UNIVERSITAT DE BARCELONA

# La Diversitat d’Artròpodes als Agro-Ecosistemes: Efectes del Paisatge, la Gestió Agronòmica, i la Composició de la Flora Arvense

## Arthropod Diversity in Agro-Ecosystems: The Effects of Landscape, Management and Assembly of Weed Communities

Berta Caballero López

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Memòria presentada per la Berta Caballero i López, per optar al grau de doctora per la Universitat de Barcelona

**Berta Caballero López**

Vist-i-plau dels directors de la tesi

| | |
|---|---|
| Dr. Xavier Sans i Serra | Dr. Juli Pujade i Villar |
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| Facultat de Biologia | Facultat de Biologia |
| Universitat de Barcelona | Universitat de Barcelona |

*A la mare, al pare i en Roger*

## Índex / Contents Pàgines / Pages

# Agraïments / Acknowledgements / Tack

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# CAPÍTOL 1.
# INTRODUCCIÓ

# 1. Introducció

La intensificació de les pràctiques agrícoles ha implicat importants canvis en la gestió i l'estructura dels agro-ecosistemes (Tilman et al., 2001). Aquesta intensificació s'ha fet palesa en els sistemes herbacis de secà mediterranis, a escala local, per la simplificació de les rotacions i l'augment en l'ús d'agroquímics (Benton et al., 2003; Sotherton, 1998; Stoate et al., 2001). A escala regional, ha suposat la simplificació dels paisatges agrícoles, amb la desaparició de nombrosos hàbitats naturals i l'empobriment de la vegetació dels marges. Aquest procés ha comportat que els paisatges constituïts per un mosaic d'elements relacionats per una sèrie de fluxos (materials, energia, organismes, etc.), com són els conreus i els hàbitats associats, hagin estat substituïts per uns espais homogenis dominats pels monocultius on les taques de vegetació natural han passat a ser escasses i fragmentades (Benton et al., 2003; Robinson & Sutherland, 2002).

Durant els primers 35 anys d'aquesta intensificació agrícola la producció mundial de gra es va doblar, però aquest procés va implicar simultàniament importants costos mediambientals (Krebs et al., 1999; Tilman et al., 2001) com la pèrdua de diversitat (Gliessman, 2000). En aquest context, el 1993 es va signar el Conveni sobre la Biodiversitat, d'àmbit internacional, per tal de promoure estratègies de conservació, i així, intentar contrarestar, entre altres, els efectes adversos de la intensificació agrícola. En el marc europeu, aquest conveni va impulsar una sèrie de mesures agroambientals basades en incentius econòmics, i adreçades als agricultors per tal d'introduir pràctiques agrícoles més sostenibles (http://www.cbd.int/convention). La transformació a la producció agrària ecològica, que fou una d'aquestes mesures agroambientals proposades, ha tingut un important ressò mediàtic a causa de les seves implicacions en la seguretat alimentària. Els productes ecològics es cultiven sense emprar agroquímics de síntesi (Lampkin, 2002), i en general provenen d'uns sistemes agrícoles més diversificats. La pressió social per aconseguir aliments saludables ha implicat un augment de la superfície dedicada a la producció ecològica, que ja supera el 4% de la terra agrícola europea (Eurostat, 2008), de la qual els conreus herbacis anuals i les pastures en representen una part important. Els conreus de cereals constitueixen un dels sistemes agrícoles més intensificats en relació a la intensa llaurada, i l'ús extensiu de fertilitzants i de pesticides. Aquesta excessiva pressió ambiental comporta, en molts casos, la dràstica transformació del paisatge, l'empobriment del sòls i l'acceleració de processos irreversibles d'erosió (Lacasta & Meco, 2002).

Durant la darrera dècada s’han dut a terme nombrosos estudis comparatius entre sistemes cerealistes ecològics i convencionals per tal d’aprofundir en els processos i mecanismes responsables de la pèrdua de biodiversitat en els agrosistemes. De manera general, es considera que la gestió ecològica dels sistemes agrícoles afavoreix l’abundància i la diversitat, tan de la flora com de la fauna, tot i que també s’han destacat resultats divergents respecte aquesta tendència (Bengtsson et al., 2005; Hole et al., 2005). La diversitat de flora arvense i de pol·linitzadors tals com abellots i papallones es troba afavorida per una gestió ecològica dels camps de cereals per la rotació de cultius i l’absència en l’ús de pesticides i fertilitzants químics (Bengtsson et al., 2005; Fuller et al., 2005). Per contrapartida, la resposta d’altres grups taxonòmics és neutra o fins hi tot negativa (Purtauf et al., 2005; Shah et al., 2003; Weibull & Östman, 2003). Aquesta manca d’una uniformitat en la resposta dels diferents taxa davant de la gestió ecològica sovint s’ha justificat en relació a limitacions metodològiques com l’escàs nombre de rèpliques, la diversitat de respostes dels taxons, i a les diferències en les escales de treball, ja que sovint no s’ha tingut en compte l’efecte de la complexitat del paisatge que envolta els camps estudiats (Bengtsson et al., 2005; Hole et al., 2005). El fet però que estudis que consideren escales de treball equivalents i comparen la diversitat dels mateixos grups d’artròpodes entre sistemes ecològics i convencionals (Feber et al., 2007; Weibull & Östman, 2003) també mostrin resultats variables fa pensar que altres factors poden actuar.

La variabilitat de les practiques agrícoles dins de cadascun dels tipus de gestions comparades és un factor important que caldria tenir en consideració, doncs el nombre mitjà d’aplicacions de pesticides per any als camps convencionals és molt més alt a Alemanya i al Regne Unit que a altres països europeus (fig. 1). En aquest context, els resultats de la comparació entre la gestió ecològica i la convencional en un ambient molt intensificat no tenen perquè poder ser extrapolades a un context on els

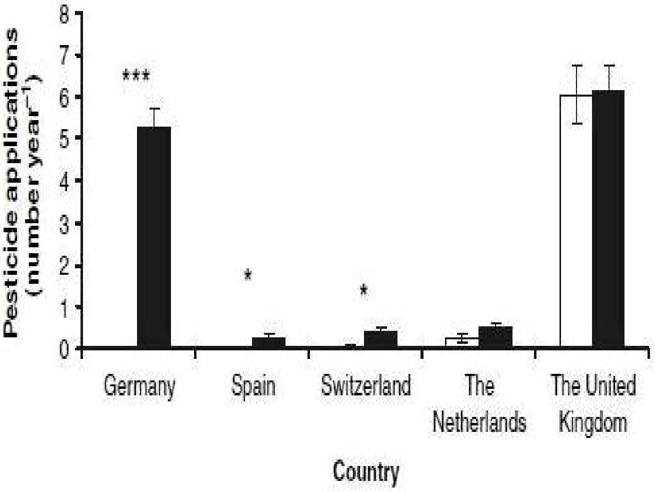

**Fig. 1** Nombre d’aplicacions de pesticides en camps que s’acullen a mesures agro-ambientals (barres blanques) i sense aquestes mesures (barres negres) a cinc països europeus. Les dades mostrades son mitjanes ± ES; $*P < 0.05$; $***P < 0.001$.
Original de Kleijn et al. (2006).

agricultors convencionals emprin els agroquímics amb precaució. Així, en el marc agrícola espanyol, on les produccions de cereal són baixes [European Commission (Eurostat, 2008)] a causa de la escassa pluviometria, els agricultors intenten rebaixar els costos de producció mitjançant la reducció d'agroquímics. Per això l'ús d'herbicides és freqüent en la gestió convencional, mentre que els fungicides i insecticides són rarament emprats. L'ús d'insecticides en els camps convencionals és una de les principals causes de les dràstiques diferències en la comunitat d'artròpodes entre els conreus de cereal ecològics i convencionals (Feber et al., 2007; Wickramasinghe et al., 2004). En conseqüència, en un context lliure d'insecticides seria d'esperar que les diferències entre ambdós tipus de gestions fossin escasses.

Per altra banda, les característiques de les finques agrícoles també poden afectar els resultats de les comparacions. Així, les parcel·les de la major part de finques agrícoles de Catalunya es troben distribuïdes pel territori de manera discreta, mentre que a bona part d'Europa les parcel·les d'un mateix propietari es troben totes agrupades (Fuller et al., 2005). Aquest fet implica que molts camps ecològics en el context agrari català es trobin immersos en paisatges agrícoles gestionats de manera convencional.

## *1.1 L'escala d'estudi*

Els estudis que aborden l'efecte de la intensificació agrícola sobre l'abundància i diversitat de l'artropodofauna, que s'han dut a terme generalment a escala de camp o finca, han fet palès que les pràctiques agrícoles intensives comporten la reducció de la diversitat d'espècies i l'alteració de les relacions entre espècies. Els darrers anys però, els investigadors, a més, han incorporat l'escala de paisatge als estudis amb l'objectiu de valorar la importància relativa de l'ús del sòl dels conreus propers i dels hàbitats associats. Alguns d'aquests treballs destaquen que la abundància d'espècies dins els hàbitats agrícoles sovint depèn més de l'estructura del paisatge que envolta els camps estudiats que del tipus de gestió implementada en els mateixos (Holzschuh et al., 2007; Purtauf et al., 2005; Schmidt et al., 2005). Altres autors han destacat que també existeix una interacció entre ambdós factors, doncs les poblacions de papallones i abellots que depenen de la gestió i de l'estructura del paisatge només es veuen afavorides a les parcel·les amb gestió ecològica en paisatges simples (Rundlöf et al., 2008).

La comprensió dels factors que afecten la biodiversitat dels agrosistemes requereix una aproximació multi-escala (Clough et al., 2005). La consideració dels factors locals, indicadors de la qualitat d'hàbitat, i dels factors més globals, com l'estructura i composició del paisatge, és essencial per entendre els patrons espacials i temporals d'abundància i diversitat dels organismes que colonitzen els conreus. La gran complexitat de l'anàlisi multi-escala requereix disposar d'un bon coneixement de la biodiversitat dels indrets d'estudi i de nombrosos recursos econòmics i humans. L'escàs coneixement de l'artropodofauna dels agrosistemes herbacis extensius de secà del NE de la península Ibèrica ha comportat que aquesta tesi hagi plantejat diversos estudis a escala de camp (capítols 4.1- 4.4). D'altra banda, els estudis previs sobre les poblacions d'àfids i els seus depredadors (Bommarco, 1999; Ekbom & Wiktelius, 1985; Östman et al., 2001) a diferents escales d'estudi a la regió de Skåne (Suècia) han permès poder dur a terme un treball a escala de paisatge (capítol 4.5).

## *1.2 Els grups estudiats i l'aproximació adoptada*

Els artròpodes han representat el grup diana de tots els estudis inclosos en aquesta tesi. El fet d'escollir-los com a grup indicador de l'efecte de la intensificació a escala de camp i de paisatge es recolza en una sèrie de raons: (i) els artròpodes són fàcils de capturar, i per tant, son adequats per a fer un monitoratge temporal, (ii) presenten curts períodes inter-generacionals, el que fa que responguin ràpidament als canvis ambientals (Holland et al., 2005; Kremen et al., 1993) i (iii) dins dels artròpodes trobem representants d'un ampli ventall d'estratègies vitals i papers funcionals (Kremen et al., 1993; Maleque et al., 2006).

Clàssicament els estudis entomològics s'han dut a terme des d'una perspectiva taxonòmica, on el nombre de grups emprats com a indicadors era reduït i els espècimens eren identificats fins el nivell específic. Recentment però s'ha posat en dubte la utilitat d'estudis centrats en un únic grup tròfic (Hartley & Jones, 2003) o en un nombre escàs de famílies (Brose, 2003; Melnychuk et al., 2003) a causa de la dificultat de generalitzar les prediccions de com respon l'artropodofauna a la gestió agronòmica a partir d'un reduït nombre de taxons (Voigt et al., 2007). Una aproximació alternativa és l'ús de nombrosos taxons com a indicadors, identificats a nivells taxonòmics alts com ara família, superfamília o ordre. Aquesta perspectiva, que ha estat proposada per diversos treballs (Biaggini et al., 2007; Hughes et al., 2000; Ruano et al., 2004; Wickramasinghe et al., 2004), és idònia quan el ventall de grups capturats és ampli, i el coneixement a nivell específic de molts d’aquests grups és limitat. En aquesta tesi però, hem combinat ambdues perspectives per tal d’aprofitar els avantatges de cadascuna d’elles. Els capítols 4.1 i 4.2 es basen en l’estudi d’un ampli nombre de grups d’artròpodes identificats fins a nivell de família o superfamília, mentre que els capítols 4.3, 4.4 i 4.5 són treballs que es centren en grups concrets com els àfids i els seus parasitoids (capítol 4.3), els insectes fitòfags (capítol 4.4), i els àfids i els seus enemics naturals (capítol 4.5). En aquests casos, la identificació a nivell d’espècie era imprescindible per entendre millor les interaccions entre els diferents taxons.

Per últim, en aquesta tesi també hem analitzat la comunitat d’artròpodes des d’una perspectiva funcional. El gran nombre de famílies que van ser identificades en els capítols 4.1 i 4.2 es van classificar en set estratègies alimentàries (fitòfags-succionadors, fitòfags-mastegadors, consumidors florals, omnívors, sapròfags, parasitoids i depredadors) segons el tipus d’alimentació que presentaven, ja que en la major part dels casos les espècies contingudes dins d’una mateixa família comparteixen l’estratègia alimentaria. Quan les famílies presentaven divergències tròfiques es va necessitar l’ajuda d’especialistes per tal d’identificar els gèneres o espècies dominants per tal d’atorgar al grup sencer la seva correcta estratègia alimentària.

L’estudi dels artròpodes ha estat, a més, complementat amb l’anàlisi de les comunitats vegetals dels camps de cereals per tal d’estudiar la relació entre els artròpodes i els productors primaris. La major abundància i diversitat de la flora arvense dels conreus de cereals ecològics respecte dels convencionals constatada per diversos estudis al centre d’Europa (Gibson et al., 2007; Hald, 1999; McLaughlin & Mineau, 1995; Moreby et al., 1994) i a la regió mediterrània (Romero et al., 2008), ens va portar a hipotetitzar que la major diversitat vegetal dels camps ecològics podria anar associada a una major diversitat dels artròpodes. Per aquesta raó, els capítols 4.2 i 4.3 apleguen l’estudi simultani de la comunitat vegetal i els artròpodes per tal d’aprofundir en la relació entre les plantes i els artròpodes a nivell funcional (capítol 4.2) i a nivell taxonòmic (capítol 4.3).

# CAPÍTOL 2.
# OBJECTIUS

# 2. Objectius

L'objectiu general d'aquesta tesi ha estat conèixer la comunitat d'artròpodes dels conreus de cereals a diferents escales espacials, en relació a la diversificació dels hàbitats, per tal d'aprofundir en els mecanismes que incentiven la biodiversitat de l'artropodofauna. Els estudis continguts en aquesta memòria s'han fonamentat en l'assumpció que una major diversificació (i) de les comunitats vegetals arvenses i de les espècies cultivades (monocultius *vs*. policultius) com a conseqüència de la gestió agronòmica i (ii) del paisatge podria comportar un augment de la diversitat de la comunitat d'artròpodes. Els objectius concrets van ser:

i Estudiar l'efecte de la gestió agronòmica sobre l'abundància i la riquesa dels artròpodes en conreus de blat a la regió mediterrània mitjançant la comparació de parcel·les ecològiques i convencionals (capítols 4.1, 4.2, 4.3).

ii Comparar la resposta dels artròpodes en relació amb la gestió agronòmica segons una aproximació taxonòmica o funcional basada en grups alimentaris (capítol 4.1).

iii Analitzar l'efecte de les característiques de les comunitats vegetals dels camps de blat (ecològic *vs*. convencional) sobre l'abundància i la riquesa dels artròpodes des d'una perspectiva funcional (capítol 4.2) i taxonòmica (capítol 4.3).

iv Estudiar l'efecte del tipus de cultiu (monocultiu *vs*. policultiu) i la densitat de sembra sobre la comunitat de fitòfags (capítol 4.4).

v Analitzar l'efecte de la complexitat del paisatge sobre l'abundància d'àfids, parasitoids i predadors especialistes i generalistes en els conreus de cereals ecològics (capítol 4.5).

vi Estudiar l'efecte dels diferents grups d'enemics naturals sobre les poblacions d'àfids en els conreus de cereals mitjançant experiments amb barreres d'exclusió (capítol 4.5).

# CAPÍTOL 2’.
# OBJECTIVES

# 2’. Objectives

The present study aims at acquiring a detailed knowledge of arthropod communities in arable land systems relative to habitat diversification at different spatial scales, in order to understand mechanisms enhancing biodiversity of agro-ecosystems. This study is based on the assumption that richness of arthropod communities could be enhanced by increasing both landscape complexity and richness of weed communities and crops (monoculture *vs*. polyculture) through farming management. The specific objectives of this work are:

i To assess the effect of farming management on the abundance and richness of the community of arthropods in dry-land cereal fields comparing organic and conventional free-insecticide fields in the Mediterranean region (Chapters 4.1, 4.2, 4.3).

ii To compare arthropod responses in relation to farming management obtained from the feeding group approach and the taxonomical approach (Chapter 4.1).

iii To analyse the effect of plant communities on the abundance and richness of arthropods in arable land systems (organic *vs*. conventional) using a functional (Chapter 4.2) and a taxonomical approach (Chapter 4.3).

iv To study the effect of crop type (monoculture *vs*. polyculture) and crop density on the phytophagous community of insects (Chapter 4.4).

v To examine the effect of the surrounding landscape complexity on the abundance of aphids, parasitoids, and specialist and generalist predators in organic cereal fields (Chapter 4.5).

vi To test the ability of different enemy groups to depress aphid populations by excluding flying predators and parasitoids, ground-living predators, or both, in a field experiment (Chapter 4.5).

# CAPÍTOL 3.
# MATERIAL I MÈTODES

# 3. Material i Mètodes

## *3.1 Sistemes i àrees d’estudi*

Per tal de respondre als objectius plantejats, es van dissenyar quatre models d’estudi. El primer i segon model d’estudi es van dur a terme a escala de camp o parcel·la, per tal d’avaluar l’efecte de la gestió agrícola (convencional *vs*. ecològica) i l’efecte del tipus de cultiu (monocultiu *vs*. policultiu) sobre la comunitat d’artròpodes en un context de cereals de secà (objectius i, ii, iii i iv). Ambdós models es van desenvolupar a Montblanquet, municipi de Vallbona de les Monges (Urgell). El paisatge agrícola d’aquesta àrea d’estudi és relativament complex i és constituït per conreus herbacis (40% de la superfície), principalment de cereals, envoltats per una rica vegetació natural i semi-natural pròpia del clima sub-mediterrani.

L’anàlisi de l’efecte de la complexitat del paisatge sobre l’abundància d’àfids i els seus enemics naturals (objectiu v) va requerir ampliar l’escala d’estudi del tercer model. Aquest estudi es va realitzar a la regió de Skåne (Suècia), on la llarga trajectòria d’estudis previs, a nivell de camp i finca, sobre els àfids i els seus depredadors naturals va constituir una sòlida base de coneixements per dur a terme l’estudi a escala de paisatge. El contrast entre el paisatge simple del sud-oest de la regió dominat per conreus de cereals (< 95% de la superfície ocupada per conreus) i el paisatge complex del nord-est on els conreus de cereals alternen amb pastures perennes i fragments de bosc (> 50% de la superfície ocupada per hàbitats no cultivats) oferia un marc idoni per estudiar l’efecte de la complexitat paisatge. A més, la suau topografia i el clima força homogeni de la regió va permetre evitar les correlacions entre l’estructura del paisatge i els factor abiòtics. El quart sistema també es va dur a terme a la regió de Skåne i va consistir en un estudi experimental, on es va analitzar l’efecte dels enemics naturals en la regulació de les poblacions d’àfids en conreus de cereals (objectiu vi), mitjançant l’experimentació amb barreres d’exclusió.

## El primer sistema d'estudi (Capítols 4.1, 4.2 i 4.3)

El disseny experimental va consistir en la selecció de vuit camps de blat (*Triticum aestivum* L.), dels quals quatre eren ecològics i els restants eren convencionals. Els camps ecològics (en blau, fig. 2), per sistema, seguien una rotació triennal de cereal/lleguminosa/policultiu, mentre que els camps convencionals alternaven el cultiu de civada amb el de blat (en taronja, fig. 2). La fertilització dels camps ecològics es duia a terme mitjançant adobs verds i aports ocasionals de gallinassa, i la dels camps convencionals combinava l'ús de purins i de fertilitzants químics. El control de la vegetació arvense era mecànic als camps ecològics, mentre que els camps convencionals eren regularment tractats amb herbicides. Cap del camps seleccionats utilitzava insecticides o fungicides.

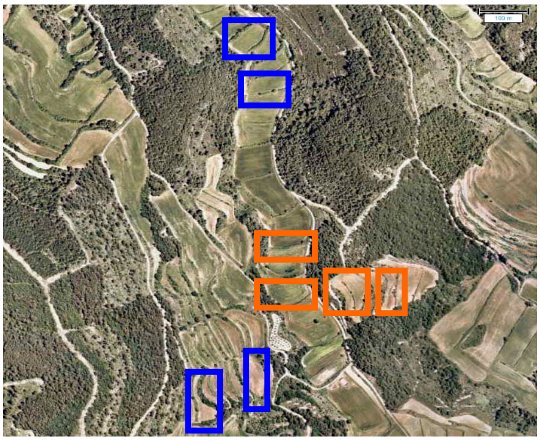

**Fig. 2** Ortofotomapa de Montblanquet amb els 8 camps de cereal marcats. Els camps marcats amb blau corresponen als ecològics mentre que els quadres vermells situen els camps convencionals.

Tot i que varem intentar que els camps ecològics i convencionals no diferissin en forma ni en mida, a l'hora de seleccionar els camps varem considerar més important la homogeneïtat de la vegetació dels marges. Per aquesta raó, els camps convencionals (mitjana ± ES; 4.08 ± 0.8 ha) eren més grans que els camps ecològics (2.19 ± 0.3 ha; $\chi^2_{\mathrm{df}} = 5.78_1$, $P = 0.016$), i la relació entre el perímetre i l'àrea era més gran en els camps ecològics (0.09 ± 0.01) que en els convencionals (0.06 ± 0.01; $\chi^2_{\mathrm{df}} = 4.85_1$, $P = 0.028$). La distancia màxima entre ells no superava 1 km, per tal de minimitzar les diferències dels factors abiòtics.

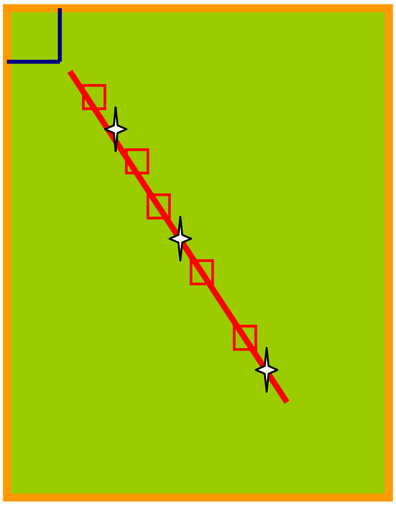

**Fig. 3** Esquema del transsecte de 100 m. Els quadrats simbolitzen les 5 parcel·les de 1 $m^2$ i les estrelles les 3 trampes d'intercepció de vol.

A cada camp es va establir un transsecte de 100 m (fig. 3) disposat al llarg d'una de les diagonals, i a una distància de 25 m del marge, on es van instal·lar 3 trampes d'intercepció del vol i es van delimitar 5 parcel·les de 1$m^2$ .

## El segon sistema d'estudi (Capítol 4.4)

L'estudi de l'efecte del tipus de cultiu (monocultiu *vs*. policultiu) i la densitat de sembra sobre la comunitat de fitòfags es va dur a terme mitjançant parcel·les experimentals. L'hivern de 2004, es va delimitar una parcel·la de 150 × 50 m en un camp que havia estat gestionat seguint les directrius de l'agricultura ecològica durant més d'una dècada.

La parcel·la es va dividir en 4 blocs equidistants de 35 × 10 m. A cada bloc es van delimitar 24 micro-parcel·les de 2 × 3 m (fig. 4-5).

**Fig. 4** Panoràmica del camp ecològic experimental dividit en les 96 micro-parcel·les.

Es van sembrar set tipus de cultius, tres en condició de monocultiu (nap -*Brassica napus*-, ordi -*Hordeum distichon*- i veça -*Vicia sativa*-) i quatre en condició de policultiu (nap-ordi, nap-veça, ordi-veça, i nap-ordi-veça). Tots els cultius es van sembrar a tres densitats (alta, intermèdia i baixa). Els diferents tipus de cultius i densitats es varen assignar aleatòriament entre les micro-parcel·les de cada bloc. Tres micro-parcel·les de cada bloc es van deixar sense sembrar (control) per avaluar l'efecte de la flora arvense sense cultiu sobre els insectes fitòfags (fig. 5). Es va fer un seguiment periòdic sobre l'evolució de la comunitat vegetal, però en aquest treball nomes es mostrarà l'efecte d'aquesta comunitat vegetal sobre la població d'insectes en un moment donat.

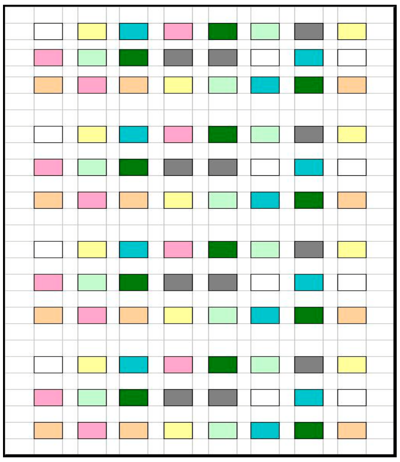

**Fig. 5** Esquema de la distribució dels quatre blocs on els 8 tractaments es distribuïen aleatòriament.

Aquest disseny experimental forma part d'un projecte més ampli desenvolupat pel grup de recerca emergent Ecologia dels Sistemes Agrícoles de la Universitat de Barcelona i de la tesi doctoral de l'Albert Romero.

## El tercer sistema d'estudi (Capítol 4.5)

El disseny experimental per estudiar l'efecte de la complexitat del paisatge sobre l'abundància d'àfids, parasitoids i predadors especialistes i generalistes en els conreus de cereals ecològics va consistir en la selecció de 12 sectors circulars de paisatge de 2 km de radi al llarg d'un gradient de heterogeneïtat del paisatge (fig. 6).

L'estudi va incloure des de paisatges molt simples (98% de la superfície del sòl ocupada per terres llaurades) fins paisatges més complexes on només el 10% de la superfície era ocupada per terres llaurades. La selecció dels sectors es va dur a terme mitjançant l'anàlisi del mapa d'usos del sòl del Departament d'Agricultura Suec de 2005 (amb ArcView 9.2.2) i visites a les diferents zones.

Dins de cada sector de paisatge es van escollir dos camps de cereals d'estiu (blat o ordi indistintament) gestionats ecològicament. Dins de cada camp es van emprar diferents mètodes de mostreig per tal de poder estudiar l'efecte de la complexitat del paisatge sobre els àfids dels cereals i els seus enemics naturals (especialistes i generalistes).

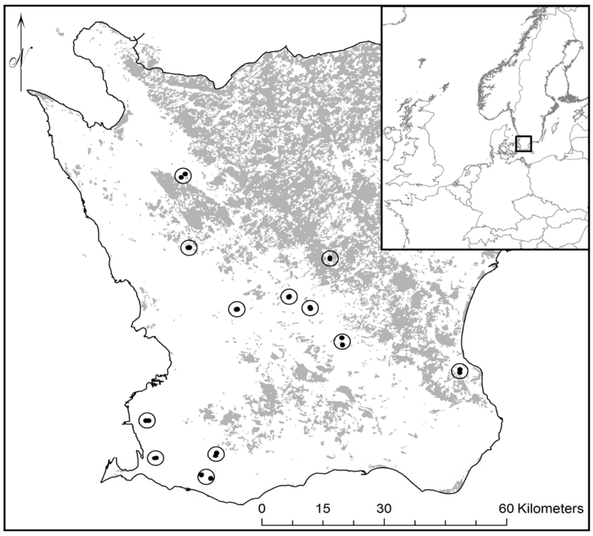

**Fig. 6** Mapa d'Skåne on s'indica amb cercles els 12 paisatges estudiats (2 km de radi). Dins de cada cercle es situen els dos camps seleccionats.

## El quart sistema d'estudi (Capítol 4.5)

L'efecte dels diferents grups d'enemics naturals sobre les poblacions d'àfids en els conreus de cereals ecològics es va estudiar mitjançant un experiment amb barreres d'exclusió.


**Fig. 7** Panoràmica de l'experiment amb barreres d'exclusió.

Aquest experiment es va dur a terme entre meitats de Juny i finals de Juliol del 2007. Es van seleccionar 6 camps d'ordi gestionats ecològicament els quals es trobaven disposats en dos dels dotze sectors de paisatge que treballàvem en el tercer model d'estudi, on la proporció de terra llaurada anualment era del 70% aproximadament. A cada camp es van delimitar 24 parcel·les circulars de 0.75 m diàmetre, les quals es trobaven a 2 m de distancia entre elles (fig. 7). Els quatre tractaments, cadascun replicat 6 vegades van ser assignats aleatòriament dins de cada camp.

El tractament control (fig. 8a) servia per conèixer la densitat d'àfids en condicions «normals». La comparació entre la densitat d'àfids dels diferents tractaments, on s'excloïa algun grup de depredadors o tots ells, i la densitat d'àfids en el tractament control permetia avaluar quin era l'efecte dels depredadors sobre les poblacions d'àfids.

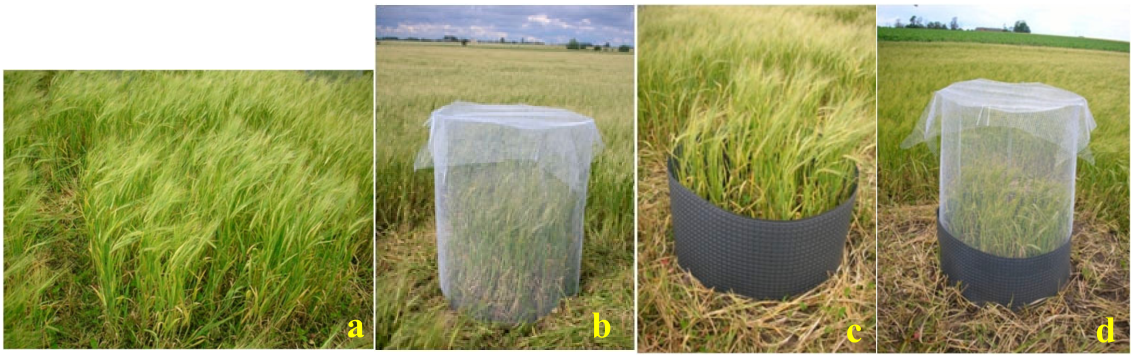

**Fig. 8** Imatges dels quatre tractaments establerts en l'experiment de les barreres d'exclusió. **a**/ Obert, **b**/ Exclusió de depredadors voladors i parasitoids, **c**/ Exclusió de depredadors caminadors i excavadors, **d**/ Tractament que combina els dos dispositius anteriors i permet excloure a tots els depredadors.

L'exclusió de depredadors voladors i parasitoids (fig. 8b) es feia mitjançant gàbies elaborades amb una xarxa metàl·lica de 8 mm de malla impregnades externament amb una cola aplicada amb esprai. Aquestes gàbies permetien excloure depredadors com *Coccinella septempunctata* i *Propylea quatuordecimpunctata* i parasitoids afidòfags com són els bracònids i els figítids alhora que facilitaven la ventilació del dispositiu i, en conseqüència, evitaven modificacions de les condicions micro-climàtiques. La part basal de la malla es deixava sense encolar per permetre l'accés dels depredadors caminadors i excavadors.

L'exclusió de depredadors caminadors i excavadors, tals com els caràbids i les aranyes, es feia mitjançant barreres de plàstic disposades verticalment (fig. 8c) que s'elevaven 30 cm sobre terra i s'enterraven 10 cm. Dins de cada barrera de plàstic s'instal·lava una trampa de caiguda de material viu amb una obertura de 12 cm de diàmetre que estava permanentment activa mentre va durar l'experiment. Els depredadors capturats en aquestes trampes eren comtats i extrets fora de les mateixes. Els altres artròpodes capturats es tornaven a deixar dins la barrera. A més, periòdicament es treien a mà les teranyines trobades.

El tractament d'exclusió total (fig. 8d) contenia els dispositius dels dos tractaments anteriors per tal d'impedir l'accés d'ambdós grups de depredadors. Mitjançant aquest tractament es feia palès com evolucionarien les poblacions d'àfids dels agrosistemes si no estiguessin sotmesos a una gran pressió depredadora.

## *3.2 Mètodes de mostreig*

El desenvolupament d’aquesta tesi doctoral ha requerit la utilització de diversos mètodes de mostreig, l’elecció dels quals ha tingut en compte l’objectiu de l’estudi, les característiques dels grups estudiats i les escales temporals i espacials. Els mètodes de mostreig emprats però, tenen en comú, que permeten obtenir mesures relatives d’abundància ja que estan relacionades amb la densitat i l’activitat dels individus. Seguidament s’exposen breument agrupats en: mètodes de captura passiva, mostreig en una àrea coneguda i recol·lecció de tiges.

