Universidad de León
Departamento de Biodiversidad y Gestión Ambiental
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Comunidades de artrópodos en cultivos de trigo. El papel de regadío en ambientes agrícolas mediterráneos

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Memoria de Tesis Doctoral presentada por **Octavio Pérez Fuertes**, Licenciado en Biología para optar al grado de Doctor por la Universidad de León

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A mi familia

y amigos

Por la razón o la fuerza

Enseña del Escudo Nacional y lema patrio de Chile

Parte de los resultados expuestos en la presente memoria han dado lugar a las siguientes **Comunicaciones a Congresos tanto Nacionales como Internacionales:**

- **Octavio Pérez Fuertes**, Patricia Mateo Tomás, Ángel de Frutos Tena, Nicolás Pérez Hidalgo y Pedro Pérez Olea. *“Biodiversidad de Artrópodos en cultivos de trigo con diferente uso agrícola: estudio a nivel taxonómico de Orden”*. XXVI Jornadas de la asociación Española de Entomología. Biodiversidad y Conservación en Sierra Nevada. Granada, España 2009.

- **Octavio Pérez Fuertes**, Sergio García Tejero, Nicolás Pérez Hidalgo, Patricia Mateo Tomás y Pedro Pérez Olea. *“Diferencias en la diversidad y composición de la comunidad de artrópodos en cultivos de trigo de regadío y secano en un área mediterránea”*. XXVIII Jornadas de la Asociación española de Entomología. La importancia económica de los artrópodos. Ponferrada, España, 2011.

- **Octavio Pérez Fuertes**, Sergio García Tejero, Nicolás Pérez Hidalgo, Patricia Mateo Tomás y Pedro Pérez Olea. *“Effects of irrigation on Arthropod diversity in a Mediterranean agricultural landscape”*. 12th European Ecological Federation. Ávila, España 2011.

- **Octavio Pérez Fuertes**, Sergio García Tejero, Nicolás Pérez Hidalgo, Amonio David Cuesta Segura, Federico García García, Mª Ángeles Marcos García, José Manuel Michelena Saval, Patricia Mateo Tomás y Pédro Pérez Olea. *“Respuestas de la riqueza de artrópodos a la intensificación agrícola por regadío en campos de trigo: ¿Coinciden los patrones de taxones superiores e inferiores?”*. XXX Jornadas de la Asociación española de Entomología. Salamanca, España 2013.

- **Octavio Pérez Fuertes**, Nicolás Pérez Hidalgo, Sergio García Tejero, Amonio David Cuesta Segura, Federico García García, Mª Ángeles Marcos García, José Manuel Michelena Saval, Patricia Mateo Tomás y Pédro Pérez Olea. *“Diferencias en la estructura trófica de la comunidad de pulgones y sus acompañantes en cultivos de trigo de secano y regadío”*. VIII Congreso Nacional de Entomología Aplicada. XIV Jornadas Científicas de la SEEA. Mataró, España 2013.

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Introducción

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Situación actual de la agricultura

Los paisajes agrícolas cubren en la actualidad más del 40% de la superficie terrestre, y tienen un papel fundamental en la conservación de la biodiversidad global, incluyendo especies amenazadas (Tilman *et al*., 2002; Tscharntke *et al*., 2005; Norris, 2008). A nivel mundial la superficie está aumentando para incrementar la producción agrícola y así satisfacer a una creciente población (casi 7000 millones de personas en 2015; FAOSTAT, 2015), que se espera que se duplique en el 2050 (Tilman *et al*., 2001, 2002; Green *et al*., 2005). El paisaje agrícola representa el 40% de la superficie de la Europa de los 28 (174,1 millones de hectáreas; Eurostat, 2013) y concentra gran parte de la biodiversidad (Pimentel *et al*., 1992), incluyendo en ocasiones especies endémicas y amenazadas (European Environment Agency, 2004). En las últimas décadas estas áreas han sufrido importantes cambios debido, por una parte, al éxodo rural del campo a la ciudad, con procesos asociados de abandono de tierras marginales o baja productividad (Baldock *et al*., 1996; Pointereau *et al*., 2008), y por otra, al cambio en las prácticas agrícolas orientadas a aumentar la producción mediante su intensificación (Benton *et al*., 2003).

En el año 2015 se registraron en España 16.984.656 ha de tierras de cultivo dedicadas a la obtención de productos agrícolas (excluyendo prados, pastizales y superficies forestales), lo cual representa el 34% de la superficie nacional (MAGRAMA, 2015). España, es uno de los países europeos que presenta una agricultura menos intensificada (Donald *et al*., 2001), pero al igual que en el resto de países del mundo se tiende a aumentar la superficie sometida a agricultura intensiva.

La intensificación agrícola

La intensificación es el cambio en las prácticas agrícolas orientadas a aumentar la producción. Es llevada a cabo mediante el incremento en la mecanización y aplicación de fertilizantes y biocidas, disminución de la superficie de barbecho y de los linderos, el monocultivo y la implantación de diferentes sistemas de regadío (Schläffer & Schmid, 1999; Benton *et al*., 2003) (Figura 1). Por ejemplo, la aplicación de fertilizantes en los últimos 50 años ha aumentado en un 500%; un 800% sólo para nitrógeno (Matson *et al*., 1997; Tilman *et al*., 2001; FAOSTAT, 2015).

Figura 1. Aspecto aéreo de una parte de nuestra área de estudio, en el entorno agrícola de Fresno de la Vega (León, España), donde colinda la agricultura de intensiva regadío (izquierda) con la extensiva de secano (derecha). Se puede apreciar la concentración parcelaria y la reestructuración de caminos y parcelas en la zona intensiva.

Este cambio en el manejo de los cultivos ha producido un deterioro en la biodiversidad (Krebs *et al*., 1999; Benton *et al*., 2003) mediante la reducción de la heterogeneidad espacial a diferentes escalas y la fragmentación del hábitat (Stoate *et al*., 2001; Benton *et al*., 2003; Ockinger & Smith, 2007), todo ello asociado a la pérdida de especies (Steffan-Dewenter & Tscharntke, 1999; Steffan-Dewenter *et al*., 2002; Weibull *et al*., 2003). La cantidad y la calidad del hábitat disponible para las especies se reduce (Dover & Sparks, 2000) y de este modo, muchas de las especies que en el pasado eran comunes en zonas agrícolas hoy se han vuelto raras, o simplemente han desaparecido (Krebs *et al*., 1999). Por ejemplo, están bien documentadas las alteraciones que la intensificación provoca en las comunidades de aves ligadas a medios agrícolas (ver Tucker & Heath, 1994; Suárez *et al*., 1997; Donal *et al*., 2001), en artrópodos (Wilson *et al*., 1999; Holzschuh *et al*., 2007; Batáry *et al*., 2012) y plantas (Mountfield *et al*., 1993; Hyvönen & Salonen, 2002).

La pérdida de biodiversidad se traduce en una disminución de los servicios que presta el ecosistema (Hooper *et al*., 2005), principalmente en lo que se refiere al control de plagas (Tscharntke *et al*., 2005; Geiger *et al*., 2010), polinización de cultivos (Biesmeijer *et al*., 2006) y fertilidad del suelo (Brussaard *et al*., 1997). Se ha comprobado que la intensificación agrícola disminuye la biodiversidad, comparada tanto con la agricultura ecológica (e.g. Tybirk *et al*., 2004; Krauss *et al*., 2011; Ponce *et al*., 2011), con la agricultura con baja aplicación de químicos (e.g. Hyvönen & Salonen, 2002) o con agricultura controlada con programas agro-ambientales (e.g. Knop *et al*., 2006; Holzschuh *et al*., 2007; Roth *et al*., 2008), como la que se lleva a cabo en Zonas de Especial Protección para las Aves (ZEPA). Por ello, la intensificación es considerada la principal causa de extinción de especies y pérdida de biodiversidad a nivel mundial (Robinson & Sutherland, 2002; Tilman *et al*., 2002; Benton *et al*., 2003; Kleijn & Sutherland, 2003; Green *et al*., 2005; Wilson *et al*., 2010; Foley, 2011).

La mayoría de los estudios indican que la intensificación tiene un impacto negativo en los artrópodos (Hyvönen & Salonen, 2002; Tybirk *et al*., 2004; Herzog *et al*., 2005; Knop *et al*., 2006; Holzschuh *et al*., 2007; Roth *et al*., 2008; Krauss *et al*., 2011; Ponce *et al*., 2011; Prieto-Benítez & Méndez, 2011). Sin embargo, otros muestran que tiene efectos positivos en la abundancia, riqueza y diversidad (Weibull *et al*., 2000; Kleijn *et al*., 2001; Melnychuk *et al*., 2003; Weibull & Östman, 2003; González-Estébanez *et al*., 2011). Todavía se conoce poco acerca de la contribución de cada tipo de sistema o de gestión agrícola (regadío y secano) a la conservación de la biodiversidad (Tscharntke *et al*., 2005a), aunque sí se sabe que el sistema agrícola usado es el factor más influyente (Holzschuh *et al*., 2007; González-Estébanez *et al*., en revisión). Estas diferencias se deben posiblemente a las diferencias existentes en los grupos estudiados y en las condiciones particulares de los sistemas agrícolas utilizados.

Al igual que el resto de países mediterráneos, en España una forma importante de intensificar la producción agrícola es mediante la implantación del regadío en superficies anteriormente dedicadas a una agricultura extensiva de secano (Suárez, 1997; MAGRAMA, 2015). Sólo el 16% de la superficie cultivada del territorio español es de regadío, pero genera el 65% de la producción, lo que es indicativo del potencial productor de esta forma de explotación agraria (MAGRAMA, 2013).

El regadío

Los sistemas agrícolas de regadío se basan en la aplicación de agua de forma más o menos efectiva, al menos una vez, durante el período de siembra o desarrollo del cultivo. Existen diversas modalidades, en función de la manera en la que el agua es llevada hasta las plantas. Uno de los más comunes a nivel nacional es el riego tradicional, por superficie, gravedad o inundación (27,36%; MAGRAMA, 2014), en el que el agua se mueve por el efecto de la gravedad a través de canalizaciones. Otras modalidades incluyen riego por aspersión, riego automotriz y riego localizado, pudiendo presentar, según los casos, canalizaciones subterráneas.

El regadío es uno de los principales métodos para incrementar la producción agrícola, con un aumento en superficie del 117% a nivel mundial en los últimos años. Aunque los sistemas de regadío representan sólo el 20% de la superficie cultivada total, producen el 40% de la producción agrícola (FAO, 2011). Otro ejemplo de la efectividad que tiene el regadío es que la producción agrícola ha crecido 2,5-3 veces en los últimos 50 años, con un incremento de sólo el 12% de la superficie cultivada (FAO, 2011). La implantación de diferentes sistemas de riego supone un importante beneficio para las explotaciones permitiendo que sean más competitivas, a través del incremento de la producción. Un ejemplo de su importancia actual es que sin ellos, la producción global de cereales disminuiría un 20% (Siebert *et al*., 2010).

El 70% del agua que se gasta tanto en España (Franco & Herrero, 2008) como a nivel mundial (Postel *et al*., 1996; Gleick *et al*., 2009) se utiliza en agricultura. El agua es un recurso clave y limitante, particularmente durante la sequía estival característica de climas mediterráneos (Blondel *et al*., 2010). Este período seco determina importantes diferencias entre agrosistemas con clima mediterráneo y clima atlántico o continental, ya que en climas atlántico-continentales, como el que tienen en países del centro y norte de Europa, no hay período seco (Fig. 2)

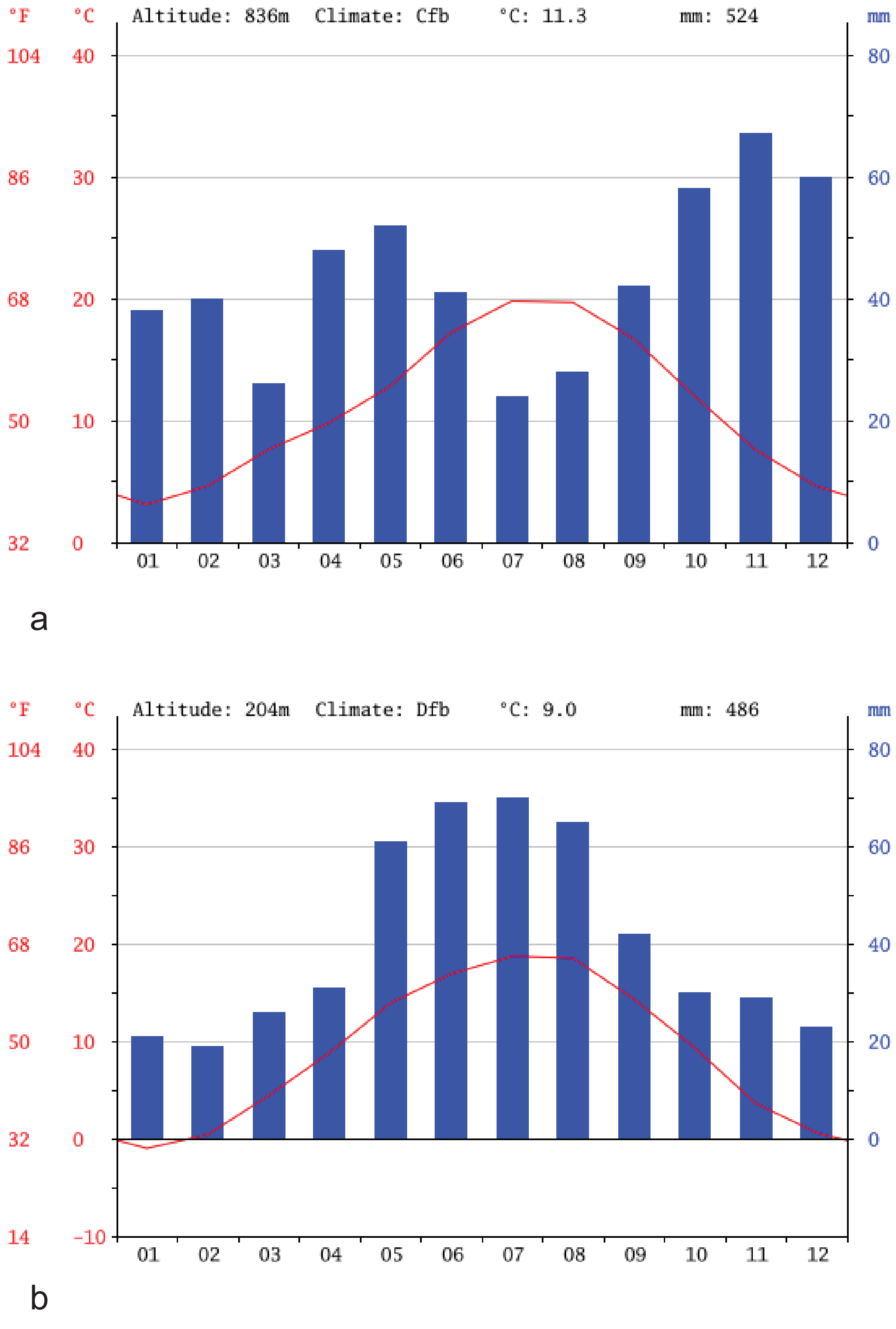

Figura 2. Climogramas correspondientes a: a) una zona mediterránea (Santas Martas, León, España, situada en nuestra área de estudio), b) una zona continental (Praga, Republica Checa) (Tomado de CLIMATE-DATA.ORG, 2015). Se observa una diferente distribución de las precipitaciones (barras) a lo largo del año, con una disminución de las mismas y un aumento de las temperaturas (línea roja) en la zona mediterránea en los meses centrales del año, julio y agosto.

En el sur de Europa el regadío mitiga la escasez de agua durante la sequía estival típica del clima mediterráneo (Blondel *et al*., 2010), incrementando la producción agrícola (van der Velde *et al*., 2010). Este cambio en las prácticas agrícolas tiene asociados varios problemas ambientales, tales como la inundación de valles, drenaje de acuíferos para extraer agua, incremento en el uso de componentes químicos, disminución de los barbechos y de la rotación de cultivos, e incluso salinización del suelo (Ruiz, 1990; Herrero & Snyder, 1997; Stoate *et al*., 2001). Además, la mayoría de las consecuencias del regadío se extienden más allá de los propios límites del cultivo (Stoate *et al*., 2001), afectando a todo el ecosistema. En algunas áreas mediterráneas, el regadío está modificando grandes superficies agrícolas de alto valor ecológico (p.e. Zonas Agrícolas de Alto Valor Natural; High Nature Value farming areas; Paracchini *et al*., 2008) como las dedicadas a la agricultura extensiva de secano (llamadas pseudo-estepas cerealistas; Suárez *et al*., 1997; Oñate *et al*., 2007). Estas áreas presentan unas características peculiares, que están viéndose alteradas por el cambio en el sistema de producción agrícola con efectos negativos comprobados en poblaciones de aves (Tella & Forero, 2000; Brotons *et al*., 2004; Laiolo, 2005; de Frutos & Olea, 2008; de Frutos *et al*., 2015). Sin embargo, su efecto sobre otros componentes de la biodiversidad agrícola (p.e. artrópodos) es todavía poco conocido (pero ver González-Estébanez *et al*., 2011; González-Estébanez *et al*., en revisión para mariposas).

Frente a los problemas asociados con la agricultura intensiva de regadío (incremento en la aplicación de biocidas y fertilizantes, reducción de linderos, dominancia de monocultivos, disminución de la heterogeneidad espacial, reducción de zonas no cultivadas, disminución en la rotación de cultivos; ver sección anterior), la agricultura extensiva de secano, que utiliza menor cantidad de insumos, mantiene unas condiciones, *a priori*, más favorables, y algunos autores sostienen que genera un menor impacto ambiental que la agricultura intensiva, manteniendo así mayor biodiversidad (Krebs *et al*., 1999; Tybirk *et al*., 2004). La extensiva está reconocida como un tipo de gestión fundamental para la conservación de la biodiversidad en muchas partes del mundo (Krebs *et al*., 1999; Altieri, 2004) y sin embargo, estas zonas se están perdiendo debido a la intensificación agrícola, particularmente en Europa (Strijker, 2005; Paracchini *et al*., 2007).

Los artrópodos en los ecosistemas agrícolas

Los artrópodos son esenciales para el funcionamiento del ecosistema agrícola (Daily, 1997; McGeoch, 1998); proporcionan valiosos servicios tales como polinización, control de plagas, producción vegetal, reciclado de nutrientes y recursos alimenticios para otros animales (Daily *et al*., 1997; Wilson *et al*., 1999). También son considerados útiles indicadores de la pérdida de biodiversidad (McGeoch, 1998; Marshall *et al*., 2003; Biaggini *et al*., 2007) y pueden reflejar los cambios ambientales causados por la intensificación agrícola (Schläpfer & Schmid, 1999; Steffan-Dewenter *et al*., 2002; Weibull & Östman, 2003; Hole *et al*., 2005; Knop *et al*., 2006; Ockinger & Smith, 2007).

Se ha visto que las diferentes formas de intensificación afectan negativamente a las poblaciones de artrópodos terrestres (Schmidt *et al*., 2005; Clough *et al*., 2007; Holzschuh *et al*., 2007;….), siendo de hecho el grupo más perjudicado (Thomas *et al*., 2004). Sin embargo, la mayor parte de la información que se tiene acerca del efecto de la intensificación agraria sobre la biodiversidad, procede de estudios llevados a cabo en países del norte y centro de Europa, comparando agricultura convencional y ecológica, siendo escasos los trabajos que conciernen a la región mediterránea (Stoate *et al*., 2001; Tscharntke *et al*., 2005), a pesar de las evidentes diferencias ambientales entre ambas regiones. En la región mediterránea existen todavía relativamente pocos trabajos, y los que hay también comparan esos dos tipos de agricultura: convencional vs. ecológica (Caballero-López *et al*., 2010, 2012; Ponce *et al*., 2011 para artrópodos y plantas, Romero *et al*., 2008; Chamorro *et al*., 2011; José-María *et al*., 2011 para plantas, Hadjicharalampous *et al*., 2002; Cotes *et al*., 2010, para artrópodos pero no en cereales). Además, hoy en día existe muy poca información científica generada del impacto de la intensificación impulsada por la agricultura de regadío en la biodiversidad (ver apartado anterior).

El estrés hídrico que se produce durante los meses estivales en lugares con clima mediterráneo (comentado en el apartado anterior) afecta seriamente a los artrópodos. Por ejemplo, la tasa de supervivencia y reproducción de los pulgones decrece en plantas sometidas a estrés hídrico (Summer *et al*, 1983, 1986; Fereres *et al*, 1988; Pons *et al*., 1993; Pons & Tatchell, 1995). Por lo tanto, una mayor disponibilidad de agua en condiciones de regadío, particularmente durante el período de sequía estival, podría mejorar las condiciones del ambiente e incrementar la calidad de los recursos (vegetación) para los herbívoros y sus depredadores a través de un efecto cascada

(Tscharntke *et al*., 2005a). Además, un incremento de humedad no solo incrementará la producción dentro del propio cultivo, sino también en los linderos, que constituyen un refugio para los artrópodos en paisajes agrícolas (Tscharntke *et al*., 2005a).

Es poco probable que los resultados que se obtienen en el norte y centro de Europa puedan ser extrapolados a la región mediterránea (Kleijn *et al*., 2003, Hole *et al*., 2005), con el consiguiente riesgo de aplicar aquí medidas de gestión y conservación inadecuadas. Esto podría además impedir o limitar el desarrollo de nuevas estrategias de gestión y conservación más adecuadas para los agrosistemas de zonas mediterráneas (Holzschuh *et al*., 2007; Whittingham *et al*., 2007; Kleijn & Sutherland, 2003).

