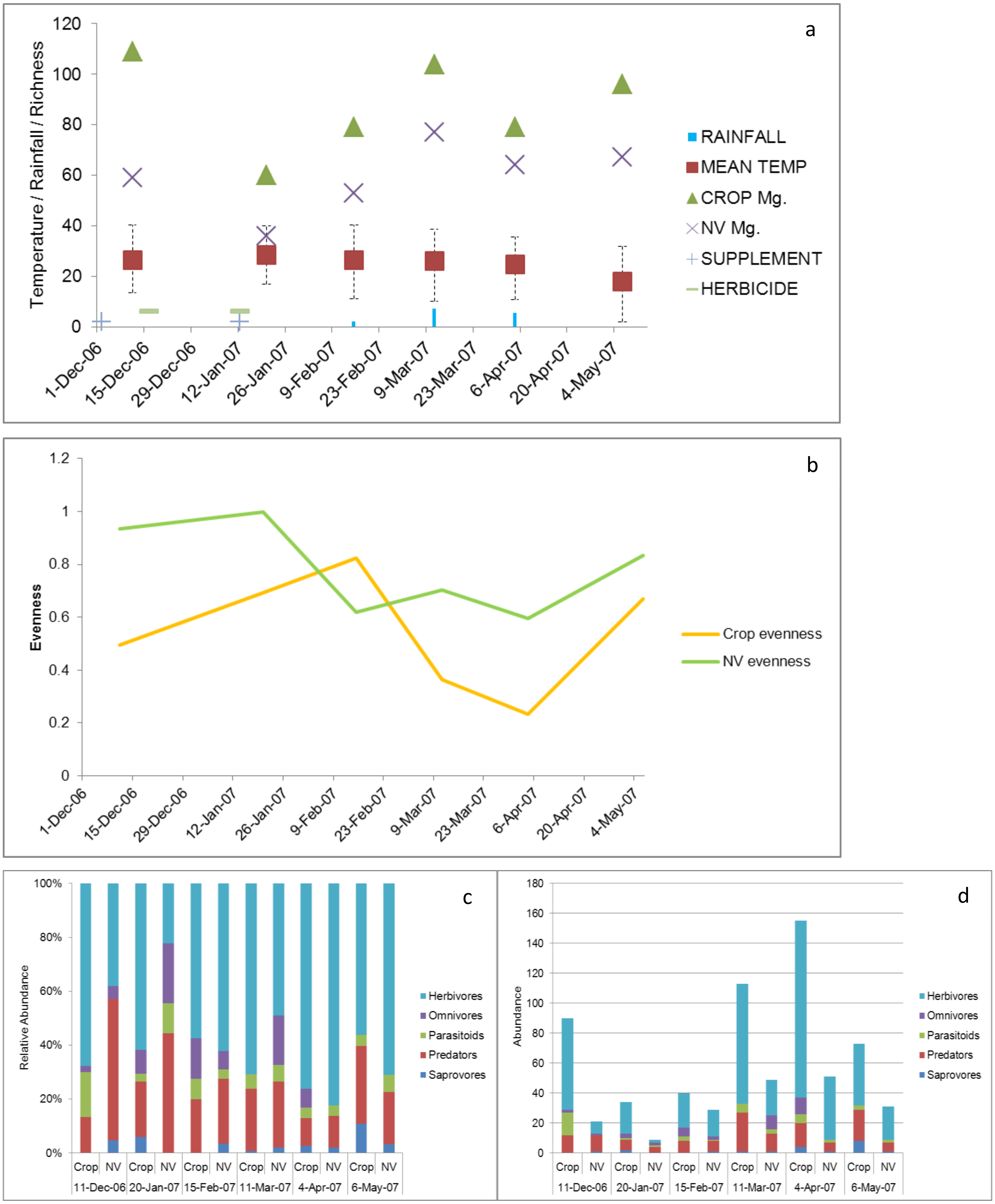

Fig. 5.7. The effect of temperature, rainfall and various agricultural practices on a) arthropod species richness (Margalef index; Crop Mg. and NV (natural vegetation) Mg.) within crop and NV and how it relates to b) evenness, c) relative abundance and d) absolute abundance at GVN2, orchard 46 (5.7a and 5.7b shows two-weekly interval timeline on x-axis; 5.7c and 5.7d show actual sampling dates on x-axis).

In orchard 51, prior to the first sampling the ground cover was mowed, and this may have had an influence on species richness within the crop (Fig. 5.8a). Here natural vegetation evenness (Fig. 5.8b) is almost double that of the crop, while abundance of the crop is higher than that of the natural vegetation, with predators and parasitoids accounting for approximately 30% of the abundance (Figs. 5.8c & d). After the first sampling period, supplement and herbicide were applied within the crop habitat and as a result a large decrease in species richness of the crop and an even larger decrease in natural vegetation species richness was recorded. Concurrently, an increase in crop evenness and a decrease in natural vegetation evenness occurred, with abundance in both habitats decreasing. An increase in omnivores within the natural vegetation during the second sample was also observed (Figs. 5.8c & d). The increase in omnivores resulted in the decrease in evenness in the natural vegetation habitat. After sampling period 2 only supplement was applied, which was followed by an increase in natural vegetation and crop richness. Natural vegetation richness is higher than crop richness, suggesting that the natural vegetation recovers more rapidly than the crop after a disturbance event. One of the causes could be ascribed to the intense agricultural activities that occur within the crop setting. After low rainfall immediately prior to sampling period 3, evenness recovered. However, in the subsequent period evenness decreased dramatically, with an increase in the overall abundance primarily the result of herbivores. During the last three sampling periods crop richness was higher than natural vegetation richness and its numbers fluctuate synchronously. Guild composition is also synchronous over time and responds in a similar manner to the only abiotic factor (*i.e.* rainfall) during this period.

In orchard 59, there was a continuous decrease in crop and natural vegetation richness following the two applications of a growth supplement (Fig. 5.9a). Another reason for the decrease in richness during the second sampling may be the result of high temperatures and low rainfall. The proportion of omnivores in the total sample during this time increased to a greater extent than during any other sampling period in all orchards. There was a concurrent decrease in crop evenness (Fig. 5.9b) during the second sampling period as a result of the increase in omnivores. It is only after the application of herbicide and fungicide that the richness increased dramatically during the third sampling period; and an increase in predator numbers resulted in an increase in evenness within the crop and the natural vegetation; and the guild structure of the crop and the natural vegetation appear to be similar. The increase in evenness may be explained by the decrease in omnivores, whilst the increase in predators indicates an increase in prey. The only possible explanantion for this may be as a result of herbicide application, since herbicide exposure may have varying significant impacts on both pest and beneficial arthropod groups (Egan *et al.* 2014).

By providing habitat, floral resources, and other food resources, plant diversity in semi-natural habitats is essential for maintaining diverse communities of beneficial arthropods that provide pollination and biological control services (Isaacs *et al.* 2009). While most herbicides do not appear to be directly toxic to arthropods (Norris & Kogan 2005), herbicides do affect plant nutrient levels and hormone pathways used in defense, both of which may influence plant susceptibility to herbivores (Bohnenblust *et al.* 2013).

However, in most instances where arthropods are affected by herbicides, the driving mechanism often appears to be changes in features of the vegetation, such as plant species composition, habitat structure, or the ability of plants to defend themselves from herbivores (Norris & Kogan 2005, Taylor *et al.* 2006). Therefore, if low-dose herbicide exposures affect plant community structure and function, arthropod communities may change due to factors like reduced availability or suitability of host plants.

Egan *et al.* (2014) showed that plant and arthropod biodiversity can be altered by non-target herbicide exposures at specific low doses, however, certain habitat types may be much more resistant to disruption from herbicide drift. Changes in the structure and function of plant and arthropod communities are less influencial, though it may depend on species composition, successional patterns, and timing of herbicide exposure.

During sampling period 4, after heavier rainfall, the richness within the crop decreased and the abundance of herbivores (Fig. 5.9d) increased dramatically. The results suggest that the abundance on the natural vegetation recovers more slowly and then only for a short while, before the cooler temperatures start to influence arthropod abundance. It is only towards the final sampling period that the crop and orchard seemed to recover, with high richness and high evenness.

In orchard 62, fairly similar patterns to the previous orchards occur, with richness decreasing (Fig. 5.10a) during the second sampling period, evenness decreasing (Fig. 5.8b) and the proportion of omnivores in both the crop and natural vegetation increasing (Fig. 5.10c). After application of herbicide and crop supplement evenness increases and abundance decreased. Thereafter richness remained more or less constant until the final sampling period, when it increased dramatically. The abundance within the crop remained higher than in the natural vegetation throughout the season, reflecting sufficient availability of resources (Fig. 5.10d).

During the GVN2 survey, a range of agricultural activities were conducted in all the orchards (Figs. 5.7 to 5.10) prior to samples 1 and 2 being taken. These include supplement and herbicide application in all the orchards and mowing (agripractice) in orchard 51 (Fig. 5.8a). There is a clear decrease in arthropod species richness in all the orchards within the crop and natural vegetation between sampling periods 1 and 2. The results suggest that the supplement and herbicide application contribute to the decrease in species richness within the crop and the natural vegetation, although it is only applied within the crop side. Natural vegetation decrease is presumed to be based on pesticide drift from the crop.

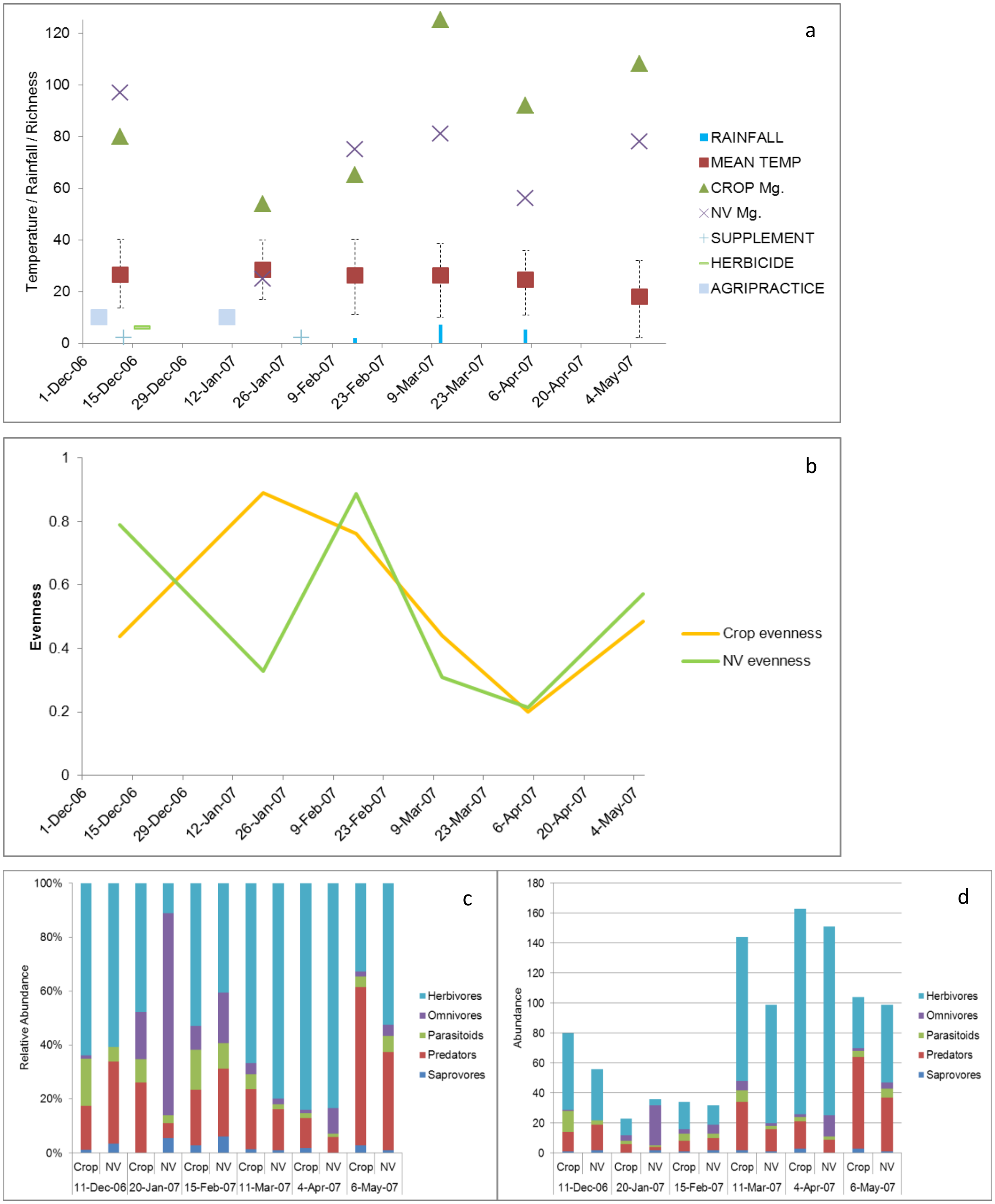

Fig. 5.8. The effect of temperature, rainfall and various agricultural practices on a) arthropod species richness (Margalef index; Crop Mg. and NV (natural vegetation) Mg.) within crop and NV and how it relates to b) evenness, c) relative abundance and d) absolute abundance at GVN2, orchard 51 (5.8a and 5.8b shows two-weekly interval timeline on x-axis; 5.8c and 5.8d show actual sampling dates on x-axis).

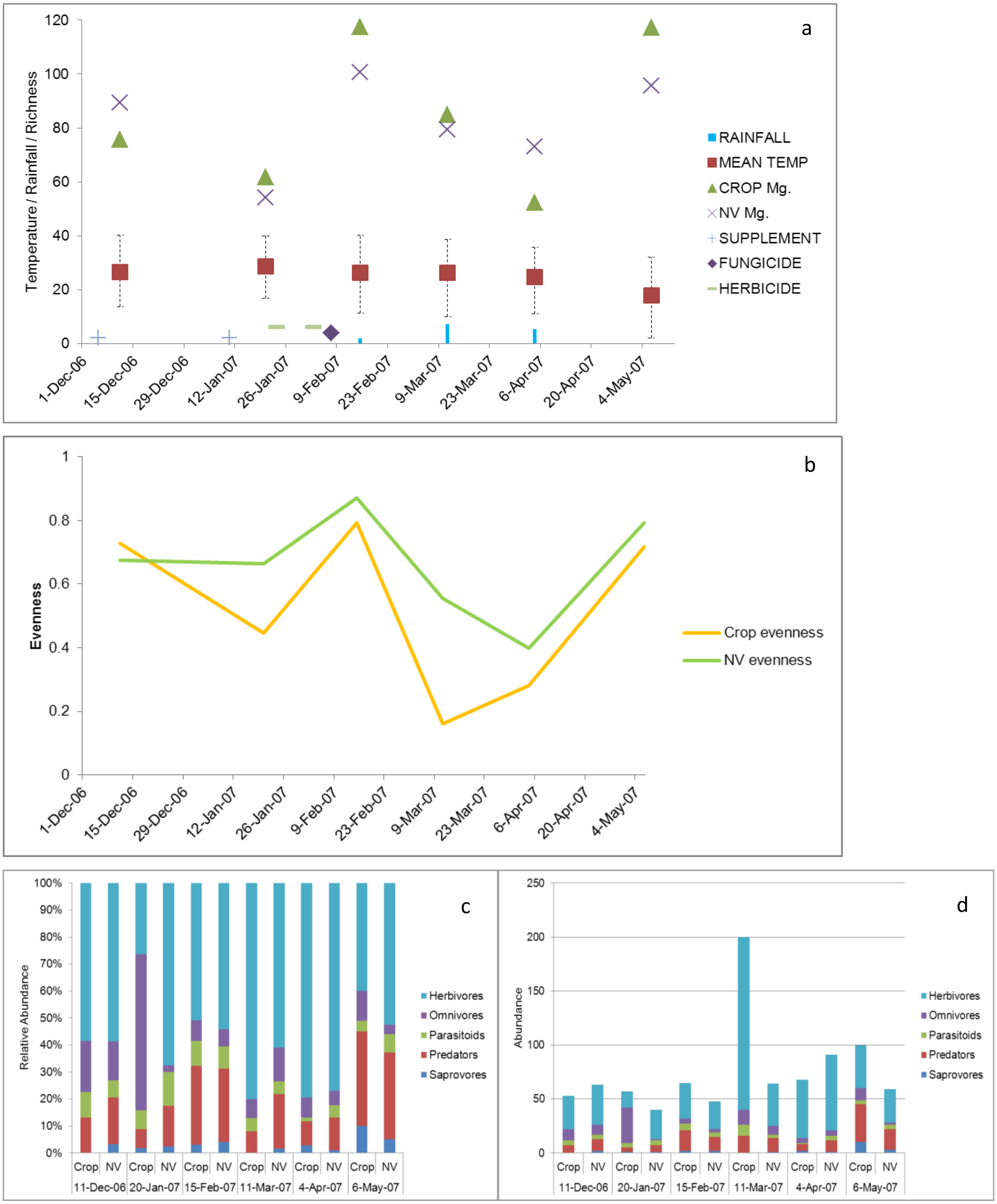

Fig. 5.9. The effect of temperature, rainfall and various agricultural practices on a) arthropod species richness (Margalef index; Crop Mg. and NV (natural vegetation) Mg.) within crop and NV and how it relates to b) evenness, c) relative abundance and d) absolute abundance at GVN2, orchard 59 (5.9a and 5.9b shows two-weekly interval timeline on x-axis; 5.9c and 5.9d show actual sampling dates on x-axis).

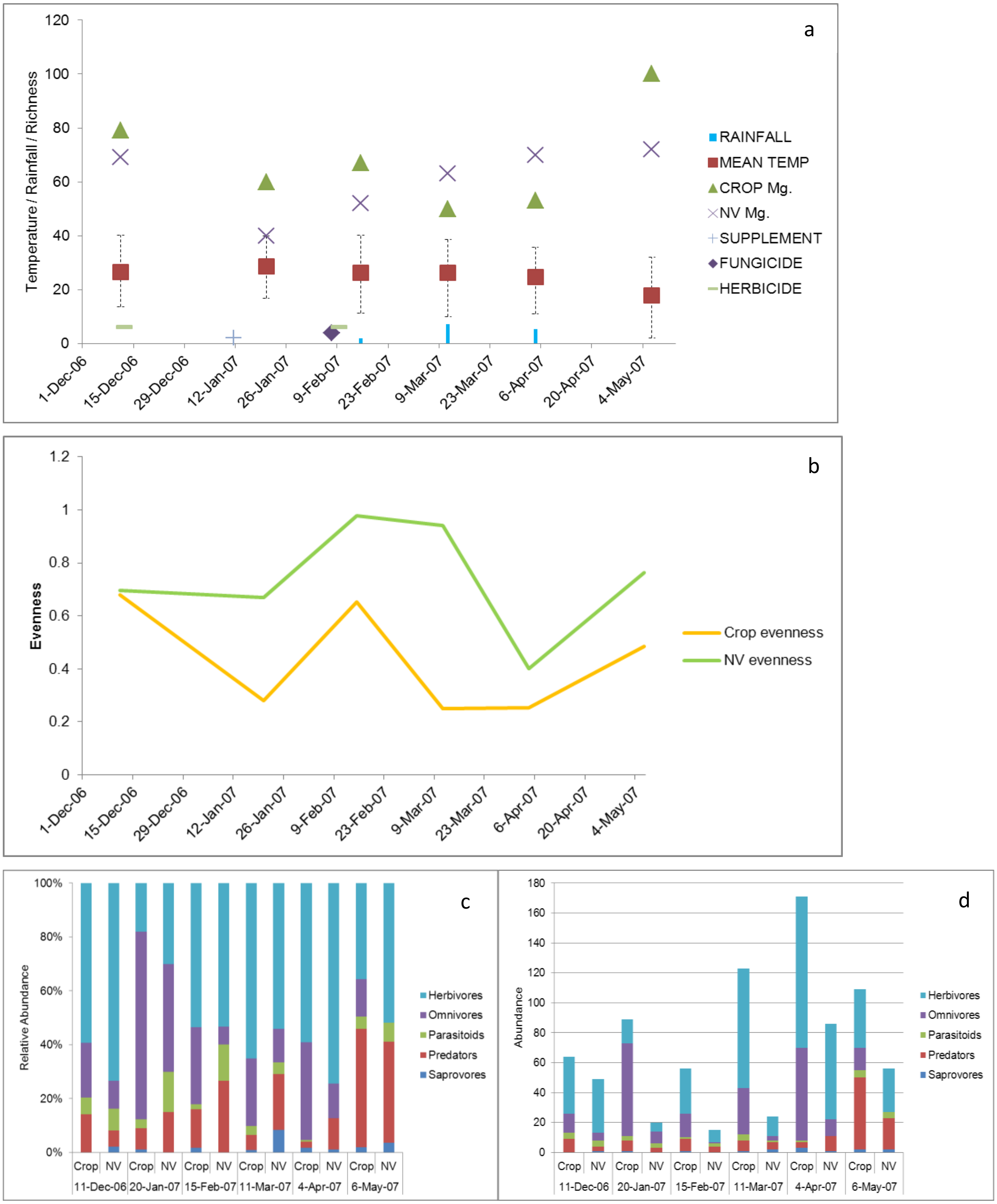

Fig. 5.10. The effect of temperature, rainfall and various agricultural practices on a) arthropod species richness (Margalef index; Crop Mg. and NV (natural vegetation) Mg.) within crop and NV and how it relates to b) evenness, c) relative abundance and d) absolute abundance at GVN2, orchard 62 (5.10a and 5.10b shows two-weekly interval timeline on x-axis; 5.10c and 5.10d show actual sampling dates on x-axis).