### MÈTODES DE CAPTURA PASSIVA

#### **Trampes d’intercepció (Capítol 4.1)**

Les trampes d’intercepció són emprades per capturar petits insectes que volen per sobre dels camps i que al xocar amb els vidres de la trampa tenen tendència a caure a l’interior del recipient col·lector (Koricheva et al., 2000). Les trampes d’intercepció dissenyades per al nostre estudi consistien en un dipòsit extern de plàstic blanc (150 mm alçada, 200 mm diàmetre intern) fixat a un suport de fusta d’1.5 m i un dipòsit intern de plàstic transparent (140 × 180 mm) amb dues plaques de metacrilat (30 × 30 cm) entrecreuades. El dipòsit intern, que aproximadament contenia 1L de solució salina i sabonosa per tal de disminuir la tensió superficial de l’aigua, recollia els insectes que queien al xocar passivament amb les parets de metacrilat. Les plaques de metacrilat i el dipòsit intern eren mòbils per tal de facilitar el periòdic buidat de les trampes. Durant el mes d’abril es va delimitar un transsecte de 100 m en una de les diagonals de cada camp i a una distància de 25 m del marge. A cada transsecte es varen instal·lar tres trampes a una distància de 50 m entre elles (fig. 9). En total van ser emprades 24 trampes disposades en 8 camps durant 4 setmanes de recol·lecció.

**Fig. 9** Imatge de les 3 trampes d’intercepció col·locades en un transsecte de 100 m.

### Trampes de caiguda (Capítol 4.5)

Les trampes de caiguda són idònies per capturar els artròpodes caminadors i excavadors d’una àrea determinada (Duelli et al., 1999). Les trampes que varem utilitzar consistien en un recipient de plàstic transparent de 12 cm de diàmetre i 15 cm d’alçària. Aquest recipient s’enterrava procurant que quedes ben arran de terra i, mirant de modificar el mínim l’entorn proper a la trampa per tal de garantir el seu bon funcionament. Les trampes eren protegides per una teulada de 25 × 25 cm per evitar el sobreeiximent de les mateixes en cas de pluja (fig. 10). El líquid contingut a les trampes era una solució salina i sabonosa per tal de conservar les mostres i disminuir la tensió superficial de l’aigua, respectivament.

Es van instal·lar tres trampes a cada camp disposades a intervals de 33 m al llarg d’un transsecte de 100 m, que es trobava a una distància de 30 m del marge. En total varem col·locar un total de 72 trampes repartides en 24 camps i en 12 paisatges distribuïts al llarg d’un gradient de complexitat.

**Fig. 10** Imatges del dispositiu instal·lat a les trampes de caiguda.

## MOSTREIG EN UNA ÀREA CONEGUDA

### Mostreig a escala de parcel·la (Capítols 4.2 i 4.3)

L’efecte de la gestió agronòmica sobre la comunitat vegetal i l’artropodofauna associada es va avaluar a partir de l’estudi de 5 quadrats (1 × 1 m) per camp, separats per una distància de 20 m al llarg del transsecte diagonal prèviament esmentat (fig. 3). L’estudi consecutiu de la comunitat vegetal i els artròpodes en els mateixos quadrats era necessari per tal d’analitzar la interacció planta-artròpode.

En primer lloc, els artròpodes eren capturats mitjançant un aspirador de jardí adaptat per a tasques entomològiques, seguint les recomanacions de Stewart & Wright (1995). El tub de l’aspirador era subjectat verticalment i mogut continuadament per sobre de la vegetació del quadrat durant 60 segons. Aquest mètode ha estat emprat freqüentment per estudiar la comunitat d’artròpodes dels conreus herbacis (Elliott et al., 2006; Stewart & Wright, 1995), i permet recollir informació d’un ampli ventall de grups tròfics que interaccionen amb la vegetació (Letourneau & Goldstein, 2001). En segon lloc, el recobriment del blat i de les espècies arvenses eren avaluats seguint l’escala de recobriment que conté els següents intervals: 0-1, 1-5, 5-10, 10-25, 25-50, 50-75 i 75-100%. La identificació d’espècies es va fer segons de Bolòs et al. (2005). En conjunt van ser analitzats un total de 80 quadrats distribuïts en 8 camps en dos períodes de mostreig.

### Mostreig en un transsecte de distància coneguda (Capítol 4.5)

Dins de cada camp es varen delimitar dos transsectes de 100 m, que es disposaven paral·lels al marge, un es trobava a 3 m del marge i l’altre a 30 m del mateix, per tal de tenir en compte la variabilitat dins del camp.

Els primers 50 m del transsecte van ser adreçats a la inspecció d’espigues, la qual consistia en identificar i comptar els àfids allotjats en 50 espigues de cereal escollides a l’atzar. A cada espiga es revisava les espècies d’àfids que eren presents i per a cada espècie es distingia el nombre de formes alades i no alades, nimfes, adults i mòmies (àfids momificats amb una larva/pupa de parasitoid). Els àfids momificats eren portats al laboratori, per tal d’obtenir els parasitoids adults, els quals serien posteriorment identificat pels especialistes. Els segons 50 m del transsecte van ser dedicats a estimar visualment l’abundància d’enemics naturals sobre les espigues de cereal, principalment coccinèl·lids. La velocitat de desplaçament al llarg del transsecte va ser de 2 m/min i tots els depredadors vistos a 1 m a la dreta o esquerra nostra eren anotats. En el cas que la identificació dels depredadors en el camp no fos possible, es recollien mostres i es portaven al laboratori on serien identificats mitjançant les tècniques més adequades.

En conjunt, es van realitzar 96 transsectes distribuïts en 12 sectors de paisatge, en 24 camps, dos camps per sector de paisatge, i en dos períodes de mostreig. El primer mostreig es va dur a terme durant la floració del cereal i el segon es va efectuar quan el gra del cereal es trobava en fase lletosa (Zadoks et al., 1974).

**Mostreig a escala de parcel·la amb un nombre de tiges fixat (Capítol 4.5)**

El nombre d'àfids adults, alats, i nimfes de cada espècie eren avaluats en 15 espigues escollides a l'atzar dins de cada parcel·la. El nombre de depredadors i mòmies eren també anotats. Els depredadors es deixaven a la parcel·la, excepte quan es tractava del tractament d'exclusió total. Les mòmies es portaven al laboratori per tal de poder fer emergir al parasitoid que allotjaven. El primer mostreig va ser previ a la instal·lació de les gàbies d'exclusió coincidint amb la floració de l'ordi, mentre que el segon mostreig es va dur a terme quan el gra de l'ordi es trobava en fase lletosa i després que les gàbies fossin desmuntades.

## Recol·lecció de tiges **(Capítol 4.4)**

A l'estudi de l'efecte del tipus de cultiu i la densitat de sembra sobre la comunitat de fitòfags es van recollir 15 tiges de l'espècie cultivada (en el cas dels monocultius), de les espècies cultivades (en el cas dels policultius), o de les espècies arvenses majoritàries (en el cas del tractament control). Les tiges eren recollides a l'atzar a l'interior de cadascuna de les 24 micro-parcel·les de cada bloc, per tal d'evitar l'efecte marge. S'entén per mostra el total d'insectes extrets del total de tiges de cadascuna de les micro-parcel·les.

# CAPÍTOL 4.
# RESULTATS

# Capítol 4.1

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B. Caballero-López, J.M. Blanco-Moreno, J. Pujade-Villar, D. Ventura, J. A. Sánchez & F.X. Sans. The aerial arthropod community as a descriptor of farming management in arable systems: from a taxonomical to a functional approach (*submitted*).

# The aerial arthropod community as a descriptor of farming management in arable systems: from a taxonomical to a functional approach

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## Abstract

The effect of farming management on the aerial arthropod's community of dry-land arable systems was tested using both a taxonomical and a functional approach. Arthropods were identified at a family level and each taxa was classified into one of the following feeding groups: chewing-herbivores, suction-herbivores, flower-consumers, parasitoids, predators and saprovores. Arthropods were periodically monitored in order to test whether the effect of farming on the arthropod's community depended on the time of the cropping season.
The majority of taxa do not respond to management, given that just 16 out of 111 families differ between farming systems, most of them being trapped in higher numbers in conventional fields. Conversely, the functional approach reveals that the abundance of the aerial arthropod community is enhanced in conventional fields, at least in some cereal development stages. The functional approach appears to be a more efficient and robust system to carry out a multi-taxa analysis and the neutral patterns found for most of the taxa are discussed.

Contrary to what was originally estimated, the studied organic fields did not enhance the arthropod's community. Therefore, the higher fertilisation together with the lack of insecticide use in conventional fields appears to be sufficient in order to favour the presence of beneficial fauna like parasitoids, predators and saprovores.

Keywords: cereal fields, arable farming systems, feeding groups, predators, parasitoids, saprovores

# Resum

*Aquest estudi analitza l'efecte de la gestió agrícola sobre la comunitat aèria d'artròpodes dels conreus de cereals de secà des d'una perspectiva taxonòmica i funcional mitjançant la comparació de parcel·les ecològiques i convencionals. Els artròpodes en la seva majoria van ser identificats fins a nivell de família, i posteriorment agrupats en set estratègies alimentaries, segons el tipus d'alimentació de les espècies o morfo-espècies dominants de cada taxó (mastegadors, succionadors, consumidors florals, parasitoids, depredadors i sapròfags). La comunitat d'artròpodes va ser mostrejada periòdicament amb l'objectiu de valorar si la resposta dels artròpodes a la gestió varia al llarg del desenvolupament del cereal.*

*Des de la perspectiva taxonòmica, els resultats mostren que la major part de taxons no responen a la gestió, doncs nomes 16 de les 111 famílies estudiades difereixen entre les parcel·les ecològiques i convencionals, la major part de les quals presenten abundàncies significativament més elevades a les parcel·les convencionals. Per altra banda, l'aproximació funcional mostra una resposta molt més clara en relació amb la gestió, doncs l'abundància de gairebé tots els grups alimentaris de la comunitat aèria d'artròpodes augmenta a les parcel·les amb gestió convencional, com a mínim, en algun moment del desenvolupament del cultiu. La perspectiva funcional es presenta doncs com el sistema més eficient alhora de dur terme una anàlisi amb múltiples taxons.*

*Contràriament al que era d'esperar, la gestió ecològica dels conreus estudiats no afavoreix l'artropodofauna aèria. La major fertilització dels conreus convencionals i l'absència d'insecticides afavoreix la presència de fauna benèfica com ara parasitoids, predadors i sapròfags.*

## Introduction

Organic farming is generally found to enhance biodiversity in arable fields (Bengtsson et al., 2005; Hole et al., 2005). However, the comparisons between organic and conventional fields have also shown contradictory results. While greater abundance and diversity of pollinators and epigeal fauna was found in organic fields (Clough et al., 2007a; Rundlöf & Smith, 2006; Schmidt et al., 2005), in other investigations no greater amount of differences or lower abundance and diversity could be recorded in organic fields for other taxa (Purtauf et al., 2005; Shah et al., 2003; Weibull et al., 2000; Weibull et al., 2003). These contrasting results have been largely attributed to methodological shortcomings such as the lack of replication or differences in the spatial scale at which the studies were conducted (Bengtsson et al., 2005; Kleijn et al., 2004; Tscharntke et al., 2005). Nevertheless, two recent studies by Feber et al. (2007) and Weibull & Östman (2003), performed at a similar spatial scale and focused on the same taxa, reported variable results, suggesting that other significant factors are implied in the observed variability. The variation in the agricultural practices included in the different forms of management could be particular important. For instance, the number of pesticide applications per year in conventional management is much higher in Germany and in the UK than in other European countries (Kleijn *et al.*, 2006). Therefore, as pesticide and particularly insecticide applications have a direct negative influence on invertebrate communities (Hole et al., 2005), it is unlikely that the results from the studies of arthropod communities carried out in more intensively managed farmlands in Europe can be extrapolated to less intensified ones. For this reason, detailed information on the agronomic practices of the areas studied is needed in order to verify comparisons across other studies.

The Mediterranean climate is an important factor that affects negatively cereal crop yields (e.g. for 1997-2007 average wheat yield in Spain was 47% of the EU-15 average during the same period [European Commission (Eurostat, 2008)]. Thus, farmers embedded in these conditions struggling to reduce production costs by cutting down on agrochemicals to compensate the foreseeable low yields. Herbicides are routinely applied in conventional practices, while fungicides and insecticides are seldom used. The use of insecticides had been recorded as this was main reason in explaining the differences in organic and conventional cereal fields (Feber et al., 2007; Wickramasinghe et al., 2004), since the application of insecticides leads to direct mortality of arthropods and sublethal effects on its fecundity (Lampkin, 2002). As a consequence, small differences in arthropod community might be therefore expected between organic and conventional fields in the Mediterranean area where the use of insecticides is limited.

On the other hand, a number of earlier attempts at investigating the effects of farming types on arthropods have tended to concentrate either on a single trophic level (Hartley & Jones, 2003) or on an individual insect family (Brose, 2003; Melnychuk et al., 2003). Nevertheless, predictions regarding the effect of farming on arthropods based on a small number of taxa or only one trophic group may not be generalised to the entire community (Voigt et al., 2007), due to the fact that arthropods have a wide range of functional roles in ecosystems (Maleque et al., 2006). Furthermore, as an ecosystem approach at a species level cannot possibly be obtained in a context of limited financial and human resources, adequate measurable surrogates must be found.

One possibility is to evaluate the effect of farming on a large number of groups of arthropods identified at a family or at a superfamily (SpF.) level. Investigations at a family level have been validated as substitutes in the investigations at a species level (Balmford et al., 1996a; Balmford et al., 1996b; Hughes et al., 2000; Wickramasinghe et al., 2004). Although this study is presented as the simplest way to adopt a multi-taxa approach.

Another possibility is to assess the effect of farming on arthropods using a functional approach based on the form of feeding. Clough et al. (2007b) recently reported that the abundance and diversity of arthropod's feeding groups are strongly affected by farming. Thus, we grouped all identified taxons in seven feeding groups (FGs hereafter) following the proposal of Perner et al. (2003). Our FGs are based on non-phylogenetic, aggregated units of taxa playing an equivalent role in the community (Hawes et al., 2009; Voigt et al., 2007). Regardless of the approach adopted, the process of amalgamating taxa into FGs requires the assumption of the importance of certain common features. Among the most recently used approaches, the FG perspective provides a link between the presence and the function of the arthropods in the ecosystem (Hughes et al., 2000). Additionally, FG based on form-of-feeding traits has been reported as a sensitive indicator of the changes in the environmental conditions (Perner et al., 2003; Voigt et al., 2007) and farming practices (Hawes et al., 2009).

The availability of arthropod's food resources dramatically change in quantity and quality throughout the cereal cropping period, mainly due to changes of the developing status of the plant community, particularly of the crop. The community of arthropods was evaluated periodically according to the main development stages in cereal, since it was foreseen that the sampling period may affect the arthropods community and, that differences between farming practices might be detected in just some of the sampling periods.

In this study we assessed the effect of farming management on the community of aerial arthropods in dry-land cereal fields comparing organic and conventional fields free-insecticide managed in the Mediterranean region. In addition, by studying the arthropod community during the entire cropping season we not only try to test whether farming practices and sampling period have an effect, but also whether the effect of farming on the arthropods diversity depends on the time of the cropping season. As we address these objectives from a taxonomical approach and from a functional approach, we could compare whether the separation into feeding groups lead to different conclusions than those that could be drawn using a taxonomical approach. We also use our data to test the potential benefits and drawbacks of the functional approach based on feeding groups.

## Methods

### *Study area*

The study was carried out in Montblanquet, a small village in the north-east of Spain about 150 km south of Barcelona (41º29'0.9''N, 1º7'16.4''E; 627 m above sea level). The landscape is dominated by woodlands, mainly pines (*Pinus nigra*), evergreen (*Quercus ilex*) and deciduous oaks (*Q. faginea*), shrublands and perennial grasslands (*Brachypodium phoenicoides)*. The arable fields, mainly cereals, represent a small percentage of the agricultural landscape (40%) and are intermingled between natural vegetation. The climate is Mediterranean, with an average annual precipitation of 450 mm and average annual temperatures of 13ºC.

### *Experimental design*

Four organically and four conventionally-managed winter wheat fields were selected in an homogeneous area of 2 × 2 km to study the effects of management on the aerial community of arthropods in dry-land cereal fields. The organic fields were selected first, and afterwards the conventional fields, no more than 1 km apart, but detached from the organic ones. Despite trying to select fields that matched in size and shape, we considered that the homogeneity of the vegetation of the boundaries was more important than the homogeneity of the field's size and shape, as in all cases the fields were relatively small. For this reason, field size was significantly greater in conventional fields (mean ± SE; 4.08 ± 0.8 ha) than in organic fields (2.19 ± 0.3 ha; $\chi^2_{\mathrm{df}} = 5.78_1$, *P* value = 0.016). In contrast, perimeter to area ratio was significantly greater in the organic fields (mean ± SE; 0.09 ± 0.01) than in the conventional fields (0.06 ± 0.01; $\chi^2_{\mathrm{df}} = 4.85_1$, *P* value = 0.028). While weeds were controlled mechanically and fertilisation relied on green manure and occasionally hen manure in organic fields, the conventional fields were sprayed with herbicides and fertilised with a combination of pig slurry and mineral fertilisers. Pesticides other than herbicides were not applied under conventional management. The selected organic fields had been managed for more than one decade following the organic guidelines and were certified by the Catalan Council for Organic Farming (CCPAE). All selected fields were sown with winter wheat (*Triticum aestivum*) between the last week of October and the first week of November, after seedbed preparation with harrowing at 15-20 cm depth (for further details see table 1).

**Table 1** Agronomic characteristics of the fields included in the study.

| Management | Organic | Conventional |
|---|---|---|
| Crop rotation | Legume/ winter wheat polyculture/ | Winter wheat/ winter barley |
| Tillage | 3 times, 20 cm of depth | 3 times, 15 cm of depth |
| Cereal | Winter wheat cv. *Bonpain* | Winter wheat cv. *Etecho* (2 fields), *Soissons* (2 fields) |
| Sowing density [kg ha$^{-1}$] | 180-200 | 170-200 |
| Nitrogen inputs (kg N ha$^{-1}$) | Green manure and occasionally hen droppings (<160) | ~ 180 of pig slurry/year<br>< 100 of mineral N at times |
| Weed control | Mechanical | Mechanical and Chemical * |
| Pests and diseases control | None | None |

*All conventional farmers applied Glyphosate (N-(phosphonomethyl) glycine at 2.5 L ha$^{-1}$) and 2-4-D (2,4-dichlorophenoxy at 1.3 L ha$^{-1}$) as pre-emergence non-specific herbicides, Splendor 25 SC (Tralkoxidin at 1.6 L ha$^{-1}$) as a post-emergence grass herbicide and Oxytril (ioxinil, bromoxinil, and mecoprop) at 2 L ha$^{-1}$) as a broad-leave herbicide.

In order to characterize the studied field's boundary vegetation, we combined habitat field survey and photointerpretation in ArcInfo version 9.1. The area of habitats of the boundaries that covered at least 5 m of the length perimeter was measured using 1:5,000 ortophotomaps (ICC, 2005). Habitats were categorized as perennial dominated grasslands, blackthorn-bramble thickets dominated by *Rubus ulmifolius* and *Prunus spinosa,* scrubs (e.g. *Rosmarinus officinalis* and *Juniperus oxycedrus)*, mixed holm-oak and deciduous oak woodlands, pine woodlands and deciduous woodlands dominated by *Ulmus minor* and *Acer monspessulanus*. The average diversity of habitats was computed for each field using the Shannon-Wiener index. The average habitat diversity did no differ significantly among organic and conventional fields ($\chi_1^2 = 0.70$, P value = 0.403).

*Sampling*

We established in each field a 100 m-transect, diagonally from the field boundary towards the centre, allowing for a strip 25 m wide to avoid the edge effect. Within each transect three flight interception traps (FIT) at 50-m intervals were placed. Each trap consisted of an outer white plastic cup (150 mm height, 200 mm internal diameter) supported by 1.5 m-height wooden stick and an inner plastic cup (140 × 180 mm) with 2 30 × 30 cm fixed plexiglas crossed pieces. The inner plastic cup contained approximately 1L of a NaCl-solution as a preservative solution and a drop of detergent to decrease the surface tension. So far, there is no general consensus about the most effective trap colour (Campos et al., 2000; Missa et al., 2009; Wickramasinghe et al., 2004), we chose white as we considered that this colour would cause a less attractive effect. FIT are useful for catching many small insects that are flying about in the surrounding area and have a tendency to fly downwards when hitting a wall (Koricheva *et al.*, 2000). The content of the traps were collected after 8 days and the traps were re-opened every 10-18 days depending on the cereal development stages. Thus, the trapping commenced at the cereal booting stage on the 7th of May 2004. The second and the third sampling were carried out at flowering and at milk-ripe wheat stages respectively, and the last trapping was completed on the 13th of July 2004, which coincides with the cereal development stage of soft dough according to Zadoks et al. (1974) scale. The average daily maximum temperatures during the spring sampling period ranged from 18 to 33 ºC. Although our trap catches correspond to measurements of activity-density more than total abundance numbers we will use the abundance term to simplify explanations.

The use of a family level approach is particularly useful when a FG perspective is required, as the majority of the family members belong to the same feeding group (see some considerations later). For this reason most arthropods were identified to a family level, although there were a few exceptions in relation to the sorting pattern. For instance, when the members of a family appears to present different feeding preferences (e.g. Drosophilidae, Opomizidae) their individuals were determined to genus or species/morphospecies level and, the most predominant feeding habit was used to assign to the entire group. Non-insect material was mostly sorted to order, and Lepidoptera was not sorted to families, since being of a wet material they were considered useless. In other cases, taxa from Apoidea, Curculionoidea, Scaraboidea and Staphylinoidea were identified at a superfamily level because of taxonomic difficulties.

Most taxa were classified in seven FGs: omnivores, saprovores, parasitoids, predators, chewing-herbivores, suction-herbivores, and flower-consumers. In turn, the feeding groups enclosed different feeding strategies and the assignment of these groups of taxa was based mainly on field observations and literature review. Complementary expert advice was also sought (see Acknowledgements). Saprovores category included: mycetophagous, plant saprovores, animal saprovores and scavengers. Granivorous, plant-chewers, gallicolous and miners were enclosed in the chewing-herbivorous category, while plant-sap suckers belong to the suction-herbivorous category. The flower-consumers comprised flower predators, pollen consumers and nectarivorous. When arthropods showed different feeding preferences in larvae and adult stages (see Appendix 1), they were assigned to both FGs in order to consider their whole lifetime impact. Some Coleoptera families were difficult to identify, thus they were considered in the total abundance, but however were excluded from the functional group analyses. Other groups such as most parasitoids in adult stage do not feed or their effect is so small that it is considered negligible, thus they were categorised in their adult stage without a trophic interaction.

### *Statistical analyses*

We tested the effects of farming management, sampling period and their interaction on: (a) higher taxa of arthropods (mostly families) and (b) feeding groups. To account for the fact that data sampled in the same fields was not independent, we used mixed models in which we included field as a random factor (Pinheiro & Bates, 2000).

The wide rank of groups investigated using the taxonomical approach prevents a homogenous analysed model. When count data was not overdispersed we used generalised linear mixed models with Poisson distribution (most taxonomic groups). Conversely, when count data appeared over-dispersed we tested the most appropriate distributional response for each case either negative binomial or zero-inflated negative binomial distribution (Bohning *et al.*, 1999).
With regards to the functional approach, we used linear mixed models with normal error distribution; FGs were square-root-transformed when required and the generalised linear

approach did not meet requirements. Residuals were examined for departures from linearity, normality and homoscedasticity.

Significance in the different predictors included in the models was obtained by using likelihood ratio tests. The library lme4 (Bates et al., 2008) was used to analyse together with normal and Poisson regression models, while the library glmmADMB (Skaug & Fournier, 2006) was used to analyse with negative binomial and zero inflated models. All statistical analyses were performed in R 2.8 (R Development Core Team, 2008).

## Results

### *Taxonomical approach*

A total of 25,776 arthropods belonging to 11 orders were collected: 22,500 were identified to family or SpF. level (Appendix 1). Several descriptive measures about arthropod's catches such as the mean number of individuals and taxa collected per survey and, the catch rates in organic and conventional fields are summarised in table 2. Only organic fields showed exclusive taxa after excluding singletons and doubletons.

**Table 2** Summary of main measures about arthropod catches during the whole sampling period. Data are means ± SE.

| | Organic | Conventional |
|---|---|---|
| No. individuals | 12,593 | 13,184 |
| No. taxa | 105 | 102 |
| Individuals survey$^{-1}$ | 2,784.3 ± 362.2 | 2,887.3 ± 603.9 |
| Taxa survey$^{-1}$ | 75.8 ± 6.6 | 69.0 ± 6.3 |
| Catch rate (mean individuals trap day$^{-1}$) | 33.2 ± 1.1 | 34.4 ± 2.4 |
| Catch rate (mean individuals day m$^{-2}$) | 92.1 ± 12.0 | 95.5 ± 20.0 |
| No. of taxons exclusive (% of total) [b] | 3 (2.9) | 0 (0) |

[b] Excluding singletons and doubletons

The total abundance and the total family richness of arthropods varied significantly between samplings, while they did not differ among organic and conventional fields (table 3). But the significant interaction between the management and sampling period relating to the total abundance indicates that its response to farming management varies in relation to the sampling time (table 3).

Out of the 111 families of arthropods recorded in organic and conventional fields, Aphididae (19.9% of all individuals) was by far the most abundant family, followed by the 8.9% of SpF.

Staphylinoidea (Coleoptera), the 8.3% of SpF. Apoidea (Hymenoptera) and the 6.5% of Chloropidae (Diptera).

**Table 3** Effects of management system, sampling period, and their interaction on the total arthropods family richness and the total abundance, and the abundance of several SpF. and families of arthropods. The most appropriate response distribution model in each case was specified. P = Poisson, N = Negative binomial, ZN = Zero-inflated Negative binomial. Only taxa with a significant response to farming management or the interaction between farming management and sampling period are shown. In bold taxa that was significantly higher in organic than in conventional fields. Significance for the different predictors included in the models was obtained by means of likelihood ratio tests.

| | Model | Management | | Sampling | | Interaction | |
|---|---|---|---|---|---|---|---|
| | | $\chi^2_{df=1}$ | *P* value | $\chi^2_{df=3}$ | *P* value | $\chi^2_{df=3}$ | *P* value |
| Total abundance | P | 0.08 | 0.774 | 2177.6 | < 0.001 | 100.77 | <0.001 |
| Total family richness | P | 0.76 | 0.382 | 81.85 | < 0.001 | 1.66 | 0.645 |
| Carabidae | N | 1.88 | 0.170 | 30.23 | < 0.001 | 12.66 | 0.005 |
| SpF. Scaraboidea | P | 2.37 | 0.124 | 60.22 | < 0.001 | 33.87 | 0.001 |
| SpF. Staphylinoidea | P | 0.74 | 0.388 | 1753.5 | < 0.001 | 94.60 | 0.001 |
| Anthomyiidae | P | 0.88 | 0.349 | 370.34 | < 0.001 | 78.66 | <0.001 |
| **Bibionidae** | **P** | **4.09** | **0.043** | **951.54** | **< 0.001** | **31.95** | **0.001** |
| Chironomidae | ZN | 4.35 | 0.037 | 74.92 | < 0.001 | 4.84 | 0.184 |
| Chloropidae | P | 3.95 | 0.047 | 1051.3 | < 0.001 | 117.95 | <0.001 |
| Ephydridae | P | 1.03 | 0.311 | 60.80 | < 0.001 | 10.79 | 0.013 |
| Lonchopteridae | P | 4.39 | 0.036 | 47.58 | < 0.001 | 8.99 | 0.029 |
| Phoridae | P | 0.97 | 0.323 | 122.24 | < 0.001 | 32.22 | <0.001 |
| Sciaridae | P | 10.32 | 0.001 | 519.68 | < 0.001 | 5.94 | 0.114 |
| Sphaeroceridae | P | 3.80 | 0.051 | 206.87 | < 0.001 | 3.01 | 0.390 |
| Braconidae | P | 5.43 | 0.020 | 48.53 | < 0.001 | 4.36 | 0.225 |
| Encyrtidae | N | 10.71 | 0.001 | 33.23 | < 0.001 | 1.54 | 0.674 |
| Ichneumonidae | P | 2.17 | 0.141 | 26.59 | < 0.001 | 7.62 | 0.054 |
| Pteromalidae | P | 0.20 | 0.658 | 4.09 | 0.252 | 9.49 | 0.023 |

The abundance of most of the analysed taxa varied significantly during the sampling period (table 3). But the abundance of the 70% of aerial captured families (only considering the groups with more than 20 individuals after pooling samplings) was not affected by farming management (data not shown). Conversely, eight aerial arthropod families showed a response to management; seven of these with a significant (or marginally significant) higher abundance in conventional fields rather than in organic ones (table 3). These were five dipteran families (Chironomidae, Chloropidae, Lonchopteridae, Sciaridae, Sphaeroceridae) and two hymenopteran families (Braconidae and Encyrtidae). The same pattern of abundance became evident in another 8 families; however only a small amount of sampling data reflect the significant interaction between the farming system and the sampling period (table 3). These were three coleopteran groups (Carabidae, SpF. Scaraboidea, SpF. Staphylinoidea), three dipteran families (Anthomyiidae, Ephydridae, Phoridae) and two hymenopteran families (Ichneumonidae, Pteromalidae).

Other families such as Tenthredinidae, Psychodidae or Bibionidae tend to present a different pattern being more abundant in organic fields, but the Bibionidae family was the only significantly more abundant one on organic fields compared to conventional fields (table 3 and Appendix 1).

*Functional approach*

The flower-consumers (33.5%) constituted the most abundant category, whereas saprovores (20.8%) and suction-herbivores (18.6%) appeared to be of a lower abundance, and the remainder included omnivores (9.8%), predators (7.3%), chewing-herbivores (5.3%), and parasitoids (4.7%). The richest functional feeding group was flower-consumers, containing more than a quarter of the total number of families, followed by parasitoids (21.6%), saprovores (17.6%), suction-herbivores (11.5%), predators (10.1%), chewing-herbivores (9.5%), and the omnivorous group with a 3.4% (Appendix 1).

The mean number of individuals of chewing-herbivores, flower-consumers, omnivores, saprovores, parasitoids and predators tended to be higher in conventional fields rather than in organic ones (Fig.1), although the majority did not appear to be significantly effected by management (table 4).

The temporal patterns of abundance varied among the different FGs (Fig. 1). Saprovores in organic fields and chewing-herbivores in organic and conventional fields showed a similar temporal trend with a maximum abundance during the wheat flowering (Fig. 1a). However, saprovor’s abundance in conventional fields illustrated a completely different pattern, with a similar level between the first and the second sampling and then a sudden decrease became apparent after the second one. The abundance of suction-herbivores in organic and conventional fields, and that of omnivores in conventional fields reached its maximum during the milk-ripening stage (Fig. 1c). Finally, flower-consumers (Fig. 1b), parasitoids (Fig. 1d) and predators (Fig. 1e) showed a similar tendency with a drastic increase between the first and the second sampling period and a kind of stabilization of average values between flowering and soft dough stages.

**Table 4** Effects of farming management, sampling period, and their interaction on the abundance and family richness of the different feeding groups. All feeding groups with a significant response to farming management or the interaction between farming management and sampling period show a higher abundance/richness in conventional fields. Significance for the different predictors included in the models was obtained by means of likelihood ratio tests.

| | Management | | Sampling | | Interaction | |
|---|---|---|---|---|---|---|
| | $\chi^2_{df=1}$ | *P* value | $\chi^2_{df=3}$ | *P* value | $\chi^2_{df=3}$ | *P* value |
| **Abundance** | | | | | | |
| Chewing-herbivores | 0.09 | 0.768 | 77.43 | < 0.001 | 14.34 | 0.002 |
| Flower-consumers | 2.02 | 0.154 | 25.06 | < 0.001 | 10.15 | 0.017 |
| Omnivorous | 3.56 | 0.059 | 23.87 | < 0.001 | 20.43 | 0.001 |
| Parasitoids | 5.94 | 0.015 | 63.06 | < 0.001 | 10.10 | 0.018 |
| Predators | 2.33 | 0.127 | 73.48 | < 0.001 | 12.68 | 0.005 |
| Saprovores | 0.66 | 0.416 | 92.67 | < 0.001 | 33.43 | <0.001 |
| Suction- herbivores | 2.49 | 0.114 | 271.39 | < 0.001 | 2.64 | 0.450 |
| **Family richness** | | | | | | |
| Chewing-herbivores | 0.00 | 0.999 | 51.28 | < 0.001 | 1.42 | 0.700 |
| Flower-consumers | 0.00 | 0.999 | 42.18 | < 0.001 | 2.47 | 0.482 |
| Omnivorous | 0.29 | 0.589 | 14.87 | 0.002 | 0.179 | 0.981 |
| Parasitoids | 0.36 | 0.548 | 74.55 | < 0.001 | 8.02 | 0.045 |
| Predators | 0.80 | 0.371 | 55.97 | < 0.001 | 6.25 | 0.100 |
| Saprovores | 1.46 | 0.227 | 65.39 | < 0.001 | 2.47 | 0.481 |
| Suction- herbivores | 0.98 | 0.322 | 60.72 | < 0.001 | 5.37 | 0.147 |

The changes in the temporal pattern of abundance between organic and conventional fields can explain the inability to find a significant management effect on FGs of arthropods. However, a significant interaction between farming management and the sampling data reflect that at least in certain sampling periods many functional components of arthropod community was indeed affected by management (Fig. 1, table 4). The abundance of parasitoids is the only one that showed the same tendency during the entire season, being significantly greater in the conventionally-managed fields (Fig. 1d, table 4). In contrast, the abundance of suction-herbivores shows a strong response in relation to the sampling period (table 4), but did not reveal any relation to farming management, since the abundance was similar among organic and conventional fields (Fig.1c).