Daños en la producción agrícola

Las pérdidas en la producción agrícola debidas a las plagas se evitan normalmente usando plaguicidas (Östman *et al*., 2001). Sin embargo, la aplicación de insecticidas, efectivos a corto plazo sobre éstas, tienen efectos negativos a largo plazo, por actuar sobre los depredadores naturales de los agentes plagas (Krauss *et al*., 2011). Una manera alternativa para evitar las pérdidas consecuentes en la producción es el uso y potenciación de depredadores naturales, lo que se denomina control biológico de plagas. Por ejemplo, dentro de la familia Aphididae (Hemiptera) se encuentran los pulgones de los cereales, que tienen una gran importancia como plagas (Fuente-Contreras & Niemeyer, 2000). Sus enemigos naturales (depredadores y parasitoides) son pieza clave para controlar sus poblaciones (Pons *et al*., 1993; Pons & Eizaguirre, 2000) debido a la estrecha relación trófica que mantienen con ellos (Schmidt *et al*., 2003; Freier *et al*., 2007).

En los últimos tiempos el control biológico de plagas ha recibido mucha atención debido a los beneficios medioambientales que conlleva en comparación con el uso de biocidas, además de la mejor opinión pública en favor de la reducción de la aplicación de plaguicidas y una producción agrícola menos agresiva (Tilman *et al*., 2002). El control natural de plagas puede reducir la pérdida de producción sin el uso de plaguicidas, evitando así la contaminación de la producción y del medio ambiente (Östman *et al*., 2003) y reduciendo los costes a largo plazo.

Grupos estudiados

Esta tesis se centra en grupos de artrópodos relacionados con los cultivos de trigo. En concreto, estudiamos la familia Aphididae y su fauna acompañante: Coccinellidae, Neuroptera, Syrphidae, Heteroptera, Aphidiinae y Formicidae.

Los pulgones (Hemiptera, Aphididae) de los cereales son una de la principales plagas a nivel mundial (Fuente-Contreras & Niemeyer, 2000) y pueden generar grandes pérdidas de producción (Kieckhefer *et al*., 1995; Schmidt *et al*., 2003; Thies *et al*., 2011). Algunas especies como *Rhopalosiphum padi* (Linnaeus) pueden llegar a reducir la producción de cebada hasta en un 52% (Östman *et al*., 2003). Estas pérdidas se producen tanto por su acción directa como por las enfermedades que transmiten, por ejemplo, el virus del enanismo amarillo de la cebada (BYDV; Osler *et al*., 1987; Šutić *et al*., 1999). Los principales pulgones que afectan a los cereales en ecosistemas europeos son *Metopolophium dirhodum* (Walker), *Sitobion avenae* (Linnaeus) y *R. padi* (Linnaeus) (Schmidt *et al*., 2003; Phoeling *et al*., 2007), los cuales se encuentran también en España (Castañera & Gutiérrez, 1983; Pons *et al*., 1989, 1993). Otras especies de interés agrícola también presentes en la Península Ibérica son *Diuraphis noxia* (Mordvilko), *Schizaphis graminun* (Rondani), *Sipha elegans* Del Guercio y *Sipha maydis* (Passerini) (Blackman & Eastop, 2002; Lumbierres *et al*., 2007; Poehling *et al*., 2007).

Los depredadores de pulgones se pueden dividir en dos grupos, generalistas y afidófagos especialistas (Müller & Godfray, 1999). El primero incluye especies de Heteroptera. El segundo, depredadores de Coccinellidae (Coleoptera), Chrysopidae (Neuroptera) y Syrphidae (Diptera) (Schmidt *et al*., 2003; Freier *et al*., 2007), y parasitoides de Aphidiinae (Hymenoptera, Braconidae) (Sigsgaard, 2002; Schmidt *et al*., 2003; Thies *et al*., 2005). Unos y otros son eficientes, en grado diverso, como controladores de pulgones.

Algunas especies de hormigas (Hymenoptera, Formicidae), además de tener importancia en zonas agrícolas por influir en el crecimiento de herbáceas y las condiciones del suelo (Peck *et al*., 1998), la tienen como mutualistas de pulgones, ya que cuidan de ellos, los protegen, y los pueden transferir de una planta a otra cuando las condiciones no les son favorables, obteniendo a cambio la melaza que producen éstos (Sudd, 1987).

Área de estudio

El área de estudio (Figura 3) abarca una extensión aproximada de 1500 km^2 en el sur este de la provincia de León, al noroeste de España (centrado en 42°33 N, 5º31 W) entre las localidades de Valencia de Don Juan, Grajal de Campos, Cea y Vega de Infanzones. Geológicamente se asienta sobre materiales terciarios (Herrero, 1995). La elevación media es de 800 m.s.n.m. Bioclimáticamente pertenece al piso supramediterráneo de la región biogeográfica Mediterránea (Penas *et al*., 1995). Presenta unas precipitaciones anuales que oscilan en el rango 436-515 mm y una temperatura media mínima de 8 ºC y máxima de 13 ºC.

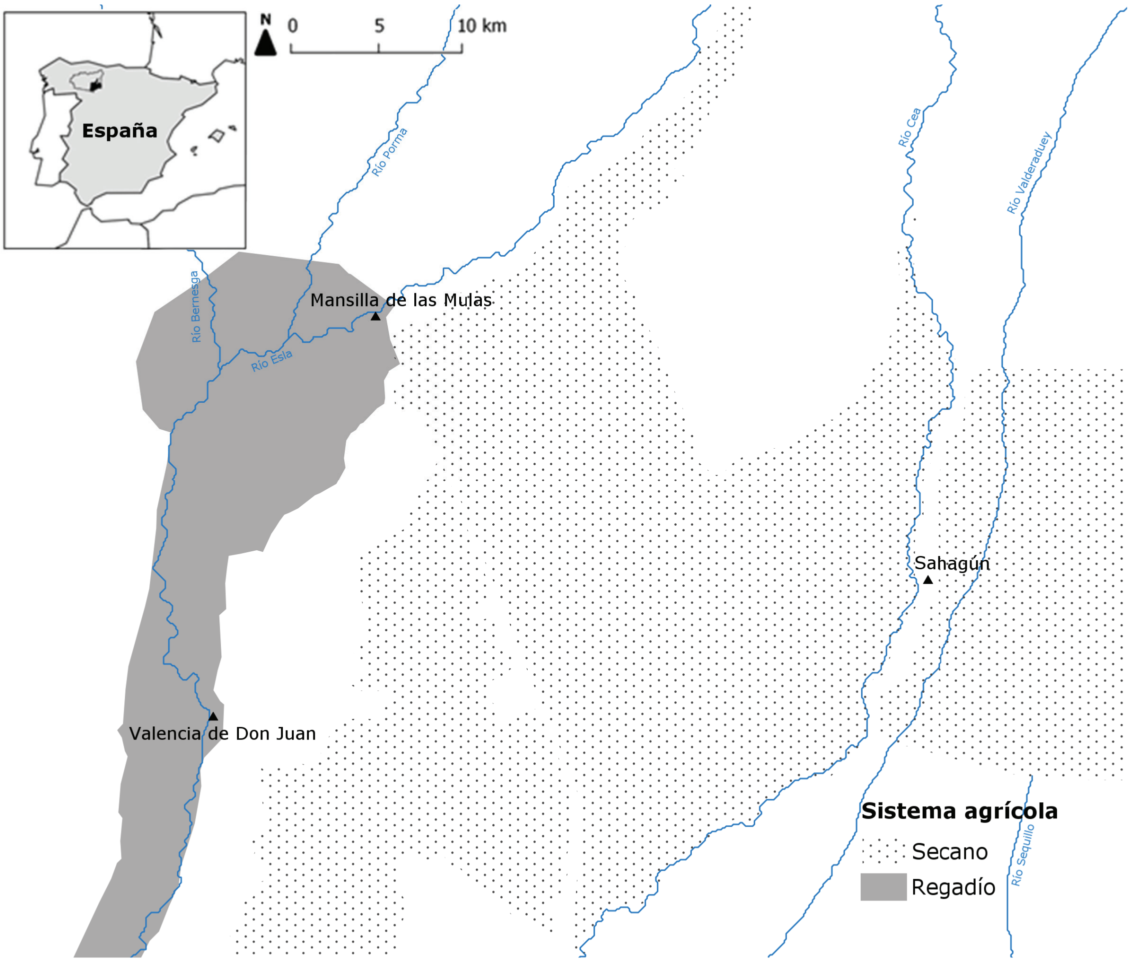

Figura 3. Localización del área de estudio en el noroeste de España (área negra en el mapa de España). Se señalan también las poblaciones y los ríos más importantes.

La densidad de población es baja (12,08 habitantes/km^2; Escolar & González, 2008), y ha sufrido un evidente declive desde los años cincuenta del siglo pasado hasta nuestros días (INE, 2015), con abandono del medio rural (debido a la emigración hacia las ciudades) y con el envejecimiento de sus habitantes.

La agricultura es el principal uso del suelo, ocupando el 85% de la superficie total del área de estudio, y es el factor que determina el paisaje de la zona. En ella se diferencian dos grandes subáreas contiguas en función del manejo agrícola. Una subárea con agricultura intensiva de regadío (Regadío), y otra con agricultura extensiva de secano (Secano).

La subárea de regadío tiene una superficie de aproximadamente 34.000 ha. y su sustrato es de conglomerados fluviales, arenas, limos y arcillas de terrazas. Inicialmente comenzó siendo una zona de secano, pero la construcción de acequias permitió el cambio a regadío hace más de 20 años. El tipo de regadío es tradicional, con un sistema combinado de canales abiertos, unos de hormigón elevados sobre el nivel de suelo (Figura 4a y b), y otros excavados en el terreno (Figura 4c y d), en los que el agua se mueve por gravedad. Estos últimos se encuentran naturalizados, estando poblados los más grandes por anfibios y peces. El maíz (*Zea mays* L.) ocupa el 59% de la superficie cultivada, seguido en importancia por el trigo de regadío (*Triticum* spp., 10%) y la alfalfa (*Medicago sativa* L., 2%). Los barbechos representan el 14% de la superficie de cultivo y también hay plantaciones de chopo que suponen el 3% de la superficie agrícola.

Figura 4. Aspecto de los canales de riego tradicional; a y b) canales de hormigón, c y d) canales naturalizados.

La subárea de secano tiene casi 130.000 ha y el sustrato está formado principalmente por margas, conglomerados, arenas y arcillas de terrazas y glacis, y el suelo presenta un relieve con suavidad de terrenos prácticamente desarbolados. El sector más importante es el cerealista (65%), dominado por trigo de inverno (*Triticum* spp. 21%) y avena (*Avena sativa* L., 20%). La cebada (*Hordeum vulgare* L., 12%), el centeno (*Secale cereale* L., 7%) y el maíz (*Zea mays* L., 5%) también están presentes, así como las legumbres (23%). Las rotaciones interanuales de cultivos permiten que los barbechos representen casi el 40% de la superficie total y también hay plantaciones de chopo (*Populus* spp. 2%) y pino (*Pinus* spp. menos del 1%). La subárea de secano se incluye dentro de lo que se han denominado pseudo-estepas cerealistas (véase Oñate *et al*. 2007 y Suárez *et al*. 1997), las cuales fueron incluidas en el programa regional de Estepas Cerealistas (MAPA, 1994) cuyo objetivo básico era el mantenimiento y la reintroducción de métodos de producción agraria compatibles con la conservación de la fauna de las estepas cerealistas de Castilla y León (Monsalve, 1993). Estos hábitats mantienen importantes poblaciones de aves esteparias amenazadas, como la avutarda *Otis tarda* Linnaeus, el cernícalo primilla *Falco naumanni* Fleischer o la calandria común *Melanocorypha calandra* Linnaeus (Suárez *et al*., 1997; Olea *et al*., 2004; De Frutos *et al*., 2015). La subárea de secano recuerda en sus características paisajísticas a la más conocida Tierra de Campos, con la cual limita por el Sur (río Cea), y de la cual quedan incluidas 30.000 ha en la subárea de secano, en el entorno de Sahagún (Plans, 1970; Díez & García, 1990; Sánchez, 1987; Consejería de Medio Ambiente, 1999).

Los cereales son el cultivo predominante en ambas subáreas, siendo el trigo uno de los más abundantes (>10% de la superficie de cada subárea; ver arriba). El trigo es una planta herbácea anual, de la cual se obtiene alimento para humanos (principalmente para la fabricación de harinas panificables) y pienso para ganado, y forraje. En la actualidad se cultiva en casi todo el mundo, siendo uno de los cultivos más importantes, con una producción mundial de 715.909.258 toneladas (FAOSTAT, 2015). En España el trigo se cultiva en régimen extensivo de secano (Figuras 5a y b) o en régimen intensivo de regadío tradicional (Figuras 5c y d), y es uno de los cereales más importantes a nivel nacional, con una producción media anual en el quinquenio 2007-2011 de 6.161.800 toneladas, sólo superado por la cebada (MAGRAMA, 2015). En un sistema agrícola de secano el trigo recibe únicamente el agua procedente de la lluvia, mientras que en regadío se le suministra agua siempre que el cultivo lo necesita. Esta aportación extra hace que las plantas de trigo no sufran estrés hídrico, obteniéndose un rendimiento medio anual de 5.211 kg/ha en Castilla y León en los últimos 13 años y de 6.400 kg/ha en la provincia de León en el año 2013 (Anuario de Estadísticas Agrarias CyL, 2013). Por su parte, una parcela con un régimen de secano presenta un rendimiento medio anual de 3.413 kg/ha en Castilla y León en los últimos 13 años y de 3.200 kg/ha en León en el año 2013 (Anuario de Estadísticas Agrarias CyL, 2013).

En nuestra área de estudio, el trigo de invierno se siembra en otoño, crece durante el invierno y primavera, y se cosecha en el mes de julio.

Figura 5. Paisaje típico de una zona cerealista con; a y b) agricultura extensiva de secano, c y d) agricultura intensiva de regadío. Nótese en la imagen b, el estrés hídrico sufrido por la vegetación durante los meses de junio y julio.

En la subárea de secano se incluyen 2 zonas con características especiales:

La ZEPA (Zona de Especial Protección para las Aves) Oteros-Campos (Código ES0000194), declarada en el año 2000 (Red Natura 2000) (Figura 5b). Ocupa una superficie de 31.685 ha en las que se llevan a cabo medidas de protección agroambiental, tales como uso de menor cantidad de biocidas, presencia de mayores superficies de barbecho, cosecha del cereal posterior al 15 de julio, prohibición o limitación de vedas de caza, etc. , con el objetivo de proteger el medio ambiente y las aves.

También se incluye parte de la zona conocida como “Los Payuelos” (MAGRAMA, 2002), que fue declarada como regable (*Subzona regable de Payuelos*) dentro del Plan Nacional de Regadíos y del Plan Hidrológico Nacional, con una superficie total de 66.575 ha. Ambos planes contemplaban la transformación de 45.173 ha (MAPyA, 2005) de secano a regadío. Se practica en ella una agricultura extensiva de secano, donde los cultivos de cereales y sus barbechos cubren el 74% del área (Olea *et al*., 2004).

Para analizar el efecto que la implantación del regadío podría tener en la zona de secano de Los Payuelos, se inició en el año 2007 un estudio multidisciplinar que pretendía observar ese cambio sobre diferentes grupos de animales y plantas [proyecto titulado *“Impacto de la intensificación agraria sobre la biodiversidad. Implicaciones para una gestión agrícola sostenible”*, financiado por la Junta de Castilla y León (SEK02B06) y el Ministerio de Educación y Ciencia (CGL2006-05047/BOS), con el Dr. Pedro Pérez Olea y el Dr. Francisco Javier Purroy Iraizoz como investigadores principales respectivamente]. Los trabajos que se han ido publicando a lo largo de los últimos años arrojan resultados dispares en función del grupo estudiado. Así, mientras que para las plantas que viven dentro de los cultivos la riqueza total, el número medio de especies por campo y la diversidad beta son mayores en secano (Fagúndez *et al*., en revisión), en pulgones y su fauna asociada la tendencia general es que la abundancia, riqueza y diversidad dentro de cultivos sea mayor en regadío (esta Tesis). En mariposas, la riqueza y diversidad a escala de paisaje también es mayor en regadío, no así la abundancia (González-Estébanez *et al*., 2011; González-Estébanez *et al*., en revisión). Por su parte, la transformación en regadío no supone cambios importantes en la riqueza ni abundancia de especies de aves, aunque sí en su composición, particularmente de las esteparias amenazadas (de Frutos *et al*., 2015). Éste parece ser un resultado común: en todos los grupos se produce un cambio significativo en la composición de especies y en sus abundancias relativas en las comunidades biológicas asociadas a cada tipo de gestión agrícola.

8- Objetivos y estructura de la tesis

Con el objetivo de comprobar el efecto de los diferentes tipos de regímenes agrícolas (regadío frente a secano) sobre la comunidad de artrópodos, se seleccionaron cultivos de trigo durante los años 2007 y 2009. En ellos se muestrearon todos los artrópodos (ver material y métodos en cada capítulo) y se seleccionaron aquellos que estaban directamente ligados al cultivo para el desarrollo de los tres estudios que se presentan (ver punto 5 de esta introducción).

Esta memoria se compone de capítulos independientes, cada uno de ellos con unos objetivos específicos comentados brevemente a continuación, y detalladamente explicados en cada capítulo.

Capítulo 1- Se evalúa el efecto de la intensificación agrícola mediante regadío en la diversidad de artrópodos en campos de trigo de invierno. Se valora el efecto del sistema agrícola (regadío frente a secano) y la estructura del hábitat sobre la abundancia, riqueza, diversidad y composición de varios grupos de artrópodos.

Capítulo 2- Se compara la variación temporal en la abundancia de artrópodos en cultivos de trigo de invierno durante gran parte de su desarrollo vegetativo (desde el 1 de mayo al 15 julio, justo antes de la cosecha). Se valora el efecto que el sistema agrícola (regadío frente a secano) tiene sobre la abundancia de individuos en la comunidad de artrópodos ligados a los pulgones.

Capítulo 3- Se comprueba la utilidad del sistema de sustitutos, es decir, el uso de taxones superiores como indicadores de taxones inferiores a nivel de especie con el fin de optimizar metodologías de muestreo en estudios de diversidad de artrópodos en paisajes agrícolas mediterráneos. Se comprueba además si las correlaciones entre grupos sustitutos y grupos sustituidos cambian según el sistema agrícola (regadío frente a secano).

I

Irrigation effects on arthropod communities in Mediterranean cereal agro-ecosystems

Efectos del regadío en la comunidad de artrópodos en agro-ecosistemas cerealistas mediterráneos

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Resumen

La intensificación agrícola ha tenido un fuerte efecto sobre el medio ambiente en las últimas décadas. La intensificación a través del regadío es una transformación común a nivel mundial, particularmente en países europeos, pero sus efectos sobre la biodiversidad raramente se han estudiado. Hemos evaluado los efectos del régimen agrícola y la estructura del hábitat sobre la abundancia, riqueza, diversidad y composición de artrópodos en campos de trigo de invierno sometidos a agricultura de regadío y de secano en tierras de cultivo de una zona mediterránea al noroeste de España. Para tener una mejor percepción de la respuesta de los artrópodos al regadío, hemos estudiado 6 grupos con necesidades ecológicas distintas (i.e. Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera y Coccinellidae) a nivel de especies (147 especies). Los campos de regadío presentaron mayor abundancia (Aphididae y Coccinellidae), riqueza (Aphididae, Aphidiinae y Coccinellidae) y diversidad (Aphidiinae, Coccinellidae y Syrphidae), mientras que los campos de regadío solo presentaron mayor riqueza de especies de Formicidae. La composición de especies difirió entre regímenes agrícolas en Coccinellidae, Formicidae y Heteroptera. El tamaño medio de cultivo influenció positivamente la riqueza de Coccienllidae y Heteroptera, y la diversidad de Coccinellidae.

Nuestros resultados sugieren que el regadío estimuló la diversidad de la mayoría de grupos de artrópodos incrementando la producción vegetal durante la sequía estival.

Abstract

Agricultural intensification has strongly affected the environment in last decades. Intensification by irrigation is a common transformation worldwide, particularly in Mediterranean countries, but its effects on biodiversity have rarely been studied. We evaluated the effects of farming system and habitat structure on arthropod abundance, richness, diversity and species composition in irrigated and rainfed winter wheat fields in a Mediterranean farmland in NW Spain. To gain a more complete insight of the arthropod response to irrigation, we studied six groups with different ecological needs (i.e. Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera and Syrphidae) at species level (147 species). Irrigated fields held higher arthropod abundance (Aphididae and Coccinellidae), species richness (Aphididae, Aphidiinae and Coccinellidae) and diversity (Aphidiinae, Coccinellidae and Syrphidae), while dry fields only held higher species richness of Formicidae. Species composition differed between farming systems for Coccinellidae, Formicidae and Heteroptera. The mean size of the surrounding fields positively influenced abundance and richness of Coccinellidae and Heteroptera, and diversity of Coccinellidae.

Our results suggest that irrigation boosted diversity of most arthropod groups by enhancing plant production during the summer drought.

Introduction

Agricultural intensification, implemented during the last decades to increase crop production, is considered the main driver of species extinction and biodiversity loss worldwide (Robinson & Sutherland, 2002; Tilman *et al*., 2002; Benton *et al*., 2003; Kleijn & Sutherland, 2003; Green *et al*., 2005; Wilson *et al*., 2010). It leads to a reduction of habitat heterogeneity with important ecological consequences (Benton *et al*., 2003). Intensively managed farmlands have been proved to decrease biodiversity, compared either with organic farming (e.g. Tybirk *et al*., 2004; Krauss *et al*., 2011; Ponce *et al*., 2011), low-input farming (e.g. Hyvönen & Salonen, 2002) or farming under agri-environmental schemes (e.g. Knop *et al*., 2006; Holzschuh *et al*., 2007; Roth *et al*., 2008).