Overall evenness is the highest during sampling period 3 in most of the orchards (Figs. 5.8b, 5.9b & 5.10b), although during this time abundance (Figs. 5.8d, 5.9d & 5.10d) is low, if not the lowest. The results suggest that evenness and abundance should be observed separately from each other, thereby providing more insight into community structure and function.

In all orchards, after rainfall, during sampling periods 4 and 5, there was a sudden dramatic increase in abundance (Figs. 5.7d – 5.10d) of the overall arthropod species communities and a lower rate of increase on the crop's side; however, there was a decrease in evenness. This suggests that there was an increase in certain generalist herbivore species.

During the CON1 and CON2 surveys, natural vegetation richness (Figs. 5.11a & 5.12a) constantly remained higher than crop richness, and crop evenness (Figs. 5.11b & 5.12b) was slightly higher than natural vegetation evenness, remaining more or less at an equilibrium, except during the final sampling period after crop harvest. The abundance (Fig. 5.11d & 5.12 d) during both seasons remained higher within the natural vegetation than in the crop, while the proportion of respective guilds (Figs. 5.11c & 5.12c) remains similar throughout CON1 and CON2. The results clearly show that the crop and natural vegetation have connectedness as a result of less intense agricultural practices compared the orchards at GVN. This may also explain the constant guild structure which is maintained throughout the season.

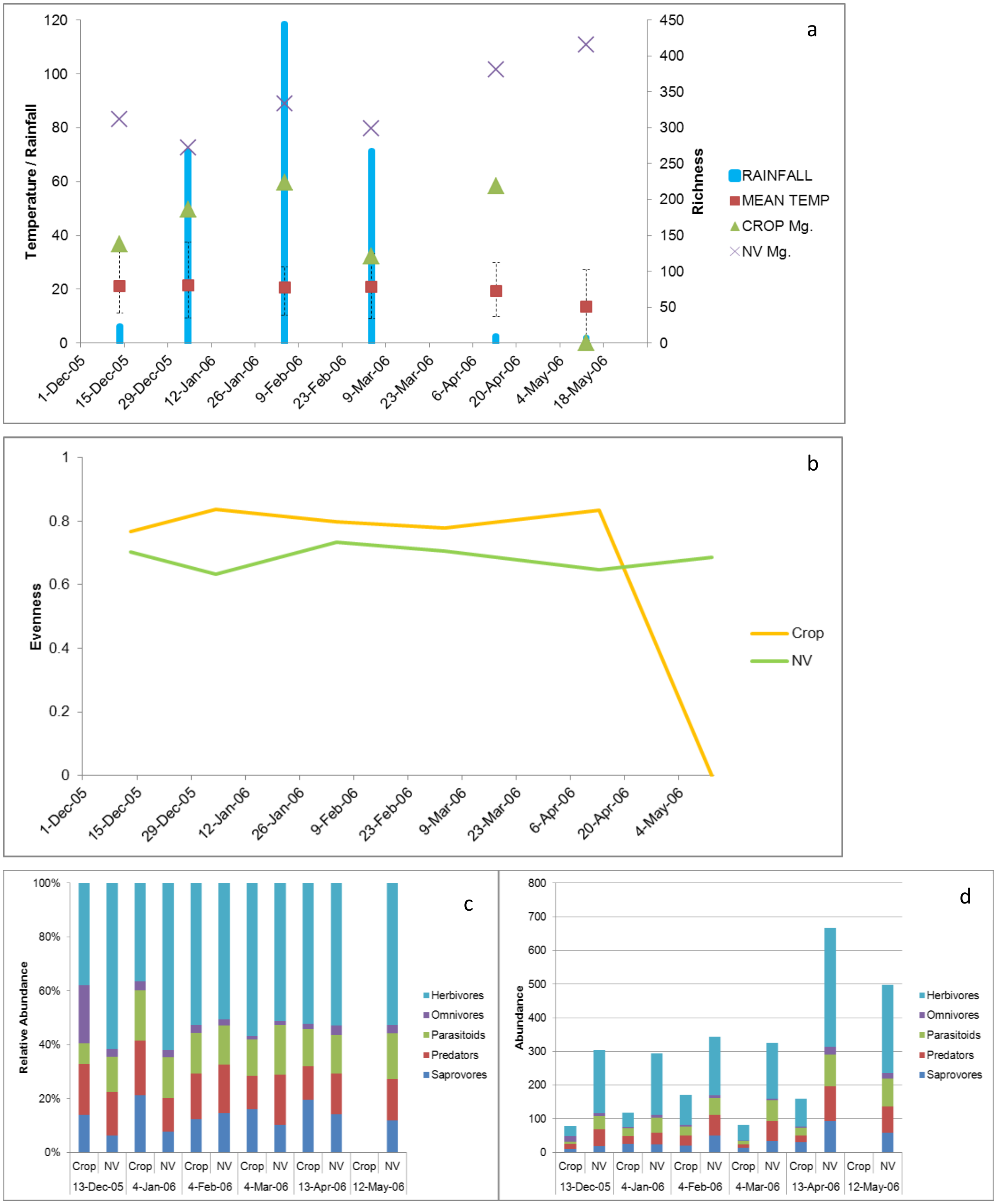

Fig. 5.11. The effect of temperature, rainfall and various agricultural practices on a) arthropod species richness (Margalef index; Crop Mg. and NV (natural vegetation) Mg.) within crop and NV and how it relates to b) evenness, c) relative abundance and d) absolute abundance at CON1 (5.11a and 5.11b shows two-weekly interval timeline on x-axis; 5.11c and 5.11d show actual sampling dates on x-axes).

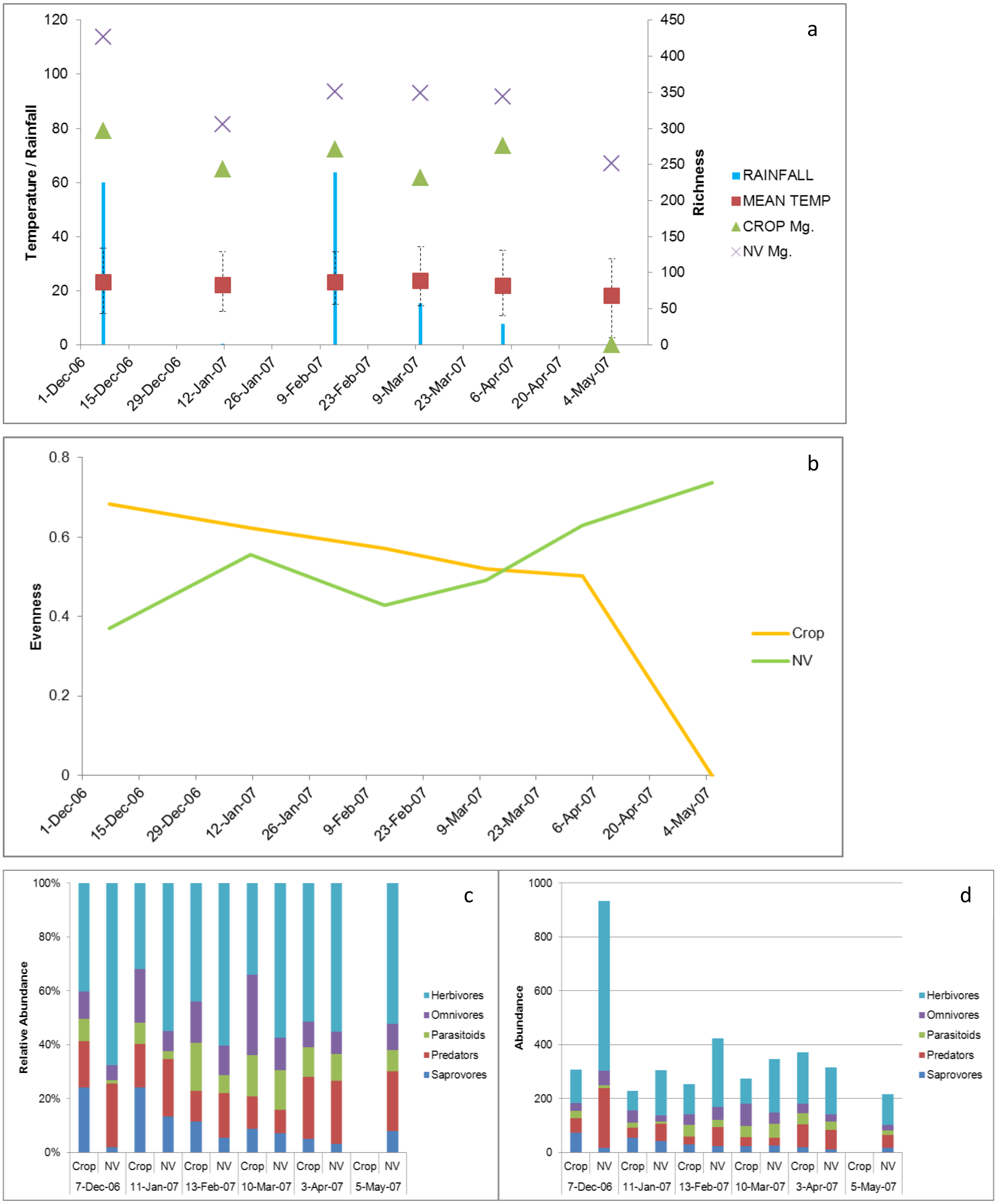

Fig. 5.12. The effect of temperature, rainfall and various agricultural practices on a) arthropod species richness (Margalef index; Crop Mg. and NV (natural vegetation) Mg.) within crop and NV and how it relates to b) evenness, c) relative abundance and d) absolute abundance at CON2 (5.12a and 5.12b shows two-weekly interval timeline on x-axis; 5.12c and 5.12d show actual sampling dates on x-axes).

The absence of disturbances on account of agricultural activities at CON have appropriate consequences, since few variations of richness, evenness and abundance took place between the crop and surrounding natural vegetation. Harvesting of the crop had an obvious effect on all these factors. When comparing CON and GVN regarding these variables *viz*. species richness, evenness and abundance, it is evident that the dramatic fluctuations encountered at GVN were a consequence of intense agricultural practices.

At GVN growth supplement seemed to affect arthropod biodiversity. Zinc sulphate has been shown to have a deterrent feeding effect on the larvae of *Spodoptera littoralis,* retarding their development and growth. Furthermore, the accumulation of zinc in the tissues of the larvae seems to be the factor leading to the induction of sterility in the newly emerged moths (Salama & El-Sharaby 1972). Supplement dosages to crops require high accuracy, since incorrect dosage of Zinc can make plant tissue either tolerant or vulnerable to pest attack (Sarwar 2011).

Mowing of cover crops between the tree rows at GVN as an agripractice had a negative effect on arthropod diversity. In general, grassland management is an important part of nature conservation and agriculture and grass in fields must be cut at appropriate times so that the system can rejuvenate or recover from management over a period of years (Morris & Plant 1983). Obvious damage could be casualties caused by mowers, destruction to spider webs or ant nests, elimination of nectar and pollen food sources for flower-visiting insects, alterations in micro-climate affecting less-mobile arthropods such as larva and pupa that cannot seek alternative suitable sites and homogenisation of the vegetation with the damage of many micro-habitats (Cattin *et al.* 2003, Gardiner & Hill 2006). Noordijk *et al*. (2010a) suggest that to promote ground-dwelling arthropods in productive grassland edges, a management practice of mowing twice a year, including the removal of cuttings, is recommended; and to further promote arthropod survival some vegetation refuges must be left intact after mowing events. Several vegetation characteristics exist that can promote arthropod diversity, but the number of flowering plant species and total flower abundance appear to represent the most suitable and most easily monitored aspects of these characteristics that significantly mirror arthropod diversity (Noordijk *et al.* 2010b). The relative contribution of immigration and reproduction to crop field population increase of predators is often complex. This also applies to population decrease within a crop as a result of emigration and mortality. Disentangling these processes offers insight into the seasonal dynamics of immigration and emigration in agroecosystems and the potential for re-establishment after disturbance (Schellhorn *et al*. 2014). Active and passive dispersal mechanisms used by the same predators can result in different spatial scales of movement,

Diversity can also change with key ecological processes such as competition, predation, and succession, each of which alter proportional diversity through changes in evenness without any change in species richness. Consequently, diversity should always be separated into its components (richness and evenness). A division can provide insight into community function (McNaughton 1977, Wilsey & Potvin 2000) and, possibly, into systematic biological effects (Gaston 2000). However, neither richness nor evenness are reliable independent measures of differences in diversity, compared with the performance of the combined statistic (Kempton & Taylor 1974). The analysis in this chapter indicates that diversity reflects effects of evenness and richness components along with their intercorrelations.

5.4 CONCLUSION

With reference to the hypothesis (*viz. Hypothesis 3:* If arthropod richness and abundance are dependent and affected by climate and weather conditions, and agricultural practices (pesticides, fertilizers, patch size, cover crops and surrounding vegetation), then the correct choice of agricultural management practices will improve arthropod species richness, abundance and evenness), arthropod richness and abundance are dependent and affected by climate and weather conditions, and agricultural practices and thus the correct choice of agricultural management practices indeed improve arthropod species richness, abundance and evenness. Generally, species richness and abundance of vegetation was observed to be related to species richness and abundance of arthropods. It is evident that a link exists between vegetation and abiotic factors and arthropod richness and abundance. In this study it can thus be assumed that any disturbance occurring on or around the crop may have an effect on associated arthropod species richness and abundance. Spatial scales at which cues are detected to initiate emigration or immigration of the different trophic guilds under field conditions remain ambiguous and need further study (Schellhorn *et al.* 2014). Landscape features determine the functional connectivity of the landscape and may potentially determine where biocontrol services will be provided (Schellhorn *et al.* 2014). It has already been established in previous chapters that evenness can be employed as a measurement of arthropod pest status, whereas in this chapter species evenness emerges as a measurement of the effectiveness of a specific management technique that is applied. Therefore more precautions need to be taken by farmers to ensure less damage to the natural environment, which, in turn, will have less devastating effects on biodiversity.

CHAPTER 6

THE EFFECTIVENESS OF AN AGROECOSYSTEM INTEGRITY INDEX THAT USES ARTHROPODS AS AN INDICATOR

6.1 INTRODUCTION

Where species abundance together with the species richness might give an indication of ecological integrity, it is the ecosystem services that are of vital importance in an agroecosystem. These ecosystem services possess functional qualities and fulfil an important role within the agroecosystem. The functional characteristics of species strongly influence ecosystem properties. Functional qualities operate in a range of contexts, including the effects of dominant species, keystone species, ecological engineers, and species interaction (*e.g.* competition, facilitation, mutualism, disease, parasitism and predation) (Bruno *et al*. 2003).

The flows of these ecological services and ecological disservices depend on, first, how agroecosystems are managed on site and, second, on the diversity, composition, and functioning of the surrounding landscape (Tilman 1999). Species richness, abundance and evenness alone are not suitable indicators for the assessment of farming system effects on different expressions of biodiversity. Relative abundance alone is not always a good predictor of the ecosystem-level importance of a species, as even relatively rare species, such as a keystone predator, can strongly influence pathways of energy and material flows (Hooper *et al.* 2005).

Research suggests that, in future, biodiversity monitoring programmes should consider incorporating an indicator set of functional biodiversity (Duelli & Obrist 2003) and that for the determination and description of agroecosystem functional groups, the bio-functionality approach should be followed. For instance, a wide range of ecological services and ecological dis-services result in benefits and costs, respectively, to agriculture (Table 6.1). Services and disservices are supplied by a variety of species, functional groups, and guilds over a range of scales and are influenced by human activities both intentionally and unintentionally (Zhang *et al.* 2007). Processes that can be improved by biodiversity management, or alternatively functional groups that are effective, should be protected to maintain the processes they provide (Noss 1990).

Table 6.1. Major ecosystem services and disservices to agriculture, the scales over which they usually are provided, and the main guilds or communities from which activities are supplied (modified from Zhang *et al.* 2007).

Ecosystem services or dis-services	Agricultural fields only	Agroecosystem (Farm Property)	Landscape surrounding agroecosystem
Services			
Soil fertility and formation, nutrient recycling	Microbes, invertebrate communities, legumes	Vegetation cover	
Soil retention	Cover crops	Cover crops	Riparian vegetation
Pollination	Ground-nesting bees	Bees and other insetcs	Insects
Pest control	Predators and parasitoids (*e.g.*Araneae, Chalcidoidea)	Predators and parasitoids (*e.g.*Araneae, Chalcidoidea, birds and bats)	
Water provision and purification		Vegetation around drainages and dams	Vegetation cover in watershed
Genetic diveristy	Crop diversity for pest and disease resistance		
Climate regulation	Vegetation influencing microclimate (*e.g.* older orchards)	Vegetation influencing microclimate	Vegetation influencing stability of local climate, rainfall, temperature, humidity
Disservices			
Pest damage	Insects, snails, birds, fungi, bacteria, viruses, weeds	Insects, snails, birds, fungi, bacteria, viruses, weeds	Insects, snails, birds, fungi, weeds
Competition for water from other ecosystems	Weeds, other vegetation	Vegetation cover near drainage areas	Vegetation cover in watershed
Competition for pollination services	Flowering weeds	Flowering weeds	Flowering vegetation in watershed

The average local species richness (alpha-diversity) is not generally considered to be a valuable and applicable aspect of biodiversity. However, ecological resilience (Gunderson *et al.* 2009) and sustainability of ecosystem services (Loreau *et al.* 2001, Hooper *et al*. 2005, Kremen 2005) may be heavily reliant on local species richness, especially if considered in the context of beta diversity. Bioindicator-based studies use living components of the environment under study, especially those with high diversity, such as the invertebrates and applied aspects such as pollination (Kremen *et al*. 2007), pest control (Moonen & Barberi 2008) and biological invasions, as the key to assess the transformations and effects. This dependence may become aggravated in the light of the prospect of major global environmental changes, such as global warming and management changes in agriculture and forestry (Loreau *et al*. 2003, Allison 2004, Kassar & Lasserre 2004).

McGeoch (1998) reviews the existing criteria on biodiversity indicators. These criteria include cost efficiency, effectiveness, whether indicators can be sampled and sorted easily, whether they correlate with trophic levels and functional groups, whether they demonstrate a well-defined and measurable distribution over a range of habitats, and are representative of related and unrelated taxa. However, because there is always a compromise between the inherent complexity of biodiversity and the simplicity of what is, in fact, affordably measurable; these criteria, in reality, cannot all be combined (Schmeller 2008).

Facilitating identification of biota (biodiversity) for non-experts is an important goal that must be achieved if bioindicators are to be applied to read the environment and its quality. However, having said this, measures of ecosystem services still need further development in many circumstances for this to become a reality (Boyd & Banzhaf 2006). The aim of this chapter is therefore to devise a monitoring scheme and a biodiversity indicator for the average local species richness of arthropods in the context of ecological services.

The fourth objective in this chapter is to determine the relationship between the arthropod species richness and abundance, and the proposed AFI (Agroecosystem Function Index), which is based upon the economic value of species richness.

Hypothesis 5: If the AFI is dependent on the economic value of species richness, then an increase in the AFI should be effective for indicating a functional gain as a result of an increase in arthropod species diversity.

6.2 Methodology

The proposed AFI is calculated by allocating a standard value to morphospecies. The AFI is a value derived from the scale value (Table 6.2) derived from Simoncini (2009) and it can be used as a standard or benchmark value on the basis of which to compare from which to derive any future analysis. These scale values are then used throughout the analysis as to set a benchmark value as a standard. The values are based upon morphospecies function which is fulfilled within the ecosystem and that add a value to the specific crop. According to Moonen and Barberi (2008) it would be more accurate to consider as 'functional groups' all clusters of biota providing the same agroecosystem service. For instance, yield reduction can be considered a negative primary production service caused by crop antagonists, and production provided by the functional groups could include increased nutrient cycling. These functions contribute towards a viable crop, which, in turn, possesses a monetary value. Thus, it can be said that these scale values are derived from an economic point of view and are based upon a standard value that must be determined by using either the natural surrounding environment as a benchmark or a case study of the specific crop, or both as a guideline.