Similarly to abundance, sampling period had a strong effect on the family richness of all FGs, but the family richness of most FGs did not respond to farming management. However, the family richness of parasitoids showed a significant interaction between farming management and the sampling period, reflecting an enhanced richness of this group in conventional fields only in specific sampling periods (table 4).

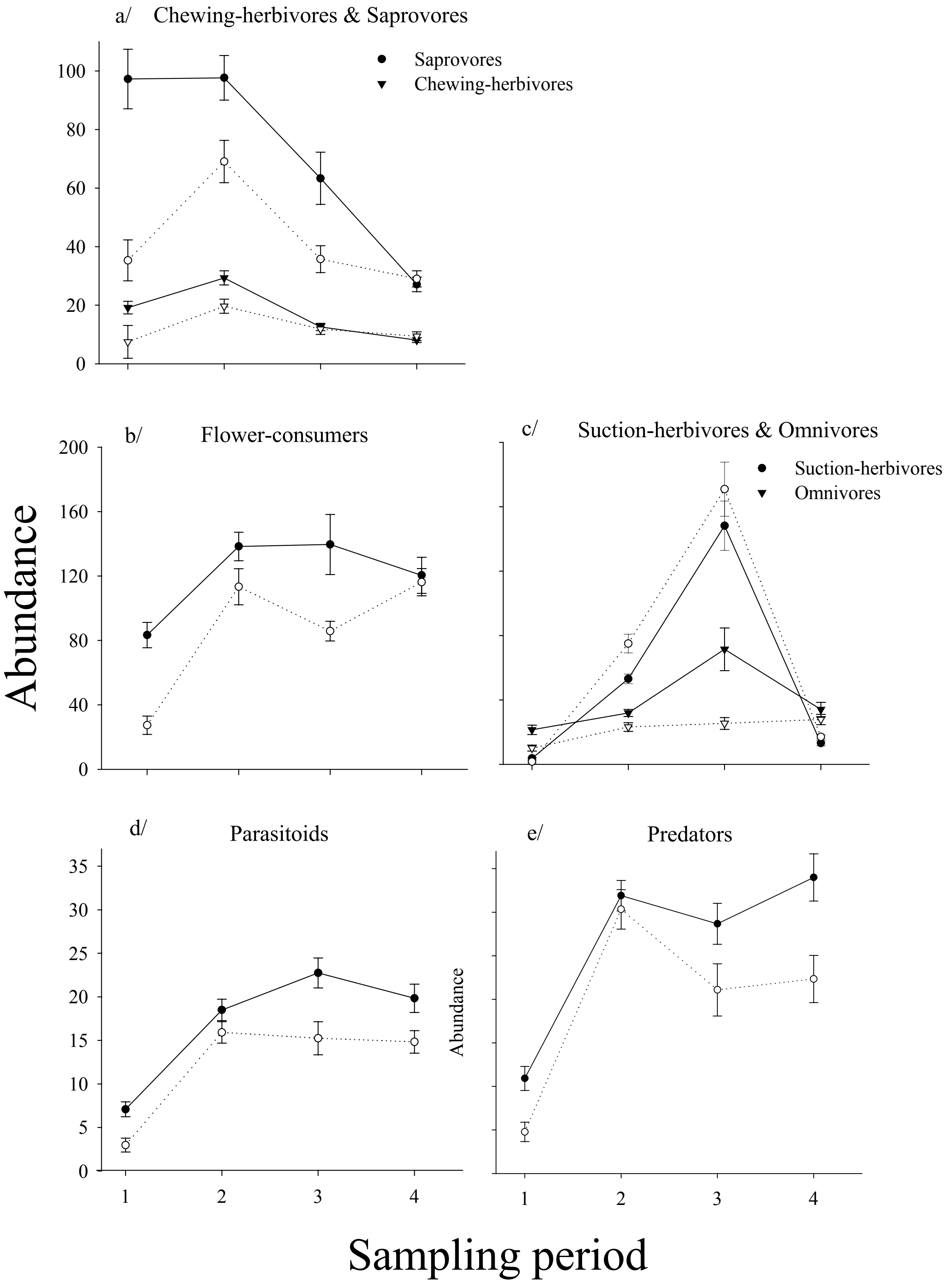

**Figure 1** Abundance, assessed as activity-density measures, of the seven feeding groups in organic (open symbols, dotted line) and conventional fields (close symbols, solid line) for each sampling period. The sampling period's units were represented by four stages of wheat development according to Zadoks'scale. 1 = booting, 2 = flowering, 3 = milk-ripe and 4 = soft dough. Data are means ± SE.

# Discussion

*Taxonomical approach*

In general, the community of aerial arthropods does not respond to management thus reflecting that the majority of captured aerial families do not vary among conventional and organic fields. Although Wickramasinghe et al. (2004) also reported a neutral response of the aerial arthropod's community to farming management in arable fields; our investigation is the first to reveal this effect in a large number of arthropod groups during the entire cropping season. Similar practices in organic and conventional fields free of insecticides in the dry arable land appears as the most suitable explanation to the lack of response from the majority of the examined taxa. Likewise Weibull et al. (2003) explained the small differences in butterflies, carabids, rove-beetles and spiders between farming systems because the management practices did not differ a great deal.

We selected fields with similar neighbouring habitats in order to avoid the effect of differences in the abundance and the complexity of the associated habitats on the community of arthropods (Krebs et al., 1999; Robinson & Sutherland, 2002). Other authors have reported that field size and perimeter-area ratio might affect the arthropod's richness and abundance. However, the absence of differences between farming systems regardless of their differences in size and perimeter-area ratio seems to discard its effect. To sum up, an absence of differences between organic and conventional fields for most taxa of community of arthropods in the dry land context could have been explained because the most important factors conditioning arthropod populations in arable systems (pesticides used and associated habitats characteristics) did not show any considerable variations between farming practices.

The lack of response to management of most taxa also appears to dismiss the findings reported by earlier attempts (Moreby & Southway, 1999; Robinson & Sutherland, 2002) regarding the indirect negative effect of the regular use of herbicides within invertebrate populations by killing off their food plants. Nevertheless, the higher presence of Bibionidae in organic fields, which in adult stage are mainly forb pollinators, could prove that there is an indirect affect of herbicide also in aerial groups. Thus the enhancement of their presence in organic fields might be attributed to the richer plant community in organic fields (unpublished data). Although we can not ignore the possibility that Bibionidae are responding to a higher edge effect resulting from the high perimeter-area ratio in organic fields.

Otherwise, species within the same family can vary in food preferences and in life-history strategies. Thus, we can not discount that some of the neutral patterns could be due to the high taxonomic level not being sufficiently sensitive in some cases. For instance, not all aphids that thrive in arable fields are crop pest species, because some species living on weeds may be providing some weed control (Norris and Kogan, 2000). In this sense the lack of response to farming management of Aphididae family might be explained by a high heterogeneity of patterns of the species contained within this family. However, the family level study is an appropriate perspective of analysis for the 16 families that differ between farming management, most of them being trapped in higher numbers in conventional fields during the entire cropping season or during specific stages of cereal development. Curiously, some of those families (e.g. Carabidae or Staphylinodea) have been previously reported as good indicators of management.

Our findings indicate that the abundance of Chironomidae and Sciaridae were enhanced in conventional fields. These findings are in accordance with Frouz's review (1999) of soil dwelling Diptera who highlight that Chironomidae and Sciaridae increases substantially in pig slurry fertilised fields, because the slurry improves feeding conditions of larvae and can also act as an important oviposition attractant for dipteran females (Weber, 1993). Unfortunately little is known about other dipteran families like Anthomyiidae, Chloropidae, Ephydridae, Lonchopteridae and Phoridae in arable systems, although the greater activity-density shown in conventional fields could also be directly or indirectly related to the higher N supply in conventionally-managed fields.

Braconidae and Encirtidae are primary parasitoids with a large diversity of hosts. Therefore, the greater abundance of arthropods in conventional fields might offer them a higher availability of potential hosts. This suggests that where the entire community of arthropods is favoured, the presence of generalist parasitoid groups like these is also benefited by a wide spectrum of potential hosts.

### *Functional approach*

The functional approach reveals that the abundance of most feeding groups is affected by management. Although the consistency of response of the FGs to management seems to contradict the non-homogenous taxonomic pattern, both approaches suggest an enhancement of the arthropod community in conventional fields. The differential point between the two perspectives is the response intensity. From the taxonomic perspective only 15 families appeared positively related to conventional management, with regards to the functional one most FGs respond to management. But this fact is not rather surprising given that it has been previously suggested that a functional approach may generate more robust responses than a taxonomical one (Clough et al., 2007). The neutral patterns presented by the majority of the taxonomic groups are due to the large dispersion of the data, given the high variability of the species included in each family. Likewise, the number of specimens included in many of these families is relatively low, rendering modelling difficult for some of these taxonomic groups. The amalgamation of families according to feeding strategies decreases the dispersion of the data. As a result, more homogeneous analyses can be performed and more robust tendencies may be obtained, responding to the type of management in a more consistent way. Therefore, the functional approach appears to be a more efficient system to carry out a multi-taxa analysis.

The interaction between management and the sampling period is significant in most groups, although this is not the case within the management factor. This might be explained because abundances in certain sampling periods are not high enough to modulate the responses correctly by using statistical tests. Additionally, the correct identification of the response to farming requires evaluating the performance of arthropod community throughout the cropping period because arthropod's resources change dramatically with the cereal development.

Conventional fields showed higher abundances in most FGs (Fig.1), but there is a significant resemblance between the temporal patterns of both management types. However, there is a clear exception: the activity-density response of saprovores in organic fields was similar to that of chewing-herbivores, indicating a close temporal pattern of resource use. As Wardle et al. (1999) demonstrated, detritivorous arthropods in organic fields feed on plant debris being returned by the weeds community into the soil.

Conversely, saprovores in conventional fields showed an alternative pattern, being much higher in the first and second sampling than in the remaining. As pig slurry is usually applied at the end of winter and early spring, the enhancement of the saprovores communities in conventional fields are presumably responding to the moment that slurry is applied. The different temporal pattern of organic and conventional saprovores communities indicates that the main difference between the two compared managements is the type and the intensity of fertilisation. Therefore, as Clough et al. (2007) revealed, the overall higher activity-density of saprovores in conventional fields might indicate good soil health and high potential productivity, which is in accordance to the reported higher mean crop yield in conventional fields (4,000-4,100 kg ha$^{-1}$ in conventional vs. 2,000-2,200 kg ha$^{-1}$ in organic fields, farmers *pers. com.*).

Hence, the higher abundance levels of most FG (plant-feeders, predators and parasitoids) in conventional fields at least in some sampling periods might be attributed to the response of the whole ecosystem taking advantage from the higher fertilisation. This also suggests that the N supplies are not only essential in order to guarantee a sustainable crop yield, but as well in order to maintain important roles on the agro-ecosystem such as organic matter recycling, predation and parasitism.

The lack of relation between suction-herbivores and farming management is one of the most striking results because it contradicts previous investigation's findings that suction-herbivores, particularly aphids, were favoured by higher N supplies (Duffield et al., 1997). One possible explanation might be that suction-herbivores were also favoured by conventional management, but as predators and parasitoids were enhanced in these fields a better biological control could occur. An alternative explanation could be that feeding-form perspective is not accurate enough for all taxa. For instance suction-herbivores category is mainly represented by aphids which share the feeding-strategy but not the host preferences. Thus, the suction-herbivores category might be mixing aphid's specialists in forbs with aphid's specialists in grasses, hindering the interpretation. Lastly, taking into account that our methodological approach does not address on the trophic interactions among FGs, more research is required to gain further insights into the relative role of fertilisation on trophic interactions in arable land agroecosystems in a Mediterranean climate.

A consistent response could not be found to farm management regarding the family richness of FG. Nevertheless, our findings are in accordance with earlier studies that simultaneously tackled the effects of farming management and landscape complexity on arthropod's diversity and they highlighted that species richness were more related to landscape complexity and perennial-dominated habitats availability than to management (Dauber et al., 2003, Holzschuh et al., 2007).

## Conclusions

The comparison of the community of aerial arthropods among organic and conventional fields from a taxonomic and a functional point of view shows that the response was much more robust by the latter. In addition, the functional approach has two major advantages: Firstly as it can be adopted from an adaptable taxonomic level, this implies that it saves time and money to have a multi-taxa approach. Secondly by adopting a FG approach a better assessment of the system response might be made. Additionally, using a FG approach of consumers provide an encouraging step forward to achieving greater understanding of the agro-ecosystem functioning. This functional approach should therefore be more widely applicable to different ecological systems and geographic regions than traditional taxonomic approaches.

Somewhat surprisingly, the community of arthropods was not enhanced in the studied organic fields in spite of their management without pesticides and a rotational scheme that includes cereals, legumes and polycultures. Similar trends might have been anticipated in organic and conventional fields, or even a higher abundance of arthropods in organic fields related to a richer and higher abundance of species due to the absence of herbicides. However, our results have shown that the high level of fertilisation of conventional fields and the lack of insecticides appear to be sufficient to enhance the whole arthropod community.

The results obtained in this study are specific to the location and investigated ecosystem. However, to test the effect of common agricultural practices in a given region on a large number of taxa, the first necessary step is to test new approaches, such as the feeding group perspective. Further studies are required taking into account other cropping systems in different geographical contexts to present the feeding group approach as the robust tool that can clear up the role of management in the regulation of arthropod populations.

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# Appendix 1

Total activity-density of arthropods captured by flight interception traps in organic and conventional fields. [a] Only families with a total abundance of pooled samplings higher than two are shown. Classification of all of them with respect to the feeding strategy is specified in juvenile (LF) and in adult stage (AF). **F**-Flower consumers, **C**-Chewing- herbivores, **O**-Omnivorous, **S**-Saprovores, **SP**-Suction-herbivores, **Pa**-Parasitoids, **Pr**-Predators, ◊-Non-functional role defined and **wti**-without trophic importance. The feeding categories were based on literature review and specialist advisor (see text for details).

| Order | Family [a] | Conventional | Organic | LF | AF |
|---|---|---|---|---|---|
| Coleoptera | Cantharidae | 31 | 32 | Pr | Pr |
| | Carabidae | 113 | 69 | Pr | Pr |
| | Cicindellidae | 0 | 4 | Pr | Pr |
| | Coccinellidae | 15 | 10 | Pr | Pr |
| | SpF. Curculionoidea | 39 | 51 | C | C |
| | Oedemeridae | 11 | 4 | S | F |
| | SpF.Scaraboidea | 128 | 88 | C | F |
| | SpF.Staphylinoidea | 1,201 | 1,100 | S | S |
| | *unidentified* | 1,162 | 1,370 | ◊ | ◊ |
| Diptera | Agromyzidae | 48 | 36 | C | F |
| | Anthomyiidae | 254 | 215 | C | F |
| | Asteiidae | 5 | 1 | S | F |
| | Bibionidae | 76 | 347 | S | wti |
| | Bombyliidae | 39 | 44 | Pa | F |
| | Calliphoridae | 5 | 12 | S | F |
| | Carnidae | 21 | 22 | S | F |
| | Cecidomyiidae | 618 | 537 | O | F |
| | Ceratopogonidae | 218 | 270 | S | F |
| | Chamaemyiidae | 5 | 3 | Pr | wti |
| | Chironomidae | 332 | 185 | S | F |
| | Chloropidae | 1,167 | 514 | O | F |
| | Conopidae | 5 | 3 | Pa | F |
| | Dolichopodidae | 37 | 34 | Pr | Pr |
| | Drosophilidae | 207 | 208 | S-C | S |
| | Empididae | 15 | 18 | Pr | Pr |
| | Ephydridae | 157 | 125 | C | F |
| | Heleomyzidae | 1 | 2 | S | S |
| | Hybotidae | 119 | 94 | Pr | Pr |
| | Limoniidae | 1 | 3 | S | S |
| | Lonchopteridae | 80 | 30 | S | wti |
| | Milichiidae | 16 | 16 | S | F |
| | Mycetophilidae | 14 | 24 | S | wti |
| | Muscidae | 27 | 44 | ◊ | F |
| | Opomyzidae | 9 | 7 | C | wti |
| | Otitidae | 0 | 5 | C | F |
| | Phoridae | 633 | 498 | Pr | F |
| | Psychodidae | 149 | 208 | wti | F |
| | Sarcophagidae | 18 | 37 | ◊ | F |
| | Scatopsidae | 76 | 53 | S | S |
| | Sciaridae | 686 | 506 | S | F |
| | Sepsidae | 3 | 11 | S | F |
| | Simuliidae | 13 | 11 | wti | F |
| | Sphaeroceridae | 382 | 170 | S | S |
| | Syrphidae | 15 | 6 | Pr | F |
| | Tachinidae | 32 | 35 | Pa | F |
| | Tephritidae | 5 | 24 | C | F |
| | Tipulidae | 7 | 3 | S | F |

# Appendix 1- continued

| Order | | | Family [a] | Conventional | Organic | LF | AF |
|---|---|---|---|---|---|---|---|
| Hemiptera | Heteroptera | | Anthocoridae | 96 | 66 | SP | SP |
| | | | Coreidae | 1 | 3 | SP | SP |
| | | | Lygaeidae | 24 | 39 | SP | SP |
| | | | Miridae | 82 | 94 | SP | SP |
| | | | Pentatomidae | 1 | 7 | SP | SP |
| | | | Tingidae | 0 | 3 | SP | SP |
| | Homoptera | | Aphididae | 2,288 | 2,837 | SP | SP |
| | | | Cicadellidae | 25 | 33 | SP | SP |
| | | | Cixidae | 7 | 4 | SP | SP |
| | | | Cercopidae | 24 | 52 | SP | SP |
| | | | Delphacidae | 5 | 2 | SP | SP |
| | | | Psillidae | 21 | 29 | SP | SP |
| Hymenoptera | Symphyta | | Cephidae | 1 | 2 | C | F |
| | | | Tenthredinidae | 44 | 119 | C | wti |
| | Apocrita | Parasitica | Aphelinidae | 11 | 4 | Pa | wti |
| | | | Braconidae | 185 | 128 | Pa | wti |
| | | | Ceraphronidae | 47 | 33 | Pa | wti |
| | | | Cynipidae | 17 | 10 | C | wti |
| | | | Diapriididae | 16 | 25 | Pa | wti |
| | | | Encyrtidae | 50 | 13 | Pa | wti |
| | | | Eulophidae | 85 | 65 | Pa | wti |
| | | | Eupelmidae | 2 | 2 | Pa | wti |
| | | | Eurytomidae | 10 | 21 | Pa | wti |
| | | | Figitidae | 5 | 7 | Pa | wti |
| | | | Ichneumonidae | 31 | 20 | Pa | wti |
| | | | Megaspilidae | 25 | 17 | Pa | wti |
| | | | Mymaridae | 54 | 35 | Pa | wti |
| | | | Ormyridae | 1 | 4 | Pa | wti |
| | | | Platygasteridae | 46 | 36 | Pa | wti |
| | | | Proctotrupidae | 18 | 10 | Pa | wti |
| | | | Pteromalidae | 53 | 48 | Pa | wti |
| | | | Scelionidae | 63 | 52 | Pa | wti |
| | | | Signiphoridae | 2 | 4 | Pa | wti |
| | | | Torymidae | 3 | 9 | Pa | wti |
| | | | Trichogrammatidae | 5 | 3 | Pa | wti |
| | | Aculeata | SpF.Apoidea | 1,034 | 1,109 | F | F |
| | | | Bethylidae | 16 | 11 | Pa | wti |
| | | | Chrysididae | 1 | 2 | Pa | F |
| | | | Dryinidae | 3 | 1 | Pa | Pr |
| | | | Formicidae | 56 | 76 | O | O |
| | | | Pompilidae | 2 | 2 | Pa | wti |
| | | | Scoliidae | 6 | 4 | Pa | F |
| Dermaptera | | | | 2 | 1 | O | O |
| Isoptera | | | Rhinotermitidae | 5 | 2 | wti | C |
| Lepidoptera | | | - | 121 | 128 | C | F |
| Neuroptera | | | Chrysopidae | 52 | 69 | Pr | S |
| Psocoptera | | | Peripsocidae | 63 | 27 | O | O |
| Acarina | | | | 38 | 40 | SP | SP |
| Araneae | | | | 228 | 182 | Pr | Pr |
| **Total** | | | | **12,593** | **13,184** | | |

# Capítol 4.2

B. Caballero-López, J.M. Blanco-Moreno, N. Pérez, J. Pujade-Villar, D. Ventura, F. Oliva & F.X. Sans. A functional approach to assessing plant-arthropod interaction in winter wheat (*submitted*).

# A functional approach to assessing plant-arthropod interaction in winter wheat

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## Abstract

This paper deals with the effect of farming management and plant community characteristics on arthropod communities by means of comparing organic and conventional, insecticide-free, winter wheat fields in the Mediterranean region. Arthropods and plants were surveyed sequentially in each plot within each field. Arthropods were identified to family and each taxa was classified into one of the following feeding groups: chewing-herbivores, suction-herbivores, flower-consumers, omnivores, parasitoids, predators and saprovores. Plant species were classified into three functional groups (grasses, forbs and legumes).

Management had no significant effect on the abundance or family richness of overall arthropod abundance and on most of the separate feeding groups. In contrast, plant community and, in particular, the cover of grasses and legumes affected the whole community of arthropods. This suggests that plant community characteristics at smaller scale than field must be taken into account to achieve a better comprehension of arthropods' response to the effect of management.

Although is still soon to have a clear perception of the importance of weeds in maintaining essential functions in arable land agroecosystems, the positive role of plant functional groups enhancing the presence of saprovores, parasitoids and predators highlights the strengths of this kind of functional approach.

Keywords: trophic strategies, farming management, feeding groups, plant functional groups, beneficial fauna.

# Resum

*L'article avalua el paper de la gestió, i la coberta vegetal sobre la comunitat d'artròpodes mitjançant la comparació de 4 camps de blat ecològics i 4 de convencionals lliures de l'aplicació d'insecticides a la regió mediterrània. A cada camp, els artròpodes i les plantes es van estudiar simultàniament en 5 parcel·les de 1m*$^2$ *distribuïdes equidistantment dins un transsecte de 100 m disposat en una de les diagonals i a una distància de 25 m del marge.*

*La major part de grups d'artròpodes capturats van ser identificats a nivell de família i classificats en set grups alimentaris: mastegadors, succionadors, consumidors florals, omnívors, parasitoids, depredadors i sapròfags. Alhora les plantes són englobades en tres grups funcionals (gramínies, lleguminoses i altres dicotiledònies).*

*La gestió agronòmica influencia l'abundància i la riquesa dels grups funcionals vegetals, però no sembla tenir un efecte directe sobre l'abundància i la riquesa total de famílies d'artròpodes, ni sobre la majoria de grups alimentaris. En contraposició, el recobriment de gramínies i lleguminoses condicionen la comunitat sencera d'artròpodes. Aquest resultat suggereix que les característiques de la comunitat vegetal a una escala menor que l'escala camp s'han de tenir en consideració per tal d'entendre la resposta dels artròpodes a la gestió agronòmica.*

*L'aproximació funcional ha permès destacar el paper positiu de la diversitat funcional de la comunitat vegetal sobre la presència de sapròfags, parasitoids i depredadors, però encara és aviat per comprendre quin és el paper de la comunitat arvense en el manteniment d'importants serveis dels agro-sistemes.*

## Introduction

Organic farming in arable land systems tends to increase weed species' richness, mainly due to the lack of herbicides and mineral fertilisers, and often more diverse crop rotational schemes (Bengtsson et al., 2005; Hole et al., 2005). However, the role of organic farming in promoting the abundance and diversity of arthropods is still a focus of debate. The comparison of different groups of arthropods between organic and conventional fields in arable systems have shown varying results (Clough et al., 2007; Purtauf et al., 2005; Schmidt et al., 2005; Shah et al., 2003; Weibull & Östman, 2003). Nevertheless, these mixed results are not too surprising, because other factors, which might also be affecting them, are poorly understood. For instance, although it is known that weeds are of central importance to arable system food webs (Hyvönen & Huusela-Veistola, 2008), the relationships between weed communities and arthropod populations has been scarcely tackled (Gabriel & Tscharntke, 2007; Gibson et al., 2006).

The highest number of linkages have been established between weed species and plant-feeding insects, because weeds serve as immediate food sources (Hyvönen & Huusela-Veistola, 2008). However, many predators and parasitoids also require pollen or nectar during their adult life stage (Bianchi & Wäckers, 2008; Jervis & Kidd, 1996). Moreover, as has been recently demonstrated, weeds within crop fields also support biodiversity at higher trophic levels, since they provide prey species with shelter and suitable reproduction sites (Marshall et al., 2003; Norris & Kogan, 2005). Thereby, considering that plants play an active role in the interplay between primary and secondary consumers (Cortesero et al., 2000), interactions between them can only be well-understood when the plant community is also considered. For this reason, the vegetation parameters of the habitat at a smaller than field scale should be considered in the comparison between organic and conventionally-managed cereal fields in arable systems. In addition, many studies comparing farming types include insecticide applications in conventional management, which is known to represent the major negative direct influence on invertebrate communities (Hole et al., 2005). Thus, the dramatical difference in insecticide use could be hiding interaction between plant and arthropod assemblages in most of these comparisons. Therefore, the comparison of organic and conventional, insecticide-free systems in a Mediterranean context appears as a suitable model to further explore the interactions between arthropod and plant communities.

On the other hand, many of the early works investigating the effects of plant communities and farming types on arthropods have tended to concentrate either on a single trophic level (Hartley & Jones, 2003) or on an individual insect family (Brose, 2003; Melnychuk et al., 2003). However, predictions regarding the effect of farming on arthropods based on a small number of taxa or only one trophic group may not be generalised to the entire community (Voigt et al., 2007) because arthropods have a wide range of functional roles in ecosystems (Maleque et al., 2006). As a whole ecosystem approach cannot possibly be obtained in a context of limited financial and human resources, adequate measurable surrogates need to be found.

One possibility is to assess plant-arthropod interaction by means of a functional approach. Plant species might be grouped according to their differences in the quality of tissues that really show an impact on arthropod communities (Haddad et al., 2001; Koricheva et al., 2000). Previous studies have pointed out that arthropods which share ecological characteristics and play an equivalent role in the community could also be grouped regardless of their taxonomic affiliation (Hawes et al., 2009; Perner et al., 2003; Voigt et al., 2007). This functional approach to arthropods based on form of feeding can provide more robust estimates because while the composition of taxa may be altered by environmental conditions, feeding groups (FGs hereafter) remain stable (Voigt et al., 2007). Whichever approach is used, the process of amalgamating taxa into FGs necessitates accepting assumptions about the importance of certain common features. Nonetheless, the FG approach based on form-of-feeding traits may be able to predict more consistent patterns than those based on taxonomic units (Clough et al., 2007; Perner et al., 2003).

We hypothesize that the total abundance and total family richness of arthropods and the abundance and family richness of each FG may not differ between organic and conventional cereal fields in insecticide-free systems under Mediterranean conditions. However, we speculate that we might detect individual patterns of abundance and richness of the different FGs of arthropods in relation to plant community characteristics, because each feeding group has specific foraging, reproduction and overwintering needs. To this end, this paper deals with the effect of farming (organic vs. conventional) and plant community characteristics on the community of arthropods. Our research goals were to assess (1) the effect of management on the total abundance and total family richness of arthropods and on the abundance and family richness of each FG of arthropods, and (2) the effect of total vegetation cover, the cover of grasses, forbs and legumes, and weed species richness, on the total abundance and total family richness of arthropods and on the abundance and family richness of each FG of arthropods.

## Methods

### *Study site*

The study was carried out in Montblanquet (NE of Spain), a small village located about 150 km south of Barcelona (41º29'0.9''N, 1º7'16.4''E; 627 m above sea level). The agricultural landscape is dominated by woodlands, mainly pines (*Pinus nigra* subsp. *salzmannii*) and evergreen and deciduous oaks (*Quercus ilex* and *Q. faginea*, respectively), scrublands and perennial dominated grasslands. The arable fields, mainly cereals, represent a small percentage of the agricultural landscape (40%) and were intermingled with patches of natural vegetation. Field boundaries were mainly colonised by perennial grasslands dominated by *Brachypodium phoenicoides* and by a mixture of blackthorn-bramble hedgerows and thickets of *Rosmarinus officinalis*. The climate is Mediterranean, with a mean annual precipitation of 450 mm and a mean annual temperature of 13 ºC.

### *Experimental design*

Four organically and four conventionally-managed winter wheat fields were selected in an homogeneous area of 2 × 2 km to study the effects of management on the community of arthropods in dry-land cereal fields. The organic fields were selected first, and afterwards the conventional fields, no more than 1 km apart, but detached from the organic ones. Despite trying to select fields that matched in size and shape, we considered that the homogeneity of the vegetation of the boundaries was more important than the homogeneity of the field's size and shape, as in all cases the fields were relatively small. For this reason, field size was significantly greater in conventional fields (mean ± SE; 4.08 ± 0.8 ha) than in organic fields (2.19 ± 0.3 ha; $\chi^2_{\mathrm{df}} = 5.78_1$, *P* value = 0.016). In contrast, perimeter to area ratio was significantly greater in organic fields (mean ± SE; 0.09 ± 0.01) than in conventional fields (0.06 ± 0.01; $\chi^2_{\mathrm{df}} = 4.85_1$, *P* value = 0.028). While weeds were controlled mechanically and fertilisation relied on green manure and occasionally hen manure in organic fields, the conventional ones were sprayed with herbicides and fertilised with a combination of pig slurry and mineral fertilisers. Pesticides other than herbicides were not applied under conventional management.

The selected organic fields had been managed for more than one decade following the organic guidelines and were certified by the Catalan Council for Organic Farming (CCPAE). All selected fields were sown with winter wheat (*Triticum aestivum*) between the last week of October and the first week of November 2003, after seedbed preparation with harrowing at 15-20 cm depth (for further details see table 1).

**Table 1** Agronomic characteristics of the fields included in the study.

| Management | Organic | Conventional |
|---|---|---|
| Crop rotation | Legume/ winter wheat/ polyculture | Winter wheat/ winter barley |
| Tillage | 3 times, 20 cm of depth | 3 times, 15 cm of depth |
| Cereal | Winter wheat cv. *Bonpain* | Winter wheat cv. *Etecho* (2 fields), *Soissons* (2 fields) |
| Sowing density (kg ha$^{-1}$) | 180-200 | 170-200 |
| Nitrogen inputs (kg N ha$^{-1}$) | Green manure and occasionally hen droppings (<160) | ~ 180 of pig slurry/year<br>< 100 of mineral N at times |
| Weed control | Mechanical | Mechanical and Chemical* |
| Pests and diseases control | None | None |

*All conventional farmers applied Glyphosate (N-(phosphonomethyl) glycine at 2.5 L ha$^{-1}$) and 2-4-D (2,4-dichlorophenoxy at 1.3 L ha$^{-1}$) as pre-emergence non-specific herbicides, Splendor 25 SC (Tralkoxidin at 1.6 L ha$^{-1}$) as a post-emergence grass herbicide and Oxytril (ioxinil, bromoxinil, and mecoprop) at 2 L ha$^{-1}$) as a broad-leave herbicide.

### *Arthropod sampling*

In each field we established a 100 m-transect, diagonally from the field boundary towards the centre, allowing for a strip 25 m wide to avoid the edge effect. Within each transect, five 1 × 1 m plots at 20-m intervals were surveyed. Arthropod sampling and plant survey were carried out one after the other within each plot. The arthropods were sampled using a petrol-driven Blow&Vac leaf-blower apparatus (McCullogh BVM250, Italy; sampling cylinder 60 cm high and 12 cm diameter) converted to a suction sampler according to Stewart and Wright (1995). The suction sampler was operated on full power, which we assumed would produce a constant air flow of 0.142 $m^3/s$ (manufacturer's data). The pipe was held vertically, carefully moved over the wheat plants contained in the $1m^2$ quadrate and exhaustion was performed for 60 seconds. For each plot the sampling bag was removed from the machine, enclosed in a labelled plastic bag, and stored in a portable fridge in order to prevent the activity of predators in the bag. The apparatus operator repeated the procedure five times in each field, and all samples were taken by the same two people to reduce the variability of sampling. In spite of the drawback of suction samplers, which generate activity-density measurements and not absolute abundance measurements, this method has been shown to provide a sound representation of all trophic levels interacting with vegetation (Letourneau & Goldstein, 2001), and is used extensively to study arthropods in crops (Elliott et al., 2006; Stewart & Wright, 1995). Arthropod sampling was carried out between 10:00 and 19:00 under sunny weather (temperature > 20 ºC), and was performed twice, at different stages of wheat development (Zadoks et al., 1974), at the beginning of wheat anthesis stage between the 25th and 27th May and the mid milk-ripe stage between the 24th and 26th of June, 2004. As one sampling campaign lasted 2 days, the 8 fields were sampled in random order to prevent a systematic bias due to day-time. The average daily maximum temperatures during the spring sampling period ranged from 20 to 33 ºC.