Intensification is carried out through the increase in mechanization and input of fertilizers and biocides, monocultural schemes and irrigation (Benton *et al*., 2003; José-María *et al*., 2010). According to FAO (2011), agricultural production has grown 2.5-3 times in the last 50 years, with an increase of just 12% of cultivated land. Irrigation has been one of the main methods to enhance agricultural production, growing 117% worldwide. Although irrigated systems represent only 20% of total cultivated land, they account for 40% of the worldwide production.

In Southern Europe irrigation mitigates water scarcity during the summer drought to enhance agricultural production (van der Velde *et al*., 2010). In some areas of this region, irrigation is affecting vast extensions of farmlands of high conservation value (e.g. High Nature Value farming areas; Paracchini *et al*., 2008) devoted to dry extensive agriculture (so-called cereal steppes; Oñate *et al*., 2007). This agricultural change has negative effects on birds (Tella & Forero, 2000; Brotons *et al*., 2004; Laiolo, 2005; de Frutos & Olea, 2008), but its effects on other components of farmland biodiversity (e.g. arthropods) are still unknown (but see González-Estébanez *et al*., 2011 for butterflies). Arthropods are essential for ecosystem functioning (McGeoch, 1998) in agricultural landscapes (Daily, 1997), providing valuable services such as pollination, pest control, plant productivity, nutrient recycling and food resources for other animals (Daily *et al*., 1997; Wilson *et al*., 1999). They are also considered useful indicators of biodiversity loss (McGeoch, 1998; Marshall *et al*., 2003; Biaggini *et al*., 2007) and can reflect the environmental changes caused by agricultural intensification (Schläpfer & Schmid, 1999; Steffan-Dewenter *et al*., 2002; Weibull & Östman, 2003; Hole *et al*., 2005; Knop *et al*., 2006; Ockinger & Smith, 2007).

In this paper we evaluate the effect of agricultural intensification through irrigation on arthropod diversity in winter wheat fields. We assessed the effect of farming system (dry vs. irrigated) and habitat structure on arthropod abundance, richness, diversity and species composition. González-Estébanez *et al*. (2011) found that irrigation mitigated the effects of summer drought for butterflies, which increased in species richness. We predict that enhanced water availability during the summer drought will promote plant primary production with a positive cascading effect on the abundance, richness and/or diversity of some arthropod groups in irrigated fields. We assessed if different arthropod groups responded similarly to irrigation. Specifically, we studied plant lice (Aphididae), parasitoid wasps (Aphidiinae), ladybirds (Coccinellidae), ants (Formicidae), true bugs (Heteroptera) and hoverflies (Syrphidae), all of them at species level. We predict that herbivores (Aphididae) will positively respond to irrigation in abundance, richness and diversity and that their predators (Coccinellidae and Syrphidae) and parasitoids (Aphidiinae) will follow similar patterns (Starý, 1988). Changes in Heteroptera and Formicidae are difficult to foresee due to the heterogeneity of these groups (i.e. consisting on herbivores and predators in Heteroptera, and mutualistic and non-mutualistic species in Formicidae) and their weaker relation with aphids.

Material and Methods

Study area

The study area (Figure 1) covers 1,500 km^2 in the south-east of León province, north-west Spain (centred on 42°33 N, 5º31 W). It is included in the supra-Mediterranean bioclimatic level of the Mediterranean region, with average annual precipitations between 436-515 mm and temperatures between 8-13 ºC (Penas *et al*., 1995).

Agriculture is the main land-use in the study area (85% of total surface). We classified the farmland in two categories according to the main agricultural regimes (see Table 1 for details; Figure 1): i) dry sub-area (Dry) and ii) irrigated sub-area (Irrigated).

The dry sub-area (Dry) covers almost 130,000 ha under rainfed extensive farming system. Cereals are the most extended crop (65%), dominated by winter wheat (*Triticum* spp. 21%) and oat (*Avena sativa* L., 20%). Barley (*Hordeum vulgare* L., 12%), rye (*Secale cereale* L., 7%) and maize (*Zea mays* L., 5%) are also present. Legumes are also important among crops (23%). Interannual crop rotation is applied and fallow fields represent almost 40% of the total surface. There are some poplar (*Populus* sp.) and pine

(*Pinus* sp.) plantations (2% and <1% respectively). The dry sub-area is included within the so-called pseudo-steppes (Oñate *et al*., 2007), which hold important populations of threatened steppe bird species (Suárez *et al*., 1997; Olea *et al*., 2004).

The irrigated sub-area (Irrigated) covers approx. 34,000 ha and has been devoted to irrigated farming for more than 20 years. Maize is the main crop type (59%). To a lesser extent, there are fallow fields (14%), irrigated wheat (10%), irrigated alfalfa (*Medicago sativa* L., 2%) and market gardens (1%). Presence of poplar plantations amounts to 3%.

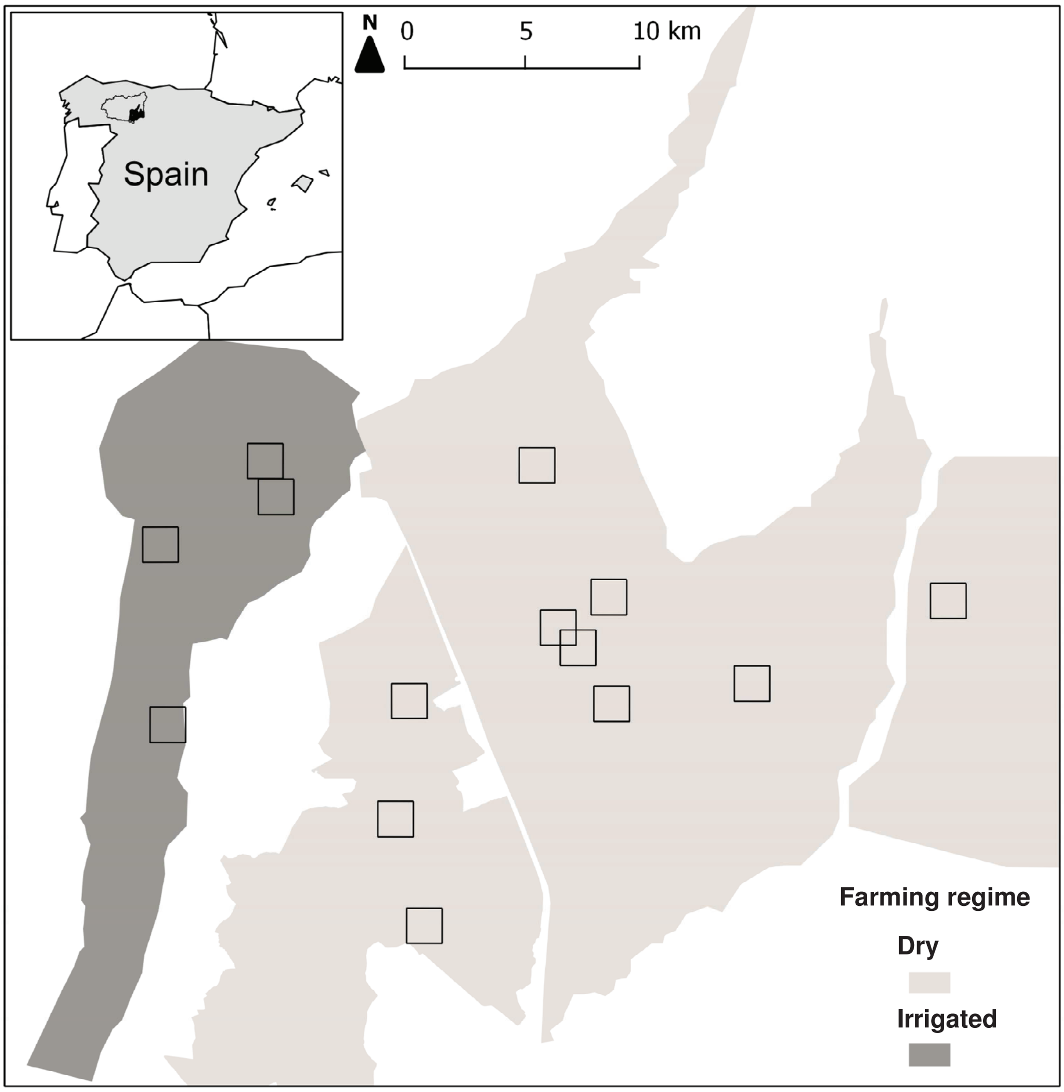

Figure 1. Location of the study area in north-west Spain (black area in the inset). Sampled fields were located inside 14 2x2 km squares (4 in Irrigated and 10 in Dry) randomly placed within the farming systems. One to five wheat fields were selected within each square, summing up to 12 fields in Irrigated and 25 fields in Dry.

Table 1. Environmental characteristics for each sub-area. Mean (±SE) values or total percentage are given for each variable.

Field data	Dry	Irrigated
Fallow surface (%)[a]	38,2	13,8
Irrigated farmland (%)[a]	7,9	100
N-P-K input (kg ha^{-1}year^{-1}) in wheat crops[b]	230 ± 44.7	616 ± 104
Yield of wheat (kg/ha)[b]	3150 ± 473	7000 ± 290
Habitat variables		
Landscape field size (ha)[c]	4.2 ± 0.3	3.7 ± 0.4
Surveyed field size (ha)[d]	4.3 ± 0.7	3.0 ± 0.6
Crop height (cm)[d]	69.7 ± 2.2	61.4 ± 3.9
Edge width (m)[d]	10.3 ± 1.9	10.5 ± 0.4
Number of trees[e]	0.2 ± 0.2	2.6 ± 0.9
Number of shrubs[e]	0.9 ± 0.2	6.4 ± 1.4

[a] Calculated as percentage within the 2 x 2 km squares.

farmers using questionnaires, N_{total}= 44 farmers.

[c] Calculated as the mean size of all fields present in a 500 x 500 m square

[d] Calculated for all surveyed fields: $N_{Irrigated}$= 25 fields, N_{Dry}= 12 fields.

[e] Mean number of trees and shrubs in a 500 m transect along the margins of the track adjacent to the surveyed fields. Edge width includes both edges of the track of field access.

Sampling method

Our study focused in winter wheat fields, one of the most economically important crops, both in the study area and worldwide. Fourteen 2 x 2 km squares were randomly placed within the farming systems (10 in Dry and 4 in Irrigated; Figure 1). One to five wheat fields were selected within each square, making a total of 25 fields in Dry and 12 fields in Irrigated. Mean distance between fields sampled in different regimes was 23.8 km (SE: 1.25; range: 13.8-44.4 km). Mean distance between surveyed fields was 15.0 km (SE: 1.2; range: 1.4-34.9) in the Dry sub-area, and 9.6 km (SE: 2.06; range: 2.3-14.3) in the Irrigated sub-area. Sampling took place before harvest (between 2nd and 26th July 2007), with the wheat grain dry and ripe (between levels 91 and 94 in Zadoks scale; Zadoks *et al.*, 1974).

Arthropods

Within each field, we sampled three consecutive 25-m transects parallel to the field margin and to the main man-made access path. Transects were at least five metres apart from each other and two metres from the field margin. Sampling was carried out using sweep-netting (Frampton & Dorne, 2007) with one sweep per step (50 sweeps per transect). Each sweep was performed to include as much plant surface as possible (stalk and spike). Sampling was carried out by the same person, with temperatures higher than 20 ºC and on days without rain or strong wind to assure that arthropods were active (Weibull & Östman, 2003). Collected arthropods were transferred into airtight plastic bags, kept in a portable fridge in the field and stored at -20 ºC in laboratory until their identification.

Selected taxa (Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera, and Syrphidae) were identified to species level (Appendix). All studied taxa (hereafter referred as groups) are related to wheat: i) directly as herbivores (Aphididae); ii) indirectly as aphid predators (Coccinellidae, Syrphidae), parasitoids (Aphidiinae), or mutualists (Formicidae); or iii) have both herbivore and predator members (Formicidae, Heteroptera) (Suay-Cano *et al*., 2002; Schmidt *et al*., 2003; Freier *et al*., 2007; Pons *et al*., 2009; Dedryver *et al*., 2010). All the groups were abundant enough (> 136 individuals) to perform analyses.

Habitat variables

We collected data on six habitat variables considered to influence arthropod diversity in agroecosystems (Benton *et al*., 2003; Holzschuch *et al*., 2007; Table 1). The mean size of the fields surrounding the sampled field (Landscape field size) was measured in a 500 x 500 metres square around each surveyed field from a digital land-use layer using ArcGIS 9.2 (Environmental Systems Research Institute Inc., Redlands, California, US). The area of each sampled field (Surveyed field size) was measured using a free Geographic Information System (GIS) for farming land management (SIGPAC, version 6.8.4, http://www.sigpac.jcyl.es/visor/). Crop height was measured in each sampled field at three random points two metres apart from each other. Edge width was measured on both sides of the field access track adjacent to the surveyed field at five equidistant points along one kilometre. Mean values for edge width and crop height were calculated for each sampled field prior to the analyses. The number of trees and shrubs were counted on the field margin parallel to the sampled transects from aerial photographs taken in 2008, with a resolution of 25 cm (Junta de Castilla y León, http://www.goolzoom.com/, GoolInvent S.L.U, accessed May 2011). Tree and shrub surveys were completed with review of on-ground pictures and verified by field surveys when necessary. Proportion of arable land was always higher than 90% in all the 2 x 2 km squares and was not considered.

Data analysis

Prior to the analyses, captured individuals were pooled for each sampled wheat field. Abundance was the total number of individuals and richness the total number of species within each studied group (Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera, and Syrphidae). Diversity was calculated as the exponential function of the Shannon-Wiener Index (Shannon & Weaver, 1948) in order to obtain “the effective number of species”, which is considered a true diversity value according to Jost (2006). Only adults were considered (except aphids) due to the difficulty of identifying larvae and nymphs to species level.

We analysed the effect of farming system (Dry vs. Irrigated) and habitat variables (see Table 2) on abundance, richness and diversity for each arthropod group using Generalised Linear Mixed Models (GLMMs). Response variables were abundance, richness and diversity of each arthropod group. Explanatory variables were farming system and habitat characteristics, included as fixed effects. The identity of each 2 x 2 km square was included as a random term to account for spatial autocorrelation, since several fields were located in the same squares. We used appropriate error distributions in the GLMMs for each type of response variable: negative binomial for abundance, Poisson for richness and Gaussian for diversity. We analysed separately: i) the individual effect of farming system on abundance, richness and diversity for each group and, ii) the effect of farming system along with habitat variables (Table 2). For the second step, we used a multi-model selection procedure (Burnham & Anderson, 2002). We included the variable farming system in all the models and performed all possible models permuting the habitat variables. The resulting models were ranked according to both their AICc (i.e. corrected Akaike Information Criterion) value and the Akaike weight of each model (ωm) (Burnham & Anderson, 2002). We selected all the habitat variables in the resultant best models (AICc < 2, i.e. within two AICc units from the model with the lowest AICc, (see Supporting Information, Table S1) and put them in a global GLMM including farming system. Variables were further sorted from this model using stepwise backward selection, removing at each step the less significant variable (i.e. that with the highest p-value), until all the variables remaining in the model were significant ($p<0.05$).

Table 2. Mean (± SE) abundance, richness and diversity per field for Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera and Syrphidae species in Irrigated and Dry farming systems. The effect of farming system and habitat variables on abundance, richness and diversity was analysed using GLMM with appropriate error distributions (negative binomial for abundance, Poisson for richness and Gaussian for diversity). 'Farming system'a was tested as a single variable and the statistic and P values are given. In 'Farming system + habitat variables'b models, variables were first selected using AIC-based methods and then by testing for significance (P<0.05). (see Methods section for more details).

	Farming system effect[a]				Farming system + habitat variables effect[b]							
	Dry	**Irrigated**	**Statistic value**	***P***	**Dry**	**Irrigated**	**L.f.s.**	**S.f.s.**	**Crop height**	**Edge width**	**No. trees**	**No. shrubs**
Abundance models												
Aphididae	43,4 ± 5,5	216 ± 71,8	25,07	<0.001*	-	+			-			
Aphidiinae	3 ± 1,4	5,1 ± 1,5	0,77	0,379								
Coccinellidae[c]	6,5 ± 1	22 ± 8,3	13,28	<0.001*	·	·	+				-	
Formicidae	24,2 ± 6,2	15,8 ± 11,3	0,77	0,379								-
Heteroptera	24,9 ± 4,7	21,2 ± 5,6	0,36	0,549			+			-		
Syrphidae	4,2 ± 1,2	6,3 ± 1,9	0,87	0,351				+				-
Richness models												
Aphididae	4,6 ± 0,4	7,6 ± 0,9	14,29	0.001*	-	+						
Aphidiinae	1 ± 0,3	2,4 ± 0,6	5,57	0.024*								
Coccinellidae	2,2 ± 0,2	3,8 ± 0,5	12,76	0.001*	-	+	+					
Formicidae[e]	3 ± 0,3	1,9 ± 0,3	4,85	0.034*								
Heteroptera	7,1 ± 0,6	7,8 ± 1	0,43	0,517			+					
Syrphidae	1 ± 0,1	1,6 ± 0,3	3,62	0,065								
Diversity models												
Aphididae	2,5 ± 0,2	3 ± 0,4	1,98	0,168								
Aphidiinae	1,4 ± 0,2	2,3 ± 0,5	5,68	0.023*								
Coccinellidae[c]	2 ± 0,2	2,7 ± 0,2	4,48	0.042*	·	·	+		-			
Formicidae	2,1 ± 0,2	1,6 ± 0,2	2,05	0,162								
Heteroptera	4,9 ± 0,3	5,4 ± 0,5	0,52	0,475								
Syrphidae	1,2 ± 0,1	1,5 ± 0,2	5,01	0.032*	-; ·	+; ·	-					

[a] Significant (*P*<0.05) values are marked with an asterisk (*).

[b] Meaning of table symbols and abbreviations: + (positive relation), - (negative relation), L.f.s. (landscape field size), S.f.s. (surveyed field size).

[c] "·" indicates cases in which farming system changes the sign of its relation when considering other habitat variables.

[d] Edge width was removed from Richness models of Formicidae since those including this explanatory variable did not converge.

Multivariate analyses were performed to explore the differences in species composition between dry and irrigated sub-areas for the arthropod groups studied. We used Principal Component Analysis (PCA) to obtain a simplified visual representation of compositional differences among sampled fields. Complementarily, Redundancy Analyses (RDA) were used to test if species composition significantly differed between dry and irrigated fields using 10,000 Monte-Carlo permutations. RDA also allowed us to identify the main environmental variables affecting species composition once the farming system was considered. Explanatory variables were chosen in the RDA models using stepwise forward selection. Variables were sequentially included when significant ($p<0.05$, 1000 permutations) according to their contribution to the model (i.e. the variables that increased most the R^2 of the model were first selected). Prior to conduct PCA and RDA, abundance data were Hellinger-transformed to reduce the influence of extreme values and the effect of double zeroes in the data matrix (Legendre & Gallagher, 2001).

Analyses were performed with R statistical package (R Development Core Team, 2010).

Results

A total of 6,095 individuals of 147 species were caught. Of which, 3,678 (60.34%) individuals and 36 species of Aphididae, 137 (2.25%) individuals and 14 species of Aphidiinae, 426 (6.99%) individuals and 12 species of Coccinellidae, 796 (13.06%) individuals and 19 species of Formicidae, 877 (14.39%) individuals and 58 species of Heteroptera and 181 (2.97%) individuals and 8 species of Syrphidae (Appendix). The highest abundances in each group were recorded for wheat pests (e.g. the aphid *Sitobion avenae* (Fabricius), 2,272 individuals, or the heteropteran *Aelia rostrata* Boheman, 151 individuals) and their predators (e.g. the coccinellid *Adonia variegata* (Goeze), 81 individuals, or the heteropteran *Orius niger* (Wolff), 191 individuals).

Mean abundance was significantly higher in Irrigated than in Dry fields for Aphididae (five times higher) and Coccinellidae (almost four times higher) (Table 2); while the remaining groups showed no significant differences between farming systems. Mean species richness was significantly higher in Irrigated than in Dry fields for Aphididae, Aphidiinae and Coccinellidae, while the opposite was true for Formicidae (Table 2). Landscape field size was the most important habitat variable, influencing abundance and richness of Coccinellidae and Heteroptera and diversity of Coccinellidae and Syrphidae (Table 2).

PCA graphs showed a clear division between Dry and Irrigated for Coccinellidae, Formicidae and Heteroptera, while the separation was less clear for Aphididae and null for Aphidiinae and Syrphidae (Figure 2). These patterns were supported by RDA results, which found significant differences in species composition between farming systems for Coccinellidae, Formicidae and Heteroptera (Table 3). Once considered farming system, Formicidae was influenced by landscape field size and number of trees (Table 3). Ant species such as *Formica gerardi* Bondroit and *Temnothorax* sp. were associated to presence of trees while *Formica rufibarbis* Fabricius and *Proformica nasuta* (Nylander) were more associated to areas with less trees and smaller mean field size.

Table 3. Results from RDA analyses testing for the effect of farming system alone and for the joint effect of farming system and habitat variables on species composition patterns of Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera and Syrphidae.

	Farming system			Farming system + Habitat variables	
	pseudo-F	*P*	% Variation	Selected variables	% Variation
Aphididae	1,83	0,054	2,25	-	2,25
Aphidiinae	1,69	0,094	1,87	-	1,87
Coccinellidae	5,95	<0.001*	12,09	-	12,09
Formicidae	4,24	<0.001*	8,25	l.f.s.[a] + trees	13,85
Heteroptera	2,97	<0.001*	5,18	-	5,18
Syrphidae	1,66	0,157	1,8	-	1,8

[a] l.f.s.= Landscape field size.