Table 6.2. Ranking of scale values assigned to the morphospecies within a sample.

Scale Value	Influence to the crop	Agricultural ecosystem function
+2	Beneficial to the crop	Predators, parasitoids, pollinators
+1	Beneficial to the immediate surrounding environment	Nutrient recyclers, niche displacers (competition)
0	Neither beneficial nor detrimental	Tourists
-1	Possibly detrimental to crop	Secondary pests (may reach pest status)
-2	Definitely detrimental to the crop	Key pests, primary pests

The proposed AFI is calculated as follows:

Step 1: Categorise arthropod morphospecies according to trophic function scale value criteria and appoint the value (provided in Table 6.2) to each morphospecies.

It is therefore proposed that the scale values can now be used in various analyses of the agroecosystem. For instance, it is possible to determine the risk factor of the arthropod species assemblages by plotting it against income or Simpson’s index of diversity.

Step 2: AFI (Agroecosystem Function Index) = sum of scale values / number of individuals

The lumped scale value of the guilds per transect were calculated and plotted on a bar chart for each season. This shows the total scale value per guild per season, as well as the overall total scale value. The AFI per transect was calculated and plotted on a bar chart, showing the total average AFI per species within the specific transect.

The sum of the scale value for the crop and natural vegetation was plotted over time for each season and compared to one another. For each sampling date the AFI value for the crop and natural vegetation was compared to each other by plotting it on a bar chart.

6.3 RESULTS AND DISCUSSION

6.3.1 Site comparison

In context of the scale value (Figs. 6.1a – 6.4a), the edge effect is evident between the crop and natural vegetation for all the sites. The negative appointed trophic values (organisms detrimental to the crop) seem to contribute to the prominence of the edges by being below the x axes. The edges are more distinguishable at transects 3 or 4 in the scale value analysis than the species abundance (Figs. 6.3 – 6.4) or species richness (Figs. 6.1 & 6.2) as discussed in Chapter 4. This shows that the trophic scale values based on benefit or loss are effective in distinguishing edge effects. Consequently these edges have the highest value in terms of function. Transects along the edge can also be distinguished as having a higher value than any of the other transects.

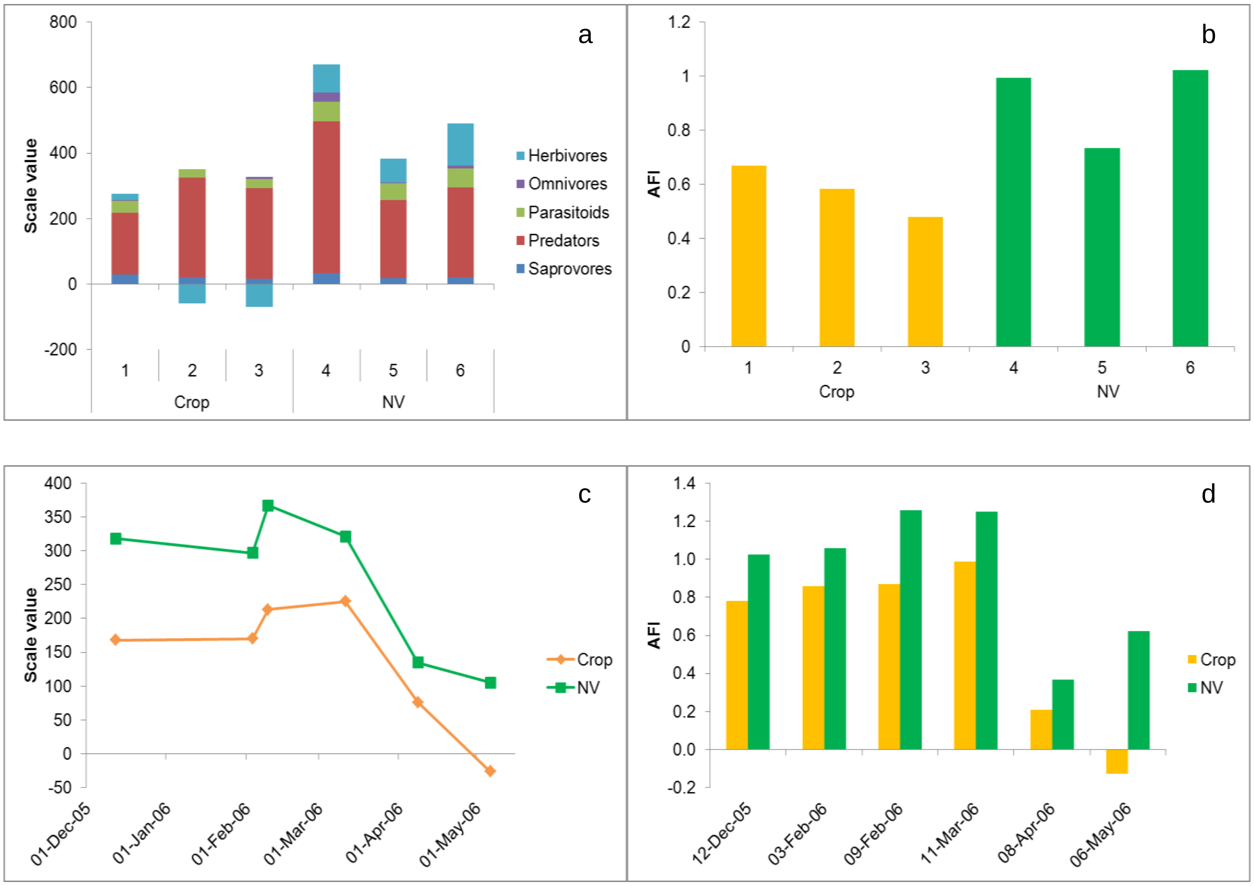

Fig. 6.1. A schematic analysis of lumped orchards at GVN1 for a) trophic scale values for each guild across the transects, b) Agroecosystem Function Index (AFI) across the transects, c) scale value for natural vegetation (NV) and crop over time and d) Agroecosystem Function Index (AFI) for NV and crop over time (c shows monthly interval timeline on x-axis; d shows actual sampling dates on x-axis).

The AFI graphs at GVN1 and GVN2 (Figs. 6.1b & 6.2b) and at CON1 (Figs. 6.4b) show a degree of prominence at the edge (transect 3 or 4), but the AFI at CON2 (Figs. 6.3b) does not show that. This could be because the CON site does not incorporate intense agricultural activities that would have an effect on ecosystem services overall. This phenomenon is reported by Hooper *et al*. (2005) who state that alteration of biota in ecosystems *via* species invasions, and extinctions caused by human activities have altered ecosystem goods and services; this has been documented for many other cases as well. The rainfall at CON1 was very high throughout the season, thus contributing to the favourable conditions in this habitat and a less distinct edge. Another explanation could be the exceptional abundance of pollinators that were present at CON within the crop. During CON2, the rainfall was less; but the crop was irrigated, thus resulting in the natural vegetation exposing a lower AFI. CON1 (Fig. 6.3a) results suggest an ideal guild composition and functional species composition for both habitats because the AFI's of the transects are very similar to each other, with an AFI of +1.3 (Fig. 6.3 b). Therefore, it is highly unlikely for a habitat to have a perfect score of +2 (*i.e.* altogether beneficial to the crop or for instance only predators). Since there are few agricultural activities at CON, it can be assumed that an ideal value that would represent all the ecosystem qualities, for instance, +1.3 is a good representation of these functional qualities.

In all the scale value analyses (Figs. 6.1c – 6.4c) dramatic changes occur over time, to the extent that scale values even reach negative values, for example the crop during GVN1 and GVN2 (Figs. 6.1c & 6.2c) and the natural vegetation during GVN 2 (Figs. 6.2c). According to this data, detrimental arthropods such as herbivores were abundant during these periods. The trophic scale value at CON1 and CON2 (Figs. 6.3c & 6.4c) also fluctuates synchronously throughout the season, although they do not fall below zero, except for the crop, which is zero during the sixth sampling period. This shows that detrimental arthropods are less abundant and that beneficial arthropods are more abundant compared to GVN. Although GVN has ground cover vegetation, intense agricultural activities that are employed at GVN may lead to the occurrence of vacant niches, which are then occupied by opportunistic arthropods, some of which may eventually become secondary or primary pests.

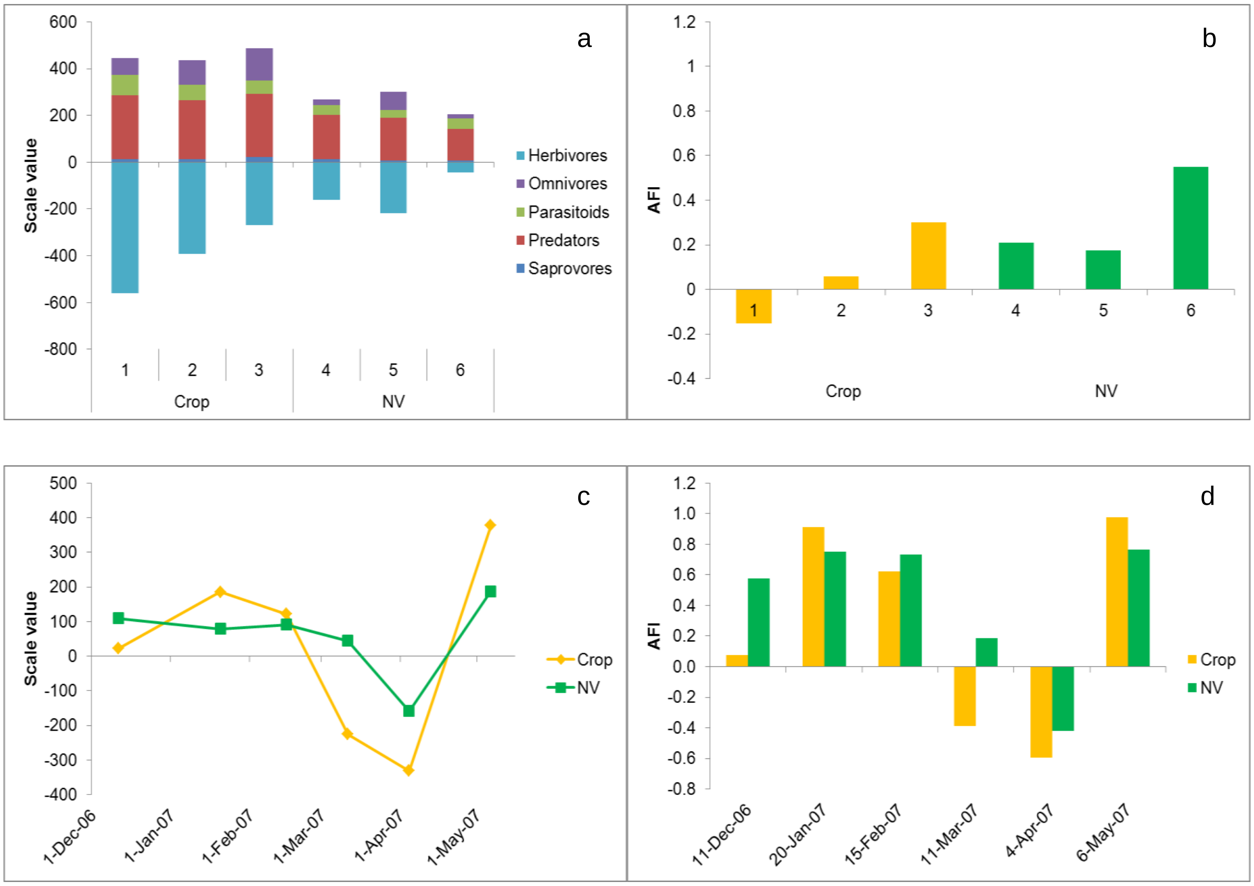

Fig. 6.2. A schematic analysis of lumped orchards at GVN2 for a) trophic scale values for each guild across the transects b) Agroecosystem Function Index (AFI) across the transects c) scale value for natural vegetation (NV) and crop over time and d) Agroecosystem Function Index (AFI) for NV and crop over time (c shows monthly interval timeline on x-axis; d shows actual sampling dates on x-axis).

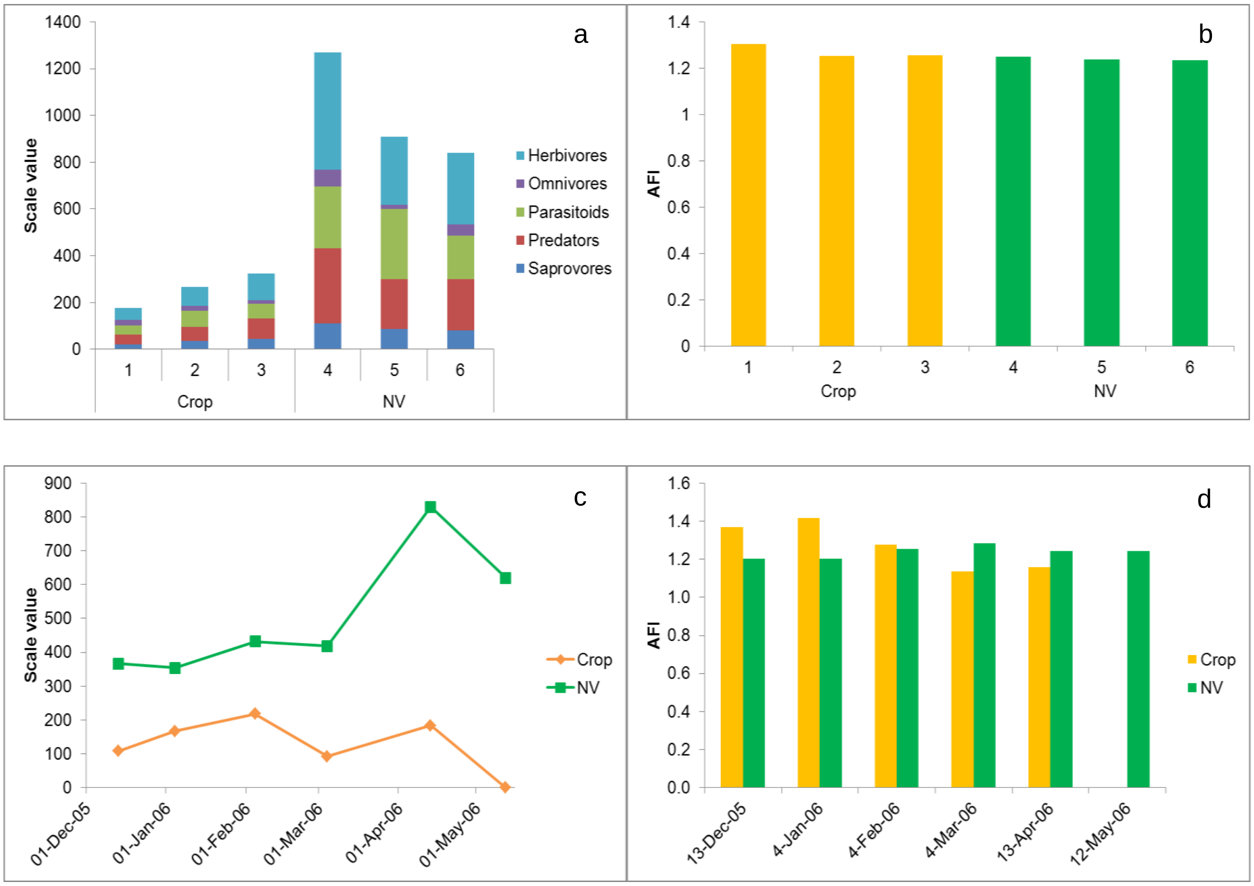

Fig. 6.3. A schematic analysis of lumped orchards at CON1 for a) trophic scale values for each guild across the transects b) Agroecosystem Function Index (AFI) across the transects c) scale value for natural vegetation (NV) and crop over time and d) Agroecosystem Function Index (AFI) for NV and crop over time (c shows monthly interval timeline on x-axis; d shows actual sampling dates on x-axis).

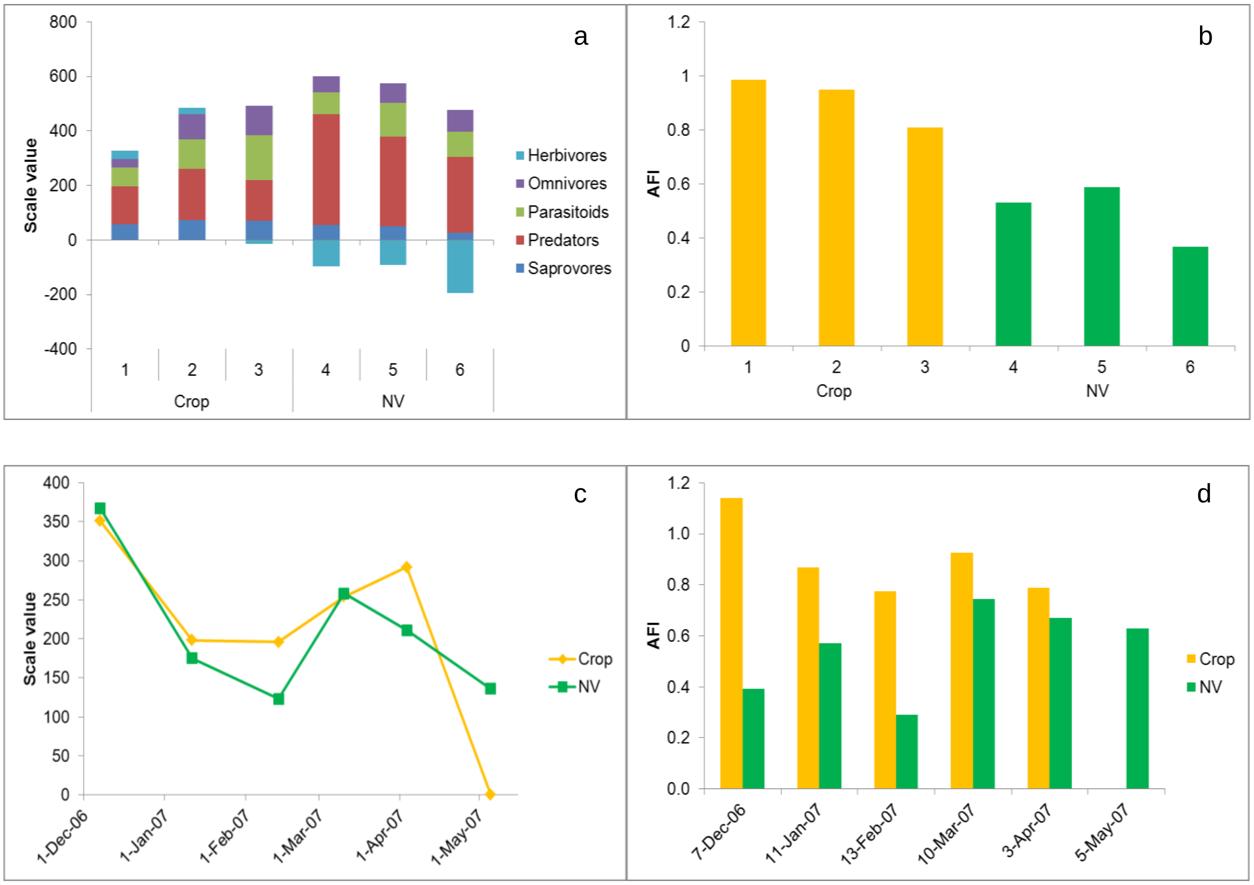

Fig. 6.4. A schematic analysis of lumped orchards at CON2 for a) trophic scale values for each guild across the transects b) Agroecosystem Function Index (AFI) across the transects c) trophic scale value for natural vegetation (NV) and crop over time and d) Agroecosystem Function Index (AFI) for NV and crop over time (c shows monthly interval timeline on x-axis; d shows actual sampling dates on x-axis).

6.3.2 Comparison within each site

At GVN1, the trophic scale value (Fig. 6.1a) is highest on the edge at transect 4 and the natural vegetation values are generally higher than the crop values. It can be seen that predators contribute most to the total values within all transects. This should not be confused with the predator abundance mentioned in Chapter 4 (Fig. 4.7a), when predator abundance and predator scale value are compared, it is evident that the abundance of predators remain approximately a third of the guild composition throughout all transects. Another important point that should be considered when comparing total scale values per transect are the herbivores, which have negative values in transects 2 and 3. These negative values result from secondary or primary pests, which are abundant within these transects.