*Arthropod processing*

Arthropod samples were frozen for sorting and identification at a later date. Catches were quantified as the total numbers of individuals, considering adults and immature stages, and were identified to family (most arthropods) or to order (Lepidoptera and Thysanoptera) level.

The use of higher taxonomic levels has been successfully tested as surrogates for inventories at species level (Balmford et al., 1996; Wickramasinghe et al., 2004), and it is particularly useful when a feeding group (FG) perspective is required, as the majority of members of a family belong to the same feeding group (but see some considerations below). For this reason most arthropods were identified to family level, although there were a few exceptions to the sorting pattern. For instance, when taxa of the same family displayed different feeding preferences (e.g. Drosophilidae, Opomizidae) their individuals were determined to genus or species in order to assign them to the most appropriate feeding group.

Most taxa were classified into one of the seven feeding groups: suction-herbivores (SP), chewing-herbivores (C), omnivores (O), flower-consumers (F), saprovores (S), predators (Pr), and parasitoids (Pa). Each FG enclosed different feeding strategies and the assignment of these groups of taxa was based mainly on field observations and literature review. Complementary expert advice was also sought (see Acknowledgements). The saprophagous category included: mycetophagous organisms, plant saprovores, animal saprovores and scavengers. Granivores, plant-chewers and miners were included in the chewing-herbivorous category, while plant-sap suckers belong to the suction-herbivorous category. Flower-consumers comprised flower predators, pollen consumers and nectarivorous. When some individuals of the same family displayed different feeding preferences (e.g. Merylidae, Staphylinidae) they were determined to genus or species in order to assign them to the most appropriate feeding group. When arthropods showed different feeding preferences in larvae and adult stages (see Appendix 1), they were assigned to both FGs in order to consider their whole lifetime impact. A small number of larvae were difficult to classify, thus they were considered in the total abundance, but excluded from FG analyses and categorised as non-functional role defined. In addition, other groups such as most parasitoids in adult stage do not feed or their effect is so small that is considered insignificant, thus they were also categorised as without trophic interaction. Although our suction catches correspond to measurements of activity-density more than total abundance numbers we will use the abundance term to simplify explanations.

### *Vegetation sampling*

Vegetation sampling was carried out twice concomitant with suction-sampling. Crop and weed cover were recorded in each plot following a ground cover scale with the following intervals: 0-1, 1-5, 5-10, 10-25, 25-50, 50-75 and 75-100%. Species cover was assigned to the midpoint of its cover-class. Plant species were classified into three functional groups (grasses, forbs and legumes). Legumes have been separated from the other forbs due to the generally higher nitrogen content of their tissues, which would make them a higher-quality resource for herbivores. Grasses have tough tissues with low nitrogen content and structural characteristics that deter plant-feeders. We did not distinguish grasses by their photosynthetic pathway ($C_3$ and $C_4$), as all grasses identified belong to the $C_3$ category. Weed species were identified according to Bolòs et al. (2005).

### *Statistical analyses*

We established the following framework for the statistical analysis of the agroecosystem's different trophic levels, considering different guidelines for the analysis of plants and arthropods which, in turn, have differentiated analyses for primary and secondary consumers.

Models of total plant cover and species richness as well as for the different plant functional groups (grasses, forbs and legumes) were analysed using farming management and sampling period as fixed factors. In addition, total plant cover was also included in all models of plant species richness to correct the expected correlation between plant abundance and species richness. Arthropod models included farming management and sampling period as fixed factors and a common set of covariables (cover of forbs, legumes and grasses and total richness of plant species) in order to test the response of arthropods to the amount of resource and its diversity.

Primary consumers (C, F, O, S, and SP) were analysed considering only these variables. However, in the analysis of secondary consumers (Pa, Pr) we considered some additional variables because of their different ecological requirements that differed depending on the focus. When we modelled secondary consumers' family richness we included the family richness of the different primary consumers' groups, which can act as potential preys or hosts. When the focus was on secondary consumers' abundance, we substituted richness measurements for their abundance counterparts (primary consumers' FG activity-density measures). The inclusion of plant related variables in secondary consumers' models accounts for the possibility of indirect effects of plant cover on their activity-density measurements.

All the models exposed were analysed by means of linear mixed models with normal error distribution, and including field as a random effect term to account for the fact that samples in the same fields are not independent (Pinheiro and Bates, 2000). Prior to analysis, collinearity of the sets of independent variables included in the models was evaluated with the variance inflation factor $1/(1-R^2)$ in order to check the model robustness (Kutner et al., 2004). Assumptions of linearity, normality, and homogeneity of variances were evaluated through examination of residuals, and count data were square-root-transformed when needed. All full models were simplified to the minimum number of significant explanatory variables by means of stepwise removal of non-significant predictors and the examination of Akaike Information Criterion.

All the analyses were performed on R 2.8 (R Development Core Team, 2008); library lme4 (Bates et al., 2008) was used for model fitting and library languageR (Baayen, 2008) was used to determine the significance of the predictors by means of Markov Chain Monte Carlo methods.

# Results

## *Plants*

Altogether, 40 weed species were recorded, 26 of these were forbs, 8 legumes and 6 grasses. 35 of those were recorded in organic fields (24 forbs, 8 legumes, 3 grasses) and only 15 (10 forbs and 5 grasses) were found in conventional fields. Most of these species occurred in one or two fields only, indicating a high variability in local occurrence (see Appendix 1). The mean total plant cover was significantly higher in conventional than in organic fields, mainly related to the higher wheat cover, and the also related higher mean yield in conventional (4,000-4,100 kg $ha^{-1}$) than in organic (2,000-2,200 kg $ha^{-1}$) fields (farmers *pers. com.*).

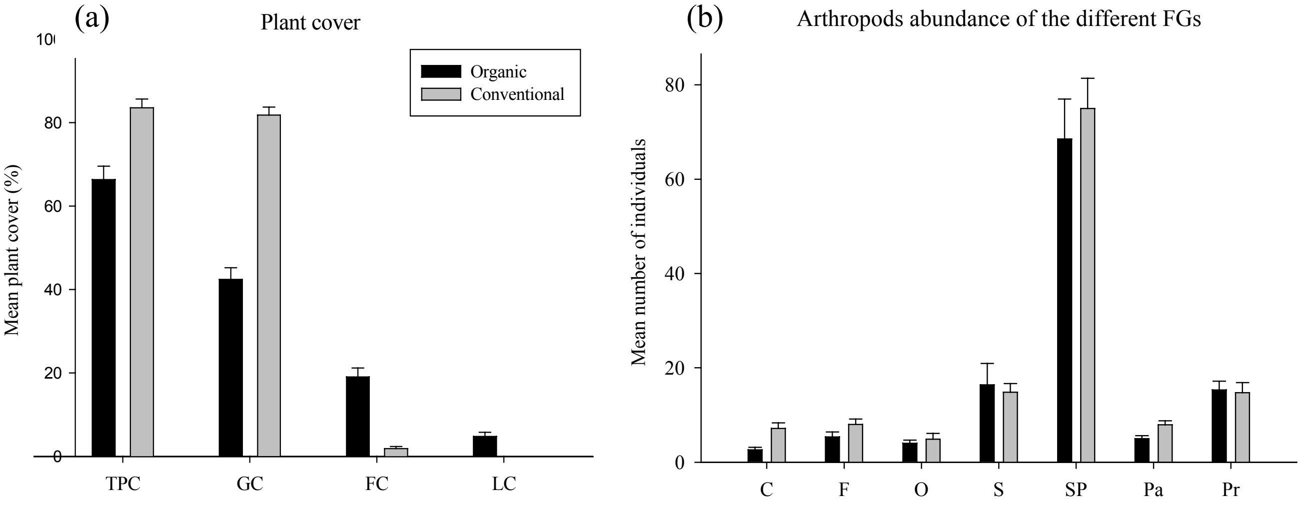

**Figure 1** (a) - Total plant cover (TPC) and cover of grasses (GC), forbs (excluding legumes) (FC) and legumes (LC). (b)- Abundance of each feeding group in organic and conventional cereal fields. C = Chewing-herbivores, F = Flower consumers, O = Omnivores, S = Saprovores, SP = Suction-herbivores, Pa = Parasitoids, and Pr = Predators. Data are means with standard error

The mean relative cover of forbs was significantly higher in organic than in conventional fields (Fig. 1a, table 2). The mean total plant species richness was more than twice as high in organic than in conventional fields (mean ± SEM: organic: 8.2 ± 0.3, conventional: 3.1 ± 0.2). While significantly higher number of forbs (mainly Brassicaceae and Polygonaceae) was found in organic than in conventional fields (organic: 4.7 ± 0.2, conventional: 1.1 ± 0.2), no significant differences in grasses (organic: 1.7 ± 0.2, conventional: 2.0 ± 0.1) between organic and conventional fields were found (Figure 1a, table 2). Furthermore, legumes exclusively thrive in the organic fields either as weeds or volunteer crops (e.g. *Vicia ervilia*).

**Table 2** The effects of farming management and sampling period on cover and species richness for plant measures. Minimum models are shown and only significant descriptors appear in the table. $P \geq 0.10$, '**.**'; $P < 0.10$, $^{(.)}$; $P < 0.05$,*; $P < 0.01$, **; $P < 0.001$, ***.

| | Farming | Sampling |
|---|---|---|
| Total plant cover | 19.05* | . |
| Grasses cover | 40.33*** | . |
| Forbs cover | - 3.01*** | -0.61* |
| Total plant richness | -5.08*** | -0.48 $^{(.)}$ |
| Grasses richness | . | . |
| Forbs richness | - 3.60*** | . |

*Arthropods*

We collected a total of 8,931 arthropods, comprising of 14 orders and 82 families. The suction- phytophagous (62%) was the most abundant category, predators (12.4%) and saprophagous (10.5%) appeared in lower abundance, and whereas the remainder included flower-consumers (5.8%), parasitoids (4.8%), chewing-phytophagous (2.5%), and omnivorous (2%) categories (Fig. 1b). The richest FG was predators, containing almost a quarter of the total number of families, followed by flower-consumers (17.3%), parasitoids (16.1%), saprovores (14.8%), suction-herbivores (13.6%), chewing-herbivores (11.1%), and the omnivores with a 2.5% (Appendix 2). The low abundance and family richness of omnivores prevented their detailed analyses.

The abundance and family richness of the entire arthropod community as well as for the different FGs differed significantly among samplings (tables 3-4), indicating the drastic changes in terms of arthropod community that occur in a short period of time in winter cereal crops. Mean total arthropod abundance tended to be larger in conventional (mean ± SE; 123.9 ± 8.4) than in organic fields (mean ± SE; 113.5 ± 10.3), but did not differ significantly, while the abundance of chewing-phytophagous was significantly greater in conventionally-managed fields (table 3). Similar to abundance, the mean total family richness tended to be higher in conventionally (mean ± SE; 20.8 ± 1.2) than in organically-managed fields (18.9 ± 1.5), but without a significant response while family richness of some feeding groups were significantly affected by management. For instance, predatory taxa exhibited significantly greater family richness in organic than in conventional fields (table 4), whereas a higher family richness of flower consumers were caught in conventional fields.

**Table 3** Minimum models for the effects of farming, sampling period, cover of grasses and legumes and plant species richness on abundance and family richness for total arthropod measures and for functional groups of primary consumers. Only significant descriptors appear in the table. $P \geq 0.10$, '**.**'; $P < 0.10$, $^{(.)}$; $P < 0.05$,*; $P < 0.01$, **; $P < 0.001$, ***. When an estimate value appears with *ns* as super index means that the best model according to AIC also included this non-significant descriptor.

| | Farming | Grasses | Legumes | Plant richness | Sampling |
|---|---|---|---|---|---|
| **Abundance** | | | | | |
| Total abundance | . | 0.05** | . | . | 3.55*** |
| Chewing-herbivores | 1.14* | . | . | . | $0.47^{(.)}$ |
| Flower-consumers | . | 0.03*** | $0.06^{(.)}$ | . | 0.88** |
| Saprovores | . | 0.02*** | . | 0.09* | 0.73*** |
| Suction-herbivores | . | . | . | . | 2.06** |
| **Richness** | | | | | |
| Total family richness | . | 0.24*** | 0.54*** | 0.67* | 13.15*** |
| Chewingherbivores | . | . | $0.08^{(.)}$ | . | . |
| Flower-consumers | 1.67** | . | . | . | 1.00** |
| Saprovores | . | 0.05*** | $0.07^{ns}$ | . | 2.10*** |
| Suction-herbivores | . | 0.03*** | 0.08* | 0.27*** | 3.04*** |

The activity-density models displayed that total abundance of arthropods, flower-consumers, parasitoids, and saprovores were positively correlated to grass cover. Moreover, the abundance of saprovores was also positively related to plant species richness, whereas the abundance of flower-consumers tends to be enhanced by a higher cover of legumes (tables 3-4). The analysis of the pattern of abundance of suction-herbivores in relation to farming and plant community parameters exhibited that the abundance was similar among organic and conventional fields and did not reveal any relation to plant community. The abundance of predators was significantly higher in plots with a higher abundance of flower-consumers and saprovores, while the abundance of parasitoids was positively related to flower-consumers and suction-herbivores (table 4).

The total family richness of arthropods and the suction-herbivore family richness were greater in plots with higher plant species richness and, were also positively related to cover of grasses and legumes. The family richness of saprovores, parasitoids and predators were significantly correlated to the grass cover, whereas the family richness of chewing-herbivores and parasitoids were closely associated to the cover of legumes (tables 3-4). Furthermore, the family richness of suction-herbivores had a significant effect on the models of predators and parasitoids while the family richness of chewing-herbivores also displayed a significant effect on the predator richness model, suggesting a relationship among these groups (table 4).

**Table 4** Summary of the minimum models for the effects of farming, sampling period, cover of grasses and legumes and plant species richness on abundance and family richness for functional groups of secondary consumers. C = Chewing-herbivores, F = Flower-consumers, S = Saprovores, SP = Suction-herbivores. Only significant descriptors appear in the table. $P \geq 0.10$, '**.**'; $P < 0.10$, (.); $P < 0.05$,*; $P < 0.01$, **; $P < 0.001$, ***.

| | Farming | Grasses | Legumes | Abundance | | | Richness | | Sampling |
|---|---|---|---|---|---|---|---|---|---|
| | | | | S | SP | F | C | SP | |
| **Abundance** | | | | | | | | | |
| Parasitoids | . | 0.01** | . | . | . | 0.23** | - | - | 0.91*** |
| Predators | . | . | . | 0.25** | 0.05* | 0.50*** | - | - | 1.17*** |
| **Richness** | | | | | | | | | |
| Parasitoids | . | 0.04*** | 0.11** | - | - | - | . | 0.38** | 1.78** |
| Predators | -1.38* | 0.05*** | . | - | - | - | 0.29* | 0.38*** | 3.10*** |

# Discussion

Plant and arthropod communities benefit differently from organic and conventional cropping of winter cereals. The higher total plant species richness and, in particular, forbs species richness of organic fields is in accordance with previous studies, which found that organic farming promotes weed diversity of agroecosystems (Gibson et al., 2006, Hyvönen et al., 2003, Romero et al., 2008). The importance of legumes in terms of abundance and diversity in organic fields has already been stated by Romero et al. (2008) in Mediterranean cereal fields. Conversely, despite large differences in the weed community between organic and conventional fields, management *per se* did not affect either the general descriptors of arthropod community or most feeding groups. These results suggest that the effects of management of cereal fields in the Mediterranean region, where insecticides are not applied, does not differ substantially between organic and conventional. Previous authors also highlighted that the small differences in species composition between farming systems, which might be due to differences in farming practices, were not really marked (Weibull and Östman, 2003, Weibull et al., 2003).

Otherwise, our findings show that vegetation parameters really do have an effect on the pattern of abundance and family richness of the entire arthropod community and of the different FGs. Accordingly, total arthropod family richness is positively related to cover of grasses and legumes, and plant species richness. Therefore, the high availability of resources provided by a rich plant community could directly or indirectly benefit arthropods. This may partly explain the mixed results of past comparisons, which did not consider the effect of plant community on arthropods when farming intensity was tested (Clough et al., 2007, Purtauf et al., 2005, Schmidt et al., 2005, Shah et al., 2003, Weibull et al., 2000, Weibull and Östman, 2003).

*Suction-herbivores and chewing-herbivores*

The number of suction-herbivores individuals across fields was similar regardless of farming, while the pattern of family richness of suction-herbivores is closely related to vegetation parameters. It would therefore appear that the strong positive effects of plant species richness and cover of grasses and legumes on suction-herbivore richness might be attributed to a bottom-up effect. Since the family richness of suction-herbivore may be benefited of the greater availability of alternative resources that might be found in a richer plant community (Haddad *et al.*, 2001). These findings are in accordance with previous studies showing that the diversity of plant-feeders is related to the diversity of their resources (Knops *et al.*, 1999; Murdoch *et al.*, 1972; Siemann *et al.*, 1998). The enhancement of chewing-herbivore richness in relation to legume cover seems to show a response to a source rich in N supply. Conversely, the abundance of chewing-herbivores did not show any relation to vegetation parameters and just showed a higher abundance in conventional fields. Because chewing-herbivores are more related to plant biomass than to plant diversity (Haddad et al., 2001), and although no biomass data were collected in the present study, it is known that plant biomass in wheat conventionally-managed fields is higher than in organic fields, due to a higher fertilisation and also higher mean yields (Poveda et al., 2006).

*Saprovores*

The saprovores community did not seem to be more diverse or to have higher abundance in organic fields (see table 3). This is contrary to the results of other studies showing positive effects of organic agriculture on taxa involved in decomposition (Clough et al., 2007, Mäder et al., 2002, Moreby et al., 1994). Nevertheless, this is not surprising because saprovores are likely to benefit from organic fertilisation and our organic and conventional fields did not differ in this aspect. The role of slurry fertilisation with respect to green manure on saprophagous arthropods still remains unclear. Otherwise, the greater abundance of saprovores in plots with higher plant species richness suggests that they benefit from a richer plant community. Little is known about the effect of weeds on soil-associated arthropod decomposers. However, Wardle et al. (1999) demonstrated that soil-associated arthropods were enhanced by a richer plant community, presumably in part due to the high quality of plant debris being returned by the weed community into the soil. In this respect, our data supports these findings, suggesting that the enhancement of saprovores in relation to a richer plant community could be due to the higher quality of weed residues.

*Flower-consumers*

Flower-consumers tend to be correlated to legume cover which provide floral food resources, such as nectar and pollen (Bianchi and Wäckers, 2008). However, the positive effect of legumes is just marginally significant in our observational data. On the other hand, we have found surprising outcomes such as the apparent positive relation between the cover of grasses and the abundance of flower-consumers. This relationship could not represent a resource-consumer relation, and thus flower-consumers may be responding to another related effect of cover of grasses independently of the amount of food available. Therefore, this pattern might be understood in terms of flower-consumers benefiting from a structurally rich environment, which can provide a shelter against the pressure of natural enemies such as predators and parasitoids (Lawton, 1983, Ritchie and Olff, 1999, Southwood et al., 1979). The importance of plant community structure influencing the movement, the duration of stay and the risk of predation mortality have been pointed out for plant-feeders (Casas and Djemai, 2002) and predatory groups (Kromp and Steinberger, 1992, Kruess and Tscharntke, 2002, Moreby et al., 1994, Norris and Kogan, 2000). Nonetheless, information on this subject is rather limited (Obermaier et al., 2008), particularly on the taxa comprised in the flower-consumer group. As Brose (2003) suggested, bottom-up control might not only be mediated by the species richness and functional groups of the plant communities so vegetation structure may be more important than previously suggested.

*Predators, parasitoids and their interactions with primary consumers*

The abundance of predators and parasitoids is mainly conditioned by the abundance of their potential prey regardless of management or plant community (table 4). Thus, higher flower-consumer abundance led to higher predator and parasitoid abundances. This response concurs with patterns emerging from the comparison of correlation coefficients among herbivores, predators and parasitoids of previous studies (Haddad et al., 2001, Koricheva et al., 2000).

The abundance of predators is also positively related to the abundance of suction-herbivores and saprovores. These findings have already been previously reported by Haddad et al. (2001) and Wardle et al. (1999). Nonetheless, the relation between suction-herbivores and predators has aroused much more controversy and attention than the interaction between saprovores and predators, due to the implications for pest management. Thus, our findings support the results of Wardle et al. (1999), which state that predators can switch between preys belonging to decomposed food-webs and those belonging to leaf-based food-webs.
Our variable taxonomic level of identification does not enable us to explore specific relations, but the strong significant relationship between the abundance of primary and secondary FG consumers emphasises the importance of adopting a functional approach to better understanding the interactions of predator-prey and parasite-host in arable-land ecosystems.

The family richness of parasitoids and predators is significantly related to family richness of plant-feeders (C and SP). These findings are in line with earlier theoretical and experimental studies, which highlighted that the diversity of predators and parasitoids was related to the diversity of their resources (Haddad et al., 2001, Knops et al., 1999). The higher diversity of secondary consumers might avoid the super-dominance of one group of primary consumers and allows a higher diversity of herbivores to coexist on the same resource (Siemann, 1998, Siemann et al., 1998).

Predator richness is favoured by organic management (table 4). Similarly, Norris & Kogan (2000) reviewed that predators were enhanced in a richer plant system because they could usually eat plants as alternative resources, but according to our results predators did not seem to respond to a greater plant diversity. In this respect, the pattern observed in relation to organic cropping could be attributed to the fact that predators may benefit from increased prey diversity in organic cropping. Parasitoids, however, showed a correlation to a cover of legumes, which indicates a direct enhancement to floral resources from legumes (Bianchi and Wäckers, 2008).

## Conclusions

The comparison of insecticide-free organic and conventional cereal fields in the Mediterranean region shows that the abundance and family richness of total arthropods and of most FGs does not vary with field-scale management factors. However, plant community characteristics at a scale smaller than field had a significant effect on the entire community of arthropods, especially the cover of grasses and legumes. This highlights that analysis of the relationships between farming and arthropods needs to take into account the plant community to study in depth the role of plant richness in determining the diversity of arthropods in higher trophic levels and, in turn, their effect on ecosystem structure and function.

Our results show that abundance and family richness of primary and secondary consumers seems to be directly affected by plant community. Thus, it remains unclear whether changes in family richness of secondary consumers are driven more by changes mediated through primary-consumer family richness, changes by direct response to plant community or a mixture of both of these.

Although a high amount of weeds during the period of crop growth is clearly contradictory to the goals of enhanced crop production, our study supports that increased weed diversity may contribute directly or indirectly to the enhancement of beneficial fauna such as saprovores, predators and parasitoids. Thus, the challenge lies in designing cropping systems that match crop production with the conservation of weed diversity, thereby creating more robust and resilient systems capable of withstanding higher levels of weed diversity to guarantee the presence of beneficial fauna, which is essential to the correct functioning of the agroecosystem.

The results obtained in this study are specific to the location and ecosystem being investigated. However, the fact that our findings based on a functional approach are in accordance with previous studies based on taxonomy supports the view that this functional approach could be more widely applied to different ecological systems and geographic regions. Moreover, it has two major advantages with respect to the taxonomic approach: (i) the level of family used in the FG groups implies a saving of time and money to have a multi-taxon approach, which appears to be better than using indicator species to monitor responses, and (ii) using an FG approach of consumers provides an encouraging step forward to achieving greater understanding of the mechanisms of naturally-occurring biological control. Nevertheless, more work is needed to further disentangle the web of interactions between plant and consumer diversity and ecosystem functioning, in order to plan how to enhance natural enemies and their ability to suppress pests by environmentally-friendly agro-ecosystem management.

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# Appendix 1

Absolute frequencies of main weed species in organic and conventional fields. Number indicates the number of plots/samples where the species has been found during the two sampling periods (see text for more details). Only species with total frequency higher than three are shown.

| | Organic | Conventional |
|---|---|---|
| **Grasses (C3)** | | |
| *Avena sativa* L. | 4 | 0 |
| *Avena sterilis* L. | 7 | 12 |
| *Bromus diandrus* Roth | 0 | 5 |
| *Bromus sterilis* L. | 0 | 4 |
| *Lolium rigidum* Gaud. | 17 | 18 |
| **Forbs** | | |
| *Anagallis arvensis* L. | 5 | 0 |
| *Anchusa italica* Retz. | 4 | 0 |
| *Centaurea scabiosa* L. | 13 | 1 |
| *Cirsium arvense* (L.) Scop. | 23 | 0 |
| *Convolvulus arvensis* L. | 30 | 5 |
| *Fumaria officinalis* L. | 6 | 1 |
| *Galium tricornutum* Dandy | 30 | 6 |
| *Lepidium draba* L. | 11 | 3 |
| *Papaver hybridum* L. | 5 | 0 |
| *Papaver rhoeas* L. | 21 | 16 |
| *Polygonum aviculare* L. | 7 | 8 |
| *Rapistrum rugosum* (L.) All. | 15 | 0 |
| *Scandix pecten-veneris* L. | 3 | 0 |
| **Legumes** | | |
| *Coronilla scorpioides* (L.) Koch | 14 | 0 |
| *Medicago lupulina* L. | 17 | 0 |
| *Medicago sativa* L. | 14 | 0 |
| *Vicia ervilia* (L.) Willd. | 3 | 0 |
| *Vicia hybrida* L. | 5 | 0 |
| *Vicia peregrina* L. | 8 | 0 |
| *Vicia sativa* L. | 9 | 0 |

# Appendix 2

Mean abundance (± *SEM)* of the different taxonomical groups in organic and conventional fields. The two surveys are included in the mean abundances. ***A*** represents the total number of catches and in brackets it is shown the number of fields where it was found (nf). *FS*$^{=}$ Animal feeding strategy. **S**- Saprovores, **F**- Flower-consumers, **O**- Omnivores, **C**- Chewing-herbivores, **SP**- Suction-herbivores, **Pa**- Parasitoids, **Pr**- Predators, ◊ No functional role defined, **wti**- without trophic importance (see text for more details).

| *Order* | *Families* | *Organic fields* | ***A*** (nf) | *Conventional fields* | ***A*** (nf) | *FS Larvae/ Adult* |
|---|---|---|---|---|---|---|
| Acari | | 63.3 ± 35 | 253 (4) | 7.0 ± 1.8 | 28 (4) | SP/SP |
| Araneae | Araneidae | 4.0 ± 0.9 | 16 (4) | 5.3 ± 2.0 | 21 (4) | Pr/Pr |
| | Clubionidae | 0.5 ± 0.3 | 2 (2) | - - - | - | Pr/Pr |
| | Gnaphosidae | 0.5 ± 0.5 | 2 (1) | 0.5 ± 0.3 | 2 (2) | Pr/Pr |
| | Linyphiidae | 8.0 ± 3.3 | 32 (4) | 31.5 ± 12.0 | 126 (4) | Pr/Pr |
| | Lycosidae | - - - | - | 0.8 ± 0.8 | 3 (1) | Pr/Pr |
| | Miturgidae | 0.5 ± 0.3 | 2 (2) | - - - | - | Pr/Pr |
| | Salticidae | 1.0 ± 0.7 | 4 (2) | 0.3 ± 0.3 | 1 (1) | Pr/Pr |
| | Sparassidae | - - - | - | 1.0 ± 0.4 | 4 (3) | Pr/Pr |
| | Tetragnathidae | 0.5 ± 0.5 | 2 (1) | 0.5 ± 0.3 | 2 (2) | Pr/Pr |
| | Theridiidae | 26 ± 16.4 | 104 (2) | 2.0 ± 0.6 | 8 (4) | Pr/Pr |
| | Thomisidae | 7.0 ± 2.0 | 28 (4) | 6.5 ± 1.4 | 26 (4) | Pr/Pr |
| Collembolla | Entomobryidae | 5.75 ± 4.0 | 23 (2) | 1.75 ± 1.0 | 7 (2) | S/S |
| | Sminthuridae | 88.8 ± 60.1 | 355 (4) | 45.3 ± 23.7 | 181 (4) | S/S |
| Coleoptera | larvae *unidentified* | 17.8 ± 5.9 | 71 (4) | 10.8 ± 3.9 | 43 (3) | ◊ |
| | Anthicidae | 1.3 ± 0.5 | 5 (3) | 1.8 ± 0.9 | 7 (3) | S/S |
| | Apionidae | 0.8 ± 0.5 | 3 (2) | - - - | - | C/C |
| | Carabidae | 2.3 ± 1.3 | 9 (4) | 2.5 ± 0.3 | 12 (4) | Pr/Pr |
| | Cerambicidae | 0.3 ± 0.3 | 1 (1) | 0.3 ± 0.3 | 1 (1) | C/◊ |
| | Chrysomelidae Bruchinae | 1.3 ± 0.5 | 5 (3) | 0.3 ± 0.3 | 1 (1) | C/FC |
| | Coccinellidae | 7.0 ± 2.4 | 28 (4) | 5.3 ± 1.3 | 21 (4) | Pr/Pr |
| | Colydiidae | 1.0 ± 0.7 | 4 (2) | 0.5 ± 0.5 | 2 (1) | S/S |
| | Corylophidae | 1.3 ± 0.5 | 5 (3) | 4.3 ± 1.7 | 17 (4) | S/S |
| | Chrysomelidae Halticinae | 4.0 ± 1.3 | 16 (4) | - - - | - | C/C |
| | Curculionidae | 2.3 ± 1.3 | 9 (2) | 0.5 ± 0.3 | 2 (2) | C/C |
| | Lathridiidae | 9.3 ± 4.8 | 37 (4) | 16.8 ± 8.4 | 67 (4) | S/S |
| | Merylidae Dasytinae | 0.8 ± 0.5 | 3 (2) | 0.5 ± 0.5 | 2 (1) | C/◊ |
| | Merylidae Malachiinae | 0.3 ± 0.3 | 1 (1) | 1.0 ± 0.4 | 4 (3) | Pr/Pr |
| | Nitidulidae | 1.8 ± 0.6 | 7 (3) | - - - | - | C/C |
| | Staphylinidae | 0.3 ± 0.3 | 1 (1) | 4.3 ± 2.0 | 17 (4) | S/S |
| Dermaptera | Forficulidae | 3.8 ± 2.2 | 15 (2) | 4.3 ± 1.5 | 17 (3) | O/O |
| Hemiptera | Aphididae | 273 ± 106.1 | 1092 (4) | 288.8 ± 64.8 | 1155 (4) | SP/SP |
| | Cercopidae | 4.0 ± 1.1 | 16 (4) | 3.0 ± 0.7 | 12 (4) | SP/SP |
| | Cicadellidae | 21.0 ± 4.3 | 84 (4) | 32.8 ± 14.7 | 131 (4) | SP/SP |
| | Cixidae | 7.3 ± 2.1 | 29 (4) | 1.5 ± 1.2 | 6 (2) | SP/SP |
| | Delphacidae | 3.3 ± 2.0 | 13 (2) | 1.8 ± 0.5 | 7 (4) | SP/SP |
| | Lygaeidae | 1.5 ± 1.2 | 6 (2) | - ± - | - | SP/SP |
| | Miridae | 2.8 ± 2.1 | 11 (2) | 1.3 ± 0.9 | 5 (2) | SP/SP |
| | Nabidae | 2.8 ± 1.6 | 11 (2) | 0.3 ± 0.3 | 1 (1) | Pr/Pr |
| | Pentatomidae | 1.0 ± 0.7 | 4 (2) | 0.8 ± 0.8 | 3 (1) | SP/SP |
| | Scutellaridae | 4.0 ± 2.5 | 16 (3) | 3.8 ± 0.9 | 15 (4) | SP/SP |

# Appendix 2- Continued

| *Order* | *Families* | *Organic fields* *mean* ± *SEM* | ***A*** (nf) | *Conventional fields* *mean* ± *SEM* | ***A*** (nf) | *FS* *Larvae/Adult* |
|---|---|---|---|---|---|---|
| Diptera | Agromyzidae | 1.0 ± 0.4 | 4 (3) | 1.0 ± 0.4 | 4 (3) | C/FC |
| | Anthomyiidae | - - - | - | 0.8 ± 0.3 | 3 (3) | C/FC |
| | Asteiidae | - - - | - | 1.8 ± 1.4 | 7 (2) | S/FC |
| | Cecidomyiidae | 17.5 ± 6.5 | 70 (4) | 7.3 ± 1.3 | 29 (4) | O/FC |
| | Ceratopogonidae | 1.8 ± 0.8 | 7 (3) | 2.0 ± 0.0 | 8 (4) | S/FC |
| | Chironomidae | 0.3 ± 0.3 | 1 (1) | 2.0 ± 1.2 | 8 (2) | S/FC |
| | Chloropidae | 2.5 ± 1.3 | 10 (3) | 15.0 ± 1.5 | 60 (4) | O/FC |
| | Dolichopodidae | 10 ± 1.8 | 40 (4) | 1.3 ± 0.8 | 5 (2) | Pr/Pr |
| | Drosophilidae | 1.3 ± 0.8 | 5 (2) | 7.0 ± 2.6 | 28 (4) | S-C/S |
| | Ephydridae | 7.5 ± 3.8 | 30 (3) | 18.8 ± 7.6 | 75 (4) | C/FC |
| | Hybotidae | 42.5 ± 7.4 | 170 (4) | 42.8 ± 6.8 | 171 (4) | Pr/Pr |
| | Lauxaniidae | 0.3 ± 0.3 | 1 (1) | 0.5 ± 0.3 | 2 (2) | S/S |
| | Lonchopteridae | - - - | - | 25.0 ± 8.3 | 100 (4) | S/wti |
| | Opomyzidae | 0.8 ± 0.8 | 3 (1) | 25.8 ± 11.9 | 103 (4) | C/wti |
| | Phoridae | 3.3 ± 0.9 | 13 (4) | 24 ± 6.1 | 96 (4) | Pr/FC |
| | Sciaridae | 10.8 ± 5.0 | 43 (4) | 4.8 ± 0.3 | 19 (4) | S/FC |
| | Sepsidae | - - - | - | 0.8 ± 0.5 | 3 (2) | S/FC |
| | Sphaeroceridae | 0.3 ± 0.3 | 1 (1) | 4.0 ± 1.1 | 16 (4) | S/S |
| Hymenoptera | Braconidae | 8.8 ± 1.5 | 35 (4) | 28.5 ± 6.3 | 114 (4) | Pa/wti |
| | Ceraphronidae | 0.8 ± 0.5 | 3 (2) | 1.0 ± 0.4 | 4 (3) | Pa/wti |
| | Diapriidae | 1.5 ± 0.6 | 6 (3) | - - - | - | Pa/wti |
| | Encyrtidae | 3.3 ± 1.9 | 13 (2) | 2.5 ± 1.3 | 10 (3) | Pa/wti |
| | Eulophidae | 4.8 ± 1.8 | 19 (4) | 8.8 ± 2.6 | 35 (4) | Pa/wti |
| | Eurytomidae | 0.8 ± 0.3 | 3 (3) | 0.5 ± 0.3 | 2 (2) | Pa/wti |
| | Figitidae | 2.0 ± 1.1 | 8 (3) | 6.5 ± 1.5 | 25 (4) | Pa/wti |
| | Formicidae | 13.8 ± 4.1 | 55 (4) | 21.5 ± 13.3 | 86 (4) | O/O |
| | Ichneumonidae | 1.3 ± 0.5 | 5 (3) | 5.0 ± 1.8 | 20 (4) | Pa/wti |
| | Megaspilidae | 0.3 ± 0.3 | 1 (1) | 1.3 ± 0.9 | 5 (2) | Pa/wti |
| | Mymaridae | 2.3 ± 1.4 | 9 (2) | 4.3 ± 1.7 | 17 (4) | Pa/wti |
| | Platygasteridae | 3.5 ± 1.3 | 14 (3) | 0.8 ± 0.3 | 3 (3) | Pa/wti |
| | Pteromalidae | 4.0 ± 0.7 | 16 (4) | 14.3 ± 3.4 | 57 (4) | Pa/wti |
| | Scelionidae | 9.8 ± 5.4 | 39 (4) | 6.3 ± 1.0 | 25 (4) | Pa/wti |
| | Torymidae | 1.0 ± 0.4 | 4 (3) | - - - | - | Pa/wti |
| Lepidoptera | | 0.5 ± 0.5 | 2 (1) | 1.3 ± 0.5 | 5 (3) | C/FC |
| Neuroptera | Chrysopidae | 17.8 ± 4.0 | 71 (4) | 21.5 ± 8.9 | 86 (4) | Pr/S |
| Psocoptera | Peripsocidae | 1.3 ± 0.6 | 5 (3) | 5.0 ± 3.4 | 20 (3) | O/O |
| Thysanoptera | | 219 ± 59.8 | 876 (4) | 408.3 ± 102.0 | 1633 (4) | SP/SP |
| Larvae indet. | | 15.8 ± 9.0 | 63 (4) | 11.0 ± 2.4 | 44 (4) | ◊ |
| **Total** | | | **3,977** | | **4,954** | |

The samples are kept in the Department of Animal Biology, Faculty of Biology (University of Barcelona).