Significant (P<0.05) values are marked with an asterisk (*).

Significance was assessed using 10,000 permutations in all models.

Discussion

In our study, farming system influenced abundance, richness, diversity and composition of six groups of arthropods. In general, irrigated fields held significantly higher abundance (Aphididae and Coccinellidae), richness (Aphididae, Aphidiinae and Coccinellidae) and diversity (Aphidiinae, Coccinellidae and Syrphidae) than dry fields (Table 2). Only Formicidae was significantly richer in dry than in irrigated fields. Species composition significantly differed between farming systems for Coccinellidae, Formicidae and Heteroptera (Table 3). Apart from farming system, landscape field size was the most influential habitat variable, affecting abundance and richness of Coccinellidae and Heteroptera, diversity of Coccinellidae and Syrphidae and species composition of Formicidae (Tables 2 and 3).

The effect of farming system on the studied groups may be explained by the

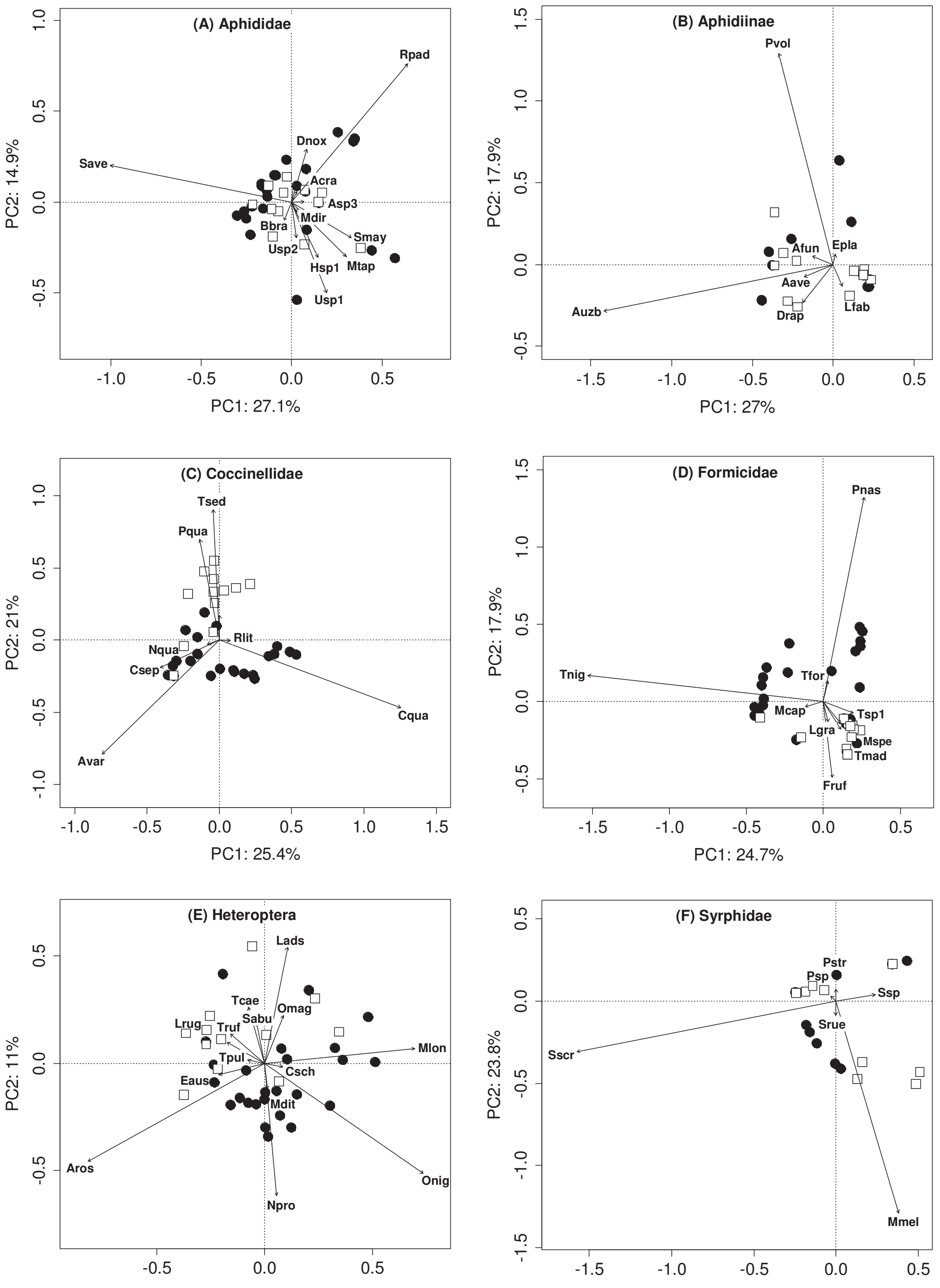

Figure 2. Plot of the first two axes of PCA on the abundance data of the species captured of: (A) Aphididae, (B) Aphidiinae, (C) Coccinellidae, (D) Formicidae, (E) Heteroptera, and (F) Syrphidae. Wheat fields are represented with symbols (Dry ●, Irrigated □) and species with arrows and abbreviated by four letters (see Appendix for correspondences). Less abundant species were removed from the figure to improve visual representation.

multiple differences between dry and irrigated fields regarding biocide and fertiliser inputs, the response of arthropods to those biocides and fertilisers, field margin extension, environmental heterogeneity, etc (Benton *et al*., 2003; Butler *et al*., 2012) (Table 1). Although the majority of studies highlight negative impacts of intensification on arthropods (Hyvönen & Salonen, 2002; Tybirk *et al*., 2004; Herzog *et al*., 2005; Knop *et al*., 2006; Holzschuh *et al*., 2007; Roth *et al*., 2008; Krauss *et al*., 2011; Ponce *et al*., 2011; Prieto-Benítez & Méndez, 2011), others agree with our results and show positive effects of intensification on abundance, richness or diversity (Weibull *et al*., 2000; Kleijn *et al*., 2001; Melnychuk *et al*., 2003; Weibull & Östman, 2003; González-Estébanez *et al*., 2011). These discrepancies could be due to differences among studies on the groups of focus or the agricultural systems. In our study, the most outstanding difference between farming systems was water availability, especially throughout summer.

Water is a key resource, particularly during the long summer drought period characteristic of Mediterranean climates (Blondel *et al*., 2010). This drought period may determine important differences between agro-ecosystems under Mediterranean and Oceanic climates, where it does not occur. Water stress has serious effects on arthropods. For example, aphids grow smaller and more slowly on plants under drought stress (Pons & Tatchell, 1995), although drought effects on aphis are not always clear-cut e.g. some aphids respond positively to intermittent drought (Banfield-Zanin & Leather, 2014). Therefore, higher water availability in irrigated fields, particularly during the summer drought, may improve environmental conditions and increase resource quality (i.e. plants) for herbivores and for their predators through a bottom-up effect (Tscharntke *et al*., 2005a). Higher humidity may not only increase plant yield within the fields but also in field margins, which are an important source of arthropods in agricultural landscapes (Tscharntke *et al*., 2005a). Indeed, while field margins remained green in the irrigated sub-area during the sampling period, they were as dry as the crop in the dry sub-area and may not have provided additional food resources. Some arthropods are known to migrate from field margins to the crop when it can provide food (Knop *et al*., 2006; Clough *et al*., 2007) and to come back to field margins when conditions are unfavourable (e.g. when harvesting) (Holland & Fahrig, 2000). Thus, some groups could benefit in this manner from the higher water availability in the agro-ecosystem.

As expected, aphid predators and parasitoids followed patterns quite similar to those of their prey. In irrigated fields, aphids and coccinelids were more abundant;

aphids, coccinelids and aphidiines were richer; and coccinelids, aphidiines and syrphids were more diverse than in dry fields (Table 2). Increased soil moisture in the irrigated sub-area may have allowed more plant individuals and species to avoid water stress and stay in better condition during summer. Higher plant quality and richness may have fostered higher aphid abundance and richness with a likely cascading effect on the abundance, richness and diversity of their predators and parasitoids. Also, milder environmental conditions may have attracted more species of aphids and their enemies to the irrigated sub-area, where they survived the summer drought. Higher humidity may have also provided a wider variety of resources such as fungi, favouring mycophagous coccinelids like *Tytthaspis sedecimpunctata* (L.) (Iablokoff-Khnzorian, 1982; Agrios, 1995). This and other differences in resource availability may also explain the change in coccinelid species composition between dry and irrigated fields. However, while higher richness of coccinelids and aphidiines in irrigated fields was coupled with higher diversity values, this was not the case for aphids. Although aphids are known to be affected by the water content of their hosts in different manners (Sagers & Goggin, 2007; Rivelli *et al.*, 2013), in our case irrigation seems to have greatly favoured particular pest species (e.g. *Sipha maydis* (Passerini) or *Sitobion avenae*), thereby reducing the evenness of aphid assemblages and rendering a non-significant increase in diversity. Finally, syrphids were more diverse but not richer in irrigated than in dry fields. Milder conditions in irrigated fields may have allowed assemblages to be more even and thus more diverse, while in the harsher conditions of dry fields only few well-adapted species dominated, resulting in lower evenness and diversity.

Formicidae was the only group significantly richer in dry than in irrigated fields. While ants are mutualists of aphids, they do not depend on them to a great extent (Sudd, 1987) so their patterns of abundance and richness do not necessarily mirror those of aphids. Most captured species are typical of dry environments (Bernard, 1968) and may have been displaced from irrigated fields. Species composition also differed between farming regimes for Heteroptera. This heterogeneous group, formed by herbivores and predators, likely responded to differences in resource quantity and quality existing between dry and irrigated croplands.

Once considered farming regime, landscape field size was the most influential habitat variable. This could be explained through a two-way effect: landscape field size may enhance habitat heterogeneity and connectivity by providing higher proportion of field edges as it decreases (Smith *et al*., 2010), and/or buffer the impact of agrochemical applications near the edge as it increases (Kleijn & van der Voort, 1997). In fact, lowered impact of agrochemicals may be behind the relationships of landscape field size with abundance and richness in Coccinellidae and Heteroptera, and with diversity in Coccinellidae (Fauvel, 1999; Bianchi *et al*., 2007; Geiger *et al*., 2010). More specific studies would be necessary to explain the relationships between mean field size and trees with Formicidae.

As predicted, increased water availability during the summer drought fostered arthropod abundance, richness and diversity in irrigated fields. Higher abundance and richness of arthropods may have important consequences for the ecosystem functioning such as increased pest or biological control pressures (Tscharntke *et al*., 2005b; Bianchi *et al*., 2007) or enhanced food resources for bats, birds, small mammals and other invertebrates (e.g. Vaughan, 1997; Wilson *et al*., 1999). However, it is important to acknowledge that in our study sampling was carried out in July when the effects of summer drought are more marked, so differences between farming regimes attributed to higher water availability could have been magnified compared to other seasons. Therefore, the effects of irrigation should be evaluated throughout the year to assess the consistency of our results. Although some groups were more abundant and diverse in irrigated, species adapted to dry conditions may be now threatened due to the transformation of the agro-environment. Further studies targeting at sensitive groups and separating pest and non-pest species should be carried out to ascertain the implications of irrigation for conservation purposes.

In this study we showed that agricultural intensification through irrigation affected several arthropod groups, at least during the summer months, when it likely mitigated the effects of the Mediterranean drought period. Higher water availability may increase resource quality for arthropods, likely fostering their abundance, richness and diversity and leading to differences in species composition. A constant source of water may have helped to maintain plant production during the summer drought, increasing the number of herbivores and their predators and parasitoids through a bottom-up effect. Predators (Coccinellidae) and parasitoids (Aphidiinae) followed the patterns in abundance, richness and diversity showed by their prey/host (Aphididae). Syrphidae were more diverse in irrigated fields, but their abundance and richness remained unaffected by farming system. Heteroptera and Formicidae, with a more heterogeneous diet and less dependent on aphids, did not follow aphid patterns. However, their species composition also differed between farming systems and species richness of Formicidae was higher in dry fields. Our results emphasise the need for more specific studies under Mediterranean climate (José-María *et al*., 2010) in order to design proper agricultural policies devoted to adequately balance habitat quality, biodiversity and productivity in the area.

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Appendix

Mean (± SE) number of individuals per field and per farming system of Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera and Syrphidae. Abbreviations correspond with those species represented in PCA plots (Fig.

Groups	Species	Abbreviation	Dry	Irrigated
Aphididae	*Acyrthosiphon pisum* (Harris)		0,04 ± 0,04	0,25 ± 0,18
	Acyrthosiphon sp.		0,00 ± 0,00	0,25 ± 0,18
	Anoecia sp.		0,08 ± 0,08	0,08 ± 0,08
	Anuraphis sp.		0,04 ± 0,04	0,00 ± 0,00
	Aphis craccivora Koch	Acra	0,76 ± 0,64	0,67 ± 0,28
	Aphis fabae Scopoli		0,00 ± 0,00	0,33 ± 0,22
	Aphis sp.	Asp3	0,40 ± 0,14	1,67 ± 0,51
	Brachycaudus cardui (L.)		0,32 ± 0,19	0,42 ± 0,26
	Brachycaudus sp.		0,12 ± 0,07	0,25 ± 0,18
	Brevicoryne brassicae (L.)	Bbra	0,04 ± 0,04	3,75 ± 2,65
	Capitophorus sp.		0,04 ± 0,04	0,00 ± 0,00
	Ctenocallis setosa (Kaltenbach)		0,00 ± 0,00	0,08 ± 0,08
	Diuraphis noxia (Mordvilko)	Dnox	1,40 ± 0,75	0,50 ± 0,23
	Holcaphis sp.		0,00 ± 0,00	0,25 ± 0,25
	Hyadaphis foeniculi (Passerini)		0,00 ± 0,00	0,25 ± 0,18
	Hyperomyzus sp.	Hsp1	0,24 ± 0,18	4,83 ± 3,44
	Macrosiphoniella tapuskae (Hottes and Frison)	Mtap	1,04 ± 0,49	0,00 ± 0,00
	Macrosiphum euphorbiae (Thomas)		0,00 ± 0,00	0,08 ± 0,08
	Melanaphis donacis (Passerini)		0,08 ± 0,06	0,00 ± 0,00
	Metopolophium dirhodum (Walker)	Mdir	0,28 ± 0,15	5,67 ± 3,01
	Myzus persicae (Sulzer)		0,00 ± 0,00	0,17 ± 0,11
	Nasonovia ribisnigri (Mosley)		0,12 ± 0,09	0,00 ± 0,00
	Protaphis terricola Rondani		0,44 ± 0,27	0,00 ± 0,00
	Rhopalosiphum padi (L.)	Rpad	9,52 ± 3,72	15,92 ± 8,20
	Saltusaphis scirpus Theobald		0,04 ± 0,04	0,00 ± 0,00
	Schizaphis graminum (Rondani)		0,00 ± 0,00	0,25 ± 0,25
	Semiaphis dauci (Fabricius)		0,04 ± 0,04	0,00 ± 0,00
	Sipha maydis (Passerini)	Smay	0,24 ± 0,17	37,50 ± 26,66
	Sitobion avenae (Fabricius)	Save	26,16 ± 3,57	134,83 ± 61,61
	Staegeriella sp.		0,04 ± 0,04	0,00 ± 0,00
	Tetraneura ulmi (L.)		0,32 ± 0,32	0,08 ± 0,08
	Thelaxes sp.		0,00 ± 0,00	0,08 ± 0,08
	Therioaphis ononidis (Kaltenbach)		0,08 ± 0,08	0,00 ± 0,00
	Therioaphis trifolii (Monell)		0,04 ± 0,04	0,00 ± 0,00
	Uroleucon sp.	Usp1	1,16 ± 0,64	1,17 ± 0,99
	Uroleucon (*Uromelan*) sp.	Usp2	0,36 ± 0,17	6,67 ± 5,51
Aphidiinae	*Adialytus ambiguus* (Haliday)		0,00 ± 0,00	0,25 ± 0,25
	Aphidius avenae Haliday	Aave	0,04 ± 0,04	0,25 ± 0,13
	Aphidius ervi Starý		0,08 ± 0,08	0,08 ± 0,08
	Aphidius funebris Mackauer	Afun	0,12 ± 0,09	0,50 ± 0,29
	Aphidius rhopalosiphi De Stefani-Perez		0,00 ± 0,00	0,33 ± 0,22
	Aphidius sonchi Marshall		0,00 ± 0,00	0,17 ± 0,17
	Aphidius uzbekistanicus Luzhetzki	Auzb	1,04 ± 0,60	1,75 ± 0,68
	Diaeretiella rapae (M'Intosh)	Drap	0,04 ± 0,04	0,92 ± 0,66
	Ephedrus persicae Froggatt		0,04 ± 0,04	0,00 ± 0,00
	Ephedrus plagiator (Nees)	Epla	0,84 ± 0,84	0,33 ± 0,19
	Lysiphlebus fabarum (Marshall)	Lfab	0,28 ± 0,18	0,17 ± 0,17
	Praon gallicum Starý		0,04 ± 0,04	0,00 ± 0,00
	Praon volucre (Haliday)	Pvol	0,48 ± 0,22	0,33 ± 0,14
	Trioxys angelicae (Haliday)		0,04 0,04	0,00 ± 0,00
Coccinellidae	*Adonia variegata* (Goeze)	Avar	1,68 ± 0,35	3,25 ± 1,84
	Coccinella septempunctata L.	Csep	1,96 ± 0,76	1,42 ± 0,70
	Coccinella sp.		0,00 ± 0,00	0,08 ± 0,08
	Coccinula quatuordecimpustulata (L.)	Cqua	1,64 ± 0,45	0,92 ± 0,40
	Nephus quadrimaculatus (Herbst)	Nqua	0,12 ± 0,09	2,25 ± 2,25
	Propylea quatuordecimpunctata (L.)	Pqua	0,00 ± 0,00	1,67 ± 0,64
	Rhizobius litura (Fabricius)	Rlit	0,88 ± 0,28	1,25 ± 0,54
	Scymnus interruptus (Goeze)		0,00 ± 0,00	1,00 ± 0,74
	Semiadalia notata (Laicharting)		0,08 ± 0,08	0,00 ± 0,00
	Stethorus punctillum Weise		0,00 ± 0,00	0,08 ± 0,08
	Thea vigintiduopunctata (L.)		0,00 ± 0,00	0,08 ± 0,08
	Tytthaspis sedecimpunctata (L.)	Tsed	0,12 ± 0,09	10,00 ± 5,70
Formicidae	*Camponotus aethiops* (Latreille)		0,04 ± 0,04	0,00 ± 0,00
	Camponotus sylvaticus (Olivier)		0,12 ± 0,12	0,00 ± 0,00
	Camponotus sp.		0,12 ± 0,09	0,00 ± 0,00
	Formica gerardi Bondroit		0,12 ± 0,07	0,50 ± 0,26
	Formica pratensis Retzius		0,20 ± 0,20	0,25 ± 0,25
	Formica rufibarbis Fabricius	Fruf	0,92 ± 0,49	1,67 ± 0,69
	Lasius grandis Forel	Lgra	0,00 ± 0,00	1,17 ± 0,99
	Messor capitatus (Latreille)	Mcap	0,40 ± 0,22	0,00 ± 0,00
	Myrmica specioides Bondroit	Mspe	0,00 ± 0,00	1,50 ± 1,41