The AFI implies that additional functional qualities are present within the natural vegetation (Fig. 6.1b), especially the edge (transect 4) and transect 6; however, the AFI value is still positive over all transects, implying that beneficial arthropods are more abundant within the natural vegetation than in the crop. In Fig. 6.1b the AFI is clearly much higher within the natural vegetation than in the crop, although, when comparing this to the abundance in Chapter 4 (Fig. 4.7a) the abundance was observed to be higher within the natural vegetation. The difference between the AFI and the species abundance emphasises the point that the AFI accentuates the actual functional qualities within a specific sample or habitat; this provides evidence that abundance and richness indices on their own are not sufficient for the purposes of importance of biodiversity in agriculture and that more focus should be placed upon indices that reflect functional qualities.

The lumped scale value of all the orchards at GVN1 (Fig. 6.1c) of the crop and the natural vegetation fluctuate synchronously over time, suggesting that the crop and the natural vegetation relate to one another in terms of ecosystem functional qualities (Duelli & Obrist 2003). The reaction of arthropod species towards any activity, whether it be biotic or abiotic, on one side of the landscape (crop or natural vegetation) will consequently also occur on the other side. The scale value provides an additional link between habitats in a functional quality context, whereas the abundance and richness has also been shown in this thesis to have a degree of connectedness between the natural vegetation and the crop. Over time the AFI graph (Fig. 6.1d) follows a trend, similar to that of the scale value, suggesting that the average functional qualities per habitat, whether on the natural vegetation or crop side, are also related to one another. It is only with the final sampling date that the crop AFI is below zero, suggesting that detrimental species are more abundant during this sampling period. When comparing this graph to the absolute abundance graph (Fig. 3.9b) in Chapter 3 there are notable difference towards the end of the season. These differences reveal the importance of the AFI where during the final two sampling periods, a significant decrease in both the crop and natural vegetation is seen on the AFI graph, whilst no change is seen in abundance. In Chapter 3, Fig 3.9b it is especially the herbivores that increase, whilst according to the AFI they are negative values and therefore detrimental to the crop. A slight decrease in the abundance of predators might also contribute to a decrease in the AFI value on both the crop and natural vegetation. Clearly the AFI can thus provide information regarding functional qualities regarding the status of beneficial arthropods.

At GVN2, as previously mentioned, the trophic scale value (Fig. 6.2a) for the beneficial arthropods is highest on the edge, at transect 3, when taking the detrimental herbivores into consideration, the total is lower than perceived. Compared to GVN1 the crop scale values are higher for the predators, parasitoids, omnivores and saprovores than the natural vegetation scale values and predators contribute less to the total values of GVN2 than GVN1 within all transects. The detrimental herbivores, however, have a much lower negative value towards transect 1. These negative values represent detrimental arthropods, such as potential pests and actual pests. When comparing this to the abundance indices in Chapter 4 (Fig. 4.8a) it is evident that the abundance on the crop side is higher relative to the natural vegetation side, although when taking the trophic value into consideration the total for transects in the crop are lower in an AFI context (Fig. 6.2b). The AFI graph assists in determining the total actual functional quality and represents the average scale value per individual captured in a specific sample. The AFI is highest on transect 6, followed by and second highest on the edge (transect 3). This implies that the edge has arthropod species with the highest AFI values and the edge transects may contribute more functional qualities than other transects. The two lowest AFI values, transects 1 and 2, are within the crop, because these transects simply have a greater number of detrimental arthropod species than any other transects within this sample. The lumped scale value of all the orchards at GVN2 (Fig. 6.2c) for both crop and natural vegetation fluctuate synchronously over time, albeit slightly less than GVN1, suggesting that the crop and the natural vegetation still relate to one another in terms of ecosystem functional qualities. Fluctuations at sampling period 3, 4, and 5 are more similar, to the extent that, during sampling period 5, even the scale values on the natural vegetation side fall below zero, thereafter increasing synchronously towards sampling period 6. Once again, as was the case at GVN1, this observation suggests that the average functional qualities present in each habitat, whether on the natural vegetation or crop side, relate to one another. The AFI bar graph in Fig. 6.2d compared to the scale value (Fig 6.2c) follows a trend similar to that of the scale value over time, suggesting that the average functional qualities per habitat, whether on the natural vegetation or crop side, also relate to one another. It is only on the 4th sampling date that the crop and the 5th sampling date, that the crop and natural vegetation AFI is below zero. This once again suggests that the detrimental species are more abundant during these periods. When comparing this graph to the absolute abundance graph (Fig. 3.10b) in Chapter 3 there are notable differences between these sampling periods. During sampling periods 4 and 5, a significant decrease is seen on the AFI graph, within the crop during sampling period 4, and the crop and natural vegetation during sampling period 5, whilst there is an increase in abundance.

Herbivores increase dramatically, and according to the AFI values these herbivores are detrimental. Clearly, these differences reveal the value of the AFI within an agroecosystem. Some combinations of species are complementary in their trends of resource use and can increase rates of productivity and nutrient retention; however, environmental conditions can influence this kind of structuring of communities. The identification of which and how many species act in a complementary manner in complex communities is just beginning to become a more pertinent research endeavour (Hooper *et al*. 2005).

When comparing the scale value at CON1 (Fig. 6.3a) and the abundance graphs in Chapter 4 (Fig. 4.9a) the crop and natural vegetation side are relatively more different to one another in scale values than in abundance values. This suggests that the species present here are mostly beneficial to agriculture. Proportionally the guilds are represented equally on the crop side and the natural vegetation side. As mentioned before, the edges are also prominent on both sides, confirming that the scale value is essential in revealing the component of functional quality within a habitat, or transect. The AFI values (Fig. 6.3b) are relatively similar to each other, while the abundance varies amongst transects in Fig. 4.9a in Chapter 4. Since the guilds are proportionally normal in the abundance graphs and the AFI value is positive at about 1.3, and there is very little difference between the transects of natural vegetation and the crop one is inclined to think that this value could be a standard value for this habitat or even the particular landscape. This is indicative of the limited few agricultural activities at CON. The scale value over time (Fig. 6.3c) shows similar patterns to the GVN sites, with synchronous fluctuation, except for the final sampling date within the crop, which is zero as a result of harvesting. Again, the synchronous trend indicates relatedness of functional qualities of the crop and the natural vegetation side. The AFI values (Fig. 6.3d) are very similar over time and, when compared to the guild abundance over time (Fig. 3.12b) in Chapter 3 have different total abundances but similar proportions in guilds, a similar deduction can be made. The abundance of guilds per transect are in a fixed proportion to one another, whilst the AFI values emphasise the functional quality of the actual proportion of the guilds.

Arthropod species present at CON2 are mostly beneficial to agriculture on the crop side with a few detrimental species on the natural vegetation side. When comparing the scale value (Fig. 6.4a) and the abundance graphs in Chapter 4 (Fig. 4.10a) the crop and natural vegetation side differ relatively more to one another with species abundance when compared to the scale value. This is the exact opposite of what was found during CON1. This suggests it could be due to the negative values of the herbivores within the natural vegetation. The guilds are not proportionally equally represented in both graphs, while at CON1, they were. As mentioned before, the edges are also prominent, confirming that the scale value is essential in revealing the component of functional quality within a habitat, or transect. The AFI value (Fig. 6.4b) is higher on the crop side than the natural vegetation side. When comparing the AFI value to abundance graphs in Chapter 4 (Fig. 4.10a) the exact opposite is seen, *i.e.* the overall abundance value is higher on the natural vegetation side. This stresses the point that no matter what the abundance value, the functional quality shown by the AFI values reveals a more accurate analysis of the diversity. Similar trends are followed by scale value over time (Fig. 6.4c) with synchronous fluctuations. When looking at the side (crop or natural vegetation) that changes first and then the one that follows, it would be possible to deduce which side effects the other. For example, after sample 4 the scale value for natural vegetation decreases, but the crop first increases and only decreases after sample 5. This might only be evident for this habitat specifically due to particular environmental conditions at the time; and reiterates the point that the crop and natural vegetation habitats can influence each other. The AFI value (Fig. 6.4d) at the first sampling date is higher on the crop than the natural vegetation side; however, the opposite applies to the abundance value (Fig. 3.13b), where the natural vegetation species are more abundant than the crop side. Even if the abundance is different to the AFI, the significance of the AFI value is important in functional quality context and in combination with the abundance portrays an improved account of the state of the ecosystem.

6.4 CONCLUSION

With reference to the hypothesis (*viz. Hypothesis* 4: If the AFI is dependent on the economic value of ecosystem services, then an increase in the AFI should be effective in indicating an economic gain as a result of an increase in arthropod species diversity), AFI is dependent on the economic value of species richness, therefore an increase in the AFI should be effective for indicating a functional gain as a result of an increase in arthropod species diversity. However, it is evident that the AFI seems to reveal more of the functional qualities because of its association with functional qualities. Change in the AFI is effective in indicating a functional gain in a habitat as a result of an increase in arthropod species diversity, thus the AFI is dependent on the economic value of species richness. Detrimental and beneficial arthropod species are detectable by means of scale value and AFI, which, for crop agriculture landscapes, is an important differentiating factor. These indices are also effective in detecting changes in edge effect and recognize the edge as an important ecological entity. Abiotic factors also seem to have an influence on the scale value and the AFI. A standard scale value or AFI can be used to set a benchmark for the functional integrity of an agroecosystem. The scale value demonstrates variations in the trophic guild structure and adds functional qualities when identifying a habitat, emphasizing the importance of a specific community that might have low richness. The AFI also provides information regarding the status of beneficial arthropods and as such scale value and the AFI analyses provide additional information, in addition to richness, abundance and evenness analyses. The trophic scale value together with the AFI shows the relatedness between crop and natural vegetation habitats. Furthermore, the AFI may possibly be applied as an effective monitoring system for pests, besides pointing out the functional qualities of an agroecosystem. When compared to bare soil ground cover vegetation results in an increase of plant diversity within orchards, which enhances the abundance of beneficial arthropods in the tree canopy (Silva *et al*. 2010). Besides direct effects on natural enemies, cover crops may have indirect impact on pests, such as over-wintering sites, and crop productivity, such as through the competition for water, soil nitrogen and soil organic matter content (Wright *et al*. 2003). In an overall habitat analysis context, it has been estimated that cover crops (as present at GVN) increased 8 of 11 ecosystem services (Schipanski *et al*. 2014). The actual relevance of using value indices such as those discussed in this chapter, is that a standard benchmark value may be established and used as a guideline to manage certain functional qualities of the crop and surrounding environment productively.

CHAPTER 7

GENERAL DISCUSSION: APPLICATION AND RECOMMENDATIONS OF AGRIBUSINESS INDICATORS

The aim of this thesis is to investigate arthropod biodiversity in the context of ecological function and agroecosystem resilience capability that may be used as indicators for a robust method for the sustainability of ecosystem services on new crops.

These indicators are based on biodiversity and ecosystem functional quality measurement by focusing on diversity indices which are less sensitive to sample size and the proposed Agroecosystem Function Index (AFI).

These indices are then incorporated into an EMS (Environmental Management System) for agriculture. The indices are first discussed. It will be a simple process to relate these indices to EMS, which will be discussed; these indicators would be combined and subsequently integrated into an EMS for agriculture.

7.1 Identification of indicators

Indicators are used to assess the condition of the environment, to identify early-warning signals of ecological problems, and to serve as barometers for trends in ecological resource conditions. Arthropods as indicators make important contributions to ecosystem processes and have absolute economic value as pollinators (Moonen & Barberi 2008), and suppressors of pest species populations (Kogan & Lattin 1993). Arthropods are also used increasingly in conservation evaluation and environmental monitoring and assessment (Kremen *et al*. 1993, Oliver & Beattie 1993).

McGeoch (1998) provides an excellent overview and lists over 30 criteria which determine biodiversity indicators and which is widely supported. The main requirements are cost efficiency, effectiveness, ease of sampling and sorting, correlating with trophic levels and functional groups, presenting a well-defined and measurable distribution over a range of habitats and being able to distinguish between related and unrelated taxa. It is realistically unachievable to combine the main requirements; this is because of the compromise between the simplicity of what is affordably measurable and the inherent complexity of biodiversity (Schmeller 2008). However, it would be of benefit to combine as many requirements as possible without influencing the value of the indicators at the land user's expense. In this regard it would seem easier to comply with the basic requirements of Niemi & McDonald (2004), who state that ecological indicators need clearly defined objectives, temporal and spatial scale recognition, assessment of statistical variability, precision and accuracy, linking with specific stressors and coupling with economic indicators. When using an ecological indicator researchers must always recognize the complexities and limitations of an ecosystem (Dale & Beyeler 2001), and need to be easily communicated. The final choice of indicators should be determined by the questions being asked and the quality of the science supporting the indicator. This information would then be used to identify the environmental aspects associated with an agribusiness and to determine the aspects that have significant impacts. An environmental aspect is defined as a component of a facility's activities, products, or services that can possibly interact with the environment. The effect of these interactions in nature may be continuous, periodic, or associated only with events. An environmental impact is defined as any alteration to the environment, whether adverse or beneficial, resulting from an environmental aspect (Speight & Singh 2014).

This thesis investigates arthropod biodiversity (species richness, abundance and evenness) in the context of ecological function and agroecosystem resilience capability that may be used as indicators of a robust method for sustainability of ecosystem services on new crops to identify diversity. On this basis and according to an overview of biodiversity and functionality by Moonen & Barberi (2008), various applications of biodiversity in agroecosystems have been identified:

1. Improvement of agroecosystem functioning which is based on definition of agroecosystem functional groups.

2. Using bioindicators which allow environmental monitoring of the state and resilience of agroecosystem processes, agroecosystem sustainability and overall biodiversity.

3. Providing indices for the conservation of species, communities and habitats.

Agricultural landscapes have been influenced by production systems targeting the maximizing of crop yield and profitability. However, there are convincing reasons for agriculture to expand the range of ecosystem services it provides to society (Swinton *et al* 2006, Fiedler *et al*. 2008). Increasing arthropod-mediated ecosystem services is one constituent that needs to be taken into consideration to meet this challenge. For example, if biological pest control and pollination services can be properly managed through conservation programs, benefits will include increased farmer profit and diminished dependence on chemical pesticides (referred to as the landscape-ecosystem service hypothesis by Tschartnke *et al*. (2004). As such proper management of region-specific plants can support biological control agents and pollinating bees through the growing season. Furthermore, basing arthropod conservation on the correct combinations of plant species is expected to improve the possibility that such programs achieve their long-term goals of supporting beneficial insects and also increase the services they provide (Isaacs *et al*. 2009).

In order to develop the strength of such a monitoring system for new crops, this study has systematically explored the nature of arthopod biodiversity in two new crops in South Africa. The implications of each phase of the investigation are discussed below.

7.1.1 The link between arthropod diversity in a new crop and bordering natural environmental landscape (cf. Chapter 3)

The aim of Chapter 3 is to determine the relationship of biodiversity indices (species richness + abundance + evenness) between a new crop and the natural environment (which together comprise an agroecosystem landscape. For this indicator sample rarefaction is necessary to determine whether sufficient sampling has been conducted.

Sample rarefaction also contributes information regarding the richness of the samples taken. Sample size becomes important, especially if the full potential of the indicator species, in this case arthropods, needs to be reached.

Detrended correspondence analysis (DECORANA) differentiates between habitats in the context of arthropod abundance. As several studies (*e.g.* Tschartnke *et al*. 2004, Isaacs *et al.* 2009) and Chapter 5 has shown arthropod richness and abundance is correlated with vegetation richness and abundance. DECORANA conveys this kind of information and is especially effective along a gradient.

A guild analysis is essential as an indicator (in combination with analyses such as ecosystem services, richness and abundance & evenness) when analyzing arthropod diversity. Trophic structure probably provides the most vivid analysis of how diversity is influenced, be it by an increase of detrimental species, such as herbivores, or an increase in beneficial organisms, such as parasitoids.

In Chapter 3 it was demonstrated that the Margalef Index positively displayed relatedness between the crop and the corresponding natural vegetation. This suggests that by comparing the richness of these two habitats to each other, one can readily determine the relatedness between them, which in turn suggests that natural vegetation serves as the source for crop sinks and places the patch dynamics principle in perspective in this regard. The arrangement of patches and corridors that constitute a landscape is a major cause of functional flows and movements through the landscape over time (Forman 1995). The local extinction rate decreases with greater habitat quality or patch size for subpopulations on separate patches, and recolonization increases with corridors, stepping stones or short inter-patch distance (equates to less isolation). All ecosystems in a landscape are interconnected, with movement of objects dropping sharply with distance from each other; however, it may be more gradual for species interactions between ecosystems of the same type (Forman 1995).

7.1.2 The spatial and temporal relationship of the edge between crop and natural vegetation (cf. Chapter 4)

The aim of Chapter 4 was to illustrate the effect of the edge between crop and natural vegetation habitats, especially by serving as a transition zone between the two. Meaningful was that cluster analyses showed that the edge transects indeed differed from more distant transects. Edge transects are known to be more diverse (in terms of richness and abundance) than other transects, however, which edge in a specific scenario contains higher diversity more often than not differs amongst sites (Thomas & Marshall 1999), as was also the case between the natural vegetation and the crop in this study. Dendrograms analysis prooved to be a quick and effective manner of lumping related transects and distinguishing between transects.

Trophic guild analysis *per se* appears to be meaningful as an indicator of arthropod diversity in terms of information content. It is important to know what the structural population responses are in terms of the guild component. Firstly, its usefulness can be viewed when it divides complex biological communities into functional units that are not restricted by taxonomic relationships. Secondly, it focusses on sympatric species with niche partitioning or roles which might be expected to have particularly high degrees of interaction or overlap in their ecology and consequently influence the structure of communities they inhabit (Basset *et al*. 2012).

Furthermore, samples were lumped and more focus was given to straightforward diversity comparison over and beween transects. For Green Valley Nuts (GVN) samples were lumped for each individual orchard, however, since the four compass directions in the crop pivot at Constantia (CON) were very similar in terms of diversity, lumping them all was the most appropriate manner of analysis. Richness and evenness of transects were compared by using a combination of diversity indices (*i.e*. Dominance, Buzas & Gibson's Evenness, Margalef's Richness and Fisher's Alpha). By using a combination of indices it becomes more simplistic to recognise differences between habitats or transects along a gradient. Further investigation regarding a specific transect by comparing it to other transects and by implementing other indices, or the proposed

Agroecosystem Function Index (AFI), may assist in the identification of a specific problem.

Buzas & Gibson's evenness and Chao-1 was used to estimate true species richness for each adjacent transect over time by lumping the orchards. Chao-1 may have benefits when sampling only occurred for short periods of time, whilst. Buzas & Gibson's Evenness is the least biased by differences in species richness and sampling efforts (Hayek & Buzas 2010).

By comparing arthropod community composition within various transects it is possible to determine in which manner richness and evenness responds to different habitats. These comparisons revealed various responses for arthropod diversity on the edge transects. Ries & Sisk (2004) suggested mechanisms which form the basis of a predictive model of edge responses that can be used for any species composition in any landscape. This model assists in the evaluation of a resource within a habitat. Negative edge responses can be the result of individuals avoiding edges of low-quality habitat, whilst positive responses result when organisms utilize resources either in richer areas near edges or in adjacent patches (Ries & Sisk 2004). For example, Warner et al. (2000) report that the larvae of brassica pod midge, *Dasineura brassicae* Winnertz (Diptera: Cecidomyidae) had a marked edge distribution within winter oilseed rape. They suggest applying these distribution patterns in terms of their relevance to integrated crop management (ICM) strategies and spatial targeting of insecticides.

Crop cultivations and orchards are in effect fragmented patches of habitat and according to Kruess & Tscharntke (1994) patch size and degree of fragmentation should be considered a potential management option. Ries & Fagan (2003) took this further and mentioned that as fragmentation increases the proportion of edge habitat will also increase. Habitat fragmentation can therefore affect natural enemies more intensely than the availability of their phytophagous hosts and as such fragmentation can reduce not only biodiversity, but also the rate of predation or parasitism. Meaningful in this regard is that the rate of parasitism is directly linked to the success of biocontrol as a management tactic. Further scenarios on this topic are that habitat isolation can be expected to buffer herbivores from predator or parasitoid trophic impact. Subsequently agricultural landscape design that maintains habitat connectivity contributes towards the biocontrol of potential or actual pests.