# Capítol 4.3

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B. Caballero-López, J.M. Blanco-Moreno, N. Pérez, J.M. Michelena-Saval, J. Pujade-Villar, E. Guerreri, F.X. Sans. Weeds and aphid-parasitoid communities benefit differentially from organic and conventional cropping of winter cereals (*submitted*)

# Weeds and aphid-parasitoid communities benefit differently from organic and conventional cropping of winter cereals

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## Abstract

It is known that plants play an active role in the interplay between aphids and parasitoids, although their interaction has scarcely been tackled. A concomitant survey of plant and insect communities in eight cereal fields (4 organic and 4 conventional) in a homogeneous area of Catalonia (NE of Iberian Peninsula) was carried out to test the effects of management and plant community on aphid and parasitoid communities (primary and secondary parasitoids). The plant community was split into functional groups (grasses, legumes and forbs), and the aphid community was divided into feeding groups according to their host preferences (specialists in grasses, forbs and legumes), as not all aphids living on cereal fields are crop pests.

Results show that organic management enhances the community of forbs and legumes, which influences the legume-specialist aphids, while management did not have a clear contribution to explaining the different groups of aphids. Grass aphids, which dominated the total catches of aphids, were enhanced in conventional fields at milk-ripe stage because of the greater cover of grasses and the higher N supplies in these fields. The greater abundance of primary and secondary parasitoids in conventional fields also appeared to respond to the higher fertilisation in conventional fields, indicating a bottom-up effect through grasses, aphids, primary and secondary parasitoids. However, the role of legumes, which exclusively thrive in the organic fields and influence the total richness of aphids and the secondary parasitoid's abundance might imply some changes in aphid-parasitoid interaction.

Keywords: farming management, cereal aphids, plant-insect interaction, aphid abundance, parasitoid diversity, aphid diversity, tri-trophic interactions.

# Resum

*La comunitat vegetal juga un paper important en la interacció entre les poblacions de fitòfags i els seus enemics naturals, però rarament ha estat considerada quan s'ha investigat la interacció entre àfids i parasitoids.*

*Aquest estudi analitza els efectes de la gestió i la comunitat vegetal sobre les poblacions d'àfids i parasitoids mitjançant el seguiment simultani de la comunitat vegetal i la comunitat d'insectes en vuit camps de cereals (4 ecològics i 4 convencionals) situats en una àrea homogènia de la Catalunya central (NE de la península Ibèrica). La flora de la comunitat vegetal es va agrupar en grups funcionals (gramínies, lleguminoses i altres dicotiledònies). Els àfids, per la seva banda, es van agrupar segons les seves preferències alimentaries (especialistes en gramínies, lleguminoses i altres dicotiledònies), mentre que la comunitat de parasitoids es va estructura segons el seu nivell tròfic: parasitoids afidòfags primaris i parasitoids secundaris.*

*La gestió ecològica afavoreix la presència de dicotiledònies i en particular, de lleguminoses, les quals, alhora, incentiven la presència d'àfids especialistes en lleguminoses, mentre que la gestió no sembla tenir un paper tan clar sobre la població d'àfids. La gestió convencional afavoreix els àfids de les gramínies, els quals dominen el total de captures d'àfids, durant el segon període de mostreig en relació a la major fertilització dels conreus que comporta un major recobriment de gramínies, principalment del blat. La major abundància de parasitoids primaris i secundaris als camps convencionals respecte als ecològics, que es pot explicar per la major fertilització que afavoreix les poblacions d'àfids, reflecteix un efecte bottom-up entre els àfids i els parasitoids primaris i secundaris.*

*El paper de les lleguminoses, les quals nomes apareixen als camps ecològics, sembla però, condicionar la riquesa total d'espècies d'àfids i la abundància de parasitoids secundaris fet que pot comportar canvis en la interacció àfid-parasitoid encara poc coneguts.*

## Introduction

Cereal aphids are major pests in several temperate areas around the world (Fuentes-Contreras & Niemeyer, 2000) and yield losses are commonly avoided by insecticide use (Östman et al., 2001). In Catalonia (NE Iberian Peninsula), cereal aphids cause direct damage to winter cereals but rarely exceed the economic injury threshold (Pons et al., 1993). One of the main reasons for this limited damage appears to be the availability of natural enemies (Pons & Eizaguirre, 2000). The large reservoirs of aphid parasitoids in winter have been highlighted as offering good potential for aphid control in cereals (Lumbierres et al., 2007) because parasitoid activity in winter and early spring is a significant factor in maintaining aphid populations below the injury threshold level during spring (Legrand et al., 2004).

The interaction between cereal aphids and parasitoids constitutes a complex system that has frequently been studied because of its implication in biological control. However, not all aphids living in cereal fields are crop pests, because there are also aphids living on weeds which may serve as an alternate resource for aphid parasitoids (Norris & Kogan, 2000).
A more theoretical, experimental background suggests the idea that plant community directly affects phytophagous insects because it acts as food but might also influence populations of secondary consumers, such as parasitoids, through an upwardly-cascading mechanism via herbivores (Hunter & Price, 1992; Knops et al., 1999).

In this sense, the comparison between organic and conventional cereal fields differing in weed community but sharing the same boundary vegetation appears to be a suitable model for exploring the effect of farming practices and plant community on aphid-parasitoid interactions. In addition, the absence of insecticide applications in dry-land cereal fields in the Mediterranean area prevents the effect of insecticides, such as direct mortality of insects and sublethal detrimental effects on their fecundity (Lampkin, 2002). Therefore, it could be expected that the greater plant diversity of organically-managed cereal fields might support greater diversity of plant-feeders (Gibson et al., 2007) and, in turn, a richer community of parasitoids through a bottom-up effect. Furthermore, considering that the availability of sugar resources depends on the abundance and richness of insect-pollinated plants (legumes and other forbs), and that increased floral subsidies may confer increased longevity and fecundity on parasitoids (Norris & Kogan, 2000; Winkler et al., 2006), we would expect a direct enhancement of parasitoid populations in organic cereal fields that harbour a more diverse plant community (Bianchi & Wäckers, 2008; Colignon et al., 2004).

Little is known about how phenological changes of plant community, mainly associated with the development stages of cereal, might imply adjustments to plant-aphid interaction throughout the cropping period. However, other study systems have suggested that host-plant phenology plays a major role in the relationship between herbivores and plants (Barat et al., 2007).

The aim of this study was to understand how farming management and plant community of winter wheat fields affects the abundance and richness of aphids, and the interactions with their primary and secondary parasitoids. Taking into account the significant spatial and temporal variability of such interactions, the relationships between plant community, aphids and their parasitoids were tested in two key moments in cereal development: in flowering and milk-ripe stages, to gain accurate knowledge of the plant-aphid-parasitoid trophic system.

The following questions are addressed: (1) How does farming management affect aphid-parasitoid interaction? (2) Does the separation into host preference groups lead to a better comprehension of factors conditioning the aphid community? (3) How does plant community influence the relationships between aphids and parasitoids?

## Material and Methods

### *Study area*

The study was carried out in Montblanquet (NE of Spain), a small village located about 150 km south-west of Barcelona (41º29'0.9''N, 1º7'16.4''E; 627 m a.s.l.). The agricultural landscape is dominated by woodlands, mainly pines (*Pinus nigra* subsp. *salzmannii*) and evergreen and deciduous oaks (*Quercus ilex* and *Q. faginea,* respectively), scrublands and perennial dominated grasslands. The arable fields, mainly cereals, represent a small percentage of the agricultural landscape (40%) and are intermingled with patches of natural vegetation.

In order to characterize the studied fields' boundary vegetation, we combined habitat field survey and photointerpretation in ArcInfo version 9.1. The area of habitats of the boundaries that covered at least 5 m of the perimeter length was measured using 1:5,000 orthophotomaps (ICC, 2005). Habitats were categorized according to the following categories: perennial grasslands, scrubs, blackthorn-bramble hedgerows, mixture of holm-oak and deciduous oak woodlands, pine woodlands and deciduous woodlands. The mean habitat diversity computed for each field did not show differences between organic and conventional fields ($\chi_1^2 = 0.70$, *P*-value = 0.403).

*Study design*

Four organically and four conventionally-managed winter wheat fields were selected in a homogeneous area of 2 × 2 km to study the effects of management and plant community characteristics on aphid-parasitoid communities in dry-land cereal fields. The organic fields (mean ± SE; 2.19 ± 0.3 ha) were selected first, and then the conventional fields were selected (4.08 ± 0.8 ha), no more than 1 km apart and not adjoining the organic fields. Despite the fact that we tried to select fields that matched in size, we considered homogeneity of vegetation in the boundaries to be more important than the homogeneity of the field size, as in all cases the fields were relatively small.

In organic fields weeds were controlled mechanically and fertilisation relied on green manure and occasionally hen manure, whereas the conventional fields were sprayed with herbicides and fertilised with a combination of pig slurry and mineral fertilisers. Pesticides other than herbicides were not applied under conventional management. The selected organic fields had been managed for more than one decade following organic guidelines and were certified by the Catalan Council for Organic Farming (CCPAE). All selected fields were sown with winter wheat (*Triticum aestivum*) between the last week of October and the first week of November 2003, after seedbed preparation by harrowing at 15-20 cm depth (for other details see table 1).

**Table 1** Agronomic characteristics of the fields included in the study.

| Management | Organic | Conventional |
|---|---|---|
| Crop rotation | Legume/ winter wheat/ polyculture | Winter wheat/ winter barley |
| Tillage | 3 times,<br>20 cm of depth | 3 times,<br>15 cm of depth |
| Cereal | Winter wheat cv. *Bonpain* | Winter wheat cv. *Etecho* (2 fields), *Soissons* (2 fields) |
| Sowing density [kg ha$^{-1}$] | 180-200 | 170-200 |
| Nitrogen inputs (kg N ha$^{-1}$) | Green manure and occasionally hen droppings (<160) | ~ 180 of pig slurry/year<br>< 100 of mineral N at times |
| Weed control | Mechanical | Mechanical and Chemical* |
| Pests and diseases control | None | None |

*All conventional farmers applied Glyphosate (N-(phosphonomethyl) glycine at 2.5 L ha$^{-1}$) and 2-4-D (2,4-dichlorophenoxy at 1.3 L ha$^{-1}$) as pre-emergence non-specific herbicides, Splendor 25 SC (Tralkoxidin at 1.6 L ha$^{-1}$) as a post-emergence grass herbicide and Oxytril (ioxinil, bromoxinil, and mecoprop) at 2 L ha$^{-1}$) as a broad-leave herbicide.

*Insect sampling*

In each field we established a 100 m-transect, diagonally from the field boundary towards the centre, allowing for a strip 25 m wide to avoid the edge effect. Within each transect, five 1 × 1 m plots at 20-m intervals were surveyed. Insect sampling and plant survey were carried out one after the other within each plot. Aphids and primary and secondary parasitoids were sampled using a petrol-driven Blow&Vac leaf-blower apparatus (McCullogh BVM250, Italy; sampling cylinder 60 cm high and 12 cm diameter) converted to a suction sampler according to Stewart & Wright (1995). The suction sampler was operated on full power, which we assumed would produce a constant air flow of 0.142 $m^3/s$ (manufacturer's data). The pipe was held vertically, carefully moved over plants contained in the $1m^2$ quadrate and exhaustion was performed for 60 seconds. For each plot, the sampling bag was removed from the machine, enclosed in a labelled plastic bag, and stored in a portable fridge in order to prevent the activity of predators in the bag. The apparatus operator repeated the procedure five times in each field, and all samples were taken by the same two people to reduce the variability of sampling. In spite of the drawback that suction samplers generate activity-density measurements and not absolute abundance measurements, this method has been extensively used to study aphids and their natural enemies in crops (Holland et al., 2004; Koricheva et al., 2000; Östman, 2002). Thereafter, we will use the abundance term instead of activity-density to simplify explanations.

Sampling was carried out between 10:00 (8:00 UT) and 19:00 (17:00 UT) in sunny weather (temperature > 20 ºC and no wind), and was performed twice, at different stages of wheat development (Zadoks et al., 1974), the beginning of wheat anthesis stage between 25th and 27th of May and the mid milk-ripe stage between 24th and 26th of June 2004. As one sampling campaign lasted 2 days, the 8 fields were sampled in random order to prevent a systematic bias due to day-time. The mean daily maximum temperatures during the spring sampling period ranged from 20 to 33 ºC.

*Insect processing*

Samples were frozen (-18 ºC) for sorting and identification at a later date. The material collected was first sorted into families, preserved in alcohol (70%) and then identified to species level by specialists.

Aphids (Hemiptera: Aphididae) were classified, according to their host preferences, into three feeding categories. Grass aphids included aphid species that feed on grasses at least in one stage of their cycle life. Species that feed mainly on legumes during most stages of the species' development were included in the category of legume aphids. The forb aphids comprised a wide range of aphid species which mainly thrive on plant species from hedgerows such as *Foeniculum vulgare* and *Prunus spinosa,* and many weeds from arable fields (e.g. Asteraceae, Boraginaceae).

Primary aphidophagous parasitoids belong mainly to the Aphidiinae subfamily (Hymenoptera: Braconidae). Aphidiinae wasps deposit their eggs inside the aphid; although reproduction is often diminished or repressed, the parasitized aphid continues to live and grow (Starý, 1988). The larval instars feed on the aphid, destroying its tissues and ultimately killing the host. Before completing its development, the parasitoid larva spins a cocoon inside or under the empty aphid skin. At this stage, the aphid skin becomes indurate and the typical "mummy" is formed (Buitenhuis, 2004; Starý, 1988). Primary parasitoids are attacked by two types of secondary parasitoids: those that attack the primary parasitoid inside the still-living aphid, and those that attack the primary parasitoid after the aphid has been mummified by the primary parasitoid (Bukovinszky et al., 2008; Sullivan, 1987).

We refer to the two types as hyperparasitoids and mummy parasitoids, respectively. Hyperparasitoids are almost exclusively Alloxystinae (Figitidae: Charipinae) and tend to be relatively specific; mummy parasitoids belong to Pteromalidae, Encyrtidae and Megaspilidae hymenopteran families and are more polyphagous.

### *Vegetation sampling*

Vegetation sampling was carried out twice, concomitant with suction-sampling. Crop and weed cover were recorded in each plot following a ground cover scale with the following intervals: 0-1, 1-5, 5-10, 10-25, 25-50, 50-75 and 75-100%). Species cover was assigned to the midpoint of its cover-class. Plant species were classified into three functional groups (grasses, forbs and legumes). Legumes have been separated from the other forbs due to the generally higher nitrogen content of their tissues, which would make them a higher-quality resource for herbivores. Grasses have tough tissues with low nitrogen content and structural characteristics that deter plant-feeders. We did not distinguish grasses by their photosynthetic pathway, as all grasses identified belong to the $C_3$ category. Weed species were identified according to Bolòs et al. (2005).

### *Data analysis*

We established the following framework for statistical analysis of the agroecosystem's different trophic levels, considering different guidelines for the analysis of plants and insects. In addition, we differentiated the analyses for richness from those for abundance of insects. Models of total plant cover and species richness and of the different plant functional groups (grasses, forbs and legumes) were analysed using farming management and sampling period as fixed factors. Total plant cover was also included in all models of plant species richness to correct the expected correlation between plant abundance and species richness.

All insect models included farming management and sampling period as fixed factors and a common set of covariates (cover of forbs, legumes and grasses and total plant species richness) in order to test the response of insects to the amount of plant resources and their diversity. Furthermore, the inclusion of plant-related variables in parasitoid models accounts for the possibility of finding indirect effects between them. Abundance and species richness of aphids (specialists in grasses, forbs and legumes) were analysed considering the aforementioned variables, while in the analyses of primary and secondary parasitoids several additional variables were included due to their different ecological requirements. When we modelled the abundance of primary parasitoids, we considered the abundance of the different aphid groups which could act as potential hosts. The abundance of the different aphid groups and the abundance of primary parasitoids were included into the model of secondary parasitoid abundance.

For the analysis of parasitoid richness we initially considered using the richness of the different aphid groups as covariates (plus primary parasitoid richness when analysing secondary parasitoids). However, after the Akaike Information Criterion examination, we preferred to keep a simpler model which only included total aphid species richness (plus primary parasitoid richness in the model for secondary parasitoids).

The wide range of variation in the groups studied prevents a homogeneous analysis model. When data was not over-dispersed, we used generalised linear mixed models with Poisson distribution (most groups), although normal error distribution after square-root-transformation was used when Poisson requirements were not met. Conversely, when data was over-dispersed, we tested the most appropriate response distribution in each case: either negative binomial or zero-inflated negative binomial distribution (Bohning et al., 1999).

Significance for the different predictors included in the models was obtained by means of likelihood ratio tests. Prior to analysis, collinearity of the sets of independent variables included in the models was evaluated with the variance inflation factor 1/ $(1-R^2)$ in order to check the model's robustness (Kutner et al., 2004). The library lme4 (Bates et al., 2008) was used for analyses with normal and Poisson regression models, while the library glmmADMB (Skaug & Fournier, 2006) was used for analyses with negative binomial models. All the statistical analyses were performed on R 2.8 (R Development Core Team, 2008).

## Results

### *Effect of farming system on plant community*

In total, 40 weed species from 17 families were recorded in 8 winter wheat fields; of these, 26 were forbs, 8 legumes and 6 grass species. The most common arable weeds in organic fields were *Convolvulus arvensis* L., *Galium tricornutum* Dandy and *Cirsium arvense* (L.) Scop., while in conventional fields the most frequent weeds were *Lolium rigidum* Gaud. and *Papaver rhoeas* L. (see Appendix 1).

The total number of species was more than twice as high in organic than in conventional fields (mean ± SEM: organic: 8.2 ± 0.3, conventional: 3.1 ± 0.2). While richness of forbs was significantly higher in organic fields (organic: 4.7 ± 0.2, conventional: 1.1 ± 0.2), no significant differences in grasses (organic: 1.7 ± 0.2, conventional: 2.0 ± 0.1) were detected between organic and conventional fields (Figure 1a, table 2).

**Table 2** The effects of farming management and sampling period on cover and species richness for plant measures. Minimum models are shown and only significant descriptors appear in the table. $P \geq 0.10$, '**.**'; $P < 0.10$, $^{(.)}$; $P < 0.05$,*; $P < 0.01$, **; $P < 0.001$, ***.

|  | Farming | Sampling |
|---|---|---|
| Total plant cover | 19.05* | . |
| Grasses cover | 40.33*** | . |
| Forbs cover | -3.01*** | -0.61* |
|  |  |  |
| Total plant richness | -5.08*** | -0.48 $^{(.)}$ |
| Grasses richness | . | . |
| Forbs richness | -3.60*** | . |

Legumes only thrive in organic fields; *Medicago lupulina* L., *M. sativa* L. and *Coronilla scorpioides* (L.) Koch. were the most frequent species.

The mean total plant cover was significantly higher in conventional than in organic fields, mainly related to the higher grass cover (Figure 1a and table 2). The mean crop yield was also greater in conventional (4,000-4,100 kg ha$^{-1}$) than in organic (2,000-2,200 kg ha$^{-1}$) fields (farmers *pers. comm.*).

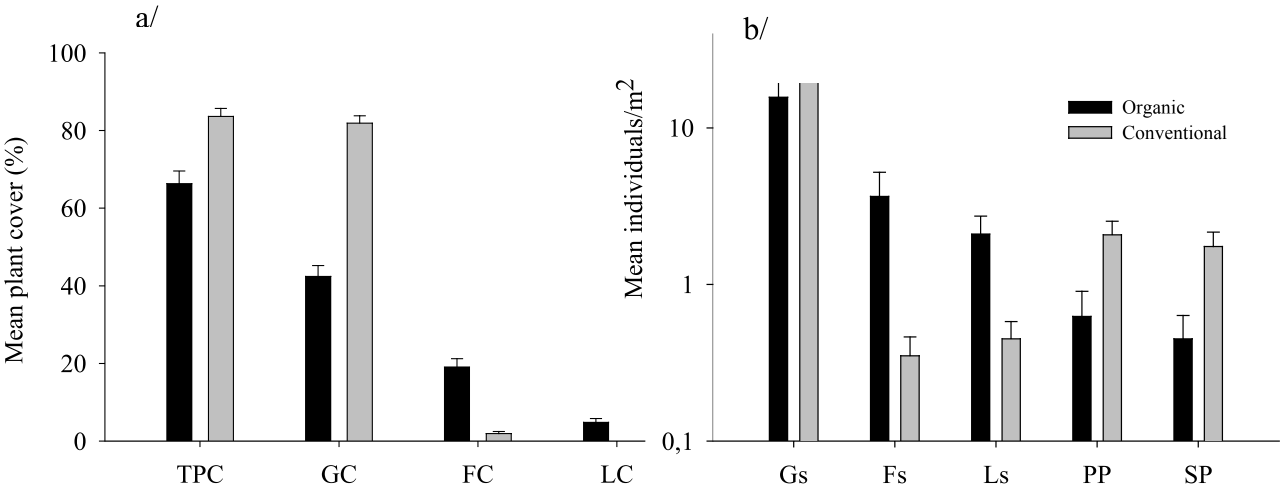

**Figure 1. (a)** Total plant cover (TPC) and cover of grasses (GC), forbs (excluding legumes) (FC) and legumes (LC) in organic and conventional fields. **(b)** Abundance of aphids and parasitoids. Gs = aphids specialist of grasses, Fs = aphids specialist of forbs, Ls = aphids specialist of legumes, PP = primary parasitoids and SP = secondary parasitoids. Data are means with standard errors.

*Overview of abundance and richness of aphids and primary and secondary parasitoids*

A total of 1,728 aphids comprising 18 species were collected. The richest aphid feeding category was grass-specialist (9 species), followed by legume-specialist (5 species) and forb-specialist (4 species).

Overall aphid populations were low during the study and grass aphids made up the dominant group (92.2% of total aphid catches). *Sitobion avenae* (Fabricius) with 66% and *Metopolophium dirhodum* (Walker) with 31% of grass aphid catches were the most commonly captured species. The remainder was made up of forb and legume aphids (Fig. 1b and Appendix 2).

108 individuals of primary aphid parasitoids were collected, belonging to Aphidiinae (Braconidae). Seven species were recorded, and *Aphidius* was the most common genus,

accounting for the 98% of specimens. All identified species prey on the main species of grass aphids captured (Michelena-Saval & González-Funes, 1987; Michelena-Saval & Oltra-Moscardó, 1987; Starý, 1976) but some species of aphids categorised as forb and legume specialist can also act as hosts (Appendix 3).

In total, 45 specimens, belonging to 4 families and seven species of secondary parasitoids were captured. *Alloxysta victrix* (Westwood) and *Phaenoglyphis villosa* (Hartig) belonging to Charipinae (Figitidae) were the most abundant hyperparasitoids, and *Asaphes vulgaris* (Pteromalidae) was the most common mummy parasitoid. Because of the more direct interaction with host defences, hyperparasitoids are typically more specialized than the generalist mummy parasitoids (Müller et al., 1999). Thus, *Alloxysta* and *Phaenoglyphis* mainly prey on *Aphidius* genus (Evenhuis, 1976; Evenhuis & Barbotin, 1977), whilst mummy parasitoids present a wider range of potential hosts, although most of them were found in Aphidiinae (Noyes, 2007).

*Effect of farming system and plant community on aphids*

Aphid abundance and richness differed significantly among sampling times (table 3), indicating that the aphid population size and its richness vary in a short period of time in winter cereal crops. In contrast, general descriptors of aphid populations were not significantly affected by management (table 3). The division of aphid community into categories according to feeding preferences allows us to expand our knowledge of the different factors affecting the aphid's appearance in cereal fields.

Grass aphids dominated total aphid catches and did not show a relation to farming management. However, the interaction between farming type and sampling period was significant (table 3). The failure to find a management effect on grass aphids could be related to the extremely low abundance of aphids in the first sampling (mean nr. indiv/$m^2$± SE : conventional 6.5 ± 5.0, organic 3.1 ± 0.4). In contrast, in the second sampling, when the cereal was at milk-ripe stage and a greater number of aphids were present (conventional 42.0 ± 9.1, organic 28.0 ± 11.0), a higher abundance of grass aphids was found on conventional fields. The abundances of forb and legume aphids apparently were not significantly affected by farming system, while a relation to plant community characteristics was revealed. Thus, the abundance of legume specialists was significantly enhanced by a cover of legumes, and the abundance forb specialists was negatively related to cover of grasses (table 3).

The total richness of aphids did not show any relation to management, but was significantly enhanced by legume cover. Aphids specialised in forbs showed significantly greater species richness in organic fields than in conventional ones. The richness of grass aphids, as occurred with their abundance, was significantly higher in conventional fields during the second sampling, as shown by the significant interaction between farming and sampling period (table 3).

### *Effect of farming system, plant community and aphids groups on parasitoids*

Unlike the aphid pattern, farming system significantly affected the parasitoid community. The abundance and richness of primary and secondary parasitoids were significantly higher in conventional fields than in organic ones (Fig. 1b and table 3).

The abundance of primary and secondary parasitoids was also significantly related to the availability of their potential hosts. Thus, the abundance of primary parasitoids was considerably enhanced by the presence of grass aphids, whilst the presence of secondary parasitoids was positively related to the abundance of primary parasitoids (table 3). Furthermore, the abundance of secondary parasitoids was marginally favoured by a greater cover of legumes (table 3).

Similarly, the richness of primary and secondary parasitoids was associated with local host richness. Species richness of primary parasitoids was positively related to the richness of total aphids and the richness of secondary parasitoids was closely associated to the richness of primary parasitoids.

**Table 3** Models for the effects of farming, sampling period, their interaction, and cover of plant functional groups on abundance and species richness of aphids, primary and secondary parasitoids. The abundance of the different specialist groups of aphids was also included in the models of abundance of primary and secondary parasitoids as potential preys. When the focus was on richness of primary and secondary parasitoids we substituted abundance measures of potential preys for the total richness of aphids. Further details in material and methods section. Only significant descriptors appear in the table. The most appropriate response distribution model in each case was specified: $^1$ Negative binomial, $^2$ Poisson, $^3$ Gaussian. $P \geq 0.10$, '**.**'; $P < 0.10$, $^{(.)}$; $P < 0.05$,*; $P < 0.01$, **; $P < 0.001$, ***; "-" is a variable non-included in the model and spec. = specialist.

| | | | | | | | Prey abundance | | | | Prey richnes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Farming management (FM) | Sampling period (SP) | FM x SP | Forbs cover | Legume cover | Grass cover | Forbs aphids | Grasses aphids | Legume aphids | Primary parasitoids abundance | Total Aphid richness | Priamry parasitoids richness |
| **Aphids** | | | | | | | | | | | | |
| Abundance | | | | | | | | | | | | |
| Total $^1$ | . | 2.23*** | 1.01* | . | . | . | - | - | - | - | - | - |
| Grasses spec.$^1$ | . | 2.05*** | 1.21** | . | . | . | - | - | - | - | - | - |
| Forbs spec.$^1$ | . | 3.77*** | . | . | . | -1.21** | - | - | - | - | - | - |
| Legume spec.$^2$ | . | 3.59*** | . | . | 0.58*** | . | - | - | - | - | - | - |
| Richness | | | | | | | | | | | | |
| Total $^2$ | . | 1.19*** | . | . | 0.13* | . | - | - | - | - | - | - |
| Grasses spec. $^2$ | . | 0.51*** | 0.82* | . | . | . | - | - | - | - | - | - |
| Forbs spec.$^2$ | -1.15* | 2.44*** | . | . | . | . | - | - | - | - | - | - |
| Legume spec.$^2$ | . | 3.09*** | . | . | . | . | - | - | - | - | - | - |
| **Primary parasitoids** | | | | | | | | | | | | |
| Abundance $^3$ | 0.78*** | . | . | . | . | . | . | 0.23*** | . | - | - | - |
| Richness $^3$ | 0.88*** | . | -0.53* | . | . | . | - | - | - | - | 0.23** | - |
| **Secondary parasitoids** | | | | | | | | | | | | |
| Abundance $^2$ | 1.52** | 3.78*** | . | . | 0.29$^{(.)}$ | . | . | . | . | 0.29* | - | - |
| Richness $^2$ | 1.12** | 3.42*** | . | . | . | . | - | - | - | - | . | 0.32* |

# Discussion

*Effect of farming system on plant community*

The statement that organic farming promotes weed diversity in agroecosystems (Gibson et al., 2006; Hyvönen et al., 2003; Romero et al., 2008) is also supported by our data, since the total plant species richness and the richness of forbs were clearly enhanced in organic fields. The finding that legumes, in terms of abundance and diversity, appear only in organic fields is not novel since it has been previously reported by Romero et al. (2008) in Mediterranean cereal fields. However, the contribution of the plant functional groups to explaining the patterns of insect community differs among groups. While the presence of non-legume forbs in the plant community had no significant effect on any group of insects examined, the presence of legumes appeared to be a major determinant of abundance and richness of aphids and parasitoids (table 3). Koricheva et al. (2000) suggested several factors which may explain beneficial effects of legumes on insect populations. Legumes, through symbiotic fixation, may increase the availability of nitrogen which is often a limiting nutrient for herbivores. Moreover, legumes provide extra floral resources such as pollen or nectar, which represent an important food resource for many herbivores and their natural enemies. This might explain the marginally positive relationship between legumes and abundance of secondary parasitoids.

The higher total plant cover and higher grass cover in conventional fields than in organic ones could be explained by the greater amount of fertilisers (pig slurry and mineral fertilisers) during the season, and the long-term use of auxin herbicides (such as 2,4-D) to control selectively broad-leaved weeds (Kudsk & Streibig, 2003).

*Effect of farming system and plant community on aphid-parasitoid abundance*

Our results show that the abundance of grass aphids at milk-ripe stage was clearly enhanced in conventional fields. The greater grass cover and the higher N supplies in conventional fields therefore appear to be the most suitable explanations for the higher abundances of grass aphids in these fields. In particular, because the two most abundant species captured, *S. avenae* and *M. dirhodum,* were benefited in winter wheat fields when the annual application of nitrogen is above 190 kg N $ha^{-1}$ (Duffield et al., 1997), as in our conventionally-managed fields. In the same way, Hasken & Poehling (1995) reported that nitrogen input was probably the most significant factor influencing the development of cereal aphid populations, mainly because higher aminoacid contents in the phloem sap of those plants favoured their development. In addition, nitrogen fertilisation extended the growth period, so that plants were convenient host plants for aphids for a longer time.