	Pheidole pallidula (Nylander)		0,00 ± 0,00	0,08 ± 0,08
	Proformica nasuta (Nylander)	Pnas	3,60 ± 0,96	0,00 ± 0,00
	Tapinoma sp.		0,04 ± 0,04	0,00 ± 0,00
	Tapinoma erraticum (Latreille)		0,24 ± 0,24	0,08 ± 0,08
	Tapinoma madeirense Forel	Tmad	0,68 ± 0,26	0,00 ± 0,00
	Tapinoma nigerrimum (Nylander)	Tnig	16,28 ± 5,70	10,17 ± 9,99
	Temnothorax sp.	Tsp1	0,36 ± 0,20	0,33 ± 0,26
	Tetramorium caespitum (L.)		0,12 ± 0,09	0,00 ± 0,00
	Tetramorium forte Forel	Tfor	0,96 ± 0,33	0,08 ± 0,08
	Tetramorium semilaeve Andre		0,04 ± 0,04	0,00 ± 0,00
Heteroptera	*Adelphocoris lineolatus* (Goeze)		0,16 ± 0,07	0,08 ± 0,08
	Adelphocoris vandalicus (Rossi)		0,00 ± 0,00	0,17 ± 0,17
	Aelia acuminata (L.)		0,04 ± 0,04	0,17 ± 0,11
	Aelia rostrata Boheman	Aros	3,24 ± 0,60	5,83 ± 2,81
	Auchenodes costalis (Lethierry)		0,04 ± 0,04	0,00 ± 0,00
	Berytinus montivagus (Meyer-Dür)		0,04 ± 0,04	0,08 ± 0,08
	Brachycarenus tigrinus (Schilling)		0,08 ± 0,05	0,00 ± 0,00
	Brachyplax tenuis (Mulsant and Rey)		0,04 ± 0,04	0,00 ± 0,00
	Calocoris roseomaculatus (De Geer)		0,28 ± 0,17	0,00 ± 0,00
	Campylomma annulicorne (Signoret)		0,00 ± 0,00	0,08 ± 0,08
	Chlamydatus pullus (Reuter)		0,00 ± 0,00	0,08 ± 0,08
	Chorosoma schillingii (Schilling)	Csch	0,40 ± 0,20	0,00 ± 0,00
	Conostethus venustus (Fieber)		0,08 ± 0,05	0,00 ± 0,00
	Coreus marginatus (L.)		0,00 ± 0,00	0,42 ± 0,29
	Deraeocoris flavilinea (A. Costa)		0,00 ± 0,00	0,08 ± 0,08
	Deraeocoris ribauti Wagner		0,08 ± 0,05	0,08 ± 0,08
	Dictyla echii (Schrank)		0,00 ± 0,00	0,17 ± 0,11
	Dicyphus geniculatus (Fieber)		0,12 ± 0,06	0,00 ± 0,00
	Dolycoris baccarum (L.)		0,20 ± 0,10	0,17 ± 0,11
	Eurydema oleracea (L.)		0,00 ± 0,00	0,33 ± 0,22
	Eurydema ornata (L.)		0,16 ± 0,07	0,00 ± 0,00
	Eurydema ventralis Kolenati		0,04 ± 0,04	0,08 ± 0,08
	Eurygaster austriaca (Schrank)	Eaus	1,08 ± 0,41	0,58 ± 0,23
	Gampsocoris punctipes (Germar)		0,04 ± 0,04	0,00 ± 0,00
	Geocoris megacephalus (Rossi)		0,04 ± 0,04	0,00 ± 0,00
	Hallodapus suturalis (Herrich-Schaeffer)		0,04 ± 0,04	0,00 ± 0,00
	Hoplomachus thunbergii (Fallén)		0,08 ± 0,05	0,00 ± 0,00
	Horistus orientalis (Gmelin)		0,16 ± 0,09	0,00 ± 0,00
	Liorhyssus hyalinus (Fabricius)		0,00 ± 0,00	0,67 ± 0,51
	Lopus decolor (Fallen)		0,24 ± 0,20	0,00 ± 0,00
	Lygus adspersus (Schilling)	Lads	2,08 ± 0,93	0,67 ± 0,33
	Lygus pratensis (L.)		0,00 ± 0,00	0,08 ± 0,08
	Lygus punctatus (Zetterstedt)		0,00 ± 0,00	0,58 ± 0,58
	Lygus rugulipennis Poppius	Lrug	0,44 ± 0,18	1,25 ± 0,99
	Macroplax fasciata (Herrich-Schaeffer)		0,00 ± 0,00	0,08 ± 0,08
	Megalocoleus longirostris (Fieber)	Mlon	4,40 ± 1,89	0,00 ± 0,00
	Metopoplax ditomoides (A. Costa)	Mdit	0,80 ± 0,64	0,00 ± 0,00
	Microplax interrupta (Fieber)		0,20 ± 0,13	0,00 ± 0,00
	Nabis provencalis Remane	Npro	1,64 ± 0,40	0,58 ± 0,23
	Nabis pseudoferus Remane		0,24 ± 0,10	0,33 ± 0,14
	Nysius ericae (Schilling)		0,00 ± 0,00	0,25 ± 0,13
	Nysius graminicola (Kolenati)		0,04 ± 0,04	1,42 ± 1,15
	Oncotylus punctiger Reuter		0,16 ± 0,09	0,00 ± 0,00
	Orius majusculus (Reuter)	Omaj	0,00 ± 0,00	1,50 ± 0,91
	Orius niger (Wolff)	Onig	6,56 ± 2,54	2,25 ± 1,11
	Orthops basalis (A. Costa)		0,00 ± 0,00	0,08 ± 0,08
	Oxycarenus pallens (Herrich-Schaeffer)		0,08 ± 0,05	0,00 ± 0,00
	Phytocoris varipes Boheman		0,00 ± 0,00	0,67 ± 0,43
	Plagiognathus chrysanthemi (Wolff)		0,24 ± 0,17	0,08 ± 0,08
	Platycranus minutus Wagner		0,00 ± 0,00	0,08 ± 0,08
	Rhopalus parumpunctatus Schilling		0,00 ± 0,00	0,08 ± 0,08
	Stictopleurus abutilon (Rossi)	Sabu	0,64 ± 0,31	0,33 ± 0,33
	Tingis ampliata (Herrich-Schaeffer)		0,00 ± 0,00	0,08 ± 0,08
	Tingis auriculata (A. Costa)		0,08 ± 0,08	0,08 ± 0,08
	Trigonotylus caelestialium (Kirkaldy)	Tcae	0,04 ± 0,04	0,75 ± 0,22
	Trigonotylus pulchellus (Hahn)	Tpul	0,36 ± 0,16	0,08 ± 0,08
	Trigonotylus ruficornis (Geoffroy)	Truf	0,16 ± 0,12	0,75 ± 0,41
	Xylocoris obliquus A. Costa		0,08 ± 0,08	0,00 ± 0,00
Syrphidae	*Melanostoma mellinum* (L.)	Mmel	0,32 ± 0,15	1,92 ± 1,12
	Melanostoma scalare (Fabricius)		0,00 ± 0,00	0,08 ± 0,08
	Paragus quadrifasciatus Meigen		0,00 ± 0,00	0,08 ± 0,08
	Paragus strigatus Meigen	Pstr	0,08 ± 0,08	0,00 ± 0,00
	Paragus sp.	Psp	0,00 ± 0,00	0,08 ± 0,08
	Sphaerophoria rueppelli (Wiedemann)	Srue	0,00 ± 0,00	0,50 ± 0,29
	Sphaerophoria scripta (L.)	Sscr	3,76 ± 1,15	3,58 ± 1,43
	Sphaerophoria sp.	Ssp	0,04 ± 0,04	0,08 ± 0,08

Table S1.

Results of the AICc-based selection of GLMM models. Best models (DeltaAICc<2 from the best model) analysing the effect of farming system along with habitat variables on mean abundance[a], richness[a] and diversity[a] per field for Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera and Syrphidae species in Irrigated and Dry farming systems.

	Intercept	Crop height	Edge width	S.f.s.	L.f.s.	Shrub	Farming system	Trees	df	logLik	AICc	Delta	Weight
Aphidiidae													
Abundance	5,1422	-0,0202	NA	NA	NA	NA	+	NA	5	-192,458	396,8515	0	0,1365
	3,7681	NA	NA	NA	NA	NA	+	NA	4	-193,994	397,238	0,3865	0,1126
	5,085	-0,0232	0,0003	NA	NA	NA	+	NA	6	-191,69	398,18	1,3285	0,0703
Richness													
	1,5169	NA	NA	NA	NA	NA	+	NA	3	-17,0632	40,8537	0	0,1662
	1,8131	NA	NA	NA	-0,0708	NA	+	NA	4	-16,1583	41,5667	0,713	0,1164
Diversity													
	2,4792	NA	NA	NA	NA	NA	+	NA	4	-55,4395	120,129	0	0,1543
	2,7891	NA	-0,0003	NA	NA	NA	+	NA	5	-54,6172	121,1698	1,0409	0,0917
	2,5152	NA	-0,0004	0,0918	NA	NA	+	NA	6	-53,5639	121,9279	1,7989	0,0628
	2,2387	NA	NA	0,0563	NA	NA	+	NA	5	-55,0224	121,9802	1,8513	0,0611
Aphidiinae													
Abundance	0,0356	NA	NA	NA	NA	NA	+	NA	4	-79,9925	169,235	0	0,1509
	-0,444	NA	NA	0,1479	NA	NA	+	NA	5	-79,411	170,7575	1,5225	0,0705
	-0,3002	NA	0,0005	NA	NA	NA	+	NA	5	-79,4433	170,8221	1,5871	0,0682
Richness													
	-0,4829	NA	NA	NA	NA	NA	+	NA	3	-24,2815	55,2903	0	0,1742
	-0,7263	NA	0,0003	NA	NA	NA	+	NA	4	-23,5338	56,3175	1,0272	0,1042
Diversity													
	1,3752	NA	NA	NA	NA	NA	+	NA	4	-48,2168	105,6836	0	0,176
	1,0611	NA	0,0003	NA	NA	NA	+	NA	5	-47,0333	106,0021	0,3184	0,1501
Coccinellidae													
Abundance	0,7655	NA	NA	NA	0,2631	NA	+	-0,2368	6	-111,811	238,422	0	0,2408
	1,7722	-0,013	NA	NA	0,2374	NA	+	-0,2419	7	-111,037	239,9361	1,5141	0,1129
Richness													
	0,1125	NA	NA	NA	0,1535	NA	+	NA	4	-7,6246	24,4992	0	0,1934
Diversity													
	0,686	NA	NA	NA	0,311	NA	+	NA	5	-45,207	102,3496	0	0,1995
	2,0554	-0,0173	NA	NA	0,27	NA	+	NA	6	-44,0912	102,9824	0,6328	0,1454
Formicidae													
Abundance	3,2222	NA	NA	NA	NA	-0,2151	+	NA	5	-143,313	298,5615	0	0,2251
	4,5388	-0,0191	NA	NA	NA	-0,2058	+	NA	6	-142,728	300,256	1,6945	0,0965
	2,7956	NA	0,0004	NA	NA	-0,2164	+	NA	6	-142,852	300,504	1,9425	0,0852
Richness[b]													
	1,0863	NA		NA	NA	NA	+	NA	3	-16,0483	38,8238	0	0,2526

	0,816	NA		NA	0,0625	NA	+	NA	4	-15,6954	40,6408	1,817	0,1018
	1,6011	-0,0074		NA	NA	NA	+	NA	4	-15,7266	40,7032	1,8794	0,0987
Diversity													
	1,325	NA	NA	NA	0,1903	NA	+	NA	5	-43,2604	98,4562	0	0,1076
	2,1386	NA	NA	NA	NA	NA	+	NA	4	-44,636	98,522	0,0658	0,1042
	3,2723	-0,0165	NA	NA	NA	NA	+	NA	5	-43,3716	98,6786	0,2224	0,0963
	2,356	-0,012	NA	NA	0,1423	NA	+	NA	6	-42,6212	100,0423	1,5862	0,0487
Heteroptera													
Abundance	2,6138	NA	-0,0004	NA	0,2192	NA	+	NA	6	-144,909	304,618	0	0,1841
	2,6865	NA	-0,0004	NA	0,2198	-0,071	+	NA	7	-143,647	305,1561	0,5381	0,1407
	2,7739	NA	-0,0004	NA	0,1889	NA	+	-0,0765	7	-144,156	306,1741	1,5561	0,0846
Richness													
	1,5488	NA	NA	NA	0,0954	NA	+	NA	4	-18,8976	47,0451	0	0,1364
	1,9648	NA	NA	NA	NA	NA	+	NA	3	-20,5842	47,8956	0,8505	0,0892
	1,9308	-0,0048	NA	NA	0,0836	NA	+	NA	5	-18,5174	48,9702	1,9251	0,0521
	2,4109	-0,0065	NA	NA	NA	NA	+	NA	4	-19,8962	49,0424	1,9973	0,0503
Diversity													
	4,8779	NA	NA	NA	NA	0,1624	+	NA	5	-69,7929	151,5214	0	0,1162
	5,0394	NA	NA	NA	NA	NA	+	NA	4	-71,1409	151,5318	0,0104	0,1156
	7,188	-0,0311	NA	NA	NA	NA	+	NA	5	-70,1349	152,2053	0,6839	0,0826
	6,7639	-0,027	NA	NA	NA	0,1462	+	NA	6	-69,0318	152,8637	1,3423	0,0594
	4,1167	NA	NA	NA	0,2124	NA	+	NA	5	-70,7076	153,3506	1,8292	0,0466
	3,9104	NA	NA	NA	0,2165	0,1737	+	NA	6	-69,3135	153,4269	1,9055	0,0448
Syrphidae													
Abundance	0,6373	NA	NA	0,1559	NA	NA	+	NA	5	-95,2424	202,4203	0	0,125
	0,821	NA	NA	0,1381	NA	-0,1138	+	NA	6	-94,0917	202,9834	0,5631	0,0943
	0,567	NA	NA	0,186	NA	NA	+	-0,1527	6	-94,4384	203,6768	1,2565	0,0667
	4,0238	-0,0352	NA	NA	NA	-0,1691	+	NA	6	-94,7052	204,2104	1,7901	0,0511
	0,8606	NA	-0,0003	0,1699	NA	NA	+	NA	6	-94,7309	204,2618	1,8415	0,0498
Richness													
	0	NA	NA	NA	NA	NA	+	NA	3	-13,9728	34,673	0	0,1884
	0,3931	NA	NA	NA	-0,0946	NA	+	NA	4	-13,634	36,5179	1,845	0,0749
	0,0347	NA	NA	NA	NA	-0,0402	+	NA	4	-13,6579	36,5658	1,8928	0,0731
Syrphidae													
	2,5038	-0,0121	NA	NA	-0,1148	NA	+	NA	6	-18,2141	51,2283	0	0,159
	1,5376	NA	NA	NA	-0,0865	NA	+	NA	5	-20,2649	52,4653	1,237	0,0856
	1,1707	NA	NA	NA	NA	NA	+	NA	4	-21,7079	52,6657	1,4375	0,0775
	2,5639	-0,0122	NA	NA	-0,1253	NA	+	-0,0368	7	-17,6624	53,1868	1,9585	0,0597

[a] Meaning of table symbols and abbreviations: + (categorical variable included in the model), L.f.s. (landscape field size), S.f.s. (surveyed field size), df (degrees of freedom), Loglik (Log-likelihood), AICc (Akaike's Information Criterion), NA (Not included in the model).

[b] Edge width was removed as explanatory variable in Richness model of Formicidae since the models including this variable did not converge.

II

Seasonal variation of Mediterranean wheat aphid-based multi-trophic communities under dry and irrigated farming regimes

Variación estacional de comunidades multi-tróficas basadas en pulgones de cereales en regímenes de secano y regadío en una zona mediterranea.

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Resumen

La intensificación agrícola ha tenido un fuerte impacto en el medio ambiente en las últimas décadas. La implantación del regadío como medida de intensificación es una transformación común en todo el mundo, que también se realiza en los países mediterráneos, pero sus efectos en las especies plaga apenas se han estudiado. Se han evaluado los efectos del régimen agrícola y la variación temporal en la abundancia de pulgones de los cereales y sus depredadores (Chrysopidae, Coccinellidae, Syrphidae), parasitoides (Aphidiinae) y mutualistas (Formicidae) en campos de trigo de regadío y secano en una zona agrícola mediterránea den el noroeste de España. La abundancia de todos los grupos salvo Formicidae incrementó en campos de regadío a medida que la estación avanzó, alcanzando el máximo al final de junio (Aphididae, Chrysopidae, Aphidiinae) o al comienzo de julio (Coccinellidae, Syrphidae), y luego disminuyeron. Coccinellidae y Aphidiinae fueron más abundantes en campos de regadío durante todo el período de muestreo. Aphididae y Syrphidae sólo lo fueron en los muestreos centrales, pero en los primeros (Syrphidae) y en los últimos (ambos grupos) fueron más abundantes en campos de secano. La abundancia de Chrysopidae no fue influenciada por el régimen agrícola, mientras que los formícidos fueron más abundantes en campos de trigo de secano que en regadío y su número no sufrió cambios importantes con el paso del tiempo. Nuestros resultados sugieren que el regadío incrementa la producción primaria durante la sequía estival, estimulando la abundancia de pulgones de los cereales, lo que a su vez favorece la abundancia de sus depredadores (Coccinellidae, Syrphidae) y parasitoides (Aphidiinae).

Summary

Agricultural intensification has strongly affected the environment in last decades. Intensification by irrigation is a common transformation worldwide, particularly in Mediterranean countries, but its effects on pest species have rarely been studied. We evaluated the effects of farming system and seasonal variation on the abundance of wheat aphids and that of their predators (Chrysopidae, Coccinellidae, Syrphidae), parasitoids (Aphidiinae) and mutualists (Formicidae) in irrigated and dry winter wheat fields in a Mediterranean farmland in NW Spain. All groups but Formicidae increased in abundance in irrigated fields as the season advanced, peaked at the end of June (Aphididae, Chrysopidae, Aphidiinae) or at the beginning of July (Coccinellidae, Syrphidae) and decreased again. Coccinellidae and Aphidiinae were more abundant in irrigated than in dry fields during the whole sampling period, but this was true for Aphididae and Syrphidae only in the middle of the season and not in the first (Syrphidae) and last surveys (both groups). The abundance of Chrysopidae was not influenced by farming regime, while Formicidae were more abundant in dry than in irrigated fields and their numbers did not change with time. Our results suggest that irrigation enhanced plant production during the summer drought, boosting cereal aphid abundance, which in turn favoured some of their predators (Coccinellidae, Syrphidae) and parasitoids (Aphidiinae).

Introduction

In Southern Europe, like in other parts of the world, irrigation is commonly used to enhance agricultural production (van der Velde *et al*., 2010) at the cost of converting vast areas of dry extensive cereal agroecosystems into irrigated areas (e.g., in Spain; MAGRAMA, 2013). Irrigation negatively affects birds (Tella & Forero, 2000; Brotons *et al*., 2004; Laiolo, 2005; De Frutos & Olea, 2008), but its effects on other important agricultural fauna such as arthropods are little known (but see González-Estébanez *et al*., 2011 for butterflies; Pérez-Fuertes *et al*., 2015 for other arthropods; Caballero-López *et al*., 2010, 2012 for arthropods comparing organic vs. conventional). Therefore, we hardly know how pest species and their companion fauna respond to the change from extensive dry farming to intensive irrigated.

Cereal aphids (Hemiptera, Aphididae) are major pests worldwide (Fuentes-Contreras & Niemeyer, 2000) that can cause massive yield losses (Kieckhefer *et al*., 1995; Schmidt *et al*., 2003; Thies *et al*., 2011) by feeding or as vectors of barley yellow dwarf virus (BYDV) (Osler *et al*., 1987; Šutić *et al*., 1999). The main cereal aphid pests in European ecosystems are *Sitobion avenae* (L.), *Metopolophium dirhodum* (Walker) and *Rhopalosiphum padi* (L.) (Schmidt *et al*., 2003; Phoeling *et al*., 2007), which are also important in Spain (Castañera & Gutiérrez, 1983; Pons *et al*., 1989, 1993). Other species found on wheat are *Diuraphis noxia* (Mordvilko), *Schizaphis graminun* (Rondani), *Sipha elegans* Del Guercio and *Sipha maydis* (Passerini) (Blackman & Eastop, 2002; Lumbierres *et al*., 2007; Poehling *et al*., 2007).

In spite of their agricultural importance, aphids have received little attention in cereal crops in Spain and just three species are officially considered as wheat pests, *S. avenae, Rhopalosiphum maidis* (Fitch) and *R. padi* (MAGRAMA, 2015). This evidences a lack of knowledge that hinders proper control policies in accordance to ecological needs and life cycles. Aphids are frequently found on crops and, although they rarely exceed the threshold of economic injury (Pons *et al*., 1993), species such as *R. padi* can reduce barley production up to 52% (Östman *et al*., 2003).

The most important factors affecting the development of aphid populations are temperature, plant quality and natural enemies (Pons *et al*., 1993; Pons & Eizaguirre, 2000), which are in turn interrelated. Cold (-6 ºC; Pons *et al*., 1993) or hot (30 ºC; Dean, 1974) temperatures are limiting factors for aphid population development and may have constraining effects on plants. Plant quality is largely influenced by water, and water-stressed plants can negatively affect the survival and reproduction rates of aphids (Summer *et al*., 1983, 1986; Fereres *et al*., 1988; Pons *et al*., 1993). Natural enemies can limit aphid populations, but their abundance may be highly influenced by that of their prey, since bottom-up control is common in predator (Freier *et al*., 2007) and parasitoid (Petermann *et al*., 2010; Scherber *et al*., 2010) food chains. The abundance of natural enemies may also be limited by the availability of adult food sources such as nectar and pollen, which presence may have a marked effect on natural pest control (Tylianakis *et al*., 2004). Lacewings (Neuroptera, Chrysopidae), ladybirds (Coleoptera, Coccinellidae), hoverflies (Diptera, Syrphidae) and parasitoid wasps (Hymenoptera, Braconidae, Aphidiinae) can use extra-field nectar sources and spread into surrounding crops (Freeman Long *et al*., 1998; Nicholls *et al*., 2001) where they can help controlling pest populations (White *et al*., 1995; Tylianakis *et al*., 2004). Multiple enemy species may act synergistically on their shared prey (Losey & Denno, 1998; Colfer & Rosenheim, 2001), meaning a better control of cereal aphid populations. Finally, biological control of cereal aphids is likely to vary over season (Östman *et al*., 2001; Thies *et al*., 2005) depending on abiotic factors and abundance of overwintering individuals (Östman *et al*., 2001).

Arthropods are essential for ecosystem functioning (McGeoch, 1998) in agricultural landscapes (Daily, 1997), providing valuable services such as pollination and pest control (Daily *et al*., 1997). Natural enemies of aphids can be split in two groups, general predators and aphidophagous specialists (Müller & Godfray, 1999). The second group holds specific aphid predators such as Chrysopidae, Coccinellidae and Syrphidae, which effectively contribute to control cereal aphid populations (Müller & Godfray, 1999; Schmidt *et al*., 2003; Freier *et al*., 2007), and parasitoids such as Aphidiinae, considered by several authors the most important controller of cereal aphids (Schmidt *et al*., 2003; Thies *et al*., 2005), due to their species-specific host-parasitoid relation (Sigsgaard, 2002). On the contrary, ants (Hymenoptera, Formicidae) may power aphid populations since some species are mutualists of aphids, which protect them from predators and even transfer them between food plants (Sudd, 1987). However, aphid-ant mutualism seems uncommon for cereal aphids (Suay-Cano *et al*., 2002)

Biological pest control has recently received great attention, due to its environmental benefits compared to the massive use of biocides, and the better public opinion in favour of reduced pesticide applications and environmentally sound cereal production (Tilman *et al*., 2002). Natural pest control may help reduce the loss of yield without using pesticides, thus avoiding food contamination and environmental pollution (Östman *et al*., 2003). In fact, insecticide applications may be discouraged as they have short-term effects on cereal aphids, and negative long-term effects on natural pest controllers (Krauss *et al*., 2011), thus limiting their efficiency.