***7.1.3 The sensitivity of arthropod diversity towards abiotic factors in new crop and surrounding natural vegetation environments* (*cf. Chapter 5*)**

In Chapter 5 it was investigated whether a relationship exists between biotic (vegetation) and abiotic factors (climate, weather and agricultural practices, such as pesticides, fertilizers, patch size, cover crops and surrounding vegetation), and arthropod richness, abundance and evenness. A simple regression analysis revealed that arthropod abundance is correlated to the abundance of vegetation, which confirms that cover crops (as at GVN) increased an estimated 8 of 11 ecosystem services (Schipanski *et al*. 2014). Abiotic factors were recorded at the sites and are presented at the specific times that they occurred. The *Margalef index* was calculated for the crop and the natural vegetation for each orchard and pivot compass direction over time. These were then compared to each other and correlated with the abiotic factors previously mentioned. Functional categorization of agricultural landscapes for supporting predator populations should integrate the spatial and temporal heterogeneity of the landscape and explicitly account for the disturbance regimes. This allows for the identification of relevant landscape features and targeted mitigation strategies to buffer impacts of disturbance and to facilitate recolonization (Schellhorn et al. 2014).

Buzas and Gibson's Evenness was used to calculate this aspect of biodiversity for the crop and the associated natural vegetation per sampling date. After the arthropod taxa were identified to morphospecies, they were broadly grouped according to trophic structure (*i.e.* herbivores, predators, parasitoids, saprivores and omnivores). The variation of both absolute and relative trophic composition was analysed per season for the crop and the natural habitat at Green valley Nuts (GVN) and Constantia (CON) sites. The crop and the natural habitat were then compared with each other over a temporal scale.

There seemed to be an inverse relationship between richness and evenness. In instances where richness increases and evenness decreases it may be a warning that certain species are increasing due to favourable conditons, reflecting the establishment of unwanted herbivores as primary pests. Results suggest that the efficacy of edges for use in possible biological control practises greatly depends on ecological successional age coupled to unkown environmental variables.

In the above context a scenario with high evenness and low richness or low evenness and high richness might be detrimental to the ecosystem. Both these circumstances represent separate situations, with the first scenario representing a situation where low diversity causes a particular species to easily influence the evenness and emanating in an outbreak of the species (Crowder *et al.* 2010).

Throughout Chapters 3, 4 and 5 evenness is suggested as a measurement of potential pests or even of the effectiveness of a management technique used. According to Hillebrand *et al.* (2008) ecological effects of disrupted evenness have received little attention and developing strategies for restoring evenness remains a challenge. In farmlands, agricultural pest-management practices often result in an altered food web structure and communities dominated by a few common species, which together can contribute to pest outbreaks (Matson *et al.* 1997, Tylianakis *et al.* 2007, Hillebrand *et al.* 2008, Macfadyen *et al*. 2009). By measuring the evenness one can ascertain the extent to which certain species have contributed to altered food web structure.

7.1.4 **The effectiveness of an agroecosystem integrity index that uses arthropods as an indicator (*cf. Chapter 6)***

Regarding Chapter 6, it was investigated whether the relationship between the arthropod species richness and abundance, and the proposed AFI (Agroecosystem Function Index), is based upon the economic value of species richness. It is argued that

Arthropod-Mediated Ecosystem Services (AMES) help to maintain agricultural productivity, as advocated by Isaacs *et al*. (2009), who also state that maximizing survival and reproduction of beneficial arthropods, necessitates reduction of pesticide inputs. Overall basic ecosystem services such as pollination, natural pest control, nutrient recycling, seed dispersal and niche displacement (which leads to competition) and niche availability will always be important in agriculture.

Losey & Vaughan (2006) estimated the value of ecosystem services by insects to be \$0.38 billion for nutrient recycling, \$3.07 billion for pollination and \$4.49 billion for natural pest control. Noteworthy in this regard is that Niemi & McDonald (2004) suggest that some sort of intermediate level of taxonomic aggregation may be required which optimizes the trade-off between sensitivity and variability in producing a useful ecological indicator. The suggested trophic scale value, which is similar to that of Simoncini (2009), is appointed to each morphospecies (*i.e.* -2, -1, 0, +1, +2) and from this the Agroecosystem Function Index (AFI) is calculated (as seen in Chapter 6), which is essentially an index of an functional qualities provided by arthropods within an agricultural ecosystem context.

The trophic scale value adds economic value to monitoring arthropods in an ecosystem services context. These scale values will differ between different crop habitats and different natural habitats, just as species associations will also differ. A specific crop and habitat will have a certain calibrated ’benchmark’ or biodiversity value. It is suggested that the benchmark value be that of an agro-ecosystem that exhibits least disturbance or has been subject to moderate agricultural practices. It is furthermore suggested that the AFI is calibrated by sampling the edges of crop fields. Ideally the standard ’benchmark” value has to be maintained as time progresses.

As seen in Chapter 6 the AFI accentuates the difference in species composition between crop habitats and natural habitats. Detrimental and beneficial arthropod species are detectable by means of scale value and the AFI, which, for crop agriculture landscapes, is an important differentiating factor. These indices are also effective in detecting changes in edge effect and recognize the edge as an important ecological entity. The scale value demonstrates variations in the trophic guild structure and adds functional qualities when identifying a habitat, emphasizing the importance of a specific community that might have low richness. The AFI also provides information regarding the status of beneficial arthropods and as such scale value and the AFI analyses provide important additional information, in addition to richness, abundance and evenness analyses. The trophic scale value together with the AFI shows the relatedness between crop and natural vegetation. Furthermore, the AFI may possibly be applied as an effective monitoring tool for pests, besides pointing out the functional qualities of an agroecosystem.

The AFI contributes a different perspective to diversity indices. For example, Table 7.1 represents five hypothetical samples with their richness and abundance. The difference between the samples is highlighted by red cells. These cells represent different dominant species within the total species richness and each of these species have been appointed a different scale value. The abundance of each of these species influences the scale value (which is denoted by the AFI column). It can be seen that Simpson's index and Simpson's index of diversity (the orange cells) remain unchanged, whilst the AFI changes for every sample. The change is dependent on the scale value of the dominant species within each sample. From this one can deduce that diversity indices are not sensitive to functional changes, but that the AFI index can detect changes regarding the functional role of arthropods within an ecosystem.

Table 7.1. A hypothetical example showing the constituents of each sample and highlighting the values of the Simpson's Index and Agroecosystem Function Index.

		Sample 1			Sample 2			Sample 3			Sample 4			Sample 5		
Morphospecies	**Scale**	**n**	**n(n-1)**	**AFI**	**n**	**n(n-1)**	**AFI**	**n**	**n(n-1)**	**AFI**	**n**	**n(n-1)**	**AFI**	**n**	**n(n-1)**	**AFI**
Chrysomelidae sp.5	-1	1	0	-1	1	0	-1	1	0	-1	1	0	-1	1	0	-1
Chrysopidae	2	1	0	2	1	0	2	1	0	2	1	0	2	1	0	2
Cicadellidae	1	1	0	1	1	0	1	10	90	10	1	0	1	1	0	1
Coccinellidae sp.1	2	1	0	2	10	90	20	1	0	2	1	0	2	1	0	2
Coccinellidae sp.2	2	1	0	2	1	0	2	1	0	2	1	0	2	1	0	2
Coreidae	-1	1	0	-1	1	0	-1	1	0	-1	10	90	-10	1	0	-1
Culicidae	0	1	0	0	1	0	0	1	0	0	1	0	0	10	90	0
Curculionidae sp.1	**-2**	**10**	**90**	**-20**	1	0	-2	1	0	-2	1	0	-2	1	0	-2
Drosophilidae sp.1	1	1	0	1	1	0	1	1	0	1	1	0	1	1	0	1
Drosophilidae sp.2	1	1	0	1	1	0	1	1	0	1	1	0	1	1	0	1
Σ	5	19	90	-13	19	90	23	19	90	14	19	90	-4	19	90	5
Simpson's index			0.263			0.263			0.263			0.263			0.263	
Simpson's index of diversity			0.737			0.737			0.737			0.737			0.737	
AFI				-0.68			1.21			0.74			-0.21			0.26
Σ scale/number of species	0.5															

7.2 A hypothetical account of the proposed model

A model is proposed (Figs. 7.1 – 7.4) which could be utilized as an indicator that aids in decision-making of agro-ecosystem management strategies, of which the AFI would be one. The mentioned figures are <u>hypothetical</u> situations where the AFI value (x-axis) and a monetary value (y-axis) are plotted against each other, over time (z-axis). The monetary value above and below the x-axis does not necessarily have to represent a value above or below zero. It may, however, represent a threshold value specifically linked to arthropod ecosystem services. Income and expenses that are directly related to the crop and the management thereof, may be used to determine the comparative monetary value.

Fig. 7.1 shows a hypothetical situation where both the AFI (*e.g.* sample 1 & 4 in Table 7.1) and the monetary value are negative or at a loss. This suggests that there has been a poor yield as a result of species reaching pest status. This might also suggest that a potential pest has crossed an economic threshold and become an actual pest (*e.g.* Curculionidae sp.1 in sample 1 or Coreidae in sample 4)

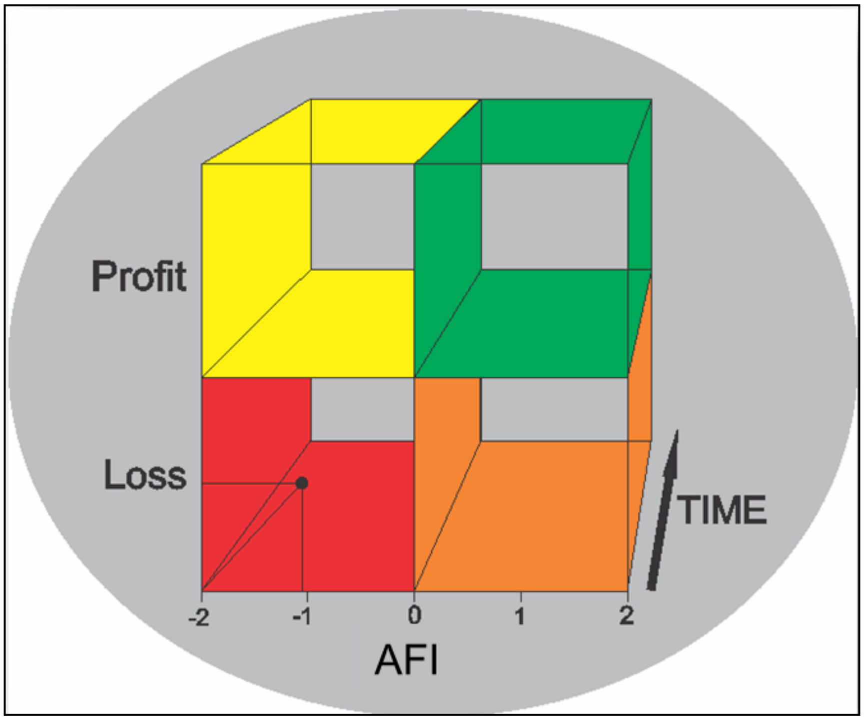

Fig. 7.1. A scenario where the AFI has a negative value and the economy of an agribusiness runs at a loss.

Fig. 7.2 shows a hypothetical scenario where the economic situation is profitable, but the AFI is negative (*e.g.* sample 1 & 4 in Table 7.1). When a landscape is prepared for crop cultivation it becomes a disturbed landscape, where initial species loss is followed by species succession that, over time, will result in biodiversity increase. Ensuing management practices, whether intense or moderate, should eventually determine the general condition of the ecosystem. If, on one hand, intense management practices are followed (*e.g.* broad spectrum pesticide application), this will affect ecosystem integrity drastically, in turn leading to higher risk and eventually economic loss. On the other hand, if management is less intense, there is less risk (*e.g*. a species specific pesticide application) and as a result the effect on the ecosystem is less drastic. This in turn has a lower possibility of influencing the economic outcome.

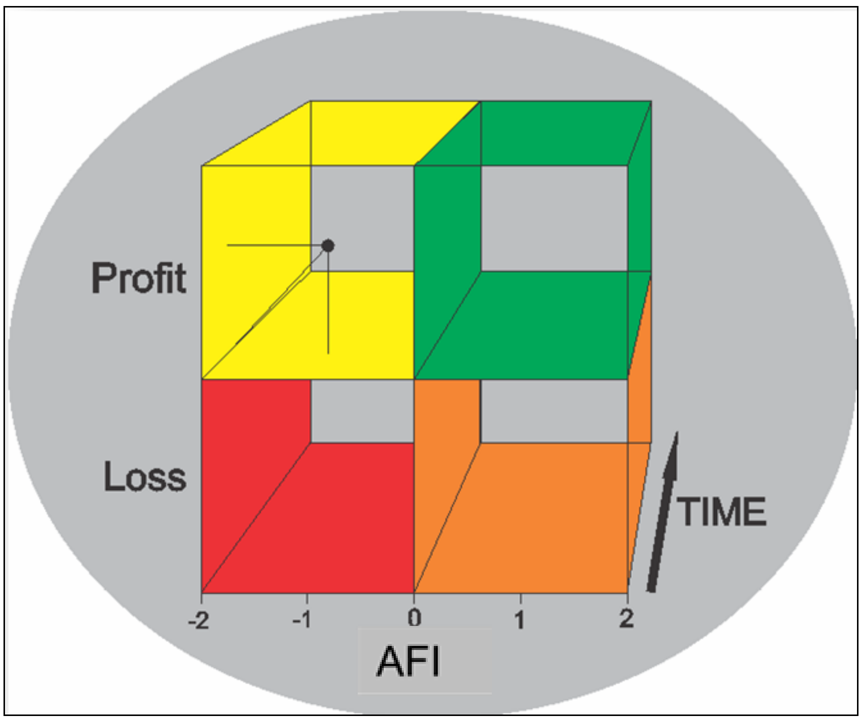

Fig. 7.2. A scenario where the AFI is negative and the economy of an agribusiness shows a profit.

Fig. 7.3 shows a hypothetical scenario where the economic situation is negative, but the AFI is positive (*e.g.* sample 2, 3 & 5 in Table 7.1). This would suggest that the economic situation has been influenced negatively by something other than arthropod diversity. It may even have something to do with crop physiology or an abiotic factor. Another reason for this could be a pest species with a low threshold value which was not detected during sampling and has caused damage which influences the economic situation negatively. Monitoring the signs and symptoms of certain pests might then be an additional viable solution in in addressing the situation.

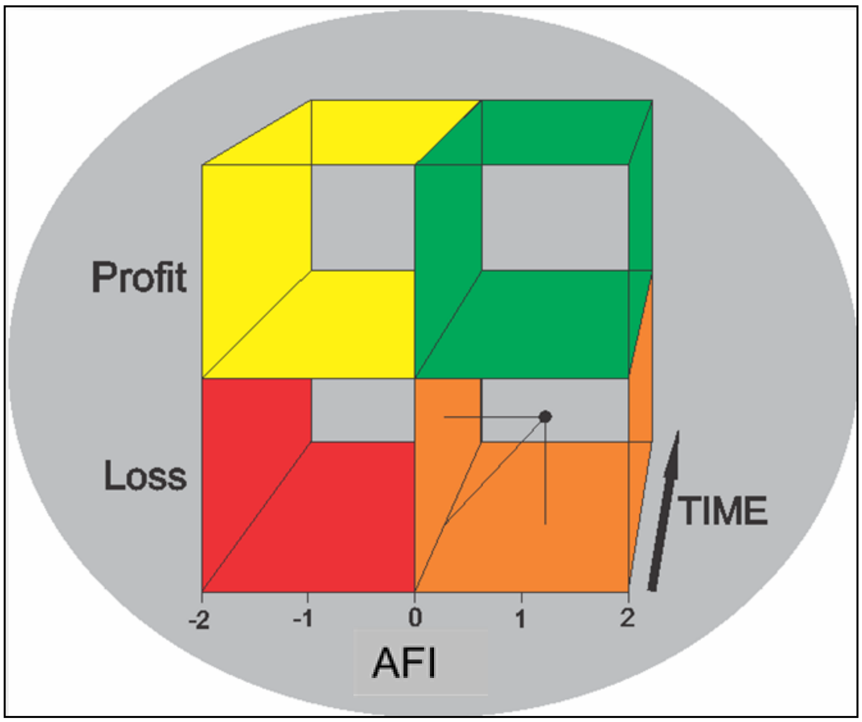

Fig. 7.3. A scenario where the AFI is positive and the economy of an agribusiness is at a loss.

Fig. 7.4 shows a hypothetical scenario where the economic situation is positive and the AFI is positive (*e.g.* sample 2, 3 & 5 in Table 7.1). This would suggest a more sustainable scenario with a positive economic breakdown and a positive AFI value. In this scenario there could be less dependence on agricultural management activities and more dependence on ecological management practices or biological control (for instance the Coccinellidae sp.1 in sample 2), which have more long term advantages and have a lower possibility of affecting crop yield or economic thresholds negatively. It is envisaged that the situation in Fig. 7.4, where profit and AFI are positively correlated, would be the aim of a good farmer, who would base his profitability on securing a positive AFI. This is essentially the strategy that this study hopes to convey.

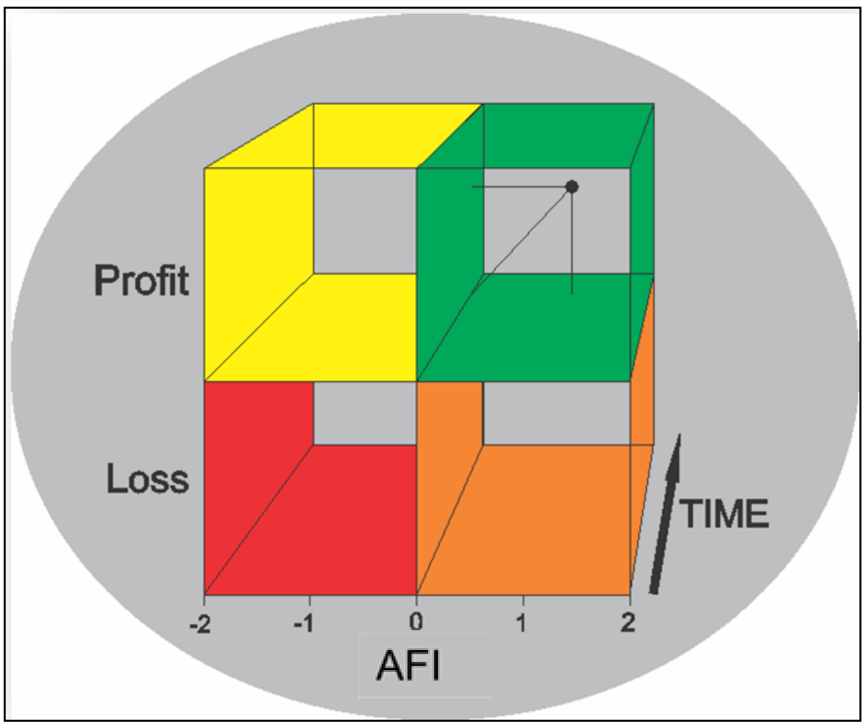

Fig. 7.4. A scenario where the AFI is positive and the economy of an agribusiness shows a profit.

Several agricultural activitities are deemed detrimental to diversity and ecosystem services and these agricultural activities challenge overall agroecosystem management as a sound and reliable practice. Agroecosystem management focussing on increased biological and functional diversity could have the following advantages (Moonen & Barberi 2008):

1. Prevention of invasive species, in natural or semi-natural habitat, or the control of dominant weed species in agroecosystems.
2. Increase of agroecosystem resilience and stability by the presence of temporarily redundant species which gain importance following agroecosystem changes or disturbance.
3. Improved agroecosystem functioning (in terms of processes or magnitude of processes) in species-poor agroecosystems on a short time scale.

7.3 Basics of an Environmental Management System

An Environmental Management System (EMS) is a management tool for improving environmental performance during a defined process of planning, implementation and review (Fig. 7.5); see appendix B for a more complete process and can be used to manage the interaction between an agribusiness and the environment (Carruthers 2007).

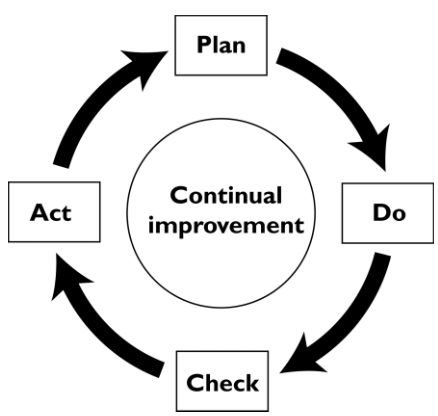

Fig. 7.5. The basic management cycle, which the Environmental Management System would necessarily follow.

EMS aims to improve the overall environmental performance of an agribusiness which should be monitored through measurements, and managed by indicators. Measurements can include cost benefit analysis and economic thresholds. Indicators are variables that summarize or otherwise simplify relevant information about the state of a complex system (Carruthers & Tinning 2003). The correct evaluation of environmental performance arises from the choice of adequate ‘‘raw’’ data and from the relationships among ‘‘raw’’ data sets.