Nonetheless, according to our findings, the higher amount of fertilisers in insecticide-free conventional fields not only benefits the abundance of grass aphids. The higher abundance of primary parasitoids appears to be associated to the greater abundance of grass aphids, and the abundance of secondary parasitoids was also enhanced in conventional fields because it is in these fields where the abundance of primary parasitoids is greater. Considering that all the species of primary parasitoids identified in our study attack grass aphids such as those of the genus *Sitobion* and *Rhopalosiphum*, and that all the collected secondary parasitoids parasitise species of our main genus of primary parasitoids *Aphidius*, we may suggest that the high fertilisation in conventional fields triggers changes in the entire community of specialist parasitoids. Thus, the significant relationships among the abundances of grass aphids, primary and secondary parasitoids could be addressed as a cascade-up mechanism mediated by density dependent factors.

The positive relation between grass aphids and primary parasitoids is in line with studies that reported a density-dependent relation between aphids and specialist aphidophagous parasitoids (Colfer & Rosenheim, 2001; Helms et al., 2004; Murphy & Volkl, 1996). This indicates that the densities of our grass aphids in conventional fields might go beyond the threshold effect reported by Pareja et al. (2008), in which the parasitoid community responds to aphid density. Nevertheless, in no case was density-dependent parasitism of primary parasitoids sufficient to prevent exponential population growth of aphids within the growing season (Helms et al., 2004).

Otherwise, population densities of primary parasitoids might also appear to be strongly related in space and time with aphid densities because primary parasitoids can exploit an alternative resource such as the honeydew offered by their sap-producing hosts (Wäckers et al., 2008). In agricultural systems, feeding on sugar-rich foods such as honeydew is important for the survival of many adult parasitoids, which might have a major implication in biological pest control programs (Hogervorst et al., 2007; Leroy et al., 2009; Wäckers et al., 2008). However, information on how aphid honeydew may impact on tri-trophic relationships is still rather limited (Hogervorst et al., 2007).

The strong correlation between primary and secondary parasitoids might approach another temporal and spatial synchrony. This may imply that aphid population regulation could be further complicated if the tri-trophic interaction is considered. Because, as Höller et al. (1993) demonstrated, hyperparasitism might affect primary parasitoids population dynamics sufficiently to disrupt biological control of the host.

The lack of response by primary parasitoids to plant community contrasted with the marginal effect of legume cover on secondary parasitoid abundance. This result supports the findings of Banks et al. (2008) that secondary parasitoids may accrue greater benefits than their primary parasitoid hosts from extra floral resources.

### *Effect of farming system and plant community on aphid-parasitoid richness*

The total species richness of aphids did not differ between organic and conventional fields, but richness of total aphids was enhanced by legume cover. This pattern could be explained because legumes presumably attracted their aphid-specialists and this process occurred at local scale within fields. Conversely, the species richness of forb aphids seems to be affected by farming, showing a higher diversity in organic fields. These findings are in accordance with previous works that attributed the higher diversity of plant-feeders to a more diverse plant community (Knops et al., 1999; Murdoch et al., 1972; Siemann et al., 1998).

Contrary to expectations, the richness of primary and secondary parasitoids appears to be enhanced in conventional fields instead of organic fields. This might indicate that the high sugar sources offered by the richer plant community in organic fields did not favour primary parasitoid richness. However, as parasitoid abundance is clearly enhanced in conventional fields and richness and abundance are closely related, this is not surprising. Additionally, Powell et al. (1986) reported that the presence of weeds had little effect on those parasitoid species which mainly attacked cereal aphids, indicating that their hosts determined their presence more than plant community.

On the other hand, the positive association between richness of total aphids and primary parasitoids and, in turn, primary and secondary parasitoids, indicate an indirect effect of plant community on secondary consumers, mediated through primary consumer richness. These effects are consistent with the bottom-up hypothesis of trophic structure (Hunter & Price, 1992), which holds that primary producers can influence the diversity of herbivores, and the diversity of natural enemies responded to plant diversity via herbivores, via cascading-up mechanisms (Haddad et al., 2001; Koricheva et al., 2000). Interestingly, the fact that primary parasitoids correlate better to the total species of aphids rather than any feeding category of aphids indicates that primary parasitoids, apart from parasitizing cereal aphids, also attack forb or legume aphids. Consistently with Norris & Kogan (2000), these results show that aphids living on weeds may also serve as an alternate resource for aphid parasitoids.

## Conclusions

Dividing aphids according to their food preferences appears to be essential to achieving a better understanding of the effects of management and plant community characteristics on aphid populations. Grass aphids respond to management, while forb and legume aphids were more closely related to the local abundance or richness of their host plants.

The entire system of grass aphid-parasitoids is enhanced in conventional fields, where the abundance of grass aphids was higher, suggesting a positive relation between them. Nevertheless, unfortunately, our observational study does not enable us to distinguish between a host-parasitoid relationship and an interaction of honeydew producer-parasitoid consumer. The presence of legumes in organic fields, providing alternative hosts to primary aphid parasitoids, suggests that the effect of the plant community on secondary consumers is indirect, mediated through richness of primary consumers.

Our approach emphasises the importance of tri-trophic models (plant-aphids-parasitoids), but more experimental work is required to achieve greater comprehension of aphid population regulation.

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**Appendix 1-** Absolute frequencies of main weed species in organic and conventional fields. Number indicates the number of plots/samples where the species has been found during the two sampling periods (see text for more details). Only species with total frequency higher than three are shown.

| Vegetal groups | Organic | Conventional |
|---|---|---|
| **Grasses (C3)** | | |
| *Avena sativa* L. | 4 | 0 |
| *Avena sterilis* L. | 7 | 12 |
| *Bromus diandrus* Roth | 0 | 5 |
| *Bromus sterilis* L. | 0 | 4 |
| *Lolium rigidum* Gaud. | 17 | 18 |
| **Forbs** | | |
| *Anagallis arvensis* L. | 5 | 0 |
| *Anchusa italica* Retz. | 4 | 0 |
| *Centaurea scabiosa* L. | 13 | 1 |
| *Cirsium arvense* (L.) Scop. | 23 | 0 |
| *Convolvulus arvensis* L. | 30 | 5 |
| *Fumaria officinalis* L. | 6 | 1 |
| *Galium tricornutum* Dandy | 30 | 6 |
| *Lepidium draba* L. | 11 | 3 |
| *Papaver hybridum* L. | 5 | 0 |
| *Papaver rhoeas* L. | 21 | 16 |
| *Polygonum aviculare* L. | 7 | 8 |
| *Rapistrum rugosum* (L.) All. | 15 | 0 |
| *Scandix pecten-veneris* L. | 3 | 0 |
| **Legumes** | | |
| *Coronilla scorpioides* (L.) Koch | 14 | 0 |
| *Medicago lupulina* L. | 17 | 0 |
| *Medicago sativa* L. | 14 | 0 |
| *Vicia ervilia* (L.) Willd. | 3 | 0 |
| *Vicia hybrida* L. | 5 | 0 |
| *Vicia peregrina* L. | 8 | 0 |
| *Vicia sativa* L. | 9 | 0 |

**Appendix 2-** Mean total abundance (± SEM*)* of aphids and aphid parasitoids captured by suction sampling in organic and conventional fields. Two surveys are included in the mean abundances. Total number of specimens recorded in organic and conventional fields is also indicated. Aphids are categorized as legume-specialist, polyphagous, forb-specialist and grasses-specialist. Aphid species- Ap: *Acyrthosiphon pisum* (Harris), Ac: *Aphis craccivora* Koch, Af: *Aphis fabae* Scopoli, D-B: *Dysaphis* sp. & *Brachycaudus* sp., F: *Forda* sp., Hf: *Hyadaphis foeniculi* (Passerini), Mdo: *Melanaphis donacis* (Passerini), Mdi: *Metopolophium dirhodum* (Walker), Ph: *Phorodon humuli* (Schrank)*,* Rp: *Rhopalosiphum padi* (L.), Sg: *Schizaphis graminum* (Rondani)*,* Sm: *Sipha maydis* Passerini, Sa: *Sitobion avenae* (Fabricius), Tn: *Tetraneura nigriabdominalis* (Sasaki), Tr: *Therioaphis riehmi* (Börner)*,* Tt: *Therioaphis trifolii* (Monell), U: *Uroleucon* sp.

| | Organic | | Conventional | |
|---|---|---|---|---|
| | X ± SEM | Total | X ± SEM | Total |
| **Aphids** (Aphididae) | | | | |
| Legume specialist (Ac, Af, Ap, Tt, Tr) | 0.9 ± 0.4 | 42 | 0.2 ± 0.1 | 10 |
| Forb specialist (D-B, U, Ph, Hf) | 1.9 ± 0.9 | 75 | 0.2 ± 0.1 | 7 |
| Grasses specialist (F, Mdo, Mdi, Rp, Sm, Sa, Tn, Sg) | 15.7 ± 4.1 | 629 | 24.1 ± 4.5 | 965 |
| **Total aphids** | **18.7 ± 4.6** | **746** | **24.6 ± 4.5** | **982** |
| **Primary parasitoids** | | | | |
| Braconidae Aphidiinae | **0.63 ± 0.1** | **25** | **2.1 ± 0.3** | **83** |
| *Aphidius* sp. | 0.1 ± 0.1 | 4 | 0.7 ± 0.2 | 27 |
| *Aphidius avenae* | 0.0 ± 0.0 | 1 | 0.0 ± 0.0 | 0 |
| *Aphidius ervi* | 0.3 ± 0.1 | 13 | 0.7 ± 0.1 | 26 |
| *Aphidius rhopalosiphi* | 0.0 ± 0.0 | 1 | 0.5 ± 0.1 | 18 |
| *Aphidius uzbekistanicus* | 0.1 ± 0.1 | 4 | 0.3 ± 0.1 | 12 |
| *Diaeretiella rapae* | 0.0 ± 0.0 | 1 | 0.0 ± 0.0 | 0 |
| *Praon volucre* | 0.0 ± 0.0 | 1 | 0.0 ± 0.0 | 0 |
| **Secondary parasitoids** | **0.2 ± 0.1** | **9** | **0.9 ± 0.2** | **36** |
| Figitidae Charipinae | | | | |
| *Alloxysta victrix* | 0.2 ± 0.1 | 8 | 0.4 ± 0.1 | 14 |
| *Phaenoglyphis villosa* | 0.0 ± 0.0 | 0 | 0.2 ± 0.1 | 10 |
| Encyrtidae | | | | |
| *Syrphophagus aphidivorus* | 0.0 ± 0.0 | 0 | 0.0 ± 0.0 | 1 |
| Megaspilidae | | | | |
| *Dendrocerus aphidum* | 0.0 ± 0.0 | 0 | 0.1 ± 0.0 | 3 |
| Pteromalidae | | | | |
| *Asaphes suspensus* | 0.0 ± 0.0 | 0 | 0.1 ± 0.0 | 2 |
| *Asaphes vulgaris* | 0.0 ± 0.0 | 0 | 0.2 ± 0.1 | 6 |
| *Pachyneuron aphidis* | 0.0 ± 0.0 | 1 | 0.0 ± 0.0 | 0 |

**Appendix 3-** Relationships between aphids and Aphidiinae wasps (Braconidae) marked with signals (x ) based on literature review and expert advice.

| | *Acyrthosiphon* | *Aphis* | *Brachycaudus* | *Dysaphis* | *Macrosiphum* | *Melanaphis* | *Metopolophium* | *Phorodon* | *Rhopalosiphum* | *Schizaphis* | *Sitobion* | *Uroleucon* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Aphidius avenae* Haliday, 1834 | x | | | x | x | | | | | | x | |
| *Aphidius ervi* Haliday, 1834 | x | | x | | x | | | | x | | x | |
| *Aphidius rhopalosiphi* De Stefani-Pérez, 1902 | | | | | | | x | | x | x | x | |
| *Aphidius uzbekistanicus* Luzhetzki, 1960 | | | | | | | | | x | x | x | |
| *Diaeretiella rapae* (M'Intosh, 1855) | | x | x | x | | | | | x | x | x | |
| *Praon volucre* (Haliday, 1833) | x | | | | | x | | x | | | x | x |

# Capítol 4.4

B. Caballero-López, A. Romero, N. Pérez, D. Ventura, L. Chamorro, M. Goula & F.X. Sans. The role of intercropping on insects' diversity in dry-land field crops in a Mediterranean site. Proceedings of the European Joint Organic Congress. *EDITORS:* Bo Andreasen, C.; Elsgaard, L.;Søndergaard Sørensen & Hansen, G. pp. 212-213. DARCOF. Odense (Dinamarca). ISBN: 87-991343-0

# The role of intercropping on insects' diversity in dryland field crops in a Mediterranean site

B. Caballero-López, A. Romero, N. Pérez, D. Ventura, L. Chamorro,
M. Goula & F.X. Sans

## Resum

*L'efecte del tipus de cultiu i la densitat de sembra sobre la comunitat d'insectes en un context de secà ha estat avaluat mitjançant un experiment amb micro-parcel·les. A l'hivern del 2004 es va seleccionar una parcel·la de 150 × 50 m en un camp comercial el qual havia estat gestionat segons les directrius de l'agricultura ecològica els darrers 10 anys. Es van delimitar 4 blocs de 35×10 m i a cada bloc es van marcar 24 parcel·les equidistants de 2×3 m. Es van sembrar set tipus de cultius, tres en condició de monocultiu (nap -Brassica napus-, ordi –Hordeum distichon- i veça –Vicia sativa-) i quatre en condició de policultiu (nap-ordi, nap-veça, ordi-veça, i nap-ordi-veça). Tots els cultius es van sembrar a tres densitats (alta, intermèdia i baixa). Els diferents tipus de cultius i densitats es varen assignar aleatòriament entre les micro-parcel·les de cada bloc. Tres micro-parcel·les de cada bloc es van deixar sense sembrar (control) per avaluar la flora arvense sense cultiu. Per tal d'avaluar l'efecte del tipus de comunitat vegetal sobre la població d'insectes herbívors es recollien quinze tiges a l'atzar a l'interior de cadascuna de les parcel·les, per tal d'evitar l'efecte marge.*

*Un total de 2.055 individus inclosos en 10 ordres i 25 famílies van ser recol·lectats, dels quals els més abundants eren els àfids (Aphididae:Homoptera), els trips (Thysanoptera) i les formigues (Formicidae: Hymenoptera).*

*El monocultiu de cereal és el sistema més pobre en abundància i diversitat d'insectes, fet que porta a pensar que alguns serveis al ecosistema com el control biològic o la pol·linització podrien veure's afectats. El monocultiu de veça i els policultius amb veça, afavoreixen l'abundància i riquesa dels diferents grups d'insectes, el que reflecteix la importància del cultiu de lleguminoses per pal·liar els afectes adversos del monocultiu de cereal. En aquest sentit, la introducció de cultius amb lleguminoses en els paisatges agrícoles pot ser un mecanisme per tal d'afavorir la biodiversitat als agroecosistemes.*

# The role of intercropping on insects' diversity in dryland field crops in a Mediterranean site

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***Abstract* - This work aims to evaluate the effect of crop type and density on insects' community in the Mediterranean region. In winter of 2004, four 35m x 10m blocks (replicates) were delimited and 24 equidistant 2m x 3m plots were marked. Seven crop types (barley, vetch, turnip, barley-vetch, barley-turnip, vetch-turnip and barley-vetch-turnip) at three densities were randomly established within each block. Fifteen crop shoots per plot were randomly collected in May to evaluate insect's abundance and diversity. Our results suggest that intercrop has a positive effect on abundance of most examined groups of insects and diversity, specifically when vetch is incorporated in the mixture. Changes in abundance of aphids, trips and ants are also discussed connected with vetch presence.**

## INTRODUCTION

The range of component practices of cultural pest management that involve increasing diversity is considerable (New, 2005). Likewise, the range of benefits from such enhancement to agricultural biodiversity and its functions are also very diverse (Altieri, 1991; Altieri & Nicholls, 1999). Some of these cultural practices are the intercropping or the use of monoculture of multiple crops in an area (Letourneau & Altieri, 1999). This work aims to evaluate the role of intercropping on the abundance and diversity of herbivorous insects. Despite several studies have shown that crop diversity strongly affected the population dynamics of some specialist herbivores (Bach,1979) few studies have compared the effect that the combination of three crop species differing in functional type have on the abundance and diversity of insects in the Mediterranean region.

## MATERIAL AND METHODS

This study was carried out in Montblanquet (UTM 31T CF3495), NE of Spain. The climate at the study site is mediterranean with a mean annual temperature and precipitation of 13ºC and 450 mm, respectively. To analyze the effect of crop type and density on abundance, richness and diversity of insects we selected a commercial field, which had been managed for more than one decade following the guidelines of Organic Farming. The 50x150 m field was located in the bottom of a narrow valley (600 m above sea level). Field boundaries were colonized by dense herbaceous grasslands dominated by *Brachypodium phoenicoides and* hedges dominated by *Rubus ulmifolius* and *Prunus spinosa.* Some trees (*Quercus faginea*, *Acer campestris and A. opalus*) and shrubs from natural oak woodlands also grow in the boundaries.

In winter of 2004 four 35m x 10m blocks (replicates) were marked. In each block, 24 equidistant 2m x 3m plots were delimited. Seven crop types were sown; three sole crops: barley (*Hordeum distachion*), vetch (*Vicia sativa*), and turnip (*Brassica napus*), and four polycultures: barley-vetch, barley-turnip, vetch-turnip and barley-vetch-turnip. All crop types were sown at three densities (high, medium and low). The different crop types and densities were randomly assigned to each plot within each block. Thus, a complete combination of seven crops at three densities within each block was obtained.

In May 2005 fifteen crop shoots were randomly collected in each plot. All insects were removed and transferred to 70% alcohol and sorted at the family level. Trips, ants and aphids were sorted out by species because of their particular importance. The abundance of insects was estimated by the number of individuals of each plot. Diversity, estimated by means of Shannon's diversity index (H'), evenness (J') and family richness were calculated according to Magurran (1988). The effect of crop type and density on abundance, richness, diversity and evenness of insect communities was analysed by two-way analysis of variance, with crop type at seven levels, and density at three levels. Differences among crops and densities were analysed using DMS method. The significant degree was p<0.05. Number of individuals was transformed using $\log_{10}(x+1)$ to achieve normality and homoscedasticity of residuals. A non-parametric Kruskal-Wallis test was used when transformed data were not normalised. Analyses were carried out using the SPSS Statistical Package (2002).

## RESULTS

In total, 2055 individuals from 10 orders and 25 families of insects were identified. The number of individuals ranked from 1 to 128 per plot. Mean abundance ranked from a minimum value of 6, 33± 4, 7 indiv plot$^{-1}$ in barley plots to a maximum value of 21. 50 ± 16, 7 indiv plot$^{-1}$ in barley-vetch plots (Table 1).

The two-way ANOVA show that insects abundance (F = 4.4, df = 6, p = 0.001), diversity ($\chi^2$ = 15.38, df = 2, p = 0.017), group richness (F = 2.67, df = 7, p = 0.015) and evenness ($\chi^2$ = 18.85, df = 6, p = 0.004) differ significantly among crop types. However, no significant differences were found among densities within each crop type (p ≤ 0.05).

**Table1**. Diversity (H'), evenness (J') and family richness in the different crop types. Data (Mean ±ES) with different letter within a column are significantly different (p ≤ 0.05).

| Treat | H' | Richness | J' | Abundance |
|---|---|---|---|---|
| **V** | 1,87$_a$ ± 0,54 | 7,56$_a$ ± 1,39 | 0,57$_a$ ± 0,38 | 10,38$_a$ ± 6,7 |
| **B** | 0,78$_b$ ± 0,17 | 5,33$_b$ ± 0,52 | 0,37$_b$ ± 0,32 | 6,33$_b$ ± 4,7 |
| **T** | 1,28$_{ab}$ ± 0,19 | 6,83$_{ab}$ ± 0,76 | 0,48$_{ab}$ ± 0,13 | 13,92$_a$ ± 13,3 |
| **B+V** | 1,57$_a$ ± 0,58 | 7,92$_a$ ± 1,29 | 0,60$_a$ ± 0,26 | 21,50$_a$ ± 16,71 |
| **B+T** | 1,25$_{ab}$ ± 0,29 | 6,42$_{ab}$ ± 0,95 | 0,51$_{ab}$ ± 0,15 | 10,67$_{ab}$ ± 10,7 |
| **T+V** | 1,84$_a$ ± 0,5 | 8,13$_a$ ± 1,80 | 0,57$_a$ ± 0,15 | 13,75$_a$ ± 8,5 |
| **B+V+T** | 1,48$_a$ ± 0,45 | 7,25$_a$ ± 0,43 | 0,58$_a$ ± 0,16 | 20,64$_a$ ± 13,50 |

Lowest mean species diversity was found in barley plots, 0.78 ± 0.17 bits ind$^{-1}$. In the other crop types, there were a wide range of diversity values, which ranged from 1.25 ± 0.29 bits.Ind$^{-1}$ in barley-turnip plots to 1.87 ± 0.54 bits. Ind$^{-1}$ in vetch monoculture plots. Richness and evenness follow a similar pattern than diversity. The comparison of means show that mean family richness, diversity, evenness and

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most abundant groups of insects were herbivorous and omnivorous, such as trips (O.Thysanoptera), aphids (O.Hemiptera F. Aphididae) and ants (F.Formicidae) comprising 76% of all individuals and 35 species. Among 889 individuals and 14 species of aphids, the three most common were *Aphis craccivora* (45%), *Rhopalosiphum maidis* (34%) and *Brevicoryne brassicae* (10%) colonising almost exclusively in sole and intercrops with vetch, barley and turnip respectively. A total of 328 trips from 15 species were recorded. The most commonly trapped trips were *Trips* sp*.* (70%) mainly on vetch, vetch-turnip and vetch-barley plots. Among 77 individuals and 7 species of ants, the two most frequent were *Tetramoriom caespitum* (43%) and *Lasius cf.grandis* (27%). While 87% of individuals of *T. caespitum* were found in barley-vetch-turnip plots, all of *L. cf. grandis* individuals appeared in plots with vetch.

**Table 2.** Number of species (S) and abundance (A) of aphids, ants and trips in the different crop types.

| Treat | Aphids | | Ants | | Trips | |
|---|---|---|---|---|---|---|
| | S | A | S | A | S | A |
| V | 7 | 21 | 3 | 16 | 12 | 96 |
| B | 5 | 38 | 0 | 0 | 8 | 19 |
| T | 6 | 49 | 1 | 1 | 7 | 27 |
| BV | 6 | 368 | 4 | 14 | 8 | 90 |
| BT | 6 | 57 | 0 | 0 | 8 | 17 |
| TV | 8 | 71 | 4 | 7 | 9 | 50 |
| VBT | 7 | 285 | 5 | 39 | 7 | 29 |
| Total | 14 | 889 | 7 | 77 | 15 | 328 |

## DISCUSSION AND CONCLUSIONS

Diversity, evenness and family richness of insects' communities were higher in intercrops than in sole crops, except for vetch monoculture, that is as diverse as intercrops. Moreover crop density is irrelevant for such communities. These results support the hypotheses that crop diversification (by adding species) enhances abundance and structure of herbivorous insect's communities (Altieri, 1999). However, Koricheva (2000) remarks that plant diversity effects on invertebrate abundance were mostly indirect and mediated by changes in plant biomass and cover.

The higher abundance and diversity of herbivorous insects in plots with vetch can be related to the higher amount of food resources (flowers and extra floral nectarines) and more structural crop complexity. The potential benefits of vetch enhancing beneficial biodiversity could be reduced because of vetch also facilitate some insect pest populations like trips and aphids. Furthermore, vetch favours ant populations and consequently enhances aphids' dissemination. This pattern is supported by the positive relationship between *Lasius* cf. *grandis* and aphids in vetch plots.

In mediterranean climate, cereal (barley) monoculture clearly impoverishes insect communities and consequently several functions as natural pest control and pollination may be reduced. To minimize the undesired effects of cereal monocultures, the design of spatial and temporal combinations of crops in an area including vetch would be advisable because of its positive effect on maintaining insect abundance and diversity in the agroecosystem.

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# Capítol 4.5

B. Caballero-López , R. Bommarco, F. X. Sans, J. M. Blanco-Moreno, J. Pujade Villar, M. Rundlöf & H. G. Smith. Landscape context influence on aphids and their natural enemies (in prep.)

# Landscape context influence on aphids and their natural enemies

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## Abstract

Important ecosystem services, such as biological control, may be affected by ecological processes at landscape scale. Here we examined the effect of landscape complexity measured as proportion of arable land (PAL) on regulation of densities of cereal aphids. We monitored densities of aphids and their natural enemies across the season in 12 independent landscape sectors distributed along a gradient from structurally simple to structurally rich landscapes. In addition we set up an experiment to test the ability of different groups of enemies to depress the aphid densities.

The PAL did not significantly contribute to the explanation of either aphid or parasitoid abundances, while the abundance of coccinellids and carabids increased significantly as PAL increased. Despite the different level of feeding specialization, the predator-aphid ratios of coccinellids (aphidophagous specialist) and predatory carabids (generalist predators) displayed a similar pattern increasing with the PAL in the surrounding landscape, suggesting that they benefit from the high availability of a variety of alternative resources within cropping systems.

The cage experiment showed that specialist as well as generalist predators are able to reduce the overall number of aphids on barley tillers and, interestingly, also provided evidence of an additive effect of both groups in their ability to suppress their shared prey. The increased predator-prey ratios in cereal fields embedded in simple landscapes and the experimental evidence of an additive effect between coccinellids and carabids suggest that enemy pressure on cereal aphids is likely to increase with landscape simplification. Although the striking differences in parasitism rate among landscape sectors call for more experiments to better understand the relative role of abiotic stress factors or interannually changing crop mosaics on interannual population fluctuations that could shape local ecological processes.

Key words: aphid-predator interaction, biological control, Carabidae, Coccinellidae, generalist *vs* specialist, landscape complexity, parasitoids.

# Resum

*El control biològic és un important servei al ecosistema que sembla estar condicionat per processos ecològics a escala de paisatge. En aquest estudi s'ha avaluat l'efecte de la complexitat del paisatge, mesurat com la proporció de terra anualment llaurada (PAL), sobre la regulació de les abundàncies dels àfids del cereal. Les densitats d'àfids i els seus enemics naturals s'ha estudiat en 12 sectors de paisatge independents distribuïts al llarg d'un gradient que va des de paisatges simples (PAL > 95%) a paisatges complexos (PAL < 50%). A més, en paral·lel hem dut a terme un estudi experimental per tal de conèixer l'impacte dels diferents grups d'enemics naturals sobre la densitat d'àfids, ja que una major presència de depredador no té perquè implicar un major control de les poblacions d'àfids doncs d'altres preses poden ser preferides.*

*El PAL no explica les diferències d'abundància d'àfids i parasitoids afidòfags, mentre que l'abundància de coccinèl·lids i caràbids és afavorida quan el PAL augmenta. Tot i que coccinèl·lids (afidòfags especialistes) i caràbids (predadors polífags) difereixen en el seu grau d'especialització alimentària, la relació entre els coccinèl·lids i els àfids i la relació entre els caràbids i els àfids mostren el mateix patró en relació amb el PAL dels camps estudiats. Aquests resultats suggereixen que ambdós grups són afavorits en paisatges simplificats, fet que es pot atribuir a una major disponibilitat de preses alternatives estretament lligades amb els paisatges bàsicament agrícoles.*

*L'estudi experimental mostra que tan els depredadors especialistes voladors (parasitoids i coccinèl·lids) com els generalistes caminadors-excavadors (caràbids, aranyes) regulen les poblacions d'àfids. A més, aquest experiment també fa palès que l'efecte d'ambdós grups, a l'hora de controlar les poblacions d'àfids, és de tipus additiu.*

*La major presència de depredadors en els camps de cereals dels paisatges simplificats, lligat amb les evidències experimentals d'un efecte additiu entre grups de depredadors, suggereix que la pressió depredadora sobre els àfids dels cereals augmenta amb la simplificació del paisatge.*

*Tanmateix, el fet que no hàgim pogut trobar un patró robust del nivell de parasitisme en relació amb la complexitat del paisatge pot ser explicat per l'existència de factors abiòtics o canvis inter-annuals en el mosaic dels cultius dels paisatge agrícoles que poden modificar els processos ecològics a escala local que afecten la gestió de plagues.*

## Introduction

Current large-scale biodiversity losses in agricultural landscapes in the northern hemisphere may negatively impact ecosystem services such as biological control (Gurr *et al.*, 2003; Tscharntke *et al.*, 2007). However, little is known about the ecology of ecosystem services, limiting our appreciation of their value and ability to conserve and manage them. There is therefore a renewed interest in understanding the mechanisms of naturally-occurring biological control to enhance natural enemies and their ability to suppress pests by environmentally-friendly agro-ecosystem management (Tscharntke *et al.*, 2005).

The major insect pests in cereal crops in northern Europe are aphids (Sigsgaard, 2002), which are prey to a number of enemy species. The entomophagous arthropods that attack aphids can be divided broadly into specialists and generalists. Specialists include potentially important control agents of aphids such as parasitoids (Hymenoptera: Braconidae, Aphidiinae), and aphidophagous predators mostly from the families Coccinellidae (Coleoptera), Chrysopidae (Neuroptera), and Syrphidae (Diptera). Generalists include stenophagous predators such as ground beetles (Col., Carabidae) and spiders (Lang, 2003; Symondson *et al.*, 2002). The close dynamic link between specialist natural enemy and prey populations has classically resulted in attention being focused on specialists as potential biological control agents, but a recent review by Symondson et al. (2002) provides good examples of cases where assemblages or guilds of generalist predators were more effective than specialists at controlling pests.

There has recently been much attention paid to the effect of landscape composition on biological control (Bianchi *et al.*, 2006; Gurr *et al.*, 2003; Östman *et al.*, 2001; Tscharntke *et al.*, 2007). It has been suggested that population variability of both specialist and generalist biocontrol agents is associated with the complexity of landscapes surrounding agricultural fields (Rand & Tscharntke, 2007; Tscharntke *et al.*, 2007). Complex landscapes were associated with increased aphid mortality resulting from parasitism, so that parasitoids appeared to profit from a high availability of perennial habitats (Roschewitz *et al.*, 2005; Thies *et al.*, 2005; Thies *et al.*, 2003). In contrast, generalist predators are hypothesized to benefit from simplified landscapes, because of the ability of generalists to use alternative resources in cropping systems (Rand & Tscharntke, 2007). Hence, the effect of landscape structure may be affected by the relative effect of landscape structure on generalist and specialist natural enemies in combination with their relative effect on their aphid prey. For example, a higher natural enemy abundance may not automatically mean improved biological control, because prey other than the pest species may be preferred (Östman *et al.*, 2001). Thus, our understanding of biological control is hampered by the lack of studies simultaneously examining the importance of agricultural landscape complexity on the abundance and ability to depress prey of specialist and generalist natural enemies of specific hosts (Rand & Tscharntke, 2007).

In this study, we examine the effect of the surrounding landscape complexity on the abundance of aphids, parasitoids, and specialist and generalist predators in cereal fields. We predicted that aphids and specialist enemies (parasitoids and aphidophagous predators) should be positively affected by landscape complexity, whereas generalists should instead be negatively affected by landscape complexity. In a field experiment we also tested the ability of different enemy groups to depress aphid populations, by excluding flying predators and parasitoids, ground-living predators, or both, from experimental plots (Schmidt *et al.*, 2003). We expected both groups should have an effect on the aphid's population growth, but the experiment was designed to test if their interaction disrupted the aphids biological control or, by contrast, whether these two groups have an additive effect on the control of aphid populations.

# Methods

## Abundance of aphids and their natural enemies

### *Study region and landscape sectors*

The study was carried out in the province of Skåne, southern Sweden, which is characterised by a mixture between intensively farmed homogeneous plains and heterogeneous mixed farmland (Rundlöf & Smith, 2006). Within this region, 12 non-overlapping landscape sectors of a 2-km radius were chosen along a gradient from structurally simple, with > 95% arable land and large fields to structurally rich landscapes with > 50% non-crop habitats and smaller fields. The landscape sectors were selected so as to avoid north-south or east-west gradient in the proportion of arable land within each landscape area, in order to avoid, as far as possible, such problems as correlations between landscape complexity and abiotic factors like microclimate and soil fertility. As close as possible to the centre of the sector, we selected two organically-managed fields with a spring sown cereal (barley or wheat), but as distance between fields ranged from 260 to 2490 m, we determined individual estimates of landscape complexity for each field to be used as predictors in analyses (see above). The organic fields had been managed according to organic guidelines for at least 3 years, were only fertilised with manure and were not sprayed with any pesticides. Consequently the pest-natural enemy interaction is not disrupted by the impact of pesticides and the natural dynamic between the two trophic levels can be analysed.

The landscape complexity around each field was characterised using the proportion of annually tilled arable land (hereafter PAL) within a 500 m radius from its centre. The PAL was chosen because it represents a relatively simple, but robust and useful parameter for characterising landscape complexity (Roschewitz *et al.*, 2005). Landscape characteristics were determined using spatially explicit information on agricultural land-use (from the Swedish Board of Agriculture) analysed in ArcGIS 9.2.2. In each field, we established two 100 m-transects that ran parallel to the field edge. The first transect was located 3 m from the first drill row and the second 30 m further into the field. The first 50 m of each transect was used for the aphid counts and the second part for the natural enemy count.