In this paper we evaluate the effect of agricultural intensification through irrigation on arthropod abundance in winter wheat fields in relation to seasonal crop development. We assessed the effect of farming system (dry vs. irrigated) on the abundance of cereal pest aphids and their predators, parasitoids and mutualists through time. Specifically, we studied the abundance of wheat pest aphids and their specialised predators (i.e. lacewings, ladybirds and hoverflies), parasitoid wasps and mutualist ants. González-Estébanez *et al*. (2011) and Pérez-Fuertes *et al*. (2015) found that the irrigated system holds more abundance, richness and diversity of arthropods and that could be due to irrigation mitigates the effects of summer drought on plants. We predict that enhanced water availability during the whole period of wheat development will promote plant primary production with a positive cascading effect on the abundance of aphids and companion arthropods in irrigated fields. As preys become more abundant, predators will be able to capture more preys generating an increase in the abundance of predators.

Material and Methods

Study area

The study area (Fig. 1) covers 1,500 km^2 in the south-east of León province, north-west Spain (centred on 42°33 N, 5º31 W). It is included in the supra-Mediterranean bioclimatic level of the Mediterranean region, with average annual precipitations between 436-515 mm and temperatures between 8-13 ºC (Penas *et al*., 1995).

Agriculture is the main land-use in the study area (85% of total surface). We classified the farmland in two categories according to the main agricultural regimes (see Table 1 for details; Fig. 1): i) dry sub-area (Dry) and ii) irrigated sub-area (Irrigated).

The dry sub-area (Dry) covers almost 130,000 ha under rainfed extensive farming system. Cereals are the most extended crop (65%), dominated by winter wheat (*Triticum* spp., 21%) and oat (*Avena sativa* L., 20%), followed by barley (*Hordeum vulgare*

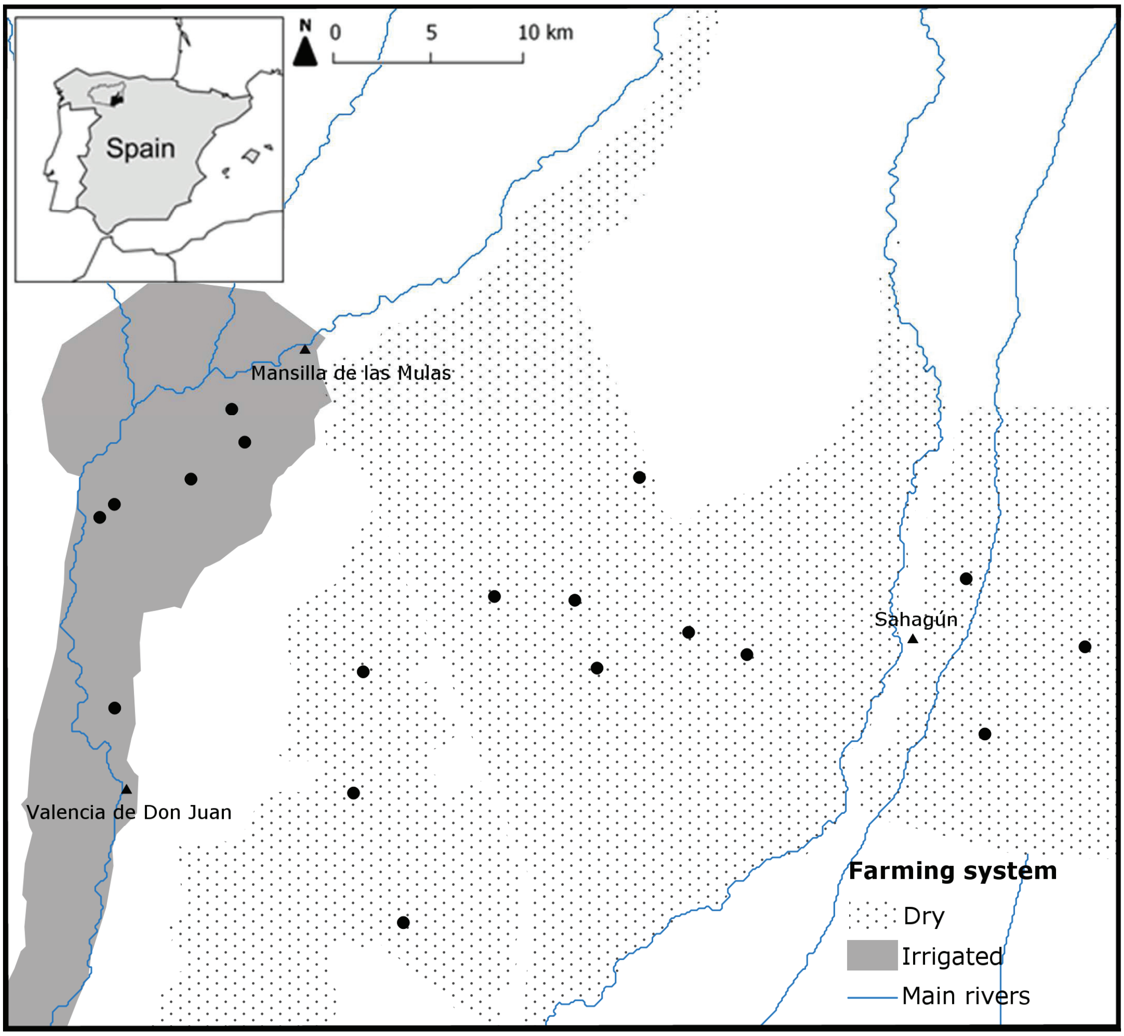

Fig. 1. Location of the study area in north-west Spain (black area in the inset). In total, 18 sampling fields (●) were randomly located, 12 in the irrigated sub-area (Irrigated) and 6 in the dry sub-area (Dry). The most important populations and rivers of the study area are shown in the map.

L., 12%), rye (*Secale cereale* L., 7%) and maize (*Zea mays* L., 5%). Legumes are also important among crops (23%). Interannual crop rotation is applied and fallow fields represent almost 40% of the total surface. There are some poplar (*Populus* spp.) and pine (*Pinus* spp.) plantations (2% and <1% respectively). The dry sub-area is included within the so-called cereal pseudo-steppes (Oñate *et al*., 2007), which hold important populations of threatened steppe bird species (Suárez *et al*., 1997; Olea *et al*., 2004).

The irrigated sub-area (Irrigated) covers approx. 34,000 ha and has been devoted to irrigated farming for more than 20 years. Maize is the main crop type (59%). To a lesser extent, there are fallow fields (14%), irrigated wheat (10%), irrigated alfalfa (*Medicago sativa* L., 2%) and market gardens (1%). Presence of poplar plantations amounts to 3%.

Table 1. Environmental characteristics for each sub-area. Mean (±SE) values or total percentage are given for each variable.

Field data	Dry	Irrigated
Fallow surface (%)[a]	38,2	13,8
Irrigated farmland (%)[a]	7,9	100
N-P-K input (kg ha^{-1}year^{-1}) in wheat crops[b]	230 ± 44.7	616 ± 104
Yield of wheat (kg/ha)[b]	3150 ± 473	7000 ± 290
Habitat variables		
Landscape field size (ha)[c]	4.2 ± 0.3	3.7 ± 0.4
Surveyed field size (ha)[d]	4.3 ± 0.7	3.0 ± 0.6
Crop height (cm)[d]	69.7 ± 2.2	61.4 ± 3.9
Edge width (m)[d]	10.3 ± 1.9	10.5 ± 0.4
Number of trees[e]	0.2 ± 0.2	2.6 ± 0.9
Number of shrubs[e]	0.9 ± 0.2	6.4 ± 1.4

[a] Calculated as percentage within the 2 x 2 km squares.

[b] Data on the amount of N-P-K fertilizer of wheat crops were obtained from farmers using questionnaires, N_{total}= 44 farmers.

[c] Calculated as the mean size of all fields present in a 500 x 500 m square around the surveyed fields.

[d] Calculated for all surveyed fields: $N_{Irrigated}$= 25 fields, N_{Dry}= 12 fields.

[e] Mean number of trees and shrubs in a 500 m transect along the margins of the track adjacent to the surveyed fields. Edge width includes both

Sampling method

Our study focused in winter wheat fields, one of the most economically important crops, both in the study area and worldwide (715.909.258 t in 2013; FAOSTAT, 2015). Eighteen fields were placed within the farming systems (12 in Dry and 6 in Irrigated; Fig. 1). Mean distance between fields sampled in different regimes was 21.7 km (SE: 1.0; range: 1.0-51.4 km). Mean distance between surveyed fields was 17.6 km (SE: 1.2; range: 3.2-38.6) in the dry sub-area, and 7.8 km (SE: 1.2; range: 1.0-16.6) in the irrigated sub-area.

Survey took place during the whole development period of wheat, from May to July 2009. Samples were collected twice a month: at the beginning (1st) and in the middle of the month (15th), resulting in a total of six samples (1st and 15th May, June and July). Developmental stage of surveyed wheat fields was registered in each sampling date at three points and measured with the Zadok's scale (Zadoks *et al.*, 1974; Fig. 2).

Arthropods

Within each field, we sampled three consecutive 25-m transects parallel to the field margin and to the main man-made access path. Transects were at least five metres

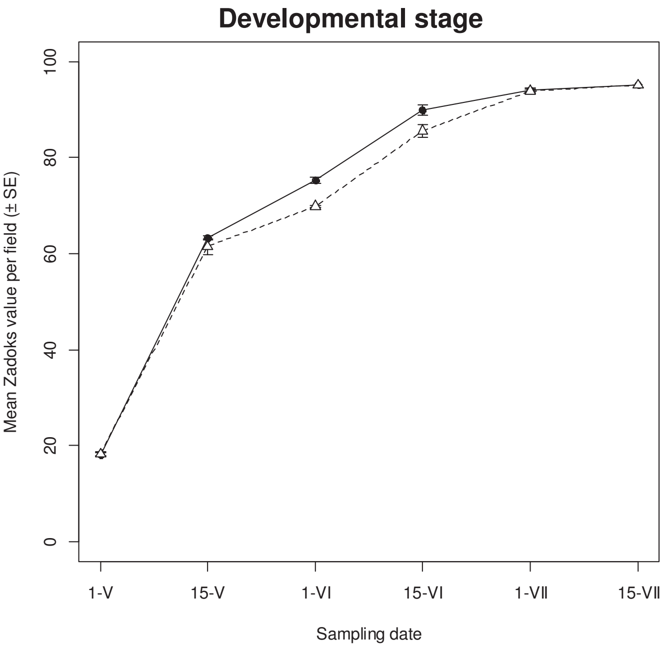

Fig. 2. Mean (± SE) wheat developmental stage per field in Dry (triangles, dashed line) and Irrigated (circles, solid line) sub-areas during the whole sampling period, from the first of May (1-V) to middle July (15-VII).

apart from each other and two metres from the field margin. Sampling was carried out using sweep-netting (Frampton & Dorne, 2007) with one sweep per step (50 sweeps per transect). Each sweep was performed to include as much plant surface as possible (stalk and spike). As aphid colonies are sessile, sampling never took place in the same part of the fields: in every survey, transects begun 5 meters further from where the last transect of the last survey finished, along the field margin.

Sampling was carried out by the same person, with temperatures higher than 20 ºC and on days without rain or strong wind to assure that arthropods were active (Weibull & Östman, 2003). Collected arthropods were transferred into airtight plastic bags, kept in a portable fridge in the field and stored at -20 ºC in laboratory until their identification.

Selected taxa (Aphididae, Chrysopidae, Coccinellidae, Syrphidae, Aphidiinae and Syrphidae) were identified to species level (Appendix). For each studied group, total abundance was calculated summing the abundance of those species related to wheat directly (aphids) or indirectly as aphid predators, parasitoids or mutualists. *S. avenae*, *M. dirhodum*, *R. padi*, *D. noxia* and *S. graminun* (Hemiptera, Aphididae) are cited as aphid species that can cause wheat pests (Castañera & Gutiérrez, 1983; Pons *et al.*, 1989, 1993; Poehling *et al.*, 2007). *S. elegans* and *S. maydis* have been considered in this study since they live on wheat (Poehling *et al.*, 2007; Blackman & Eastop, 2015) and were abundant enough to have agronomical importance, although we have not found bibliography about these species causing yield losses in cereals. Identified aphids were also separated into winged and apterae adults and nymphs. Predator, parasitoid and mutualist species were selected from the bibliography (Gourreau, 1974; Iablokoff-Khnzorian, 1982; Raimundo & Alves, 1986; Suay-Cano & Michelena, 1998; Duelli, 2001; Suay-Cano *et al*., 2002; Pons *et al*., 2003; Rojo *et al*., 2003; Schmidt *et al*., 2003; Michelena *et al*., 2004; Freier *et al*., 2007; Lumbierres *et al*., 2007; Pons *et al*., 2009; Dedryver *et al*., 2010; Akhtar, 2011).

Data analysis

Prior to the analyses, total abundance data were pooled for each sampled wheat field and visit. Aphididae nymphs could be reliably assigned to species and so were included in the study, but for the other groups only adults were considered due to the difficulty of identifying their larvae and nymphs to species level.

We analysed the influence of farming system (Dry vs. Irrigated), sampling date and their interaction on the abundance of each arthropod group using Generalised Linear Mixed Models (GLMM). Abundance was the response variable so a negative binomial error distribution was used in the models. Fixed explanatory variables were farming system and time (sampling date) and the identity of each sampling plot was included as a random term to account for the repeated measures design. Zero-inflated models were used for Syrphidae and Formicidae due to the high presence of zero values (71.3% and 61.1% of the data respectively).

Analyses were performed with R statistical package (R Development Core Team, 2010) and package *glmmADMB* (Fournier *et al*., 2012).

Results

A total of 32,033 individuals (12,447 in Dry, 19,586 in Irrigated) of 31 species were identified as aphid wheat pests and as their predators, parasitoids or mutualists. Among them, 30,313 individuals (94.6% of total abundance) and 7 species belonged to Aphididae, 532 individuals (1.7%) and 1 species to Chrysopidae, 759 individuals (2.4%) and 9 species to Coccinellidae, 63 (0.2%) individuals and 6 species to Syrphidae, 52 individuals (0.1%) and 8 species to Aphidiinae and 314 individuals (1%) and 1 species to Formicidae (see Appendix for details).

Aphididae showed a bell-shaped (i.e. quadratic) response to time, particularly clear in Irrigated. Its abundance increased as the season advanced, peaked in the middle of June (15th June) and decreased again (Fig. 3A). Time and farming regime interacted for Aphididae, whose abundance was higher in Irrigated than in Dry in most sampling dates, but the opposite was true at the beginning and at the end of the season. Winged forms were more abundant in Irrigated than in Dry, increased with the sampling season, peaked in middle June in both regimes and returned to previous values afterwards (Fig. 4).

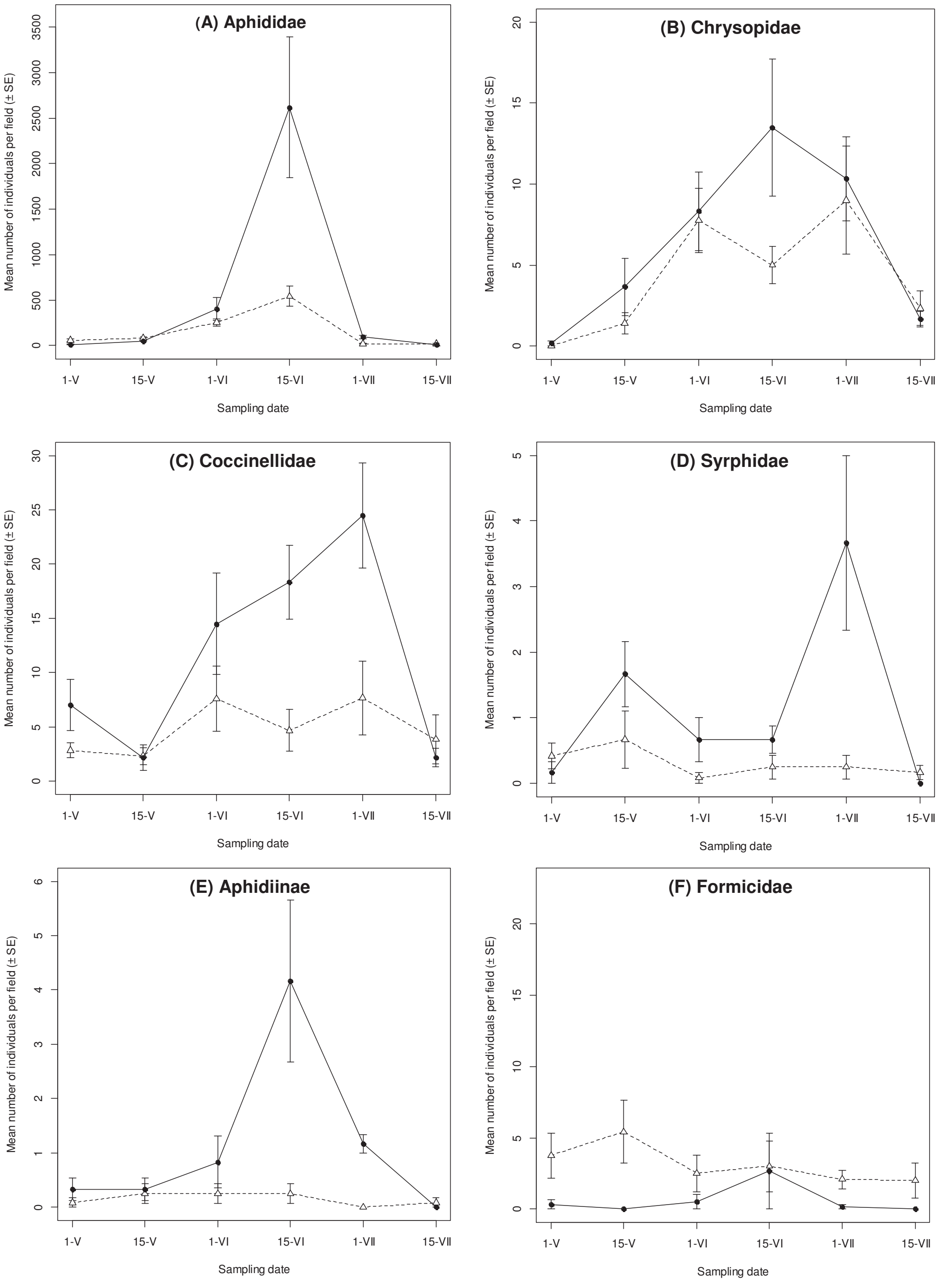

Fig. 3. Mean (± SE) abundance per wheat field in Dry (triangles, dashed line) and Irrigated (circles, solid line) sub-areas for each studied group and sampling date.

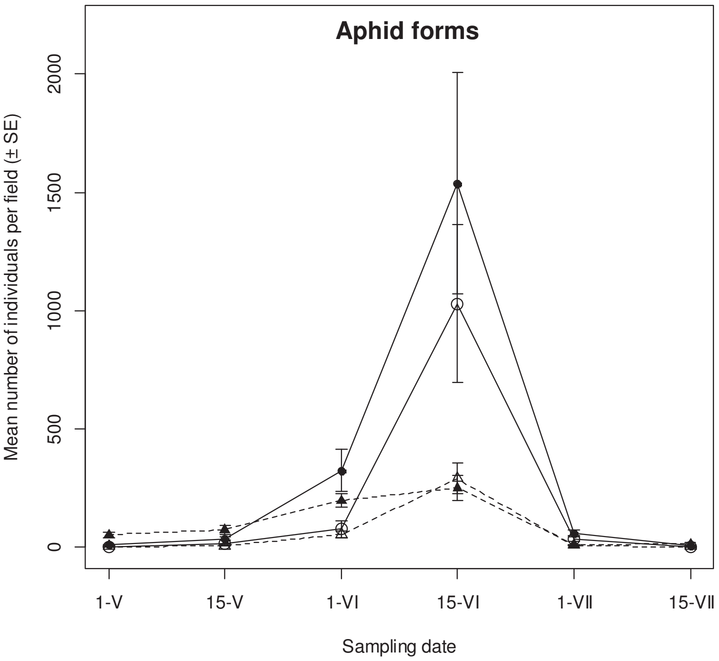

Fig. 4. Mean (± SE) abundance of aphid forms per wheat field. Apterae adults + apterae nymphs (black symbols) and winged adults + winged nymphs (white symbols) in Dry (triangles, dashed line) and Irrigated (circles, solid line) in each sampling date.

The rest of the groups, but Formicidae, followed the same bell-shaped (i.e. quadratic) showed by Aphididae. They peaked in the middle of June (15th June; Chrysopidae, Aphidiinae, Figs. 3B and E) or at the beginning of July (1st July; Coccinellidae, Syrphidae, Figs. 3C and D) and then decreased again. Two groups, Coccinellidae and Aphidiinae, were significantly more abundant in irrigated than in dry fields during the whole sampling period (Table 2). Time and farming regime interacted for Syrphidae, with higher abundance in Irrigated but at the beginning and at the end of the season. The abundance of Chrysopidae was not influenced by farming regime and that of Formicidae was higher in dry than in irrigated fields and did not change throughout the season (Fig. 3F; Table 2).

Table 2. The effect of farming system and sampling variables on Aphididae, Coccinellidae, Neuroptera, Syrphidae, Aphidiinae and Formicidae abundance was analysed using glmmADMB with appropriate negative binomial error distribution. For Formicidae and Syrphidae Zero-inflated models were used.