Since this thesis deals with indicators it is important to consider impacts and aspects, which both have to be taken into consideration for assessment, especially when dealing with agricultural management practices. According to Carruthers (2007) the identification of environmental aspects and impacts facilitates the decision on which environmental issues need to be addressed and in what order, consequently saving on costs and improving environmental conditions. Environmental aspects are elements of the activities, products or services of an organisation that can interact with the environment and which can include discharges, emissions, consumption of resources and the re-use of materials. Environmental aspects can be positive or negative.

Environmental impacts are any change to the environment, whether adverse or beneficial, wholly or partially resulting from any organisation’s activities, products or services and as such are the change to the environment that occurs as a result of the aspect. For example, the overuse of a pesticide could lead to a decline in general arthropod diversity and a resurgence of a pest population.

There are certain features that drive an EMS in agriculture. These features include natural resource management, competitiveness and community or industry values (Higgins *et al.* 2008). The needs to comply with legislation and to demonstrate effective natural resource management are important drivers regarding the state of an agricultural landscape. Access to resources, increasing costs of input and endorsement of specific standards (*e*.*g*. Globalgap) all contribute to the competitiveness as a driver (Noonan *et al.* 2010). In turn, certain expectations by the community for environmental stewardship and best management practices contribute towards community and industry values (Carruthers 2007).

The benefits of an EMS applied in an agricultural context are important for promotional purposes and by using an EMS, the management of environmental issues is approached consistently and systematically providing better information for decision-making and assists in better management of resources, leading to a reduction in risk. An EMS provides greater efficiencies and economic advantages which have potential for better access into environmentally conscious markets and improved relations with customers, regulators, employees, neighbours and financial institutions resulting in an improved business and industry image.

7.4 Incorporation of indicators into an Environmental Management System in an agricultural context

As far as indicators for crops are concerned, it is necessary that they are incorporated into a viable system that can lead to improved management of an agricultural landscape. The AFI is based on a comparison of the richness, abundance and evenness of arthropod species between the crop and the natural environment. If possible, the monitoring of arthropods should commence at a stage when the least disturbance is evident, before the onset of any intense agricultural practices and disturbances. Certain criteria need to be considered in the development of the relevant indicators, such as sensitivity towards the pests most likely to cause unacceptable damage to the crop and the likelihood of their occurrence which will be dependent on the suitability of the landscape.

Fig. 7.6 shows where indicators can contribute towards the EMS process and the relationship between the aspects of and the basic management principles of an EMS. For clarification of the flow diagram three <u>hypothetical</u> orchards (A, B and C) will be discussed in a step by step manner.

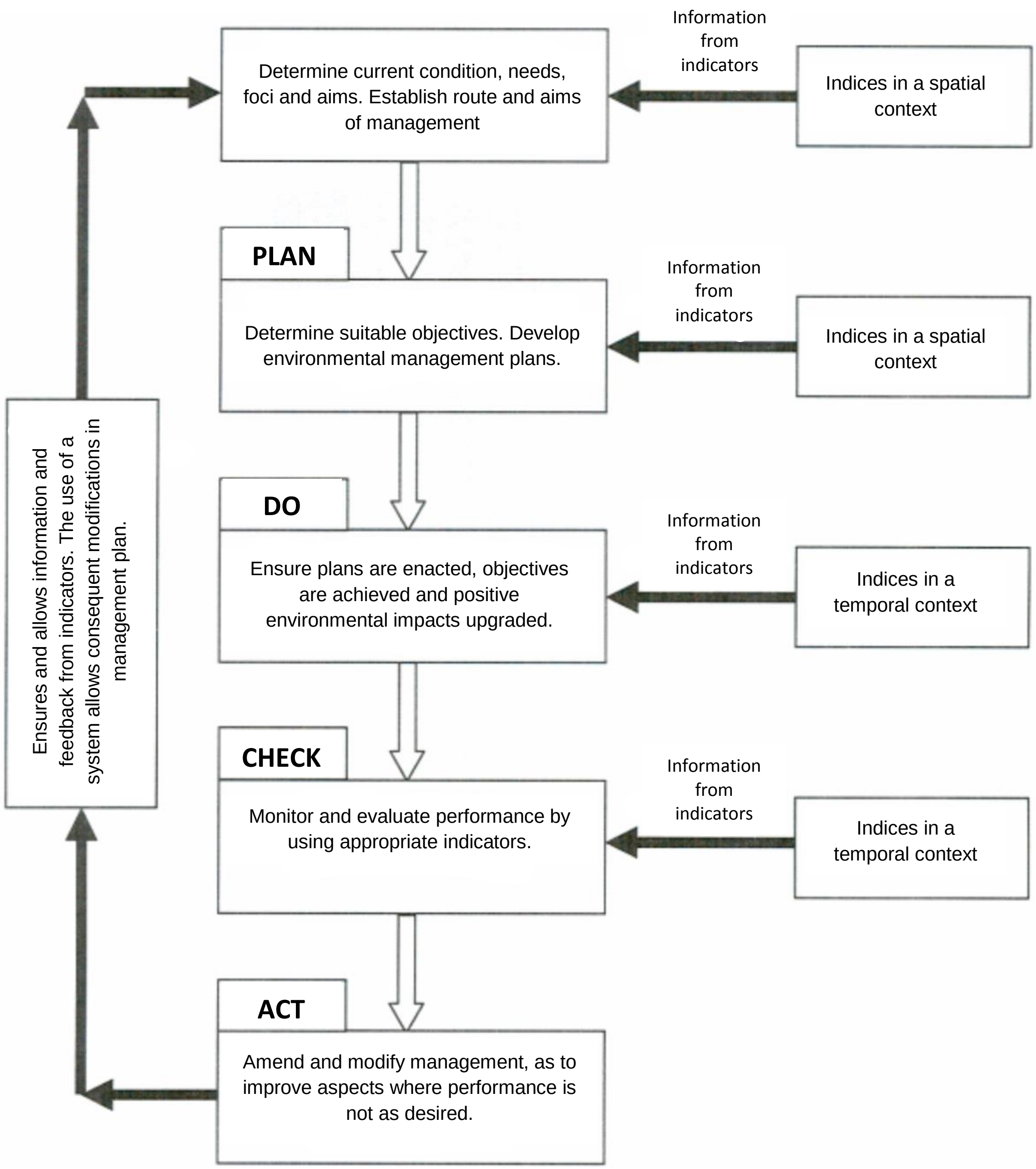

Fig. 7.6. The association between agri-indicators and an Environmental Management System (modified from Carruthers & Tinning 2003).

The first step in the EMS process is, in sequence, to determine the current condition of the agroecosystem, the needs that must to be fulfilled and the specific aims that are set.

A policy must be established taking these management aims into consideration. It is suggested that all indices in this thesis that have been dealt with in a spatial sense would, *per se*, be able to contribute towards this step. The indices would contribute towards this step in the form of a situation analysis and this information would then also be used as a basis for future temporal analyses. A broader range of sampling methods and larger samples would need to be adopted for the arthropod complex in order to establish a valid basis for future samples. An optimal sampling size needs to be determined so that the optimal species richness may be sampled that is necessary for evaluation. Arthropod richness, abundance and evenness should be determined and natural vegetation and crop vegetation (ground cover vegetation), richness and abundance should also be sampled at this stage. Identification of specific beneficial and detrimental pest species will have to be identified. The trophic value scale and AFI standard or 'benchmark' would have to be established at this point, for comparison with future samples.

At this point a low abundance of beneficial species is recorded in orchard A, a high abundance of a detrimental species in orchard B and it is established that orchard C has a low richness. Let's consider the beneficial species to be a parasitoid, the detrimental species, which is a lepidopteran, is a known sporadic pest and the guild analysis indices show that a high proportion of predators are present in orchard C. In orchard A, the low abundance of beneficial species will be detected by a combination of the AFI, which will show a low AFI value when compared to other orchards. Furthermore, the parasitoid species will have a lower abundance and a lower proportion of parasitoids will be present when compared to other orchards. In orchard B, the high abundance lepidopteran species, should be detected by a low evenness value, a low AFI value and a high proportion of herbivores in the trophic guild analysis. In orchard C, as mentioned before, the guild analysis will detect the high proportion of predators, but it will have a low evenness and a suitable diversity index, *e.g.* Margalef Index, will detect the low diversity and the AFI value will be abnormally higher than usual. This type of situation would not last long as the predators will eventually emigrate to an area that will provide more sufficient (sustainable) resources.

The second step is to determine suitable objectives and develop appropriate environmental management plans which respond to the high risk aspects identified in the first step. For example, a suitable objective for orchard A would be to increase population numbers of the parasitoid species which occurs within the crop. This can be accomplished by physically transferring parasitoids from other orchards or applying intercropping (Khan *et al*. 1997). Intercropping would increase niche availability and an increase in species diversity across trophic levels within the crop. For orchard B it would be necessary to decrease the population of the potential pest species by discontinuing both the mowing of ground cover vegetation and herbicide application (Egan *et al*. 2014). For orchard C it would be required to increase the overall species richness by also discontinuing mowing of ground cover vegetation and herbicide application, but also by increasing vegetation diversity within the crop habitat by planting native grasses. In all the previous instances plant diversity contributes to the solution, since previously mentioned insect numbers generally respond to plant diversity, structure and density, as well as the size and spatial arrangement of the habitat (Tscharntke & Brandl 2004).

The third step is to ensure that plans are enacted according to the specific objectives mentioned in step 2. In addition positive environmental impacts must also be upgraded. To achieve these one would need to follow up on the management plans mentioned in step 2, without the use of indicators. However, indicators could be used to monitor progress and in the case of orchards A, B and C one would sample the vegetation planted in step 2 and use the same indices in step 1 to verify that changes have actually taken place.

The fourth step includes monitoring and evaluating the overall performance indices by using the appropriate indicators. During the monitoring process over a season, focus could be placed upon temporal analyses for richness, abundance, evenness and AFI. These results will determine whether further action will be necessary. The final step is to amend and modify management, thereby improving aspects where performance is not as desired.

At the end of this study, it is critical to state that the development of a biomonitoring methodology, or a usable biomonitoring protocol, is a continuous process which will take many years, as will the acceptance of such by agroindustry.

7.4 CONCLUSION

There are various applications of biodiversity in agroecosystems (Moonen & Barberi 2008). Ecological function and agroecosystem resilience capability may be used as indicators for a robust method for sustainability of ecosystem services on new crops. The recommended indicators are based on biodiversity and ecosystem functional quality measurement by focusing on diversity indices which are less sensitive to sample size, and the proposed Agroecosystem Function Index (AFI). Arthropod-mediated ecosystem services is one constituent that needs to be taken into consideration when developing an indicator. Additonally, basing arthropod conservation on the relevant plant species communities is expected to improve the possibility that such programs achieve their long-term goals of supporting beneficial insects and also increasing the services they provide (Isaacs *et al*. 2009). Key ecological processes, such as competition, predation, and succession, can alter proportional diversity through changes in evenness without any change in species richness. However, neither richness nor evenness are reliable independent measures of differences in diversity, compared with the performance of the combined statistic (Beck & Schwanghart 2010).

In combination with one another, species richness, abundance, evenness and the proposed AFI can provide valuable information on a temporal and spatial scale. It is always important to consider what the purpose of an index is. When using indices certain information is lost as a result of calculations to determine the index value. A combination of indices with specific foci should be used based on the research question. Properties of diversity *viz*. richness and evenness should be treated separately (Legendre & Legendre 2012), thereby providing more insight into community function (Maestre *et al.* 2012) that may explain critical assumptions in analyses of diversity change (Orwin *et al*. 2013), At high species numbers a very close positive relationship exists between evenness and abundance. However, guilds with higher species richness do not necessarily have low evenness (Weiher & Keddy 1999). Excluding indices that are used to determine richness, abundance and evenness, the AFI adds value to arthropod morphospecies and their importance within an agroecosystem. The AFI can be used as a monitoring tool to establish whether crop management is sustainable and profitable. An Environmental Management System aims to improve the overall environmental performance of an agribusiness. By using an EMS the management of environmental issues are approached consistently and systematically providing better information for decision-making and assists in better management of resources and leads to a reduction in risk. The indices proposed throughout this study contribute towards the EMS process prior to and during the planning phase in a spatial context, thereafter they contribute on a temporal scale.

CHAPTER 8

CONCLUSIONS

This study is innovative in that it proposes an Index determined by the functional qualities of arthropods and relates a monetary value to these qualities, based on new crop case studies conducted at two contrasting agroecosystem sites, *viz.* Green Valley Nuts and Constantia, in South Africa. In this context the development of a robust methodology that can be used in an Environmental Management System (EMS) is necessary to indicate the degree of disturbance within an agro-ecosystem.

The main objectives were to determine the relationship between arthropod diversity indices (species richness, abundance and evenness) and arthropod assemblages; to determine the relationship between the edge effect reaction of arthropods and the resistance and resilience of an agroecosystem; to determine the relationship between agricultural practices (such as pesticides and fertilizers), surrounding vegetation and arthropod richness and abundance; and to determine the relationship between arthropod species richness and abundance, and the proposed AFI (Agroecosystem Function Index), which is based upon the economic value of ecosystem services.

THE CROP AND NATURAL VEGETATION

- The number of crop associated arthropod species and the number of individuals within the crop fluctuate relative to one another from one season to another.
- The arthropod diversity at the Constantia (CON) site, which has less intensive agricultural practices within the crop, is more synchronised relative to the natural vegetation.

- The arthropod diversity within the crop at the Green Valley Nuts (GVN) site has a variation of trends relative to the natural vegetation. These differences may be attributed especially to the change in resource availability and patch size within the separate habitats.

- It was confirmed that ground cover vegetation within the crop, as seen at GVN, contributes to arthropod diversity.

- Statistically the Margalef Index provides a simple analysis of diversity, while the combination of Chao-1 (being less sensitive to sample size) and Buzas's & Gibson's evenness, reveals more about community structure.

- The use of abundance analysis is inadequate to detect any changes in community structures. Diversity indices have limited application for richness, abundance and evenness, and provide limited information on the value of the species present.

- The arthropod species richness differs between a new crop and the natural environment, thus changes in diversity indices are dependent on the arthropod assemblages within both habitats.

THE EDGE EFFECT BETWEEN THE CROP AND THE NATURAL VEGETATION

- Definite edge responses were observed between crop and natural vegetation transects and these were generally predictable relative to the resources available and the habitat quality.

- Edge transitions between crop and natural vegetation are not similar *per se*, however, they expose similar tendencies in the changes they undergo regarding the arthropod assemblages and communities.

- Arthropod species abundance and evenness are important in the identification of pest species or arthropod species progressing towards pest status. It is evident that two-sided edge effect studies have the potential not only to contribute towards restoration and expansion of endangered ecosystems, but also to serve as a tool in agroecosystem management.

- According to an existing edge effect model, which is confirmed in this study, knowledge of edge effect interactions and availability of restoration resources on both sides of the edge (and at the edge itself) and the nature of the resources (whether complementary or supplementary), enable the prediction of organism response to edges.

- By understanding the causes of transition across the edges and controlling organism abundance at the edge zone, one would be able to speed up restoration and conservation, and manage agroecosystem processes successfully.

- Arthropod richness, abundance and evenness is dependent on the distance from the edge (between crop and natural vegetation), as a result of the spatial context of the different arthropod species assemblages.

BIOTIC AND ABIOTIC IMPACTS ON ARTHROPOD DIVERSITY

- Generally, species richness and abundance of arthropods was observed to be related to species richness and abundance of vegetation, demonstrating that a link exists between vegetation, abiotic factors, and arthropod richness and abundance.

- Any disturbance occurring on or around the crop, potentially has an effect on associated arthropod species richness and abundance.

- The spatial scale at which cues to initiate emigration or immigration of the different trophic guilds under field conditions are detected remain ambiguous and need further study.

- It has been established that evenness can be applied as a measurement of the pest status of arthropod species.

- Evenness also emerges as a measurement of the effectiveness of a specific management technique that is applied. Therefore more precautions need to be taken by farmers to ensure less damage to the natural environment, which, in turn, will have less devastating effects on biodiversity indicators.

- Arthropod richness and abundance are dependent on and are affected by climate and weather conditions, and thus influence the correct choice of agricultural management practices, which in turn improve arthropod species richness, abundance and evenness.

THE PROPOSED AGROECOSYSTEM FUNCTION INDEX MODEL

- The Agroecosystem Function Index (AFI) is effective in indicating a functional gain in a habitat as a result of an increase in arthropod species diversity and is therefore dependent on the economic value of species richness.

- “Detrimental” and “beneficial” arthropod species are detectable by means of a scale value and the AFI, which is an important differentiating factor for crop agriculture landscapes.

- The AFI is effective in detecting edge effect and recognizes the edge as an important ecological entity.

- Abiotic factors also have an influence on the scale value and the AFI.

- Overall a standard scale value or AFI can be used to set a benchmark for the functional integrity of an agroecosystem.
- The scale value demonstrates variations in the trophic guild structure and adds functional qualities when identifying a habitat which emphasizes the importance of a specific community that might have low richness.
- The AFI also provides information regarding the status of “beneficial” arthropods, demonstrating that scale value and AFI analyses provide information in addition to richness, abundance and evenness analyses.
- The scale value, together with the AFI, shows the relatedness between crop and natural vegetation. Furthermore, the AFI may be applied as an effective monitoring system for pests, besides pointing out the functional qualities of an agroecosystem.
- Cover crops lead to an increase of plant diversity within orchards, which enhances the abundance of beneficial arthropods in the tree canopy relative to bare soil.
- Besides direct effects on natural enemies, cover crops may have indirect impacts on pests (such as over-wintering sites that contribute to pest dynamics) and crop productivity (by competing for water, soil nitrogen and soil organic matter content).
- The use of agribusiness value indices can be established by using a standard benchmark value as a guideline to manage certain functional qualities of the crop and surrounding environment productively.
- The AFI is dependent on the economic value of species richness and therefore an increase in the AFI should be effective in indicating a functional gain as a result of an increase in arthropod species diversity.

- Ecological function and agroecosystem resilience capability may be used as indicators for a robust method for sustainability of ecosystem services on new crops.
- The recommended indicators of arthropod functional diversity are based on biodiversity and ecosystem functional quality measurement (by focusing on diversity indices which are less sensitive to sample size), as well as the proposed AFI.
- Arthropod-mediated ecosystem services are a constituent that needs to be taken into consideration when developing an indicator for arthropod functional diversity.
- Basing arthropod conservation for agricultural management on the relevant plant species communities is expected to improve the possibility of achieving long-term goals for supporting beneficial insects and increasing the services they provide.
- Key ecological processes, such as competition, predation and succession can alter proportional diversity through changes in evenness without any change in species richness. However, neither richness nor evenness are reliable independent measures of differences in diversity, compared with the performance of the combined statistic.
- In combination with one another, species richness, abundance, evenness and the proposed AFI can provide valuable information on a temporal and spatial scale necessary for decision-making.
- Cognisance should always be taken of the purpose of a specific index. Preferably a combination of indices with specific foci should be used to answer a management question.
- Properties of diversity, *viz*. richness and evenness, should be treated separately, thereby providing more insight into community function that may explain critical assumptions in analyses of diversity change.

- At high species numbers a very close positive relationship exists between evenness and abundance. However, guilds with higher species richness do not necessarily have low evenness.
- Apart from indices that are used to determine richness, abundance and evenness, the AFI adds value to a list of arthropod morphospecies and their importance within an agroecosystem.
- The AFI can be used as a monitoring tool to establish whether crop management is sustainable and profitable.
- By using an Environmental Management System (EMS) the management of environmental issues are approached consistently and systematically, providing better information for decision-making and resulting in better management of resources, which in turn leads to a reduction in risk.
- The indices proposed throughout this study contribute towards the EMS process prior to and during the planning phase in a spatial context. Thereafter they contribute on a temporal scale.