### *Crop characteristics*

Crop characteristics were measured in June and July at cereal flowering and milk-ripe stage, respectively. In each field cereal height and growth stage according to Zadoks' et al. scale (1974) were evaluated in 20 and 10 randomly selected tillers, respectively. Crop establishment and weed abundance were evaluated in five randomly-distributed 1 $m^2$squares per field. Crop and weed cover were recorded in each square following a ground cover scale with the following intervals: 0-1, 1-5, 5-10, 10-25, 25-50, 50-75 and 75-100%. Species cover was assigned to the midpoint of its cover-class. We did not distinguish between narrow- and broad-leaved weeds.

### *Arthropods monitoring*

Aphids were counted visually and identified on 100 randomly-selected shoots in the two 50 m transects. The number of winged and wingless adults, nymphs and mummies (mummified aphids hosting parasitoids) for each aphid species on each cereal shoot were counted.

The abundance of natural enemies was estimated from the count of aphid mummies and predators. Mummies were collected, reared in the laboratory and the hatched adult parasitoids were identified to species. The predator abundance was recorded using three sampling methods. First, larvae of chrysopids and syrphids were visually counted on the same shoots used to count the aphids. Second, flying predators, mainly coccinellids, were recorded by visual transect walk along the two 50 m transects. The walking speed was 2 m/min and all predators within 1 m on either side of transect were counted. Third, the ground-dwelling predators were caught using pitfall traps. The traps had a diameter of 12 cm at the mouth, were 15 cm deep and were dug down to ground level. Three pitfalls were positioned along the second transect 30 m further into the field at 30-m intervals, which contained a NaCl-solution as a preservative solution and a drop of detergent to decrease the surface tension. Transparent plastic covers (25 cm × 25 cm) were placed above the traps to prevent flooding by rain.

The transects for aphids and flying predator survey were walked one after the other between 10:00 and 19:00 hours and only during fair weather (no precipitation, light winds, minimum temperature of 17 ˚C). Ambient air temperature and percentage of relative humidity were measured prior to, and just after, transect sampling because these meteorological variables are known to affect the activity of some aphid predators (Elliott *et al.*, 1998). Sampling was carried out at cereal flowering stage from June 7th to 14th, 2007, and at milk-ripe stage between July 14th and 20th, 2007. The traps were opened for two one-week sampling periods in June and July. As one sampling campaign lasted 5-6 days, the 24 fields were sampled in random order to prevent bias due to the phenological stage of cereal. Apart from larvae stages of some predators, the entire arthropod community was determined to species. In addition, carabid beetles were sorted into trophic groups: predators, granivorous and omnivorous, according to the feeding type of adults (Purtauf *et al.*, 2005).

### *Statistical analyses*

We analysed total densities of aphids and flying natural enemies at the level of transect, while total densities from pitfall catches and species richness were analysed at field level. To account for the fact that data sampled in the same transects, fields and sectors are not independent, we used mixed models in which we included landscape sector, field (nested within landscape sector), and transect (nested within field and landscape sector) as random factors. For most models we used linear mixed models with normal error distribution. Counts were then log-transformed, proportions arcsine-square-root transformed and ratios log-transformed to achieve normality. When counts were small, we used generalised linear mixed models (SAS Proc Glimmix) with Poisson error distribution and log-link function and for proportions binomial error distribution was used (ratio between the number of aphids mummified and the total aphid abundance). We included the proportion of annually tilled arable land (PAL), distance to field margin (close or distant) and sampling period as fixed factors in the models. Interactions between PAL and field margin distance, and PAL and sampling period were also examined to see if the responses to landscape complexity depended on the sampling period or the field margin distance. We simplified the initial full model by sequentially removing non-significant fixed terms until only those with $P \leq 0.05$ remained, but always kept factors included in significant interactions. Residuals were examined for departures from normality and homoscedasticity in all analyses. Denominator degrees of freedom were estimated with the Kenward-Roger method. All statistical analyses were performed in SAS 9.1 for Windows.

## The predation cage experiment

### *Study sites*

The cage field experiment to test the predators' effect on aphid population sizes was carried out between mid June and late July, 2007, in 6 organically-managed spring barley fields, which were located in two of the twelve landscape sectors where the PAL was the main habitat (70%).

### *Treatments*

The experimental treatments were applied in a 2 × 2 factorial design with ground-dwelling predator exclusion (G), flying predator plus parasitoid exclusion (F), total exclusion (T), which was the combination of G and F, and open control (O). In each field, we delimited 24 circular plots with a diameter of 0.75 m, situated 2 m apart from each other. The four treatments, each replicated six times in each field were randomly assigned to each plot within each field. By locating plots in this way, they will contain a low but random number of aphids. In this way, we attempted to avoid possible problem that cages may constrain dispersal to, since at random location dispersal to and from the plot should equalize. In mid June we placed plastic barriers to exclude ground-dwelling predators such as spiders, carabids and staphylinids (G treatment). The barriers were circular, 0.75 m in diameter, 30 cm high and dug about 10 cm into the soil. Inside each barrier we placed a 'live' pitfall trap with a circular opening of 12 cm diameter that was permanently open throughout June and July. Ground-dwelling predators captured in these live traps were counted and removed. All other animals caught were returned into the experimental plot. In addition, web-building spiders were removed manually and repeatedly from the closed plots. Flying aphid predators and parasitoids were reduced by setting wire cages over the plots in late June (F treatment). The cages had a mesh size of 8 mm allowing airflow to avoid changes in microclimate conditions (Schmidt *et al.*, 2003) and were covered with sticky glue to intercept or deter flying predators or parasitoids. The bottom edge of the cages was left without glue to permit ground-dwelling predators access (Schmidt *pers. com.*). To impede ground-dwelling predators from climbing on shoots near the plastic barriers and preventing nearby shoots from being stuck to the sticky mesh, the surroundings of each sub-plot was mown at least 20 cm around the plot. This was done around all plots, so that any microclimatic effect should not differ between treatments.

### *Aphids and their natural enemy monitoring*

In all treatments, the numbers of adult winged, adult wingless and nymphal aphids for each aphid species were recorded on 15 randomly selected shoots in each plot. The number of predators and mummified aphids (by parasitoids) were also noted. Predators were left on the plant (except in the total predator exclusion treatment). Mummies were taken to the laboratory for rearing and identification. Ground-dwelling predators captured in these live traps were also taken to the laboratory if it was necessary for identification. The first sampling was carried out at late barley flowering, from 29th June to 2nd July 2007, before the installation of the wire cages, and the second at late milk-ripe stage, from 21st to 22nd July 2007, after the cages had been removed. Plots were sampled on dry days after dew had evaporated from the plants.

### *Data analyses*

Because of relatively low numbers, analyses were performed with generalised linear mixed models (SAS Proc Glimmix). Aphid abundances were analysed using models with Poisson error distribution and a log-link function and proportions using models with binomial error distribution and a logit link (proportion of parasitised aphids). To account for the hierarchical study design we included the random factors field (nested within the landscape sector), field ×

F, field × G to detect different responses to treatments of the aphid densities dependent on the area. We included landscape sector, ground-dwelling predator removal (binary), and flying predator plus parasitoid removal (binary) as fixed factors in the model. The final model was determined by sequentially removing non-significant fixed terms until only those with $P \leq 0.05$ remained. Residuals were examined for departures from normality and homoscedasticity in all analyses. Denominator degrees of freedom were estimated with the containment method, which gave lower and more accurate values than the Kenward-Roger method. All statistical analyses were performed in SAS 9.1 for Windows.

# Results

## Abundance of aphids and their natural enemies

### *Crop characteristics and meteorological measurements*

There were no significant differences among fields surrounded by different landscape complexities either in crop characteristics (cereal height, cereal growth stage, cereal cover and weed cover) or in meteorological conditions during sampling dates ($P > 0.05$; data not shown).

### *Aphids*

A total of 5,076 cereal aphids were counted in the 24 organically-managed fields. Although four aphid species appeared, *Rhopalosiphum padi* (63% of all aphid individuals) and *Sitobion avenae* (35.6%) were widely the most abundant aphids. The numerical responses of aphids to landscape complexity were similar for *R. padi* and *S. avenae* models ($P > 0.05$), thus pooled numbers of aphid abundances were used for the subsequent analyses.

Aphid densities varied considerably among sites ranging from 7 to 172 individuals per 100 cereal shoots at flowering and 8 to 296 at milk-ripe stage but did not differ according to the complexity of the surrounding landscape (Table 1).

In contrast, the abundance of aphids showed a clear pattern in relation to spatial location intra-field. The mean aphid abundance was significantly higher at 30 m from the field margin (mean ± SE: 130.1 ± 23.36) compared to those at 3 m from the field margin (86.3 ± 13.55).

The proportion of infested shoots followed the same pattern (Table 1), being higher at the 30 m-transects (mean ± SE: 35.3 ± 2.55%) compared to those at 3m from the field margin (26.0 ± 2.51).

**Table 1.** Effect of proportion of arable land, the distance to field margin and their interaction on abundance of aphids and their specialist natural enemies. The effect of landscape context and margin distance and their interaction were also tested for ratios such as the proportion of infested shoots by aphids, the aphid-coccinellid ratio and the parasitism rate. Bold numbers are for significant factors ($P > 0.05$).

| | Proportion of arable land | | | Distance to field margin | | | Interaction | | |
|---|---|---|---|---|---|---|---|---|---|
| Dependent variable | X ± SE | $F_{df}$ | $P$ | X ± SE | $F_{df}$ | $P$ | X ± SE | $F_{df}$ | $P$ |
| *Abundance* | | | | | | | | | |
| Aphids | -0.0 ±0.6 | $0.0_{1,12.7}$ | *ns* | -0.4 ± 0.1 | **13.45**$_{1,52.6}$ | *** | -0.2 ± 0.6 | $0.09_{1,51.7}$ | *ns* |
| Coccinellids | 4.6 ±1.1 | **11.30**$_{1,21}$ | ** | 1.8 ± 0.7 | **6.62** $_{1,49.8}$ | * | -3.1 ± 1.0 | **9.64**$_{1,50.0}$ | ** |
| *Ratios/Proportions* | | | | | | | | | |
| Infested shoots | -0.1 ±0.0 | $0.40_{1,11.8}$ | *ns* | 0.1 ± 0.1 | **20.93**$_{1,46}$ | *** | -0.1 ± 0.1 | $1.57_{1,44}$ | *ns* |
| Aphid-Coccinellids | 0.2 ±0.1 | **6.21** $_{1,45}$ | * | 0.0 ± 0.0 | 1.25 $_{1,46}$ | *ns* | 0.1 ± 0.1 | $0.23_{1,45}$ | *ns* |
| Parasitism rate | 2.0 ±2.3 | 1.29 $_{1,23.9}$ | *ns* | -0.9 ± 1.2 | 0.71 $_{1,24.9}$ | *ns* | 1.2 ± 1.5 | $0.59_{1,24.9}$ | *ns* |

*Parasitoids*

208 mummies, 180 (86.5%) *S. avenae* and 28 (13.5%) *R. padi*, were collected and reared. Out of the total aphid mummies, 66 (31.7%) hatched in the laboratory and could be determined to species, whereas 93 (44.7%) already hatched in the fields, and 49 (23.6%) did not hatch. Those that did not hatch were dissected without finding any parasitoids, most likely because the parasitoids died from fungal attacks (Van Veen *et al.*, 2008). Of the emerged parasitoids 33.3% were primary parasitoids of the species *Aphidius uzbekistanicus*, and *A. rhopalosiphi* (Hym., Braconidae, Aphidiinae), and the rest were hyperparasitoids such as *Asaphes suspensus*, *Dendrocerus carpenteri* and *Alloxysta victrix* (Appendix 1).

Aphid parasitism was about 1% at wheat flowering stage, while by the end of the cropping season, 39.5 ± 8.6% of the aphids were parasitised, although the huge variability of parasitism rate among landscape sectors ranging from 8.3 ± 8.3 to 86.9 ± 2.2% hindered finding a tendency related to PAL per landscape (Table 1).

### *Predators*

In total 440 individuals, representing 4 predatory families, were recorded in the visual surveys. Coccinellids constituted the most abundant group, accounting for 88% of all individuals. Seven species of coccinellids were recorded, but the specialist aphidophagous *Coccinella septempunctata* was the most abundant predator (76.1%) and the most common coccinellid (86.8%). The low numbers of chrysopid (mean ± SE: 0.4 ± 0.20 individuals per 100 shoots) and syrphid larvae (0.9 ± 0.28) hampered their inclusion in the detailed analyses (Appendix 2).

Coccinellid populations were larger on fields surrounded by simple landscapes, so that their abundance significantly increased as PAL increased (Table 1). The interaction between PAL and field margin distance on their abundance was also significant (Table 1), because coccinellid populations at 30 m transects from the field margin were strongly related to landscape complexity ($F_{1,28.1} = 8.24$, $P = 0.008$), while this pattern was not significantly supported by coccinellid populations at 3m transects than those close to the field margin ($F_{1,22.1} = 2.67$, $P = 0.12$). In contrast, coccinellids species richness was not related to the PAL ($F_{1,15.5} = 0.36$, $P = 0.56$) but tended to be affected by an interaction between the proportion of arable land and sampling period ($F_{1,35.3} = 5.57$, $P = 0.024$). However, in separate analyses of coccinellids species richness at first and at second sampling period, neither of them differed in relation to landscape complexity (June $F_{1,11.5} = 0.15$, $P = 0.71$; July $F_{1,16.5} = 2.23$, $P = 0.15$).

In total, 20,555 individuals were captured by pitfall trapping during the 2-week study period. Spiders were the dominant group (63.6% of the catch) followed by carabids (24.5%) and staphylinids (11.8%). A total of 5,086 carabid beetles from 47 species were caught. The three most commonly trapped carabids were *Pterostichus melanarius*, *Harpalus rufipes* and *Bembidion lampros*, and these comprised the 77.6% of all carabid species (Appendix 3). Predators were the most abundant (80%) functional feeding group, followed by granivorous (17.6%), and omnivorous (2.4%) carabids. Consequently the general pattern for all carabids is governed by predatory carabids.

The PAL did not contribute to explaining either spider or staphylinid abundances, while the abundance of carabids increased significantly as PAL increased. This pattern was mainly due to increased predatory carabid abundance, because neither the abundance of granivorous nor omnivorous carabids varied in relation with this variable. Sampling period had a minor effect on carabid abundance, except for granivorous carabids, which displayed a decrease in the second sampling period (Table 2). The species richness of predatory carabids was positively associated with the PAL in the surrounding landscape, while the total species richness of carabids just marginally increase with increasing PAL and, neither granivorous nor omnivorous carabid species richness showed significant association with PAL in the surrounding landscape. Additionally, both granivorous and predatory carabid species richness responded to the sampling period (Table 2).

**Table 2.** The effect of proportion of arable land and sampling period on different generalist groups captured by pitfall trapping. Abundance, species richness and aphid-predator ratios were studied. Bold font corresponds to significant relationships ($P < 0.05$).

| | Proportion of arable land | | | Sampling period | | |
|---|---|---|---|---|---|---|
| Dependent variable | X ± SE | $F_{\mathrm{df}}$ | *P* | X ± SE | $F_{\mathrm{df}}$ | *P* |
| *Abundance* | | | | | | |
| Spiders | -0.1 ± 0.7 | 0.01 $_{1,14.5}$ | *ns* | -0.1 ± 0.1 | 0.20 $_{1,26.2}$ | *ns* |
| Staphylinids | -0.7 ± 0.8 | 0.98 $_{1,14}$ | *ns* | 0.2 ± 0.2 | 1.66 $_{1,33.4}$ | *ns* |
| Carabids | 1.9 ± 0.8 | **6.09** $_{1,17.8}$ | * | -0.4 ± 0.2 | 3.99 $_{1,39.5}$ | *ns* |
| Granivorous carabids | 1.2 ± 0.8 | 2.33 $_{1,15.3}$ | *ns* | -0.7 ± 0.2 | **18.02** $_{1,22.6}$ | *** |
| Omnivorous carabids | -1.2 ± 1.3 | 0.80 $_{1,13.9}$ | *ns* | 0.3 ± 0.3 | 1.56 $_{1,115}$ | *ns* |
| Predatory carabids | 2.2 ± 0.9 | 5.84 $_{1,18.1}$ | * | -0.3 ± 0.2 | 2.48 $_{1,39.9}$ | *ns* |
| *Species richness* | | | | | | |
| Carabids | 0.5 ± 0.2 | 4.41 $_{1,13.1}$ | *ns* | -0.1 ± 0.1 | 1.72 $_{1,33.7}$ | *ns* |
| Granivorous carabids | 0.7 ± 0.4 | 3.39 $_{1,14.5}$ | *ns* | 0.4 ± 0.2 | **7.06** $_{1,24}$ | * |
| Omnivorous carabids | -1.7 ± 1.1 | 2.55 $_{1,9.3}$ | *ns* | 0.4 ± 0.2 | 2.84 $_{1,119}$ | *ns* |
| Predatory carabids | 0.7 ± 0.3 | **5.85** $_{1,12.4}$ | * | -0.2 ± 0.1 | **5.50** $_{1,34.3}$ | * |
| *Ratios* | | | | | | |
| Aphid-Spiders | 0.1 ± 1.2 | 0.00 $_{1,15.5}$ | *ns* | -0.1 ± 0.3 | 0.16$_{1,23.2}$ | *ns* |
| Aphid-Pr. carabids | 3.1 ± 1.3 | **5.59** $_{1,20.6}$ | * | -0.4 ± 0.3 | 1.98$_{1,22.9}$ | * |

*Natural enemy-prey ratios*

Predator-prey ratios of both coccinellids and carabids displayed a clear pattern of response to PAL; with higher values in fields surrounded by a high PAL. Despite the different level of feeding specialisation, coccinellid-aphid ratio (specialist) and carabid-aphid ratio (generalist) followed the same trend. In contrast, the ratio of aphids to spiders, the other generalist predatory group studied, was not related to PAL (Tables 1-2).

## The predation effect on aphid density in a field experiment

The open-treatment population densities for aphids, parasitoids, flying and ground-dwelling predators (of ground exclusion and total exclusion treatments) are summarized in Table 3.

Natural enemy counts in visual surveying and in pitfall trapping followed similar patterns in the six experimental fields (data not shown). The most numerous predators were polyphagous ground-dwelling predators, with the pitfall catches mainly composed of *Pterostichus melanarius* (Carabidae), and Lycosidae and Linyphiidae as cursorial spiders. Like specialist predator coccinellids, larvae of chrysopids and nabids (Hemiptera) were present, but in lower numbers (Table 3).

**Table 3.** Ambient (unmanipulated) densities of aphids and their natural enemies in the experimental fields. Aphids, parasitism rate and flying predators: individuals per 15 shoots, *n* = 36 plots (treatment O). Ground-dwelling predators: individuals captured per 'live' pitfall traps on 15 days thorough June-July, *n* = 72 (treatments –G and T before manipulation, twelve per field). Arithmetic means ± SE.

| | | | 29 June-2 July | 21-22 July |
|---|---|---|---|---|
| **aphids** | | | | |
| | | *Sitobion avenae* | 59.1 ±13.12 | 9.1±3.92 |
| | | *Rhopalosiphum padi* | 8.7±3.05 | 23.1 ± 6.46 |
| **parasitoids** | | | | |
| | Parasitism rate[a] | | 20.5 ± 6.63 | 37.5 ± 17.97 |
| **flying predators** | | | | |
| | Coccinellids | *Coccinella magnifica* | 0.1 ± 0.08 | 0 |
| | | *Coccinella septempunctata* | 0 | 0.2 ± 0.20 |
| | | *Propylea quatuordecimpunctata* | 0.3 ± 0.13 | 0.2 ± 0.20 |
| | | Coccinellid larvae | 0.1 ± 0.08 | 0 |
| | Chrysopids | Larvae | 1.1 ± 0.31 | 1.4 ± 0.68 |
| | Nabids | Larvae | 0 | 0.8 ± 0.37 |
| **ground-dwelling predators** | | | | |
| | Spiders[b] | | 4.3 ± 1.49 | 6.2 ± 1.77 |
| | Carabids | *Clivina fossor* | 1.5 ± 0.61 | 2.0 ± 0.71 |
| | | *Harpalus rubripes* | 2.5 ± 0.66 | 0.4 ± 0.40 |
| | | *Pterostichus melanarius* | 6.4 ± 2.18 | 0.2 ± 0.20 |
| | | Carabid larvae | 1.4 ± 0.39 | 0.4 ± 0.24 |

[a] Parasitized mostly by Braconidae SF. Aphidiinae

[b] Mostly Lycosidae and Linyphiidae

A total of 4 species and 3,827 individuals of aphids were recorded, and *Sitobion avenae* and *Ropalosiphum padi* were the most numerous species. Nymph was the most abundant developmental stage (74.3 ± 1.6%), whereas winged aphids were rare (1.2 ± 0.2%). Aphid infestations averaged 70.66 individuals per 100 shoots. Before the experiment started, aphid densities showed no treatment effects (F: $F_{1,5} = 2.27$, $P = 0.19$; G: $F_{1,5} = 0.27$, $P = 0.63$), while by the end of the experiment there were significant differences in abundance of aphids among treatments. These results indicate that exclusion systems worked properly. The removal of flying predators plus parasitoids led to an increase in aphid density by 73.0% ($F_{1,5} = 17.00$, $P = 0.009$), the removal of ground-dwelling predators led to a 71.4% increase in aphid populations ($F_{1,5} = 20.06$, $P = 0.007$), whereas aphid density was 259.0% higher in the total exclusion compared with the open treatment (Fig. 1). There was no significant interaction between the removal treatments (G × F: $F_{1,5} = 2.07$, $P = 0.21$). By the end of June, 20.5 ± 6.6% of the aphids collected in the experimental plots were parasitised and, on the second sampling, 37.5 ± 18.0%.

Aphids were attacked mainly by 3 species of primary parasitoids *Aphidius rhopalosiphi*, *A. uzbekistanicus* and *A. ervi*. On the first sampling, parasitism differed marginally between sectors ($F_{1,4} = 7.28$, $P = 0.054$), showing a local effect on parasitoids abundances, whereas no obvious differences between treatments were found (G: $F_{1,5} = 0.24$, $P = 0.65$; F: $F_{1,5} = 0.74$, $P = 0.43$). On the second sampling, parasitism did not differ either among treatments (G: $F_{1,4} = 0.92$, $P = 0.39$; F: $F_{1,4} = 0.50$, $P = 0.52$) or between sectors ($F_{1,4} = 0.05$, $P = 0.83$).

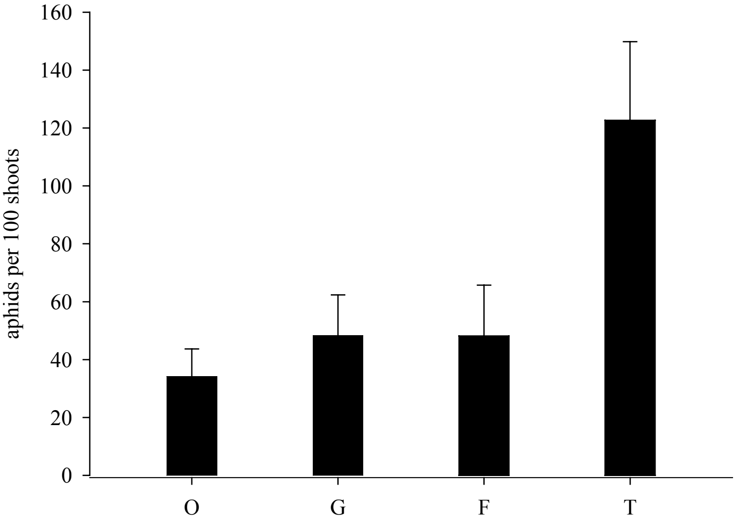

**Figure 1.** Mean ± SEM aphid densities found at the end of the experiment. O, open treatment (control); G, ground-dwelling predator removal; F, exclusion of flying predators and parasitoids; T, exclusion of all predators plus parasitoids (see text for details).

# Discussion

## Landscape effect on aphids and their natural enemies

There is evidence that diversified landscapes, because of a higher availability of perennial - habitats that provide overwintering sites, enhance cereal aphid populations (Roschewitz *et al.*, 2005; Thies *et al.*, 2005). However, in our study aphid populations did not vary in relation to the PAL. The absence of a relationship between aphid abundance and landscape complexity may have been a consequence of drastic inter-annual fluctuations of aphid populations reported in previous studies or of local factors such as the non-homogenous distribution of aphid populations intra-field, which would explain the huge variability of abundance related to the distance from the margin. Although little is known of the relative role of inter-annual weather changes for aphid-natural enemy interactions, cereal aphid populations may profit from higher temperatures and suffer from rainfall (Roschewitz *et al.*, 2005; Thies *et al.*, 2005), thus the low densities of cereal aphids at the milk ripe stage might be partially explained by the unusually cold, long rainfall period in the last fortnight of June, which may have disturbed the main period of aphid reproduction in northern Europe. The role of local factors is supported by a recent study which reported that, at the beginning of the season, when densities were low, aphids showed aggregated populations while by the end of the cereal season aphid densities became progressively more homogenously distributed at field scale (Fievet *et al.*, 2007). Therefore, the low aphid density and, the fact that the significant effect of distance from the margin persisted over the season, suggested that the distribution of aphid populations remained as in the initial stages during the whole cropping season. Thus, we cannot rule out that the low aphid population during our study could be blurring the landscape pattern response.

Contrary to what was expected, a similar number of aphid parasitoids were found in cereal fields across the gradient from structurally rich to simplified landscapes. Although most studies have found a correlation between landscape complexity and rate of parasitism (Cronin & Reeve, 2005; Thies *et al.*, 2003), conversely Vollhardt *et al.* (2008) reported that structurally complex and structurally simple landscapes supported a similar density of cereal aphid parasitoids. Accordingly, parasitoids of cereal aphids seemed to be spatially and temporally linked closely with their host species and may not need to switch to alternative host species, given that regions dominated by cereals typically provide cereal aphids continuously. On the other hand, the absence of a relationship between parasitoid abundance and landscape complexity may have been a consequence of several factors. Firstly, the low aphid densities during the milk-ripe stage may have made it difficult to find an appropriate host. Secondly, harsh abiotic conditions in the last fortnight of June, which may also have affected the aphid populations negatively, may have delayed the larval development of parasitoids (Müller & Schmid-Hempel, 1993). Thirdly, spatio-temporal landscape dynamics may be significant to organisms like parasitoids with a relatively short life-span and low dispersal rates compared to those of their hosts. In this sense, rotations of annual crops are particularly important in agricultural landscapes and it has been suggsted that parasitoid populations are more strongly influenced by interannually-changing crop mosaics than their herbivorous hosts (Thies *et al.*, 2008). Thus, inter-annual fluctuations in parasitoid populations already reported by previous studies might be due to host availability, indirect or direct effects of interannual weather and due to the fact that landscape context changed annually, indicating interannual dilution and crowding effects.

In contrast to aphids and parasitoids, specialist aphidophagous (Coccinellidae) and generalist predator (Carabidae) communities were influenced by the complexity of the landscape surrounding the organic cereal fields. The abundance of both coccinellids and predatory carabids, mainly represented by *Coccinella septempunctata* and *Pterostichus melanarius*, respectively increased with the proportion of arable land in the surrounding landscape, suggesting that a reduced complexity at landscape scale can actually enhance the communities of such predators. These findings are in accordance with results of earlier studies, which showed positive effects of surrounding agricultural habitats on highly mobile predators (Elliott *et al.*, 1998; Rand & Tscharntke, 2007), potentially able to benefit from the high availability of alternative resources within cropping systems. Recent studies have also shown that even for apparently mobile and highly dispersive insects such as hoverflies, normal field boundaries may restrict their movement between fields, so that tall boundary vegetation in complex landscapes, such as copses and woods, may impede flying predators from dispersing to nearby areas of crop fields (Wratten *et al.*, 2003). Thus, habitat structure in mosaic landscapes may constrain the spatial extent of the benefits from habitat diversification (Gurr *et al.*, 2003).

The fact that the density of spiders did not show any variation in relation to landscape complexity may seem surprising, since several authors highlighted that spider density was enhanced by high amounts of non-crop habitats in the surrounding landscape (Schmidt *et al.*, 2005b). However, other works have also reported that this pattern may just be temporary (Öberg *et al.*, 2008), or that response to landscape complexity is clear for species richness of spiders but not for their abundances. As examples, Schmidt *et al.* (2005a) reported that overall spider density responds to farming practices but not to landscape heterogeneity, and Clough *et al.* (2005) found that activity density of spiders differed in relation to field margin distance and among regions but not to the landscape context.

## Landscape effect on biological control

Because of the increased densities of coccinellids and predatory carabids, the predator-aphid ratios also increased with the proportion of arable land in the surrounding landscape, indicating a potentially better pest control in fields surrounded by a high arable land proportion. However, higher prey-predator ratio may not automatically mean a better biological control. Firstly, prey other than the one studied may be preferred (Östman *et al.*, 2001). Second, multiple enemy species may act synergistically, or additively, on their shared prey, enhancing predation pressure, or by contrast, intraguild predation may disrupt biological control (Schmidt *et al.*, 2003).

The experimental manipulations at field scale showed that flying natural enemies as well as ground-dwelling predators are able to reduce the overall number of aphids on barley tillers. Interestingly, our exclusion study revealed that the effect of ground-dwelling predators on suppressing aphid densities was as significant as the effect of flying predators plus parasitoids. However, few other exclusion studies that attempted to measure the impact of different natural enemy guilds under natural densities in field conditions (Holland *et al.*, 2008; Schmidt *et al.*, 2003) found that flying predators and parasitoids were more effective than ground-dwelling predators alone. Furthermore, the lack of significance of interaction between G and F treatments reveals that flying predators plus parasitoids and ground-dwelling predators did not interfere with each other. Thus, our exclusion study at field scale provided evidence of an additive effect of flying and ground-dwelling natural enemies in their ability to suppress cereal aphid populations. Conversely, our study design did not enable us to identify intraguild effects of the main ground-dwelling predators such as spiders and carabids, although it is well known that *Pterostichus melanarius* the most abundant ground beetle during the study period, frequently takes spiders as prey in field conditions (Lang, 2003).

Additionally, *Pterostichus melanarius* have been also associated to the disruption of biological control of aphids by preying on the mummies of a parasitoids wasp (Snyder & Ives, 2001). Although in relation to our findings aphid parasitism did not differ among treatments, thus the ground-dwelling predators did not influence the proportion of parasitised aphids. Accordingly, the suggestion that ground-dwelling predators can disrupt biological control by parasitoid wasps (Lang, 2003) was not supported by this study.

### Implication for management

The increased predator-prey ratios in cereals fields embedded in simple landscapes and the experimental evidences of an additive effect between specialist and generalist predators are suggesting a higher top-down control in simple landscapes. Although the lack of a relationship to landscape complexity and aphid abundance, in conjunction with the high variability of the degree of parasitism, call for more experiments in order to better understand the relative role of interannual changes in abiotic factors and arable crop mosaics on inter-annual population fluctuations, especially of parasitoids closely linked to their host and with relatively low dispersion capacity. This work sheds light on the unresolved issue of the mechanisms by which landscape complexity drives herbivore-natural enemy interaction. However, more studies are required to develop habitat management strategies that restore the natural pest population control in agro-ecosystems.