					Sampling date			
	Regime		Interaction		Lineal		Cuadratic	
	P	estimate	*P*	estimate	*P*	estimate	*P*	estimate
Abundance model								
Aphididae			0,013	-0,4586	<0.001	3,837	<0.001	-0,52
Chrysopidae					<0.001	3,695	<0.001	-0,455
Coccinellidae	0,004	-0,834			0,004	1,029	0,011	-0,131
Syrphidae			0,029	-0,597				
Aphidiinae	<0.001	-2,181			<0.001	2,644	<0.001	-0,372
Formicidae	0,003	1,798						

Only significant ($P<0.05$) values are shown.

Discussion

In general, irrigated fields held significantly higher abundances than dry fields (Fig. 3), especially during June and at the beginning of July. Both farming system and sampling date influenced the abundance of the studied groups. Aphid abundance increased with time, reaching a maximum in middle June and then decreasing. The rest of the groups, but Formicidae, followed aphid abundance, with maximum in middle June (Chrysopidae, Aphidiinae) or at the beginning of July (Coccinellidae, Syrphidae). Only the abundance of Chrysopidae did not differ between farming regimes, while that of Formicidae was higher in dry than in irrigated fields.

The effect of farming system on the studied groups may be explained by the multiple differences between dry and irrigated fields regarding biocide and fertiliser inputs, field margin extension, environmental heterogeneity, etc. (Benton *et al*., 2003; Butler *et al*., 2012). Although the majority of studies highlight negative impacts of intensification on arthropods (Hyvönen & Salonen, 2002; Tybirk *et al*., 2004; Herzog *et al*., 2005; Knop *et al*., 2006; Holzschuh *et al*., 2007; Roth *et al*., 2008; Krauss *et al*., 2011; Ponce *et al*., 2011; Prieto-Benítez & Méndez, 2011), others agree with our results and show positive effects of intensification on abundance (Weibull *et al*., 2000; Kleijn *et al*., 2001; Melnychuk *et al*., 2003; Weibull & Östman, 2003; González-Estébanez *et al*., 2011; Pérez-Fuertes *et al*., 2015).

Studies carried out in different sites found that aphid abundance peaked in different dates and wheat stages (see Castañera & Gutiérrez, 1985; Pons *et al*., 1989; Caballero-López *et al*., 2011), but always after anthesis (flowering; Phoeling *et al*., 2007). The date is important in order to know how aphid populations fluctuate in different regions in order to be able to forecast aphid-based yield losses and promote appropriate pest control measures over the wheat growing season. In our study, aphids peaked in middle June at the “dough development” stage of wheat (80-89 in Zadoks scale; Zadoks *et al*., 1974). Pons *et al*. (1989) also found cereal aphid abundance peaked at this stage, but in the studies of Castañera & Gutiérrez (1985) and Caballero-López *et al*. (2012) aphid maxima occurred earlier, in the “milk development” stage (70-79 in Zadoks scale). In both stages, wheat is still green and the spike is growing and accumulating nutrients in the seeds. The time-lag in cereal aphid abundance maxima is probably due to the environmental conditions that affect aphid development, such as temperature and rainfall (Dean, 1974a,b; Pons *et al*., 1993; 1989; 1995). Higher abundances of aphids in middle June coincided with the outbreak of winged forms, both in irrigated and dry sub-areas (Fig. 4). Aphid populations develop winged offspring in response to crowding, to changes in the nutritional quality of their host plants (Watt & Dixon, 1981; Walters & Dixon, 1982; Dixon, 1998; Müller *et al*., 2001) and to predator presence (Dixon & Agarwala, 1999; Weisser *et al*., 1999). These three factors may help explaining our patterns. In middle June apterous aphid populations had been growing markedly during the last month, wheat was starting to get dry and aphid predators and parasitoids were about to reach their highest abundances, so aphid populations responded by producing winged individuals able to move to more suitable habitats.

In our study, the most outstanding difference between farming systems was water availability, especially throughout summer. Increased soil moisture in the irrigated sub-area may have allowed more plant individuals and species to avoid water stress and stay in better condition during summer. Higher plant quality and richness may have fostered higher aphid abundance and richness with a likely cascading effect on the companion fauna. Aphids are known to be affected by the water content of their hosts in different ways (Sagers & Goggin, 2007; Rivelli *et al*., 2013) and water stress in host plants has negative effects on aphid survival and reproduction (Summer *et al*., 1986; Fereres *et al*., 1988). Milder environmental conditions may have attracted aphids and their enemies to the irrigated sub-area, where they could survive and multiply during the summer drought. Also, aphid wheat pests are known to benefit from higher nitrogen inputs in winter wheat fields (Hasken & Poehling, 1995; Duffield *et al*., 1997), as occurs in the irrigated sub-area.

The collapse of aphid populations took place in the first two weeks after reaching their maxima in both farming systems, as found by Pons *et al*. (1989). Warmth may have played an important role since it has been seen that temperatures over 27 ºC affects negatively *M. dirhodum* populations (Honěk, 1985; Ma *et al*., 2004) and a constant temperature of 30 ºC is the critical maximum temperature reducing the survival of *M. dirhodum*, *R. padi* and *S. avenae* to zero (Dean, 1974; Zhou & Carter, 1992). In our study site, daily maximum temperatures exceeding 30 ºC become more frequent as June advances, and even more in July (AEMET, 2015). This may be coupled with the top-down control exerted by natural enemies on aphid populations (Schmidt *et al*., 2003), contributing to their collapse.

As expected, aphid predators followed patterns quite similar to those of their prey. They appeared in low number at the beginning of the season, but increased with aphid populations, following the availability of their prey (Holland & Thomas 1997; Härry *et al*., 2008).

The only Chrysopidae species captured, *Chrysoperla carnea* (Stephens) reached its highest abundance 15 days before the other predator groups, in middle June, at the same time as aphid populations. Adults of *C. carnea* are not predators, they feed on nectar, pollen and honeydew (Duelli, 2001), and they are attracted to large patches of flowering plants (Villenave *et al*., 2006). Wheat fields offer pollen during anthesis (approximately from middle May to the beginning of June in our fields), and honeydew from aphid populations so they are attractive habitats for adult lacewings to both feed and lay eggs close to the prey of their larvae; in Irrigated, adult lacewing population followed aphid populations likely for these reasons.

Adults of Coccinellidae and Syrphidae reached highest abundances in Irrigated at the beginning of July, just fifteen days later than their prey, as already expected due to the recognized prey's density-dependence regulating mechanism (Mills, 1982; Berryman & Kindlmann, 2008). However, if maximum abundance of adult coccinellid and syrphid was in 1-VII, it is possible that their larval maximum abundance were more coincident with aphid peak. Larval stages of Coccinellidae and Syrphidae are the main predators of aphids (Lee & Kang, 2004; Cabral *et al*., 2006; Freier *et al*., 2007; Cabral *et al*., 2009), and need high requirements of energy intake for growth and to reach critical weight for pupation. The population dynamics of predator larvae may thus coincide with those of aphids in order to get an optimal performance.

Coccinella septempunctata (L.) was the most abundant ladybeetle, with a distribution highly dependent on availability of aphid prey in crops (especially in cereal ones; Bianchi *et al*., 2007). Also, as they tend to aggregate in aphid colonies, contributing to their suppression (Bianchi *et al*., 2007; Leslie *et al*., 2009), a direct link between aphid and coccinellid abundances could be expected. Syrphids were not recorded in high number, although their larvae are even considered the most important controllers of cereal aphids (Freier *et al*., 2007). However, sweep-netting may not be the best sampling method for fast flying flies. Doxon *et al*. (2011) found that vacuum sampling collects 10 times more dipteran abundance than sweep-net sampling, so the abundance of

Syrphidae might be underestimated in our study.

Aphidiinae have a closer relationship with their hosts than specialist predators. Endoparasitoid larvae develop inside aphids, which continue living and growing but their reproductive capacity is diminished or annulated, contributing to a decrease in populations (Starý, 1988). This means that Aphidiinae adult peak must coincide with aphid population maximum in order to maximize reproductive success, responding to aphid aggregation (Evans, 2008; Pareja *et al*., 2008), as is reflected in our study. Aphidiinae also use the honeydew that aphids produce (Wäckers *et al*., 2008), although parasitoid abundance is not very much influenced by honeydew availability (Hogervorst *et al*., 2007).

Formicidae was the only group significantly more abundant in dry than in irrigated fields and whose abundance did not change with time. The only species related to cereal aphids was *Tapinoma nigerrimum* (Nylander), which is typical of dry environments (Bernard, 1968). *T. nigerrimum* populations may have been displaced from irrigated fields by other species better adapted to moister conditions. Further, while ants may exert a positive influence on aphid abundance (Sudd, 1987), the effect of aphid abundance on ant number may be small since aphid honeydew is usually only one out of their many food sources (Hölldobler & Wilson, 1990).

Leaving ants apart, our results show a close relationship between aphid abundance and that of their companion fauna. Aphid, predator and parasitoid abundances were, in general, higher in irrigated than in dry fields, which is in accordance with the previous results of Pérez-Fuertes *et al*. (2015). This agrees with most results that show that abundance of predators and parasitoids is mainly conditioned by the abundance of their prey (Koricheva *et al*., 2000; Haddad *et al*., 2001; Caballero-López *et al*., 2010). It is then expected that the rapid decrease in aphid numbers in July generated a reduction in predators and parasitoids by a bottom-up effect (Caballero-López *et al*., 2012).

To our knowledge, this is the first study comparing seasonal variation of aphid populations and their companions between dry and irrigated farming systems under Mediterranean climate. We showed that agricultural intensification through irrigation promoted the abundance of most of the studied groups, especially during the dough development stage of the wheat. Higher water availability and nitrogen input may increase resource quality for aphids, likely fostering their abundance. A constant source of water may have helped to increase plant production during the summer drought, increasing the number of cereal aphids and their predators and parasitoids through a bottom-up effect. The abundance of predators and parasitoids followed the trends of their prey, being more abundant in Irrigated, especially when aphid abundance peaked. Our results emphasise the need for more specific studies under Mediterranean climate (José-María *et al*., 2010; Pérez-Fuertes *et al*., 2015; González-Estébanez *et al*., 2011) in order to design proper agricultural policies devoted to adequately balance habitat quality, biodiversity and productivity in the region. Increasing our knowledge on the mechanisms that influence pests and their natural enemies can help improving the efficiency of biological control, which may help to reduce economic costs of cereal production in the long term.

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Appendix

Total number of individuals per farming system of Aphididae, Coccinellidae, Neuroptera, Syrphidae, Aphidiinae and Formicidae.

Groups	Species	Dry	Irrigated
Aphididae	*Diuraphis noxia* (Mordvilko)	1116	435
	aa+an[1]	664	210
	wa+wn[2]	452	225
	Metopolophium dirhodum (Walker)	62	1936
	aa+an	49	1309
	wa+wn	13	627
	Rhopalosiphum padi (L.)*	144	164
	aa+an	86	105
	wa+wn	58	59
	Schizaphis graminum (Rondani)	11	28
	aa+an	10	23
	wa+wn	1	5
	Sipha elegans Del Guercio	21	306
	aa+an	21	255
	wa+wn	0	51
	Sipha maydis (Passerini)	0	107
	aa+an	0	106
	wa+wn	0	1
	Sitobion avenae (Fabricius)	10182	15801
	aa+an	6332	9815
	wa+wn	3850	5986
	Total Aphididae	**11536**	**18777**
Crhysopidae[3]	***Chrysoperla carnea* (Stephens)**	**306**	**226**
Coccinellidae	*Adalia bipunctata* (L.)	1	0
	Adonia variegata (Goeze)	41	28
	Coccinella septempunctata L.	214	141
	Coccinula quatuordecimpustulata (L.)	56	114
	Propylea quatuordecimpunctata (L.	3	46
	Rhizobius litura (Fabricius)	31	56
	Scymnus apetzi Mulsant	1	4
	Scymnus apetzoides Capra & Fursch	0	5
	Scymnus interruptus (Goeze)	0	18
	Total Coccinellidae	**347**	**412**
Syrphidae	*Episyrphus balteatus* (De Geer)	0	1
	Eupeodes corollae (Fabricius)	4	3
	Melanostoma mellinum (L.)	4	7
	Melanostoma scalare (Fabricius)	0	4
	Sphaerophoria rueppelli (Wiedemann)	1	1
	Sphaerophoria scripta (L.)	13	25
	Total Syrphidae	**22**	**41**
Aphidiinae	*Adialytus ambiguus* (Haliday)	0	1
	Aphidius ervi Starý	0	1
	Aphidius rhopalosiphi De Stefani-Perez	0	3
	Aphidius uzbekistanicus Luzhetzki	9	19
	Diaeretiella rapae (M'Intosh)	1	0
	Ephedrus persicae Froggatt	0	1
	Lipolexis gracilis Foerster	0	1
	Praon volucre (Haliday)	1	15
	Total Aphidiinae	**11**	**41**
Formicidae[3]	***Tapinoma nigerrimum* (Nylander)**	**225**	**89**
TOTAL		**12447**	**19586**

[1] aa+an: Apterae adults + apterae nymphs

[2] wa+wn: Winged adults + winged nymphs

[3] Just one species.

* *R. padi* was the only aphid related to *T. nigerrimum*.

III

Testing the effectiveness of surrogates for assessing biological diversity of arthropods in cereal agricultural landscapes

Comprobación de la efectividad de los sustitutos en la valoración de la diversidad biológica de artrópodos en paisajes agrícolas cerealistas

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Under review / En revisión

Resumen

La intensificación agrícola está alterando los patrones de biodiversidad en todo el mundo. Son necesarios métodos rápidos y efectos para controlar esos cambios en la diversidad agrícola, pero resulta una tarea costosa, tanto en tiempo como en dinero, particularmente en grupos hiper-diversos como los artrópodos. Hemos evaluado la efectividad de los sustitutos en campos de trigo con agricultura de regadío y secano en una zona mediterránea del noroeste de España, para obtener una herramienta que nos permita valorar la diversidad de artrópodos. Hemos estudiado seis grupos con diferentes necesidades ecológicas (i.e. Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera y Syrphidae) a nivel de especie (147 especies), género (105), familia (10, solo Heteroptera) y orden (19). Se analizaron las variantes de taxones superiores, de taxones cruzados y usando la riqueza, además de la correlacion en composición entre niveles para los grupos seleccionados, y la influencia del régimen agrícola. La riqueza de géneros fue un buen sustituto de la riqueza de especies en los seis grupos estudiados (R^2=0.38-0.60), al igual que el nivel de familia y orden para Heteroptera (R^2=0.37 y 0.29 respectivamente). Los análisis con taxones cruzados mostraron que los géneros de Aphididae y Aphidiinae (R^2=0.19 y 0.30 respectivamente) y especies (R^2=0.20 y 0.28 respectivamente) fueron buenos sustitutos para las especies de Aphidiinae y Aphididae respectivamente. También los géneros de Coccinellidae (R^2=0.26) y las especies (R^2=0.25) fueron buenos sustitutos para las especies de Heteroptera. Los géneros y especies de Aphididae (R^2=0.14 y 0.12 respectivamente) y de Coccinellidae (R^2=0.20 y 0.22 respectivamente) fueron buenos sustitutos de la riqueza total de especies. La composición de géneros fue el mejor sustituto para la composición de especies dentro de cada grupo. El régimen agrícola no tuvo influencia sobre las relaciones entre sustitutos y los patrones de especies en la mayoría de los casos. Nuestros resultados sugieren que el nivel de género es un útil sustituto para todos los grupos estudiados y para familias en Heteroptera. El nivel de género proporcionó un ahorro del 15 % del tiempo de identificación en Aphididae y del 80% en Coccinellidae. Esto demuestra su utilidad para valorar y controlar la biodiversidad en campos de trigo y la posibilidad de reducir costes.

Abstract

Agricultural intensification is altering patterns of biodiversity worldwide. Rapid and effective methods are needed to monitor these changes in farmland biodiversity, but it becomes both a cost- and time-prohibitive task, particularly for hyper-diverse groups such as arthropods. We evaluated the effectiveness of surrogates in irrigated and rainfed wheat fields in a Mediterranean farmland in NW Spain in order to get a rapid tool to assess arthropod biodiversity. We studied six groups with different ecological needs (i.e. Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera and Syrphidae) at species level (147 species), genus (105), family (10, only Heteroptera) and order (19) level. Higher taxa, cross-taxa and subset-taxa or total richness approaches were tested as well as the correlation in composition between levels for the selected groups, and the influence of farming regime. Genus richness was a good surrogate of species richness in all six groups studied (R^2=0.38-0.60), like family and order were for Heteroptera (R^2=0.37 and 0.29 respectively). Cross-taxa analyses showed that Aphididae and Aphidiinae genera (R^2=0.19 and 0.30 respectively) and species (R^2=0.20 and 0.28 respectively) were good surrogates for Aphidiinae and Aphididae species respectively. Also Coccinellidae genera (R^2=0.26) and species (R^2=0.25) were good surrogates for Heteroptera species. Aphididae and Coccinellidae both genera (R^2=0.14 and 0.20 respectively) and species (R^2=0.12-0.22 respectively) were good surrogates for total species richness. Genera composition was the best surrogate for the species composition inside each group. Farming regime had no influence on the relationships between surrogates and species patterns in most cases. Our results suggest that genera level is a useful surrogate for all the studied groups and family for Heteroptera. Genus level provided a saving of 15% of identification time in Aphididae and 80% for Coccinellidae. This proves its usefulness to asses and monitor biodiversity in wheat croplands and the posibility to reduce costs.

Introduction

Agricultural intensification increases crop production but at the same time it causes biodiversity loss worldwide (Robinson and Sutherland, 2002; Tilman et al., 2002; Benton et al., 2003; Kleijn and Sutherland, 2003; Green et al., 2005; Wilson et al., 2010). Irrigation is commonly used to enhance agricultural production (van der Velde et al., 2010) but at the cost of converting vast areas of dry extensive cereal agroecosystems into irrigated areas (e.g., in Spain; MAGRAMA, 2013). Irrigation negatively affects birds (Tella and Forero, 2000; Brotons et al., 2004; Laiolo, 2005; De Frutos and Olea, 2008), but its effects on other important agricultural fauna such as arthropods are little known (but see González-Estébanez et al., 2011 for butterflies; Pérez-Fuertes et al., 2015 for other arthropods).

Arthropods are apparently declining even faster than vertebrates and plants (Thomas et al., 2004), urging to find rapid methods to assess and monitor arthropod biodiversity in agricultural systems specially now with the new Common Agricultural Policy 2015-2020 (PAC 2015-2020; Official Journal of the European Unión, 2013). Arthropods are essential for ecosystem functioning of agro-ecosystems, providing valuable services such as pollination, pest control, plant productivity, nutrient recycling and a food source for other animals (Daily et al., 1997; Wilson et al., 1999). They are considered also useful indicators of biodiversity loss (McGeoch, 1998; Marshall et al., 2003; Biaggini et al., 2007) and can reflect the environmental changes caused by agricultural intensification (Schläpfer and Schmid, 1999; Steffan-Dewenter et al., 2002; Weibull and Östman, 2003; Hole et al., 2005; Knop et al., 2006; Ockinger and Smith, 2007). However, studying overall invertebrate richness is almost unachievable as trapping, manipulation and identification efforts are highly time-consuming and expensive (Nielsen and West, 1994; Gardner et al., 2008). There are three main requirements for sampling biodiversity: monetary cost, time investment and the availability of adequate technical expertise (Gardner et al., 2008). Invertebrates are laboratory time-consuming (sampling, sorting and taxonomical identification) and requires the use of expert taxonomists to obtain species-level identification, which increases laboratory costs (Gardner et al., 2008). Qi et al., 2008 stated that laboratory time expenses are 2.5 higher than field time, and that is the reason why invertebrate studies are more expensive. Moreover, the principal reason for the high cost in invertebrate studies is the requirement to identify specimens to species level in order to assess effects on species diversity (Qi et al., 2008). Reducing the costs of biodiversity assessments would allow researchers and resource managers a closer and more frequent surveillance of the ecosystem.

Several alternatives have been proposed to rapidly evaluate the diversity of a given area avoiding the difficulties of a full species inventory: (i) using richness of indicator groups (e.g. McGeoch, 1998; Cardoso et al., 2004a; Finch and Löffler, 2010), (ii) inferring diversity from environmental variables (e.g. Brennan et al., 2006; Dalleau et al., 2010), (iii) identifying morphospecies (species identification just by morphology) (Oliver and Beattie, 1996; Derraik et al., 2002) or (iv) using functional groups (Takada et al., 2008; Noordijk et al., 2010). However, the most popular alternative has been the use of higher-taxa as surrogates (Gaston and Williams, 1993; Williams, 1993; Balmford et al., 1996a,b; Mandelik et al., 2007; Shokri and Gladstone, 2009). Several studies have shown that the number of species in a given area can be predicted from genus and family levels (Gaston and Williams, 1993; Williams, 1993; Williams and Gaston 1994; Gaston and Blackburn 1995; Roy et al., 1996) and even from order (Biaggini et al., 2007).