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APPENDIX A

1. The list of morphospecies for GVN1, denoting the order, morphospecies, guild and scale. The scale is a number which represents certain ecosystem function qualities within an agroecosystem. Scale range is -2, -1, 0, 1, 2 refer to Chapter 6 for explanation.

no.	Order	Morphospecies	Guilds	Scale
1.	**Araneae**	Araneidae sp.1	Predators	2
2.		Tetragnathidae sp.1	Predators	2
3.		Oxyopidae sp.1	Predators	2
4.		Oxyopidae sp.2	Predators	2
5.		Oxyopidae sp.3	Predators	2
6.		Oxyopidae sp.4	Predators	2
7.		Thomisidae sp.1	Predators	2
8.		Salticidae sp.1	Predators	2
9.		Phasmatidae sp.1	Herbivores	1
10.	**Orthoptera**	Acrididae sp.1	Herbivores	1
11.		Acrididae sp.2	Herbivores	1
12.		Acrididae sp.3	Herbivores	1
13.		Acrididae sp.4	Herbivores	1
14.		Acrididae sp.5	Herbivores	1
15.	**Thysanoptera**	Thripidae sp.1	Herbivores	-1
16.	**Hemiptera**	Reduviidae sp.1	Predators	2
17.		Miridae sp.1	Herbivores	1
18.		Miridae sp.2	Herbivores	1
19.		Tingidae sp.1	Herbivores	1
20.		Pentatomidae sp.1	Herbivores	-1
21.		Lygaeidae sp.1	Herbivores	-2
22.		Lygaeidae sp.2	Herbivores	-2
23.		Alydidae sp.1	Herbivores	1
24.		Alydidae sp.2	Herbivores	1
25.		Cercopidae sp.1	Herbivores	1
26.		Cicadellidae sp.1	Herbivores	1
27.		Cicadellidae sp.2	Herbivores	1
28.		Cicadellidae sp.3	Herbivores	1
29.		Cicadellidae sp.4	Herbivores	1
30.		Aphididae sp.1	Herbivores	-1
31.	**Neoptera**	Chrysopidae sp.1	Predators	2
32.		Myrmeleontidae sp.1	Predators	2
33.		Myrmeleontidae sp.2	Predators	2
34.	**Coleoptera**	Cicindelidae sp.1	Predators	2
35.		Scarabaeidae sp.1	Saprovores	1
36.		Scarabaeidae sp.2	Herbivores	1
37.		Elateridae sp.1	Herbivores	1
38.		Bostrichidae sp.1	Parasitoids	-1
39.		Coccinellidae sp.1	Predators	2
40.		Coccinellidae sp.2	Predators	2
41.		Coccinellidae sp.3	Predators	2
42.		Coccinellidae sp.4	Predators	2
43.		Coccinellidae sp.5	Predators	2
44.		Chrysomelidae sp.1	Herbivores	1
45.		Chrysomelidae sp.2	Herbivores	1
46.		Curculionidae sp.1	Herbivores	1
47.		Curculionidae sp.2	Herbivores	1
48.	**Hymenoptera**	Braconidae sp.1	Parasitoids	2
49.		Braconidae sp.2	Herbivores	2
50.		Ichneumonidae sp.1	Parasitoids	2
51.		Ichneumonidae sp.2	Parasitoids	2
52.		Chalcidoidea sp.1	Parasitoids	2
53.		Sphecidae sp.1	Predators	2
54.		Halictidae sp.1	Parasitoids	1
55.		Apidae sp.1	Herbivores	2
56.		Anthophoridae sp.1	Herbivores	2
57.		Tiphiidae sp.1	Parasitoids	2
58.		Pompilidae sp.1	Parasitoids	1
59.		Vespidae sp.1	Parasitoids	2
60.		Formicidae sp.1	Omnivores	2
61.	**Lepidoptera**	Noctuidae sp.1	Herbivores	1
62.		Pyralidae sp.1	Herbivores	1
63.		Lycaenidae sp.1	Herbivores	1
64.		Geometridae sp.1	Herbivores	1
65.	**Diptera**	Ceratopogonidae sp.1	Saprovores	1
66.		Sciaridae sp.1	Herbivores	1
67.		Asilidae sp.1	Herbivores	2
68.		Syrphidae sp.1	Parasitoids	2
69.		Muscidae sp.1	Saprovores	1
70.		Muscidae sp.2	Saprovores	1
71.		Tephritidae sp.1	Herbivores	1
72.		Chloropidae sp.1	Herbivores	1
73.		Drosophilidae sp.1	Saprovores	1

2. The list of morphospecies for GVN2, denoting the order, morphospecies, guild and scale. The scale is a number which represents certain ecosystem function qualities within an agroecosystem. Scale range is -2, -1, 0, 1, 2 refer to Chapter 6 for explanation.

no.	Order	Morphospecies	Guilds	Scale
1.	**Araneae**	Araneidae sp.1	Predators	2
2.		Araneidae sp.2	Predators	2
3.		Tetragnathidae sp.1	Predators	2
4.		Theridiidae sp.1	Predators	2
5.		Theridiidae sp.2	Predators	2
6.		Linyphiidae sp.1	Predators	2
7.		Oxyopidae sp.1	Predators	2
8.		Oxyopidae sp.2	Predators	2
9.		Oxyopidae sp.3	Predators	2
10.		Oxyopidae sp.4	Predators	2
11.		Corinnidae sp.1	Predators	2
12.		Gnaphosidae sp.1	Predators	2
13.		Gnaphosidae sp.2	Predators	2
14.		Gnaphosidae sp.3	Predators	2
15.		Thomisidae sp. 1	Predators	2
16.		Thomisidae sp. 2	Predators	2
17.		Thomisidae sp. 3	Predators	2
18.		Thomisidae sp. 4	Predators	2
19.		Salticidae sp.1	Predators	2
20.		Salticidae sp.2	Predators	2
21.		Salticidae sp.3	Predators	2
22.		Salticidae sp.4	Predators	2
23.	**Odonata**	Coenagrionidae sp.1	Predators	2
24.	**Mantodea**	Mantidae sp.1	Predators	2
25.		Empusidae sp.1	Predators	2
26.		Phasmatidae sp.1	Herbivores	1
27.		Phasmatidae sp.2	Herbivores	1
28.		Phasmatidae sp.3	Herbivores	1
29.	**Orthoptera**	Acrididae sp.1	Herbivores	1
30.		Acrididae sp.2	Herbivores	1
31.		Acrididae sp.3	Herbivores	1
32.		Acrididae sp.4	Herbivores	1
33.		Acrididae sp.5	Herbivores	1
34.		Acrididae sp.6	Herbivores	1
35.		Acrididae sp.7	Herbivores	1
36.		Acrididae sp.8	Herbivores	1
37.		Acrididae sp.9	Herbivores	1
38.		Pamphagidae sp.1	Herbivores	1
39.	**Dermaptera**	Labiduridae sp.1	Predators	2
40.		Labiduridae sp.2	Predators	2
41.	**Thysanoptera**	Thripidae sp.1	Herbivores	1
42.	**Hemiptera**	Reduviidae sp.1	Predators	2
43.		Reduviidae sp.2	Predators	2
44.		Reduviidae sp.3	Predators	2
45.		Reduviidae sp.4	Predators	2
46.		Reduviidae sp.5	Predators	2
47.		Reduviidae sp.6	Predators	2
48.		Reduviidae sp.7	Predators	2
49.		Reduviidae sp.8	Predators	2
50.		Miridae sp.1	Herbivores	1
51.		Miridae sp.2	Herbivores	1
52.		Tingidae sp.1	Herbivores	1
53.		Tingidae sp.2	Herbivores	1
54.		Pentatomidae sp.1	Herbivores	-2
55.		Pentatomidae sp.2	Herbivores	-2
56.		Pentatomidae sp.3	Herbivores	-2
57.		Pentatomidae sp.4	Herbivores	-2
58.		Pentatomidae sp.5	Herbivores	-2
59.		Pentatomidae sp.6	Herbivores	-2
60.		Lygaeidae sp.1	Herbivores	-2
61.		Lygaeidae sp.2	Herbivores	-2
62.		Lygaeidae sp.3	Herbivores	-2
63.		Alydidae sp.1	Herbivores	1
64.		Alydidae sp.2	Herbivores	1
65.		Coreidae sp.1	Herbivores	-1
66.		Cercopidae sp.1	Herbivores	1
67.		Cicadellidae sp.1	Herbivores	1
68.		Cicadellidae sp.2	Herbivores	1
69.		Cicadellidae sp.3	Herbivores	1
70.		Cicadellidae sp.4	Herbivores	1
71.		Cicadellidae sp.5	Herbivores	1
72.		Cicadellidae sp.6	Herbivores	1
73.		Cicadellidae sp.7	Herbivores	1
74.		Aphididae sp.1	Herbivores	-1
75.		Aphididae sp.2	Herbivores	-1
76.	**Neuroptera**	Chrysopidae sp.1	Predators	2
77.		Chrysopidae sp.2	Predators	2
78.		Myrmeleontidae sp.1	Predators	2
79.		Myrmeleontidae sp.2	Predators	2
80.	**Coleoptera**	Carabidae sp.1	Predators	2
81.		Cicindelidae sp.1	Predators	2
82.		Scarabaeidae sp.1	Saprovores	1
83.		Scarabaeidae sp.2	Saprovores	1
84.		Buprestidae sp.1	Herbivores	-1
85.		Buprestidae sp.2	Herbivores	-1
86.		Elateridae sp.1	Herbivores	-1
87.		Elateridae sp.2	Herbivores	-1
88.		Bostrichidae sp.1	Herbivores	-1
89.		Bostrichidae sp.2	Herbivores	-1
90.		Melyridae sp.1	Herbivores	1
91.		Coccinellidae sp.1	Predators	2
92.		Coccinellidae sp.2	Predators	2
93.		Coccinellidae sp.3	Predators	2
94.		Coccinellidae sp.4	Predators	2
95.		Coccinellidae sp.5	Predators	2
96.		Coccinellidae sp.6	Predators	2
97.		Mordellidae sp.1	Herbivores	1
98.		Tenebrionidae sp.1	Herbivores	1
99.		Chrysomelidae sp.1	Herbivores	1
100.		Chrysomelidae sp.2	Herbivores	1
101.		Chrysomelidae sp.3	Herbivores	1
102.		Chrysomelidae sp.4	Herbivores	1
103.		Chrysomelidae sp.5	Herbivores	1
104.		Bruchidae sp.1	Herbivores	1
105.		Bruchidae sp.2	Herbivores	1
106.		Curculionidae sp.1	Herbivores	-1
107.		Curculionidae sp.2	Herbivores	-1
108.		Curculionidae sp.3	Herbivores	-1
109.		Curculionidae sp.4	Herbivores	-1
110.	**Hymenoptera**	Braconidae sp.1	Predators	2
111.		Braconidae sp.2	Predators	2
112.		Ichneumonidae sp.1	Parasitoids	2
113.		Ichneumonidae sp.2	Parasitoids	2
114.		Ichneumonidae sp.3	Parasitoids	2
115.		Ichneumonidae sp.4	Parasitoids	2
116.		Chalcidoidea sp.1	Parasitoids	2
117.		Chalcidoidea sp.2	Parasitoids	2
118.		Chalcidoidea sp.3	Parasitoids	2
119.		Chalcidoidea sp.4	Parasitoids	2
120.		Chalcidoidea sp.5	Parasitoids	2
121.		Chalcidoidea sp.6	Parasitoids	2
122.		Sphecidae sp.1	Predators	2
123.		Sphecidae sp.2	Predators	2
124.		Sphecidae sp.3	Predators	2
125.		Halictidae sp.1	Herbivores	1
126.		Apidae sp.1	Herbivores	2
127.		Anthophoridae sp.1	Herbivores	2
128.		Tiphiidae sp.1	Parasitoids	2
129.		Pompilidae sp.1	Parasitoids	0
130.		Pompilidae sp.2	Parasitoids	0
131.		Pompilidae sp.3	Parasitoids	0
132.		Scoliidae sp.1	Parasitoids	2
133.		Vespidae sp.1	Herbivores	1
134.		Vespidae sp.2	Herbivores	1
135.		Eumenidae sp.1	Herbivores	1
136.		Formicidae sp.1	Omnivores	1

137.		Formicidae sp.2	Omnivores	1
138.		Formicidae sp.3	Omnivores	1
139.		Formicidae sp.4	Omnivores	1
140.		Formicidae sp.5	Omnivores	1
141.		Formicidae sp.6	Omnivores	1
142.		Formicidae sp.7	Omnivores	1
143.		Formicidae sp.8	Omnivores	1
144.	**Lepidoptera**	Lepidoptera Larvae sp.1	Herbivores	-1
145.		Lepidoptera Larvae sp.2	Herbivores	-1
146.		Lepidoptera Larvae sp.3	Herbivores	-1
147.		Lepidoptera Larvae sp.4	Herbivores	-1
148.		Lepidoptera Larvae sp.5	Herbivores	-1
149.		Noctuidae sp.1	Herbivores	-1
150.		Noctuidae sp.2	Herbivores	-1
151.		Pyralidae sp.1	Herbivores	1
152.		Pieridae sp.1	Herbivores	1
153.		Lycaenidae sp.1	Herbivores	1
154.		Geometridae sp.1	Herbivores	1
155.	**Diptera**	Ceratopogonidae sp.1	Predators	2
156.		Sciaridae sp.1	Herbivores	1
157.		Asilidae sp.1	Predators	2
158.		Asilidae sp.2	Predators	2
159.		Asilidae sp.3	Predators	2
160.		Asilidae sp.4	Predators	2
161.		Bombylidae sp.1	Herbivores	1
162.		Bombylidae sp.2	Herbivores	1
163.		Bombylidae sp.3	Herbivores	1
164.		Phoridae sp.1	Parasitoids	2
165.		Syrphidae sp.1	Herbivores	1
166.		Muscidae sp.1	Saprovores	1
167.		Muscidae sp.2	Saprovores	1
168.		Sarcophagidae sp.1	Saprovores	1
169.		Sarcophagidae sp.2	Saprovores	1
170.		Tephritidae sp.1	Herbivores	1
171.		Chloropidae sp. 1	Herbivores	1
172.		Drosophilidae sp.1	Saprovores	1
173.		Drosophilidae sp.2	Saprovores	1

3. The list of morphospecies for CON1, denoting the order, morphospecies, guild and scale. The scale is a number which represents certain ecosystem function qualities within an agroecosystem. Scale range is -2, -1, 0, 1, 2 refer to Chapter 6 for explanation.

no.	Order	Morphospecies	Guilds	Scale
1.	**Araneae**	Tetragnathidae sp.1	Predators	2
2.		Linyphiidae sp.1	Predators	2
3.		Oxyopidae sp.1	Predators	2
4.		Oxyopidae sp.2	Predators	2
5.		Oxyopidae sp.3	Predators	2
6.		Thomisidae sp.1	Predators	2
7.		Thomisidae sp.2	Predators	2
8.		Salticidae sp 1	Predators	2
9.	**Mantodea**	Mantidae sp.1	Predators	2
10.	**Orthoptera**	Acrididae sp.1	Herbivores	1
11.		Acrididae sp.2	Herbivores	1
12.		Acrididae sp.3	Herbivores	1
13.		Acrididae sp.4	Herbivores	1
14.		Pamphagidae sp.1	Herbivores	1
15.		Tetrigidae sp.1	Herbivores	1
16.		Tettigonidae sp.1	Herbivores	1
17.		Tettigonidae sp.2	Herbivores	1
18.	**Dermaptera**	Labiduridae sp.1	Saprovores	1
19.		Labiduridae sp.2	Saprovores	1
20.	**Thysanoptera**	Phlaeothripidae sp.1	Herbivores	1
21.		Thripidae sp.1	Herbivores	1
22.	**Hemiptera**	Reduviidae sp.1	Predators	2
23.		Reduviidae sp.2	Predators	2
24.		Miridae sp.1	Herbivores	1
25.		Miridae sp. 2	Herbivores	1
26.		Tingidae sp.1	Herbivores	1
27.		Pentatomidae sp.1	Herbivores	1
28.		Pentatomidae sp.2	Herbivores	1
29.		Scutelleridae sp.1	Herbivores	1
30.		Scutelleridae sp.2	Herbivores	1
31.		Lygaeidae sp.1	Herbivores	1
32.		Alydidae sp.1	Herbivores	1
33.		Coreidae sp.1	Herbivores	1
34.		Coreidae sp.2	Herbivores	1
35.		Cercopidae sp.1	Herbivores	1
36.		Cercopidae sp.2	Herbivores	1
37.		Cicadellidae sp.1	Herbivores	1
38.		Cicadellidae sp.2	Herbivores	1
39.	**Neuroptera**	Mantispidae sp.1	Parasitoids	2
40.		Chrysopidae sp.1	Predators	2
41.	**Coleoptera**	Scarabaeidae sp.1	Saprovores	1
42.		Scarabaeidae sp.2	Saprovores	1
43.		Lycidae sp.1	Herbivores	1
44.		Melyridae sp.1	Herbivores	1
45.		Coccinellidae sp.1	Predators	2
46.		Coccinellidae sp.2	Predators	2
47.		Coccinellidae sp.3	Predators	2
48.		Tenebrionidae sp.1	Herbivores	1
49.		Chrysomelidae sp.1	Herbivores	-2
50.		Chrysomelidae sp.2	Herbivores	-2
51.		Apionidae sp.1	Herbivores	2
52.		Curculionidae sp.1	Herbivores	1
53.		Curculionidae sp.2	Herbivores	1
54.	**Hymenoptera**	Braconidae sp.1	Parasitoids	2
55.		Braconidae sp.2	Parasitoids	2
56.		Braconidae sp.3	Parasitoids	2
57.		Ichneumonidae sp.1	Parasitoids	2
58.		Ichneumonidae sp.2	Parasitoids	2
59.		Chalcidoidea sp.1	Parasitoids	2
60.		Chalcidoidea sp.2	Parasitoids	2
61.		Chalcidoidea sp.3	Parasitoids	2
62.		Chalcidoidea sp.4	Parasitoids	2
63.		Chalcidoidea sp.5	Parasitoids	2
64.		Chalcidoidea sp.6	Parasitoids	2
65.		Sphecidae sp.1	Predators	2
66.		Halictidae sp.1	Parasitoids	2
67.		Apidae sp.1	Herbivores	2
68.		Anthophoridae sp.1	Herbivores	2
69.		Mutilidae sp.1	Parasitoids	2
70.		Vespidae sp.1	Parasitoids	2
71.		Vespidae sp.2	Parasitoids	2
72.		Vespidae sp.3	Parasitoids	2
73.		Eumenidae sp.1	Parasitoids	2
74.		Eumenidae sp.2	Parasitoids	2
75.		Formicidae sp.1	Omnivores	2
76.		Formicidae sp.2	Omnivores	2
77.		Formicidae sp.3	Omnivores	2
78.	**Lepidoptera**	Noctuidae sp.1	Herbivores	-2
79.		Pieridae sp.1	Herbivores	1
80.		Geometridae sp.1	Herbivores	1
81.		Lasiocampidae sp.1	Herbivores	-2
82.	**Diptera**	Tipulidae sp.1	Herbivores	1
83.		Ceratopogonidae sp.1	Herbivores	1
84.		Ceratopogonidae sp.2	Herbivores	1
85.		Chironomidae sp 2	Saprovores	1
86.		Chironomidae sp.1	Saprovores	1
87.		Culicidae sp.1	Predators	1
88.		Mycetophilidae sp.1	Saprovores	1
89.		Sciaridae sp.1	Saprovores	1
90.		Asilidae sp.1	Predators	2
91.		Bombyliidae sp.1	Herbivores	1
92.		Phoridae sp.1	Saprovores	1
93.		Calliphoridae sp.1	Saprovores	1
94.		Calliphoridae sp.2	Saprovores	1
95.		Muscidae sp.1	Saprovores	1
96.		Tachinidae sp.1	Herbivores	1
97.		Diopsidae sp.1	Herbivores	1
98.		Tephritidae sp.1	Herbivores	1
99.		Tephritidae sp.2	Herbivores	1
100.		Sepsidae sp.1	Saprovores	1
101.		Sepsidae sp.2	Saprovores	1
102.		Chloropidae sp.1	Saprovores	1

4. The list of morphospecies for CON2, denoting the order, morphospecies, guild and scale. The scale is a number which represents certain ecosystem function qualities within an agroecosystem. Scale range is -2, -1, 0, 1, 2 refer to Chapter 6 for explanation.