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# Appendix 1

Number of primary parasitoids and hyperparasitoids of *Sitobion avenae* and *Ropalosiphum padi* collected in organic cereal fields surveys from June to July.

| | Aphid host | |
|---|---|---|
| | *Sitobion avenae* | *Ropalosiphum padi* |
| **Primary parasitoids** | | |
| Braconidae | | |
| *Aphidius* sp. | 1 | 0 |
| *Aphidius avenae* (Haliday, 1834) | 1 | 0 |
| *Aphidius ervi* (Haliday, 1834) | 2 | 1 |
| *Aphidius rhopalosiphi* (De Stefani-Pérez, 1902) | 3 | 5 |
| *Aphidius uzbekistanicus* (Luzhetzki, 1960) | 6 | 3 |
| **Secondary parasitoids** | | |
| Cynipidae | | |
| *Alloxysta victrix* (Westwood, 1843) | 1 | 0 |
| Megaspilidae | | |
| *Dendrocerus carpenteri* (Curtis, 1829) | 18 | 0 |
| Pteromalidae | | |
| *Asaphes suspensus* (Nees, 1834) | 25 | 0 |

# Appendix 2

Absolute numbers of predators at family level recorded in organic cereal fields surveys from June to July. Coccinellidae were sorted out by species because of their particular importance.

| **Predatory Families** | | Total Abundance |
|---|---|---|
| Coccinellidae (Coleoptera) | Coccinellidae larvae | 10 |
| | *Adalia decempunctata* (L., 1758) | 1 |
| | *Coccinella magnifica* (Redtenbacher, 1843) | 8 |
| | *Coccinella quinquepunctata* (L., 1758) | 2 |
| | *Coccinella septempunctata* (L., 1758) | 350 |
| | *Coccinella undecimpunctata* (L., 1758) | 2 |
| | *Propylea quatuordecimpunctata* (L., 1758) | 27 |
| | *Subcoccinella vigintiquatuorpunctata* (L., 1758) | 3 |
| Carabidae (Coleoptera) | | 7 |
| Chrysopidae (Neuroptera) | | 10 |
| Syrphidae (Diptera) | | 40 |
| **Total abundance of predators** | | **460** |

# Appendix 3

Overall abundances of Araneae, Staphylinidae and Carabidae recorded from pitfall traps. Carabidae were sorted out by species because of their particular importance on aphids' biological control. Only species with total number of four and above are shown. P, presence (number of fields and in brackets number of landscapes where each species were found), and their feeding groups (*g* granivorous, *o* omnivorous, *p* predator, *s* saprophagous). The nomenclature for carabids follows the European Fauna criteria (www.faunaeur.org/).

| Groups/Species names | Total | P | Feeding groups |
|---|---|---|---|
| Araneae | 13078 | 24 (12) | *p* |
| Coleoptera: Staphylinidae | 2431 | 24 (12) | *s/p* |
| *Agonum muelleri* (Herbst, 1785) | 18 | 7 (5) | *p* |
| *Anchomenus (Anchomenus) dorsalis* (Pontoppidan, 1763) | 115 | 19 (11) | *p* |
| *Bembidion quadrimaculatum* (L., 1761) | 45 | 10 (7) | *p* |
| *Bembidion tetracolum* Say, 1823 | 9 | 4 (3) | *p* |
| *Calathus* (*Calathus*) *fuscipes* (Goeze, 1777) | 96 | 16 (10) | *p* |
| *Calathus* (*Neocalathus*) *melanocephalus* (L., 1761) | 12 | 6 (4) | *p* |
| *Calathus* (*Neocalathus*) *micropterus* (Duftschmid, 1812) | 8 | 1(1) | *p* |
| *Carabus* (*Carabus*) *granulatus* L., 1758 | 5 | 4 (3) | *p* |
| *Clivina* (*Clivina*) *fossor* (L., 1758) | 123 | 19 (11) | *p* |
| *Dolichus halensis* (Schaller, 1783) | 19 | 5 (3) | *p* |
| *Loricera pilicornis* (Fabr., 1775) | 136 | 22 (12) | *p* |
| *Bembidion (Metallina) lampros* (Herbst, 1784) | 421 | 23 (12) | *p* |
| *Nebria* (*Nebria*) *brevicollis* (Fabr., 1792) | 11 | 3 (2) | *p* |
| *Patrobus atrorufus* (Ström, 1768) | 44 | 9 (7) | *p* |
| *Phyla obtusa* (Audinet-Serville, 1821) | 10 | 3 (3) | *p* |
| *Poecilus (Macropoecilus) lepidus* (Leske, 1785) | 8 | 2 (2) | *p* |
| *Prostemma (Prostemma) guttula* (Fabr., 1787) | 4 | 3 (3) | *p* |
| *Pterostichus* (*Morphnosoma*) *melanarius* (Illiger, 1798) | 2703 | 24 (12) | *p* |
| *Pterostichus* (*Platisma*) *niger* (Schaller, 1783) | 135 | 21 (11) | *p* |
| *Pterostichus* (*Pterostichus*) *cupreus* (L., 1758) | 133 | 19 (12) | *p* |
| *Trechus* (*Trechus*) *quadristriatus* (Schrank, 1781) | 41 | 14 (10) | *p* |
| *Harpalus* (*Harpalus*) *affinis* (Schrank, 1781) | 59 | 17 (11) | *g* |
| *Harpalus* (*Harpalus*) *distinguendus* (Duftschmid, 1812) | 8 | 6 (5) | *g* |
| *Harpalus* (*Harpalus*) *rufipes* (Duftschmid, 1812) | 822 | 24 (12) | *g* |
| *Amara* (*Bradytus*) *apricaria* (Paykull, 1790) | 25 | 10 (7) | *o* |
| *Amara* (*Celia*) *bifrons* (Gyllenhal, 1810) | 28 | 11 (8) | *o* |
| *Amara* (*Amara*) *similata* (Gyllenhal, 1811) | 8 | 6 (5) | *o* |

# CAPÍTOL 5.
# DISCUSSIÓ GENERAL

# 5. Discussió general

L'objectiu d'aquesta discussió és valorar les diverses metodologies emprades i, alhora resumir els resultats més significatius dels estudis abordats en aquesta memòria per tal de destacar la nostra aportació en el context del coneixement dels artròpodes dels conreus de cereals.

## Consideracions metodològiques

L'estudi dels artròpodes a diferents escales espacials (micro-parcel·la, camp, paisatge) és necessari per abordar objectius específics i en certs aspectes complementaris en relació a que les interaccions ecològiques als agro-ecosistemes són multi-escalars. L'experimentació en micro-parcel·les permet testar hipòtesis concretes, ja que ofereix la possibilitat de manipular les condicions ambientals a petita escala. A més, les experimentacions a escala local permeten testar simultàniament diversos tipus de tractaments o condicions ambientals, model que difícilment es podria implementar a una escala major, donats els elevats costos que implicaria. El capítol 4.4, que recull l'estudi de l'efecte de la diversificació dels cultius sobre la comunitat de fitòfags, i el capítol 4.5, que mostra els resultats de l'efecte dels enemics naturals sobre les poblacions d'àfids, en són dos exemples.

Els estudis a escala de camp (capítols 4.1, 4.2, 4.3), per la seva banda, permeten avaluar un nombre reduït de condicions però ofereixen una escala de treball real. El fet que la majoria dels treballs realitzats a escala de camp hagin emprat camps comercials implica que els resultats obtinguts en aquests estudis poden presentar una clara aplicació a l'hora de trobar les eines de gestió més adequades per a cada localitat. Per últim, els estudis a escala de paisatge (capítol 4.5) permeten obtenir un coneixement més complert dels mecanismes involucrats en serveis al ecosistema com el control biològic que també actuen a escales espacials superiors a la mida de camp.

El coneixement de l'artropodofauna de l'àrea d'estudi és imprescindible a l'hora de dur a terme estudis experimentals (Missa et al., 2009). La manca d'estudis previs sobre les comunitats d'artròpodes dels conreus de cereals de secà ha fet necessari l'ús de diferents mètodes de mostreig per tal d'obtenir un ampli coneixement faunístic dels artròpodes. En aquest sentit, els tres primers treballs d'aquesta tesi responen a aquesta manca de coneixement previ en els camps de cereals de secà, emprant la comparació entre camps ecològics i convencionals com a model d'estudi. L'esforç que representa l'ús de diversos mètodes de mostreig i el seguiment de la comunitat d'artròpodes durant les diferents fases del cultiu no hagués estat possible si no ens haguéssim centrat en una localitat. A més, els estudis a escala local són el primer pas necessari quan es pretén desenvolupar nous mètodes d'estudi de l'artopodofauna, com són la perspectiva multi-taxonòmica i la funcional (Wardle et al., 1999). La robustesa dels resultats que s'obtenen en una sola localitat i/o sistema ha de ser validada amb els resultats d'altres àrees on dominen altres taxons.

L'estudi a nivell de paisatge, que es pot entendre com un segon pas en la cronologia de la investigació, es va dur a terme a la regió de Skåne (Suècia). Els estudis previs sobre els artròpodes a escala local i la disponibilitat d'una xarxa de finques ecològiques distribuïdes per tota la regió van facilitar l'estudi de l'efecte de la complexitat del paisatge sobre l'abundància d'àfids i els seus enemics naturals. La escassa diversitat d'espècies d'àfid associada als camps de cereals, també va ajudar a desenvolupar l'escala de paisatge, ja que per avaluar la densitat i diversitat d'àfids es podien emprar mètodes de mostreig intra-camp molt ràpids com són els transsectes. Aquesta metodologia no es pot aplicar directament en un context mediterrani en relació a que la diversitat d'àfids en el mateix tipus d'ambient és com a mínim d'un ordre superior de magnitud (Nicolas Pérez *com. pers*).

La mida dels sectors de paisatge idònia per avaluar l'estructura del paisatge és un tema de debat, ja que depèn del grau de mobilitat de les espècies objecte d'estudi, i de les seves estratègies tròfiques (Kruess, 2003; Thies et al., 2005; Thies et al., 2003), tot i que la mesura de 2 km de radi s'ha suggerit com una de les més sensibles per àfids i els seus enemics naturals. Per aquesta raó, la caracterització de l'estructura del paisatge associada als camps de cereals s'ha dut a terme mitjançant sectors circulars de paisatge de 2 km de radi.

La perspectiva multi-taxa que hem utilitzat a partir de la consideració de les famílies i les superfamílies com indicadors, en comptes de les espècies, permet per una banda confirmar la robustesa d'aquest tipus de perspectiva, prèviament emprada per diversos autors (Balmford et al., 1996a; Balmford et al., 1996b; Biaggini et al., 2007; Wickramasinghe et al., 2004) i, per altra banda, ofereix la possibilitat de reflectir les diferents respostes que poden presentar-se a l'analitzar l'efecte de la gestió agronòmica sobre la comunitat sencera d'artròpodes (capítols 4.1 i 4.2). A més, la determinació de tots els espècimens de la comunitat d'artròpodes fins a nivell de família ha permès incorporar a l'estudi grups que rarament eren esmentats en estudis ecològics precedents i aportar dades innovadores sobre un ampli nombre de taxons relacionats amb els agrosistemes de secà de la Catalunya central.

La caracterització de la comunitat d'artròpodes des d'una perspectiva funcional a partir de l'anàlisi multi-taxa ha permès a més aprofundir en els efectes de la gestió agronòmica i les característiques de les comunitats vegetals sobre els artròpodes. La major consistència dels grups funcionals respecte dels grups taxonòmics, per tal d'entendre les relacions entre la gestió dels ecosistemes i els artròpodes, també han estat indicats per altres autors a la regió medioeuropea (Perner et al., 2003; Voigt et al., 2007). Els resultats d'aquesta tesi revelen que la perspectiva funcional és una excel·lent eina per entendre les relacions els diferents components de la xarxa tròfica en els agrosistemes mediterranis.

## La relació entre la gestió agrícola i els artròpodes

L'anàlisi de la relació entre els artròpodes i el tipus de gestió dels conreus de cereals de la regió mediterrània estudiada en aquesta tesi reflecteix que les diferències entre la gestió ecològica i la convencional no són tan clares com altres estudis centre i nord-europeus havien demostrat (Clough et al., 2007; Holzschuh et al., 2007; Weibull et al., 2000; Wickramasinghe et al., 2004). El fet que la gestió dels cereals de secà convencionals no inclogui l'aplicació d'insecticides sembla ser la principal raó de la manca de diferències entre la gestió convencional i l'ecològica per la majoria de taxons d'artròpodes. Weibull et al. (2003) ja havien suggerit que l'abundància i la riquesa dels artròpodes era semblant entre les parcel·les ecològiques i les convencionals quan l'ús d'agroquímics en la gestió convencional era reduït.

Tanmateix hem de destacar que la resposta de la comunitat d'artròpodes en front la gestió agronòmica, que s'entreveu poc clara des de la perspectiva taxonòmica, mostra un patró molt més clar mitjançant la perspectiva funcional (capítol 4.1). L'efecte de la gestió agronòmica sobre els grups funcionals de la comunitat d'artròpodes sovint es posa de manifest en determinats moments del desenvolupament del cultiu, com reflecteix la interacció significativa entre el període de mostreig i la gestió. Aquesta fenomen fa pensar que part de les respostes neutres dels artròpodes en relació a la gestió agronòmica que s'han destacat amb anterioritat es podrien explicar com a mínim per dues raons. En primer lloc, els grups taxonòmics en que s'han basat la majoria d'estudis previs són unitats de classificació que sovint apleguen espècies/morfoespècies/gèneres amb estratègies vitals i/o alimentàries diverses, en conseqüència és difícil que responguin d'una manera homogènia a un factor amb implicacions complexes sobre l'hàbitat com és la gestió agronòmica. En segon lloc, el seguiment temporal de l'abundància i la riquesa dels artròpodes coincidint amb el desenvolupament del cereal, que no han estat sempre considerats en els estudis previs, és absolutament necessari per tenir un major coneixement de la interacció entre els artròpodes i el seu hàbitat.

La resposta dels artròpodes en relació a la gestió agronòmica dels conreus de cereals, que varia al llarg del desenvolupament del cereal, també depèn de l'escala espacial. A escala de parcel·la de 1 × 1 m (capítol 4.2), alguns grups es troben afavorits per la gestió ecològica (succionadors i depredadors), altres per la gestió convencional (mastegadors i consumidors florals) i la resta mostren respostes neutres o bé més estretament relacionades amb les característiques de la coberta vegetal. A escala de camp (capítol 4.1), la gestió convencional afavoreix, en certs períodes de mostreig, la comunitat sencera d'artròpodes (fitòfags, depredadors, parasitoids, etc.). Malgrat varem hipotetitzar que la gestió ecològica podia afavorir la diversitat de la comunitat d'artròpodes, la major fertilització dels conreus convencionals estudiats ha comportat una major cobertura de la vegetació que ha resultat esser un factor d'importància clau en la incentivació de l'artropodofauna. Altres estudis ja havien però destacat que el recobriment vegetal (Koricheva et al., 2000; Melnychuk et al., 2003; Sirrine et al., 2008) i la fertilització de l'agrosistema (Birkhofer et al., 2008; Duffield et al., 1997) eren factors clau en el condicionament de les comunitats d'artròpodes.

Per altra banda, la divergència de resultats entre els capítols 4.1 i 4.2 es podria explicar per les diferències en el tipus de mostreig emprat en ambdós capítols, o bé perquè el patró dels diversos grups tròfics en relació a la gestió varia en funció de l'escala d'estudi (camp *vs.* parcel·la). Ambdues justificacions recolzarien els treballs que suggereixen que part de la variabilitat de resultats de les comparacions entre finques ecològiques i convencionals es deuen a les diferents mètodologies de mostreig i escales d'estudi emprades (Bengtsson et al., 2005; Hole et al., 2005). Tot i que també es pot interpretar pel fet que moltes de les interaccions biòtiques i abiòtiques dels ecosistemes tenen lloc a moltes escales de manera simultània i coordinada.

## La relació entre la comunitat vegetal i la comunitat d'artròpodes

La comparació de la comunitat vegetal dels conreus ecològics i convencionals seleccionats per dur a terme aquesta tesi reflecteix que la gestió convencional afavoreix una major cobertura de la vegetació a causa del major creixement del cereal i que la gestió ecològica afavoreix l'abundància i la diversitat de la flora arvense. L'estudi de la relació entre els artròpodes, la gestió i les característiques de la comunitat vegetal mostra que sovint la comunitat d'artròpodes dels camps de cereals de secà està més relacionada amb les característiques de la coberta vegetal que amb el tipus de gestió agrícola.

La major riquesa d'espècies arvenses i la major abundància de grups funcionals clau, com són les lleguminoses, té un efecte positiu directe sobre la riquesa de fitòfags (capítols 4.2 i 4.4) a causa que la major disponibilitat de recursos alternatius que incentiven la diversitat d'herbívors (Knops et al., 1999; Murdoch et al., 1972; Siemann et al., 1998). La major riquesa d'espècies vegetals però, també afecta positivament a altres grups com els sapròfags (capítol 4.2), els quals semblen beneficiar-se de l'elevada qualitat de les restes orgàniques aportades per una coberta vegetal més rica (Wardle et al., 1999). La major riquesa de fitòfags i sapròfags, com a conseqüència d'una comunitat vegetal més diversa en els camps ecològics, també comporta canvis en el següent nivell tròfic. Per això, les poblacions de depredadors són més riques en els camps ecològics (capítol 4.2), doncs responen a una major diversitat de preses potencials (Haddad et al., 2001; Knops et al., 1999).

Els parasitoids, per la seva banda, no semblen beneficiar-se d'una comunitat arvense més rica, però si que es relacionen positivament amb l'abundància de lleguminoses (capítols 4.2 i 4.4), principalment als conreus ecològics. Aquest fet es podria explicar perquè les lleguminoses ofereixen recursos florals rics en sucre que poden augmentar la fecunditat i la longevitat dels parasitoids adults (Bianchi & Wäckers, 2008).

En resum, la disponibilitat de recursos pels artròpodes en els camps de cereals depèn directa o indirectament de les característiques de la coberta vegetal. Per això, l'estudi del paper de la gestió agronòmica sobre l'abundància i la diversitat dels artròpodes ha d'incorporar l'anàlisi de la comunitat vegetal per tal d'avaluar amb més precisió les conseqüències ecològiques de la gestió i així, entendre millor la resposta dels artròpodes.

## La complexitat del paisatge sobre la comunitat d'artròpodes

La complexitat del paisatge condiciona la interacció entre els àfids i els seus depredadors. No obstant, contràriament al que s'esperava l'abundància de depredadors tan especialistes (Coccinellidae) com generalistes (Carabidae) és més gran als camps de cereals envoltats per paisatges simplificats que als envoltats per paisatges complexes (capítol 4.5). Una major disponibilitat de preses alternatives en ambients bàsicament agrícoles sembla la raó més versemblant per explicar aquest patró (Elliott et al., 1998; Rand & Tscharntke, 2007). A més, treballs recents també han suggerit que les masses boscoses, àmpliament presents en paisatges complexes i prèviament considerades com a beneficioses per a la diversitat, també poden ser interpretades com a veritables barreres pel moviment d'artròpodes voladors (Wratten et al., 2003). Així, la major estructura vertical del paisatges complexes pot contrarestar els beneficis aportats per una major diversificació d'hàbitats (Gurr et al., 2003).

L'estudi experimental per la seva banda, indica que ambdós grups d'enemics naturals: els voladors-especialistes i els caminadors-generalistes controlen el nombre d'àfids. El nostre estudi, a més, permet destacar que el paper dels caminadors-generalistes és equivalent, pel que fa a la regulació en el nombre d'àfids, al paper dels voladors-especialistes (Capítol 4.5). Aquests resultats contradiuen altres estudis experimentals, basats en barreres d'exclusió, on es destacava que els depredadors voladors-especialistes (coccinèl·lids i parasitoids) eren més efectius que els caràbids i les aranyes a l'hora de regular les poblacions d'àfids (Holland et al., 2008; Schmidt et al., 2003). Per altra banda, l'efecte additiu d'ambdós grups sobre el control de les poblacions d'àfids, té implicacions importants, doncs ens permet suggerir que en els paisatges simplificats on hi ha una major abundància de coccinèl·lids i caràbids també s'esdevé una major pressió depredadora i un millor control biològic.

En contraposició, els àfids i els seus parasitoids no semblen respondre a l'efecte del paisatge. Aquest fet suggereix que les interaccions que regulen les poblacions d'àfids dels sistemes agrícoles pot ser que tinguin lloc a diferents escales espacials i temporals. Aquest fet implica que els futurs estudis sobre la interacció àfids-enemics naturals haurien de considerar treballar a diferents escales de paisatge i simultàniament, instal·lar un dispositiu experimental que permeti corroborar que la major abundància d'enemics naturals en l'agrosistema comporta un millor control de les poblacions d'àfids.

# CAPÍTOL 6.
# CONCLUSIONS FINALS

# 6. Conclusions

Els diversos treballs recollits en aquesta memòria aborden el paper de la diversificació dels agrosistemes dels camps de cereals sobre la comunitat d’artròpodes a diferents escales espacials. Aquest capítol resumeix breument les principals conclusions de la tesi doctoral; els detalls de cadascuna d’elles es poden trobar en els diversos articles i en la discussió general.

- ✓ L’anàlisi funcional dels artròpodes que hem adoptat, basat en grups alimentaris, es presenta com un mètode robust i eficient per analitzar l’efecte de la gestió sobre un ampli nombre de grups.

- ✓ En un context mediterrani de cereals de secà, l’absència d’insecticides i la major fertilització dels camps convencionals afavoreix l’abundància de la comunitat sencera d’artròpodes. Mentre que l’anàlisi a petita escala (1 × 1 m) reflecteix que l’abundància i/o diversitat de la majoria dels grups alimentaris depèn més de les característiques de la coberta vegetal que de la gestió.

- ✓ L’abundància i la riquesa de famílies de consumidors primaris i secundaris es relaciona positivament amb la diversitat de la coberta vegetal. No obstant, queda per aclarir si la riquesa de famílies de consumidors secundaris està supeditada a la riquesa dels consumidors primaris i/o a la diversitat de la coberta vegetal.

- ✓ El àfids especialistes en gramínies i els seus parasitoids són afavorits per la major abundància de gramínies en els camps convencionals. Tanmateix, l’abundància de lleguminoses als camps ecològics incrementa la presència d’hostes alternatius dels parasitoids primaris, fenomen que suggereix que la coberta vegetal afecta indirectament la riquesa de consumidors secundaris.

- ✓ Una comunitat vegetal més diversa afavoreix l’abundància i/o la riquesa de la fauna benèfica com els sapròfags, els parasitoids i els depredadors en els agrosistemes herbacis de secà. La presència de la fauna benèfica, que té un important paper en el funcionament de l’ecosistema, és essencial per garantir uns sistemes agrícoles més robusts i resilients. Per això el repte és dissenyar sistemes agrícoles que harmonitzin la producció i la preservació de la diversitat vegetal.

- ✓ L’estudi a escala de paisatge ha permès destacar que tan els depredadors especialistes en àfids, majoritàriament *Coccinella septempunctata*, com els depredadors generalistes (*Pterostichus melanarius*) augmenten en els paisatge més simples. Aquest patró s’explica per la major disponibilitat de preses alternatives associades als hàbitats agrícoles que dominen els paisatges simplificats.

- ✓ L’experiment amb barreres d’exclusió testimonia que els depredadors especialistes i generalistes tenen un efecte additiu en el control de les poblacions d’àfids. Aquest resultat suggereix que el control biològic pot ser més eficaç en els paisatges simples on les poblacions d’ambdós grups es troben engrossides.

- ✓ Els resultats d’aquesta tesi doctoral posen en evidència la necessitat de dur a terme estudis a diferents escales espacials per tal d’aprofundir en el coneixement de les interaccions entre els diferents grups i el seu entorn. Aquestes dades proporcionen una base sòlida de coneixement, que és fonamental per dissenyar correctes estratègies de gestió.

# CAPÍTOL 6’.
# FINAL CONCLUSIONS

# 6’. Conclusions

The present study evaluated the role of diversification of agro-systems in cereal fields on the arthropod community at different scales. This section briefly summarises the main conclusions of the study. Details of each conclusion are available in the discussion and conclusion sections of each paper and in the general discussion section.

- ✓ The functional approach of arthropod community based on feeding groups appears to be more efficient than the taxonomical approach to carry out a multi-taxa analysis.

- ✓ At field level, a high amount of fertilisation together with the lack of insecticide use in conventionally-managed cereal fields seems to be sufficient to enhance the entire arthropod community in a dry-land Mediterranean context. On the contrary, at a smaller scale (1 × 1 m), most feeding groups are more influenced by the characteristics of plant community than by management type.

- ✓ The abundance and family richness of primary and secondary consumers appears to be positively correlated to a richer plant community. However, it remains unclear whether changes in family richness of secondary consumers are driven by changes in family richness of primary consumers, by direct response to plant community or by a mixture of both.

- ✓ The entire system of aphid-parasitoids of grasses is enhanced in conventional fields where the abundance of grasses is higher. Nevertheless, the presence of legumes in organic fields, providing alternative hosts to primary aphid parasitoids, suggests that the effect of the plant community on secondary consumers is indirect, mediated through richness of primary consumers.

- ✓ The increase of plant diversity in the dry arable-land agro-system directly or indirectly contributes to the enhancement of beneficial fauna such as saprovores, predators and parasitoids. Thus, the challenge lies in designing cropping systems that match crop production with the preservation of plant diversity, thereby creating more robust and resilient systems that guarantee the presence of beneficial fauna, which is essential to the correct functioning of the agro-ecosystems.

- ✓ The study at landscape scale evidences that specialist aphidophagous, mainly *Coccinella septempunctata*, and generalist predators like *Pterostichus melanarius*, increase with the proportion of arable land in the surrounding landscape. In this context, predators could potentially benefit from the high availability of alternative resources within cropping systems.

- ✓ The exclusion experiment at field scale provides evidence of an additive effect of specialist and generalist predators to depress cereal aphid populations, suggesting a higher top-down control in simple landscapes.

- ✓ Analyses at landscape scale shed light on the mechanisms by which landscape complexity drives interactions between arthropods. However, studies at smaller scales are also essential. Evaluating the effect of common agricultural practices in a given region requires taking into account a large number of taxa. Nevertheless, the combination of a landscape scale perspective and a multi-taxa approach implies huge economic and human costs. The results presented in this study evidence the need to carry out studies at various levels in order to acquire detailed information on interactions between different agents at several spatial and temporal scales. These data, thus, provide a solid base of knowledge and are essential for the design of adequate management strategies.

# CAPÍTOL 7.
# INFORMES DELS DIRECTORS

# 7. Informes dels directors

## Informe dels directors de la tesi doctoral sobre el factor d'impacte dels articles publicats i sotmesos per a la seva publicació

F. Xavier Sans Serra i Juli Pujade Villar, directors de la tesi doctoral de Berta Caballero López, presenten el següent informe sobre el factor d'impacte de les publicacions que formen part de la Tesi doctoral.

**Capítol 4.1.**

B. Caballero-López, J.M. Blanco-Moreno, J. Pujade-Villar, D. Ventura , J.A. Sánchez & F. X. Sans. The aerial arthropod community as a descriptor of farming management in arable systems: from a taxonomical to a functional approach. Sotmès per a la seva publicació a *Journal of Insect Conservation*.

**Capítol 4.2.**

B. Caballero-López, J.M. Blanco-Moreno, N. Pérez , J. Pujade-Villar, D. Ventura, F. Oliva & F. X. Sans. A functional approach to assessing plant-arthropod interaction in winter wheat. Sotmès per a la seva publicació a *Agriculture, Ecosystems and Environment*.

**Capítol 4.3.**

B. Caballero-López, J.M. Blanco-Moreno, N. Pérez , J.M. Michelena, J. Pujade-Villar, E. Guerreri, J.A. Sánchez & F. X. Sans. Weeds and aphid-parasitoid communities benefit differently from organic and conventional cropping of winter cereals. Sotmès per a la seva publicació a *Biological Control*.

**Capítol 4.4.**

B. Caballero-López, A. Romero, N. Pérez, D. Ventura, L. Chamorro, M. Goula & F.X. Sans. The role of intercropping on insects' diversity in dryland field crops in a Mediterranean site. Proceedings of the European Joint Organic Congress. EDITORS: Bo Andreasen, C.; Elsgaard, L.;Søndergaard Sørensen & Hansen, G. pp. 212-213. DARCOF. Odense (Dinamarca). ISBN: 87-991343-0.

**Capítol 4.5.**

B. Caballero-López, R. Bommarco, F. X. Sans, J. M. Blanco-Moreno , J. Pujade-Villar, M. Rundlöf & H. G. Smith. Landscape context influence on aphids and their natural enemies. Article que és previst sotmetre a *Ecography*.

Tres del cinc articles que formen part de la memòria de la tesi doctoral de Berta Caballero han estat sotmesos per a la seva publicació a revistes científiques d'àmbit internacional i que consten al Science Citation Index. El treball corresponent al segon subcapítol ha estat sotmès a *Agriculture, Ecosystems and Enviroment*, revista amb un índex d'impacte de 2,884 i que es situa al primer quartil de les àrees *Agriculture* i *Environmental Sciences* i al segon quartil de l'àrea *Ecology*. Els articles dels subcapítols 4.1. i 4.3. han estat sotmesos respectivament a *Journal of Insect Conservation* (SCI = 1,838) i *Biological Control* (SCI = 1,805), ambdues revistes estan situades al primer quartil de l'àrea *Entomology*. L'article corresponent al subcapítol 4.4. ha estat publicat als *Proceedings of the European Joint Organic Congress*, publicació que va ser acceptada després de ser avaluada positivament mitjançant un procés de revisió per parelles. L'article que recull el subcapítol 4.5. es previst sotmetre'l a la prestigiosa revista *Ecography* que es situa al primer quartil de les àrees *Ecology* i *Biodiversity Conservation* amb un impacte de 4,099.

Barcelona, 15 d'octubre de 2009

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| F. Xavier Sans Serra | Juli Pujade Villar |
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| Universitat de Barcelona | Universitat de Barcelona |

## Informe des directors de la tesi doctoral sobre la participació de la doctoranda a cadascun dels articles

F. Xavier Sans Serra i Juli Pujade Villar, directors de la tesi doctoral de Berta Caballero López, presenten el següent informe sobre la contribució de la doctoranda en les publicacions de les quals n'és primera autora que formen part de la memòria de la tesi doctoral:

### Capítol 4.1.

B. Caballero-López, J.M. Blanco-Moreno, J. Pujade-Villar, D. Ventura , J.A. Sánchez & F. X. Sans. The Aerial Arthropod Community as a descriptor of Farming Management in Arable Systems: from a Taxonomical to a Functional Approach

**Contribució de la doctoranda:** Participació en el disseny de l'estudi, recol·lecció de mostres, ordenació i determinació dels espècimens recol·lectats, anàlisi de les dades i elaboració dels resultats, redacció de la primera versió del manuscrit i revisions posteriors.

**Contribució dels altres autors**: JMBM, assessorament en les anàlisis estadístiques; JPV, direcció i supervisió del treball de laboratori, participació en la redacció; DV, participació en la determinació dels dípters; JAS, assessorament en els models matemàtics; FXS, participació en el disseny de l'estudi, supervisió i participació en la redacció.

### Capítol 4.2.

B. Caballero-López, J.M. Blanco-Moreno, N. Pérez , J. Pujade-Villar, D. Ventura, F. Oliva & F. X. Sans. A functional approach to assessing plant-arthropod interaction in winter wheat.

**Contribució de la doctoranda:** Participació en el disseny de l'estudi, recol·lecció de mostres, ordenació i determinació dels espècimens recol·lectats, anàlisis de les dades i elaboració dels resultats, redacció de la primera versió del manuscrit i revisions posteriors.

**Contribució dels altres autors:** JMBM, assessorament en les anàlisis estadístiques i participació en la redacció; JPV, direcció i supervisió del treball de laboratori, participació en la redacció; DV, participació en la determinació dels dípters; FO, assessorament en els models matemàtics; FXS, participació en el disseny de l'estudi, supervisió i participació en la redacció.

**Capítol 4.3.**

B. Caballero-López, J.M. Blanco-Moreno, N. Pérez , J.M. Michelena, J. Pujade-Villar, E. Guerreri, J.A. Sánchez & F. X. Sans. Weeds and aphid-parasitoid communities benefit differently from organic and conventional cropping of winter cereals.

**Contribució de la doctoranda:** Participació en el disseny de l'estudi, recol·lecció de mostres, ordenació i determinació dels espècimens recol·lectats, anàlisis de les dades i elaboració dels resultats, redacció de la primera versió del manuscrit i revisions posteriors.

**Contribució dels altres autors:** JMBM, assessorament en les anàlisi estadístiques; NP, determinació dels àfids; JMM, determinació dels bracònids; JPV, direcció i supervisió del treball de laboratori, participació en la redacció; EG, determinació dels encírtids; JAS, assessorament en els models matemàtics; FXS, participació en el disseny de l'estudi, supervisió i participació en la redacció

**Capítol 4.4.**

B. Caballero-López, A. Romero, N. Pérez, D. Ventura, L. Chamorro, M. Goula & F.X. Sans. The role of intercropping on insects' diversity in dryland field crops in a Mediterranean site. Proceedings of the European Joint Organic Congress. EDITORS: Bo Andreasen, C.; Elsgaard, L.; Søndergaard Sørensen & Hansen, G. pp. 212-213. DARCOF. Odense (Dinamarca). ISBN: 87-991343-0.

**Contribució de la doctoranda:** Participació en el disseny de l'estudi, recol·lecció de mostres, ordenació i determinació dels espècimens recol·lectats, anàlisis de les dades i elaboració dels resultats, redacció de la primera versió del manuscrit i revisions posteriors.

**Contribució dels altres autors:** AR, col·laboració en el disseny i l'establiment de l'experiment; NP, determinació dels àfids; DV, participació en la determinació dels dípters; LCh, col·laboració en el disseny i l'establiment de l'experiment; MG, col·laboració en el disseny i l'establiment de l'experiència i en la determinació dels homòpters; FXS, participació en el disseny de l'estudi i en l'anàlisi de dades, supervisió i participació en la redacció

**Capítol 4.5.**

B. Caballero-López, R. Bommarco, F. X. Sans, J. M. Blanco-Moreno , J. Pujade-Villar, M. Rundlöf & H. G. Smith. Landscape context influence on aphids and their natural enemies.

**Contribució de la doctoranda:** Participació en el disseny de l'estudi, recol·lecció de mostres, ordenació i determinació dels espècimens recol·lectats, anàlisis de les dades i elaboració dels resultats, redacció de la primera versió del manuscrit i revisions posteriors.
**Contribució dels altres autors:** RB, participació en el disseny de l'estudi i en la redacció; FXS, participació en l'anàlisi de les dades i en la redacció; JMBM, assessorament en les anàlisi estadístiques; JPV, participació en la redacció; MR, participació en el disseny de l'estudi; HGS, participació en el disseny, assessorament en les anàlisis estadístiques, supervisió i participació en la redacció.

Finalment certifiquem que cap dels coautors dels subcapítols abans esmentats i que formen part de la tesi doctoral de Berta Caballero López no han utilitzat ni utilitzaran implícita o explícitament cap material d'aquests capítols per a l'elaboració d'una altra tesi doctoral.

Barcelona, 15 d'octubre de 2009

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# CAPÍTOL 8.
# REFERÈNCIES / REFERENCES

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