no.	Order	Morphospecies	Guilds	Scale
1.	**Araneae**	Araneidae sp.1	Predators	2
2.		Araneidae sp.2	Predators	2
3.		Araneidae sp.3	Predators	2
4.		Tetragnathidae sp.1	Predators	2
5.		Theridiidae sp.1	Predators	2
6.		Linyphiidae sp.1	Predators	2
7.		Dictynidae sp.1	Predators	2
8.		Miturgidae sp.1	Predators	2
9.		Oxyopidae sp.1	Predators	2
10.		Oxyopidae sp.2	Predators	2
11.		Oxyopidae sp.3	Predators	2
12.		Lycosidae sp.1	Predators	2
13.		Philodromidae sp. 1	Predators	2
14.		Thomisidae sp. 1	Predators	2
15.		Thomisidae sp. 2	Predators	2
16.		Thomisidae sp. 3	Predators	2
17.		Thomisidae sp. 4	Predators	2
18.		Thomisidae sp. 5	Predators	2
19.		Salticidae sp.1	Predators	2
20.		Salticidae sp.2	Predators	2
21.		Salticidae sp.3	Predators	2
22.		Salticidae sp.4	Predators	2
23.		Salticidae sp.5	Predators	2
24.		Salticidae sp.6	Predators	2
25.		Salticidae sp.7	Predators	2
26.		Salticidae sp.8	Predators	2
27.	**Odonata**	Coenagrionidae sp.1	Predators	2
28.	**Mantodea**	Mantidae sp.1	Predators	2
29.		Mantidae sp.2	Predators	2
30.		Mantidae sp.3	Predators	2
31.	**Phasmatodea**	Phasmatidae sp.1	Herbivores	1
32.	**Orthoptera**	Acrididae sp.1	Herbivores	1
33.		Acrididae sp.2	Herbivores	1
34.		Acrididae sp.3	Herbivores	1
35.		Acrididae sp.4	Herbivores	1
36.		Acrididae sp.5	Herbivores	1
37.		Acrididae sp.6	Herbivores	1
38.		Acrididae sp.7	Herbivores	1
39.		Acrididae sp.8	Herbivores	1
40.		Acrididae sp.9	Herbivores	1
41.		Acrididae sp.10	Herbivores	1
42.		Pamphagidae sp.1	Herbivores	1
43.		Pyrgomorphidae sp.1	Herbivores	1
44.		Tetrigidae sp.1	Herbivores	1
45.		Tettigonidae sp.1	Herbivores	1
46.		Tettigonidae sp.2	Herbivores	1
47.		Gryllidae sp.1	Herbivores	1
48.	**Dermaptera**	Labiduridae sp.1	Predators	2
49.		Labiduridae sp.2	Predators	2
50.	**Thysanoptera**	Phlaeothripidae sp.1	Herbivores	1
51.		Phlaeothripidae sp.2	Herbivores	1
52.		Thripidae sp.1	Herbivores	-1
53.		Thripidae sp.2	Herbivores	-1
54.	**Hemiptera**	Notonectidae sp.1	Predators	0
55.		Notonectidae sp.2	Predators	0
56.		Reduviidae sp.1	Predators	2
57.		Reduviidae sp.2	Predators	2
58.		Reduviidae sp.3	Predators	2
59.		Reduviidae sp.4	Predators	2
60.		Reduviidae sp.5	Predators	2
61.		Reduviidae sp.6	Predators	2
62.		Reduviidae sp.7	Predators	2
63.		Reduviidae sp.8	Predators	2
64.		Reduviidae sp.9	Predators	2
65.		Reduviidae sp.10	Predators	2
66.		Miridae sp.1	Herbivores	1
67.		Miridae sp.2	Herbivores	1
68.		Miridae sp.3	Herbivores	1
69.		Tingidae sp.1	Herbivores	1
70.		Tingidae sp.2	Herbivores	1
71.		Pentatomidae sp.1	Herbivores	1
72.		Pentatomidae sp.2	Herbivores	1
73.		Pentatomidae sp.3	Herbivores	1
74.		Pentatomidae sp.4	Herbivores	1
75.		Pentatomidae sp.5	Herbivores	1
76.		Pentatomidae sp.6	Herbivores	1
77.		Pentatomidae sp.7	Herbivores	1
78.		Scutelleridae sp.1	Herbivores	1
79.		Scutelleridae sp.2	Herbivores	1
80.		Scutelleridae sp.3	Herbivores	1
81.		Scutelleridae sp.4	Herbivores	1
82.		Lygaeidae sp.1	Herbivores	1
83.		Lygaeidae sp.2	Herbivores	1
84.		Lygaeidae sp.3	Herbivores	1
85.		Lygaeidae sp.4	Herbivores	1
86.		Geocoridae sp.1	Predators	2
87.		Alydidae sp.1	Herbivores	1
88.		Alydidae sp.2	Herbivores	1
89.		Coreidae sp.1	Herbivores	-2
90.		Coreidae sp.2	Herbivores	-2
91.		Coreidae sp.3	Herbivores	-2
92.		Coreidae sp.4	Herbivores	-2
93.		Cercopidae sp.1	Herbivores	1
94.		Cercopidae sp.2	Herbivores	1
95.		Cercopidae sp.3	Herbivores	1
96.		Cercopidae sp.4	Herbivores	1
97.		Cercopidae sp.5	Herbivores	1
98.		Cicadellidae sp.1	Herbivores	-1
99.		Cicadellidae sp.2	Herbivores	-1
100.		Cicadellidae sp.3	Herbivores	-1
101.		Cicadellidae sp.4	Herbivores	-1
102.		Cicadellidae sp.5	Herbivores	-1
103.		Cicadellidae sp.6	Herbivores	-1
104.		Cicadellidae sp.7	Herbivores	-1
105.		Aphididae sp.1	Herbivores	-1
106.		Aphididae sp.2	Herbivores	-1
107.		Aphididae sp.3	Herbivores	-1
108.	**Neuroptera**	Mantispidae sp.1	Parasitoids	2
109.		Mantispidae sp.2	Parasitoids	2
110.		Chrysopidae sp.1	Predators	2
111.		Chrysopidae sp.2	Predators	2
112.	**Coleoptera**	Carabidae sp.1	Predators	2
113.		Histeridae sp.1	Predators	2
114.		Scarabaeidae sp.1	Saprovores	1
115.		Scarabaeidae sp.2	Saprovores	1
116.		Lycidae sp.1	Herbivores	1
117.		Lycidae sp.2	Herbivores	1
118.		Cleridae sp.1	Predators	2
119.		Melyridae sp.1	Herbivores	1
120.		Coccinellidae sp.1	Predators	2
121.		Coccinellidae sp.2	Predators	2
122.		Coccinellidae sp.3	Predators	2
123.		Coccinellidae sp.4	Predators	2
124.		Coccinellidae sp.5	Predators	2
125.		Coccinellidae sp.6	Predators	2
126.		Mordellidae sp.1	Herbivores	1
127.		Tenebrionidae sp.1	Herbivores	1
128.		Meloidae sp.1	Herbivores	1
129.		Anthicidae sp.1	Saprovores	1
130.		Anthicidae sp.2	Saprovores	1
131.		Chrysomelidae sp.1	Herbivores	-2
132.		Chrysomelidae sp.2	Herbivores	-2
133.		Chrysomelidae sp.3	Herbivores	-2
134.		Chrysomelidae sp.4	Herbivores	-2
135.		Chrysomelidae sp.5	Herbivores	-2
136.		Chrysomelidae sp.6	Herbivores	-2

137.		Chrysomelidae sp.7	Herbivores	-2
138.		Chrysomelidae sp.8	Herbivores	-2
139.		Chrysomelidae sp.9	Herbivores	-2
140.		Chrysomelidae sp.10	Herbivores	-2
141.		Bruchidae sp.1	Herbivores	1
142.		Apionidae sp.1	Herbivores	1
143.		Curculionidae sp.1	Herbivores	1
144.		Curculionidae sp.2	Herbivores	1
145.		Curculionidae sp.3	Herbivores	1
146.		Curculionidae sp.4	Herbivores	1
147.		Curculionidae sp.5	Herbivores	1
148.		Curculionidae sp.6	Herbivores	1
149.	**Hymenoptera**	Braconidae sp.1	Parasitoids	2
150.		Braconidae sp.2	Parasitoids	2
151.		Ichneumonidae sp.1	Parasitoids	2
152.		Ichneumonidae sp.2	Parasitoids	2
153.		Ichneumonidae sp.3	Parasitoids	2
154.		Ichneumonidae sp.4	Parasitoids	2
155.		Chalcidoidea sp.1	Parasitoids	2
156.		Chalcidoidea sp.2	Parasitoids	2
157.		Chalcidoidea sp.3	Parasitoids	2
158.		Chalcidoidea sp.4	Parasitoids	2
159.		Chalcidoidea sp.5	Parasitoids	2
160.		Chalcidoidea sp.6	Parasitoids	2
161.		Chalcidoidea sp.7	Parasitoids	2
162.		Chalcidoidea sp.8	Parasitoids	2
163.		Chalcidoidea sp.9	Parasitoids	2
164.		Chalcidoidea sp.10	Parasitoids	2
165.		Chalcidoidea sp.11	Parasitoids	2
166.		Chalcidoidea sp.12	Parasitoids	2
167.		Chrysididae sp.1	Parasitoids	2
168.		Sphecidae sp.1	Herbivores	1
169.		Colletidae sp.1	Herbivores	1
170.		Halictidae sp.1	Parasitoids	2
171.		Halictidae sp.2	Parasitoids	2
172.		Apidae sp.1	Herbivores	2
173.		Apidae sp.2	Herbivores	2
174.		Anthophoridae sp.1	Herbivores	2
175.		Mutillidae sp.1	Herbivores	1
176.		Mutillidae sp.2	Herbivores	1
177.		Vespidae sp.1	Herbivores	1
178.		Vespidae sp.2	Herbivores	1
179.		Vespidae sp.3	Herbivores	1
180.		Eumenidae sp.1	Herbivores	1
181.		Eumenidae sp.2	Herbivores	1
182.		Formicidae sp.1	Omnivores	1
183.		Formicidae sp.2	Omnivores	1
184.		Formicidae sp.3	Omnivores	1
185.		Formicidae sp.4	Omnivores	1
186.		Formicidae sp.5	Omnivores	1
187.		Formicidae sp.6	Omnivores	1
188.		Formicidae sp.7	Omnivores	1
189.		Formicidae sp.8	Omnivores	1
190.		Formicidae sp.9	Omnivores	1
191.		Formicidae sp.10	Omnivores	1
192.	**Lepidoptera**	Micropterigidae sp.1	Herbivores	1
193.		Noctuidae sp.1	Herbivores	-1
194.		Noctuidae sp.2	Herbivores	-1
195.		Thyretidae sp.1	Predators	2
196.		Pieridae sp.1	Herbivores	1
197.		Geometridae sp.1	Herbivores	1
198.		Geometridae sp.2	Herbivores	1
199.		Lasiocampidae sp.1	Herbivores	1
200.		Lasiocampidae sp.2	Herbivores	1
201.		Lepidoptera Larvae sp.1	Herbivores	1
202.		Lepidoptera Larvae sp.2	Herbivores	1
203.		Lepidoptera Larvae sp.3	Herbivores	1
204.		Lepidoptera Larvae sp.4	Herbivores	1
205.	**Diptera**	Tipulidae sp.1	Herbivores	1
206.		Ceratopogonidae sp.1	Saprovores	1
207.		Ceratopogonidae sp.2	Saprovores	1
208.		Chironomidae sp.1	Saprovores	1
209.		Chironomidae sp.2	Saprovores	1
210.		Culicidae sp.1	Saprovores	1
211.		Culicidae sp.2	Saprovores	1
212.		Simulidae sp.1	Predators	2
213.		Mycetophilidae sp.1	Herbivores	1
214.		Sciaridae sp.1	Saprovores	1
215.		Sciaridae sp.2	Saprovores	1
216.		Stratiomyiidae sp.1	Saprovores	1
217.		Tabanidae sp.1	Predators	2
218.		Asilidae sp.1	Predators	2
219.		Asilidae sp.2	Predators	2
220.		Asilidae sp.3	Predators	2
221.		Asilidae sp.4	Predators	2
222.		Asilidae sp.5	Predators	2
223.		Bombyliidae sp.1	Parasitoids	2
224.		Bombyliidae sp.2	Parasitoids	2
225.		Bombyliidae sp.3	Parasitoids	2
226.		Bombyliidae sp.4	Parasitoids	2
227.		Bombyliidae sp.5	Parasitoids	2
228.		Bombyliidae sp.6	Parasitoids	2
229.		Phoridae sp.1	Herbivores	1
230.		Pipunculidae sp.1	Herbivores	1
231.		Syrphidae sp.1	Herbivores	1
232.		Syrphidae sp.2	Herbivores	1
233.		Calliphoridae sp.1	Saprovores	1
234.		Calliphoridae sp.2	Saprovores	1
235.		Muscidae sp.1	Saprovores	1
236.		Muscidae sp.2	Saprovores	1
237.		Muscidae sp.3	Saprovores	1
238.		Muscidae sp.4	Saprovores	1
239.		Muscidae sp.5	Saprovores	1
240.		Tachinidae sp.1	Herbivores	1
241.		Tachinidae sp.2	Herbivores	1
242.		Diopsidae sp.1	Saprovores	1
243.		Diopsidae sp.2	Saprovores	1
244.		Tephritidae sp.1	Herbivores	1
245.		Tephritidae sp.2	Herbivores	1
246.		Platystomatidae sp.1	Saprovores	1
247.		Sepsidae sp.1	Saprovores	1
248.		Sepsidae sp.2	Saprovores	1
249.		Chloropidae sp.1	Saprovores	1
250.		Drosophilidae sp.1	Saprovores	1

APPENDIX B

Summary of key Environmental Management System (EMS) components and actions
This summary lists major components of an EMS and summarizes actions associated with EMS.

ENVIRONMENTAL POLICY — Develop a statement of the agribusiness commitment to the environment. Use this policy as a framework for planning and action.

PLANNING

- **Environmental aspects** — Identify environmental attributes of your products, activities and services. Determine those that could have significant impacts on the environment.
- **Legal and other requirements** — Identify and ensure access to relevant laws and regulations, as well as other requirements to which your agribusiness adheres.
- **Objectives and targets** — Establish environmental goals for your agribusiness, in line with your policy, environmental impacts, the views of interested parties and other factors.
- **Environmental management program** — Plan actions necessary to achieve your objectives and targets.

IMPLEMENTATION

- **Structure and responsibility** — Establish roles and responsibilities for environmental management and provide appropriate resources.
- **Training, awareness and competence** — Ensure that your employees are trained and capable of carrying out their environmental responsibilities.
- **Communication** — Establish processes for internal and external communications on environmental management issues.
- **EMS documentation** — Maintain information on your EMS and related documents.
- **Document control** — Ensure effective management of procedures and other system documents.
- **Operational control** — Identify, plan and manage your operations and activities in line with your policy, objectives and targets.
- **Emergency preparedness and response** — Identify potential emergencies and develop procedures for preventing and responding to them.

CHECKING/CORRECTIVE ACTION

- **Monitoring and measurement** — Monitor key activities and track performance. Conduct periodic assessments of compliance with legal requirements.
- **Nonconformance and corrective and preventive action** — Identify and correct problems and prevent their recurrence.
- **Records** — Maintain and manage records of EMS performance.
- **EMS audit** — Periodically verify that your EMS is operating as intended.

MANAGEMENT REVIEW — Periodically review your EMS with an eye to continual improvement.

Source: National Science Foundation 2001. Environmental Management Systems: *An Implementation Guide for Small and Medium-Sized Organizations*. Second Edition.

SUMMARY

Key terms: Agroecosystem indicators; New crops; Arthropods; Vegetation; Biodiversity; Functional diversity; Agribusiness; Agroecosystem Function Index; Biotic and abiotic factors; Environmental Management System.

This study is innovative in that it proposes an Index determined by the functional qualities of arthropods and relates a monetary value to these qualities, based on new crop case studies conducted at two contrasting agroecosystem sites in South Africa. The sustainability of an agribusiness depends on the conservation of its biodiversity. The development of a robust methodology that can be used in an Environmental Management System (EMS) is thus necessary by (i) implementing measures of arthropod and general vegetation biodiversity and (ii) incorporating a monetary value to functional diversity, as mechanisms to indicate the degree of disturbance within the agro-ecosystem.

The main objectives were to determine the relationship between arthropod diversity indices (species richness, abundance and evenness) and arthropod assemblages; to determine the relationship between the edge effect reaction of arthropods and the resistance and resilience of an agroecosystem; to determine the relationship between agricultural practices (such as pesticides and fertilizers), surrounding vegetation and arthropod richness and abundance; and to determine the relationship between arthropod species richness and abundance, and the proposed AFI (Agroecosystem Function Index), which is based upon the economic value of ecosystem services. Case studies were conducted to pinpoint potential indices of an ecological nature, with specific reference to the diversity indices of arthropods, as part of the methodology. Arthropods were used as an indicator community since they are prevalent, have high species diversity, are easy to sample, are important in ecosystem function, provide early detection of ecological changes and respond to environmental changes faster than vertebrates. The influence of agricultural management practices on this diversity is also taken into consideration. Quantitative and qualitative analysis revealed distinct patterns within the biodiversity at all the locations, relative to the frequency and diversity of

vegetation sampled. Thus aspects of ecology (edge-effect, guild structure and functional diversity) should indicate a relationship between communities, which in turn would indicate the level of ecosystem integrity.

The level of ecological integrity could be taken into consideration when adopting a quality Environmental Management System (EMS). Possibilities of incorporating a monetary value model, such as the Agroecosystem Function Index (AFI), to biodiversity analysis, that in turn has a bearing on ecosystem services and agribusiness, is also addressed. An EMS bio-indicator protocol is important as an aid to reduce the impact of agricultural management practices on the agro-ecosystem and to increase its functional efficiency.

OPSOMMING

Sleutelterme: Agroekostelsel aanwysers; Nuwe gewasse; Geleedpotiges; Plantegroei; Biodiversiteit; Funksionele diversiteit; Agribesigheid; Agroekostelsel Funksionering Indeks; Biotiese en abiotiese faktore; Omgewing Bestuurstelsel.

Hierdie studie is innoverend deurdat dit ‘n indeks daar stel wat deur die funksionele eienskappe van geleedpotiges bepaal word en ‘n geldwaarde daaraan koppel. Dit is op nuwe gewas gevallestudies wat by twee kontrasterende agroekostelsel studieareas in Suid Afrika uitgevoer is, gebasseer. Die volhoubaarheid van ‘n agribesigheid, hang van die bewaring van die biodiversiteit af. Die ontwikkeling van ‘n robuuste metode wat in ‘n Omgewing Bestuurstelsel gebruik kan word, vereis dat (i) maatstawwe van geleedpotige en algemene plantegroei biodiversiteit geïmplementeer word en dat (ii) ‘n geldwaarde vir funksionele diversiteit geïnkorporeer word, om as meganismes wat die vlak van versteuring binne die ekostelsel aandui, te dien.

Die vernaamste doelwitte was om die verhouding tussen geleedpotige diversiteitsindekse (spesiesrykheid, volopheid en gelykheid) en geleedpotige samestelling te bepaal; die verhouding tussen die randeffek reaksie van geleedpotiges en die weerstand en veerkragtigheid van ‘n agroekostelsel te bepaal; die verhouding tussen landboupraktyke (soos plaagdoders en kunsmis), omliggende plantegroei en geleedpotige spesiesrykheid en volopheid te bepaal; en die verhouding tussen die geleedpotige spesiesrykheid en oorvloed, en die voorgestelde Agroekostelsel Funksionering Indeks, wat op die ekonomiese waarde van die ekostelsel dienste gebasseer is, te bepaal. Gevallestudies is uitgevoer om potensiële indekse van ‘n ekologiese aard vas te stel, met spesifieke verwysing na diversiteitsindekse van geleedpotiges, as deel van die metode. Geleedpotiges is as ‘n aanwyser-gemeenskap gebruik aangesien hulle volop voorkom, ‘n hoë spesies-diversiteit het, maklik is om te versamel, belangrik is in ekostelsel funksionering, geleenthede vir vroeë opsporing van ekologiese veranderinge bied en vinniger as gewerweldes op veranderinge in die omgewing reageer. Die invloed van landbou-praktyke op hierdie diversiteit word ook in

ag geneem. Kwantitatiewe en kwalitatiewe analise het duidelike patrone in die biodiversiteit uitgewys en word, relatief tot die frekwensie en verskeidenheid van plantegroei-diversiteit wat ingesamel is, by die verskillende studiepunte waargeneem. Dus behoort aspekte van ekologie (randeffek, gildestruktuur en funksionele diversiteit) ‘n verhouding tussen gemeenskappe aan te dui, wat om die beurt die vlak van ekostelsel-integriteit aandui.

Die vlak van ekologiese integriteit kan in ag geneem word wanneer ‘n kwaliteit Omgewing Bestuurstelsel aangeneem word. Moontlikhede om ‘n geldwaarde model, soos die Agroekostelsel Funksionering Indeks, vir biodiversiteit daar te stel, wat op sy beurt ‘n invloed op ekostelsel- dienste en agrobesigheid het, word ook aangespreek. ‘n Omgewing Bestuurstelsel bio-aanwyser protokol is belangrik as ‘n hulpmiddel om die impak van landbou-praktyke op die ekostelsel te verminder en die funksionele doeltreffendheid daarvan te verhoog.