Surrogate taxa may be the most broadly tested option to reduce costs when exploring biodiversity, assessing the impact of human activities and guiding management decisions (Gaston and Spicer, 2004). Surrogates can cut the budget considerably. Balmford et al. (1996b) estimated that identifying Sri Lankan forest woody plants to genus or family level respectively saved at least 60 % and 85 % of the total budget compared to identifying individuals to species level. The use of taxa surrogates has been effective for community description of both marine and freshwater benthic fauna (Bailey et al., 2001; Thompson et al., 2003; Heino and Soininen, 2007; Shokri and Gladstone, 2009), to evaluate the effects of pollution on soil macrofauna (Migliorini et al., 2004; Nahmani et al., 2006) and monitor biodiversity of various arthropod and other invertebrate groups in agroecosystems (Biaggini et al., 2007; Cardoso et al., 2007a,b; Anderson et al., 2011). In terms of terrestrial arthropods, genus has been shown to be a suitable surrogate for species richness in Australian ant fauna (Andersen, 1995) and Mediterranean spiders (Cardoso et al., 2004a), whereas family richness was used as a surrogate for species richness in Hungarian coleopteran, dipteran and acari assemblages (Báldi, 2003). Biaggini et al. (2007) even showed that order level is a suitable surrogate for species richness in agricultural arthropod assemblages in wheat fields under intensive and organic farming. Thus, this higher taxon/species approach may be highly predictive, particularly when analyses are restricted to ecologically homogeneous regions (Balmford et al., 1996b; Roy et al., 1996; Vanderklift et al., 1998; Prinzing et al., 2003; Villaseñor et al., 2005).

A good surrogate must have a good correlation between the higher taxa richness and the species richness (Williams and Gaston, 1994) although the correlation usually drops sharply when increasing the taxonomic level of the surrogate (e.g. family, order; Balmford et al., 1996a). One group can fail as surrogate, but it can be solved using several groups with different ecological needs, which is called multi-taxa approach (Ricketts et al., 1999). Several factors can influence the relationship between groups (Gaston and Williams, 1993; Andersen, 1995), such as spatial scale (Reyers et al., 2002; Favreau et al., 2006), sampling effort (Andersen, 1995; Cardoso et al., 2004b), geographical location, (Lewandowski, 2010) and habitat perturbations and management (Perfecto et al., 2003; Kleijn et al., 2004). However, the major limitation of surrogate use is that the taxonomic level needed to get reliable results for diversity studies depends on the focus group and the study area. This occurs both in cross-taxa surrogacy (Ricketts et al., 2002; Bilton et al., 2006) and when using higher-taxa as surrogates (Villaseñor et al., 2005; Bertrand et al., 2006; Rosser and Eggleton, 2012). There are some studies that use species composition instead of species richness to analyze changes in biodiversity, but the results are not conclusive (Negi and Gadgil, 2002; Su et al., 2004). Thus, more studies combining taxa richness and composition of several groups would improve the surrogate approach and the understanding of the agroecosystem.

In this paper, we test the utility of higher taxa surrogates to assess arthropod diversity and composition patterns in Mediterranean agricultural landscapes. We explore if the correlations between surrogates and target groups are affected by fields being subjected to dry (i.e. rainfed) or irrigated farming regimes. We studied aphids (Aphididae), parasitoid wasps (Aphidiinae), ladybirds (Coccinellidae), ants (Formicidae), true bugs (Heteroptera) and hoverflies (Syrphidae) at species level. We tried genus, family (only Heteroptera) and order as surrogates for species richness and composition. We also tested if genus and species richness of any group served as surrogates for other taxa and overall species richness. This paper is to our knowledge the first attempt to analyze the use of three surrogate approaches (higher-taxa (within the same group), cross-taxa (between groups) and subset-taxa (one group vs. overall species richness)) with potential pests as aphids and their predators, parasitoids and mutualists in wheat fields in an agricultural Mediterranean area.

We tested: (i) what taxonomical levels correlate better (surrogates) with species richness; (ii) whether genus and species richness of Aphididae (trophically related to the other groups) could be a good surrogate for other taxa and overall species richness; (iii) whether farming regime influences on the relationship between surrogate and species patterns

Material and Methods

Study area

The study area (Figure 1) covers an extension of 1,500 km^2 in the south-east of León province, north-west Spain (centred on 42°33 N, 5º31 W). It is included in the supra-Mediterranean bioclimatic level of the Mediterranean region, with annual average precipitations between 436-515 mm and temperatures between 8-13 ºC (Penas et al., 1995). Agriculture is the main land-use in the study area (85% of total surface). We classified the farmland of the study area into two categories according to the main agricultural regimes (see Table 1 for details; Figure 1): (i) dry sub-area (Dry) and (ii) irrigated sub-area (Irrigated). The dry sub-area covers an extension of almost 130,000 ha under dry (i.e. rainfed) extensive farming system. Cereals are the most extended crop (65%), dominated by winter wheat (*Triticum* spp. 21%) and oat (*Avena sativa* L., 20%). Barley (*Hordeum vulgare* L., 12%), rye (*Secale cereale* L., 7%) and maize (*Zea mays* L., 5%) are also present. Legumes are also important among crops (23%). Interannual crop rotation is applied and fallow fields represent almost 40% of the total surface of this area. There are some poplar (*Populus* sp., 2%) and pine (*Pinus* sp. <1%) plantations. The dry

Table 1. Environmental characteristics for each study sub-area. Mean (±SE) values or total percentage are given for each variable.

Field data	Dry	Irrigated
Fallow surface (%)[a]	38,2	13,8
Irrigated farmland (%)[a]	7,9	100
N-P-K input (kg ha^{-1}year^{-1}) in wheat crops[b]	230 ± 44.7	616 ± 104
Yield of wheat (kg/ha)[b]	3150 ± 473	7000 ± 290
Habitat and landscape variables		
Landscape field size (ha)[c]	4.2 ± 0.3	3.7 ± 0.4
Surveyed field size (ha)[d]	4.3 ± 0.7	3.0 ± 0.6
Crop height (cm)[d]	69.7 ± 2.2	61.4 ± 3.9
Edge width (m)[d]	10.3 ± 1.9	10.5 ± 0.4
Number of trees[e]	0.2 ± 0.2	2.6 ± 0.9
Number of shrubs[e]	0.9 ± 0.2	6.4 ± 1.4

[a] Calculated as percentage within the 2x2 km squares.

[b] Data on the amount of N-P-K fertilizer of wheat crops were obtained from farmers using questionnaires, N_{total}= 44 farmers.

[c] Calculated as the mean size of all fields present in a 500 x 500 m square around the surveyed

[d] Calculated for all surveyed fields: $N_{Irrigated}$= 25 fields, N_{Dry}= 12 fields.

[e] Mean number of trees and shrubs in a 500 m transect along the margins of the track adjacent to the surveyed fields. Edge width includes both edges of the track of field access.

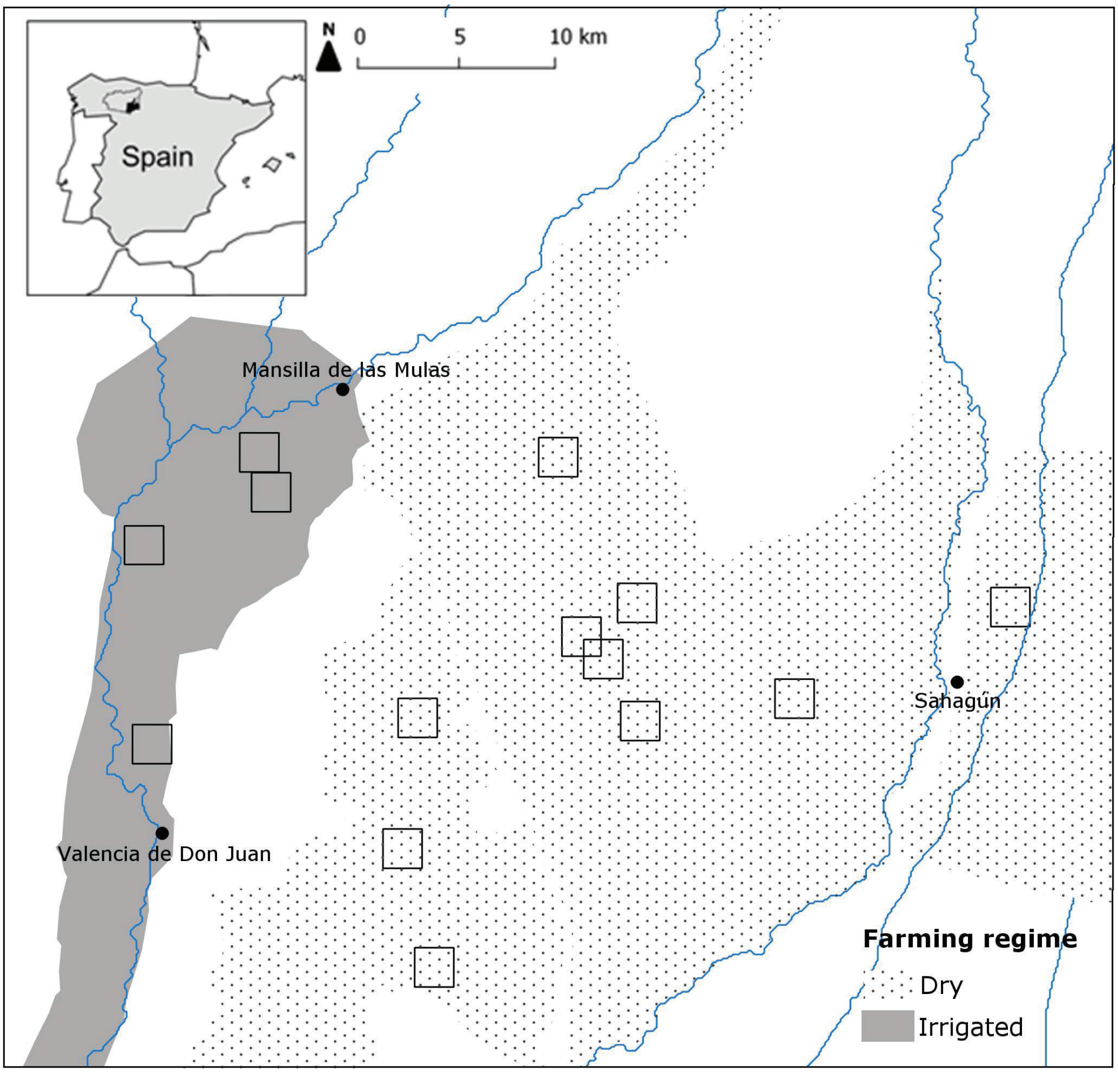

Figure 1. Location of the study area in north-west Spain (black area in the inset). Sampled fields were located inside 14 2x2 km squares (4 in Irrigated and 10 in Dry) randomly placed within the farming systems. One to five wheat fields were selected within each square, summing up to 12 fields in Irrigated and 25 fields in Dry. The most important populations and rivers of the study area are shown.

sub-area is included within the so-called pseudo-steppes (Oñate et al., 2007) formed by a vast surface of extensive dry cereal crops with important populations of threatened steppe bird species (e.g. great bustard *Otis tarda* L., lesser kestrel *Falco naumanni* Fleischer, calandra lark *Melanocorypha calandra* L.) (Suárez et al., 1997; Olea et al., 2004; De Frutos et al., 2015).

The irrigated sub-area covers an extension of approx. 34,000 ha devoted to irrigated farming for more than 20 years. Maize is the main crop type (59%). To a lesser extent, there are fallow fields (14%), irrigated wheat (10%), irrigated alfalfa (*Medicago* *sativa* L., 2%) and market gardens (1%). Poplar plantations amount to 3%.

Sampling method

Our study focused in winter wheat fields, one of the most economically important crops, both in the study area and worldwide (FAOSTAT, 2009; MAGRAMA, 2012). Fourteen 2x2 km squares were randomly placed within the farming systems (4 in Irrigated and 10 in Dry; Figure 1), according to the surface occupied by each farmland type in the study area (see above). One to five wheat fields were selected within each square, summing up to 12 fields in Irrigated and 25 fields in Dry. Mean distance between wheat fields sampled in different regimes was 23.8 km (SE: 1.25; range: 13.8-44.4 km). Mean distance between surveyed fields was 15.0 km (SE: 1.2; range: 1.4-34.9) in the dry sub-area, and 9.6 km (SE: 2.06; range: 2.3-14.3) in the irrigated sub-area. Sampling took place before harvest (between 2nd and 26th July 2007), with the wheat grain dry and ripe (levels 91-94 in Zadoks scale; Zadoks et al., 1974).

Arthropods

Within each field, we sampled three consecutive 25-m transects parallel to the field margin and to the main man-made access paths. Transects were at least five metres apart from each other and two metres from the field margin. Sampling was carried out using sweep-netting (Frampton and Dorne, 2007) with one sweep per step (50 sweeps per transect). Each sweep was performed so that included as much plant surface as possible (stalk and spike). Sampling was carried out by the same person, with temperatures higher than 20 ºC and on days without rain or strong wind in order to assure that arthropods were active (Weibull and Östman, 2003). Collected arthropods were transferred into airtight plastic bags and kept in a portable fridge in the field before being stored at -20 ºC in laboratory until their identification.

Selected taxa (Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera, and Syrphidae) were identified to species level (see Pérez-Fuertes et al., 2015). All the studied taxa (hereafter referred as groups) are related to wheat: (i) directly as herbivores (Aphididae), (ii) indirectly as predators (Coccinellidae, Syrphidae), parasitoids (Aphidiinae), or mutualists (Formicidae) of aphids, or (iii) contain both herbivores that feed on wheat and aphid predators (Formicidae, Heteroptera) (Suay-Cano et al., 2002; Schmidt et al., 2003; Freier et al., 2007; Pons et al., 2009; Dedryver et al., 2010). All groups were abundant enough to carry out analyses (max.= Aphididae (3,678 individuals)

Aphidiinae, min.= Aphidiinae (137 individuals).

Identification time (up to genus or species level) was registered for Aphididae and Coccinellidae.

Data analysis

Prior to the analyses, captured individuals were pooled for each sampled wheat field. Richness was calculated for each group as the number of species, genera, families (only for Heteroptera) and orders. Only adults were considered (except aphids) due to the difficulty to identify larvae and nymphs to species level. Analyses were carried out separately for each arthropod group.

We used Generalised Linear Mixed Models (GLMMs) with a Poisson error distribution to assess if: (i) higher-taxa richness served as surrogate for species richness of the same taxonomical group (higher-taxa): order-species, family-species, genus-species; (ii) if higher-taxa or species richness of any group served as surrogates for species richness of other taxonomical group (cross-taxa): family-species, genus-species, species-species; (iii) if higher-taxa or species richness of any group served as surrogates for overall species richness (subset-taxa): family-, genus-, species-overall richness (Figure 2). We also explored if these relationships were affected by farming regime (Dry, Irrigated). The response variable was species richness, the explanatory fixed variables were surrogate richness, farming system and their interaction. The identity of each 2x2 square was fitted as a random effect to account for the presence of fields within the same squares. When calculating overall richness, species richness of the group tested as surrogate was excluded in each case from overall richness to avoid finding worthless correlations. Models were refined by removing non-significant terms ($P>0.05$); significant interactions were further explored by testing the effect of surrogate richness separately for each farming regime. The variance explained (R^2) by the explanatory fixed variables was calculated for each model using the method in Nakagawa and Schielzeth (2013).

We used a partial Mantel tests to look for correlations between dissimilarities in surrogate and species composition, after partialling out for geographic distances between sampled fields. Both within taxon and across-taxa approaches were tested. Hellinger distances were calculated for surrogate and species composition and Euclidean distances for geographic location. Results were tested using 9999 permutations.

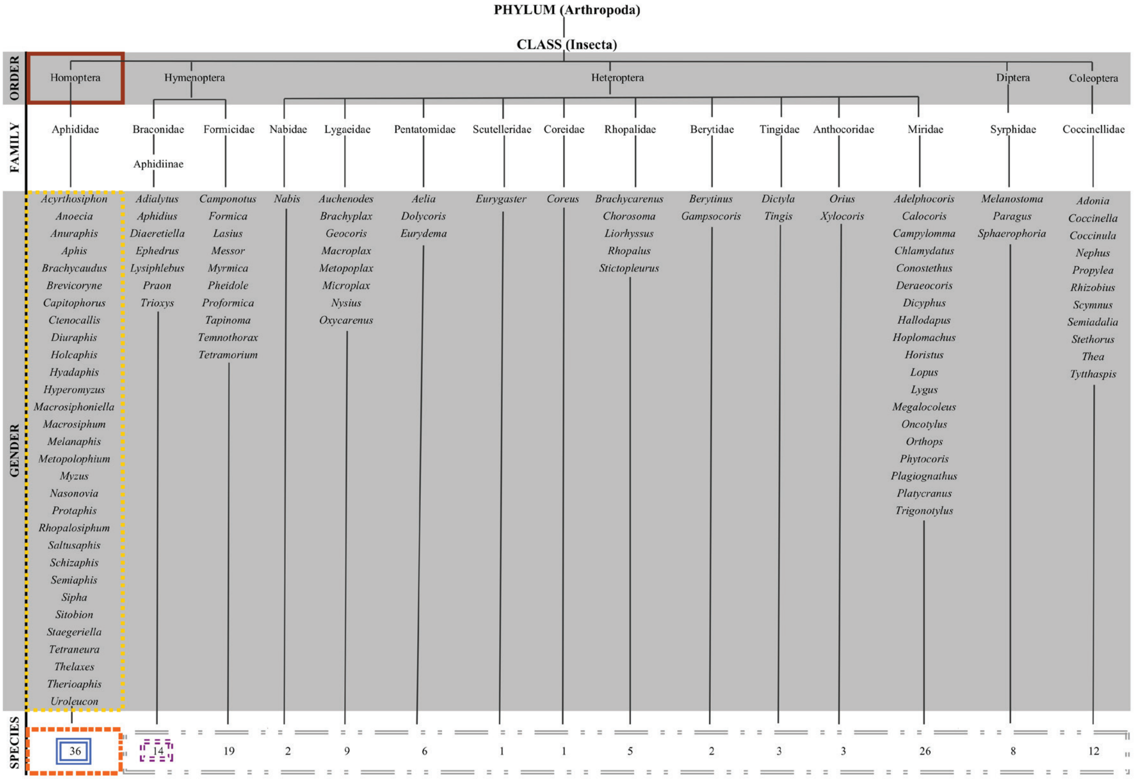

Figure 2. Different types of surrogates (simple lines in warm colors) and their targets (double lines in cold colors). Numbers at the species level represent the number of species. (i) Higher-taxa surrogates, taxa at a higher taxonomic level act as surrogates for taxa at lower levels, i.e. single brown line vs. double blue line, and single yellow dotted line vs. double blue line. (ii) Cross-taxa surrogates, taxa act as surrogates for other taxa at the same or different taxonomic level, i.e. single yellow dotted line vs. double purple dotted line and single orange dashed line vs. double purple dotted line. (iii) Total richness or subset-taxa surrogates, taxa acts as surrogates for the total richness i.e. single yellow dotted line vs. grey dashed-dotted line and single orange dashed line vs. grey dashed-dotted line. The detailed list of species is available in Pérez-Fuertes *et al*., 2015.

Analyses were performed with R statistical package (R Development Core Team, 2010) using packages “lme4” (Bates et al., 2015) for GLMM’s and “vegan” (Oksanen et al., 2015) for Partial Mantel tests.

Results

A total of 6095 individuals of 147 species were caught, belonging to the six studied groups: Aphididae (3678 individuals, 60.34% of total abundance, 36 species), Aphidiinae (137, 2.25%, 14), Coccinellidae (426, 6.99%, 12), Formicidae (796, 13.06%, 19), Heteroptera (877, 14.39%, 58) and Syrphidae (181, 2.97%, 8) (Figure 2; see Pérez-Fuertes et al., 2015).

GLMMs showed that the genus richness was a good surrogate for species richness in all groups (R^2=0.380-0.595). In addition, family and order richness were good surrogates only for species richness of Heteroptera (R^2=0.374 and 0.288 respectively; Table 2). All these relationships were not influenced by farming regime, with the exception of order-species richness of Coccinellidae and Heteroptera, where an interaction between surrogate and farming system was found. When analyzed separately for each agricultural regime, order richness did not explain species richness of Coccinellids in dry farmland (χ^2=0.968, *P*=0.325); in irrigated farmland, Coccinellidae richness increased as order richness increased (χ^2=3.877, *P*=0.049). Order richness explained Heteroptera richness in both regimes. In dry farmland Heteroptera richness decreased as order richness increased (χ^2=3.877, *P*=0.048), while both values increased in irrigated farmland (χ^2=14.513, *P*<0.001).

Table 2. Results of higher-taxa GLMMs testing for the relationship between the richness of surrogates and the species richness of the same taxonomical group taking into account differences between farming regimes (i.e. Dry, Irrigated). Only groups with at least one significant result are shown in the table. Significant P values (<0.05) are marked in bold.

	Group used as	Surrogate				Intercept		Interaction		
Surrogate level	Surrogate	*P*	r^2	estimate	s.e.m.	estimate	s.e.m.	*P*	estimate	s.e.m.
Order	Coccinellidae	0,325	0,219	-0,11	0,11	2,04	1,27	**0,048**	0,27	0,14
	Heteroptera	**0,049**	0,288	-0,12	0,06	3,35	0,7	**<0.001**	0,33	0,08
Family	Heteroptera	**<0.001**	0,374	0,22	0,05	0,93	0,24	-	-	-
Genus	Aphididae	**<0.001**	0,518	0,19	0,03	0,6	0,2	-	-	-
	Aphidiinae	**<0.001**	0,595	0,98	0,14	-1,35	0,36	-	-	-
	Coccinellidae	**<0.001**	0,38	0,33	0,06	0,01	0,24	-	-	-
	Formicidae	**<0.001**	0,47	0,48	0,09	-0,32	0,29	-	-	-
	Heteroptera	**<0.001**	0,468	0,13	0,02	1,06	0,17	-	-	-
	Syrphidae	**<0.001**	0,411	0,93	0,2	-1,11	0,36	-	-	-

Cross-taxa analyses only showed significant results at genus and species levels for some groups without any influence of farming regime (Table 3). Genus and species richness of Aphididae were surrogates for species richness of Aphidiinae and vice versa (R^2=0.189-0.299). Similarly, genus and species richness of Coccinellidae predicted species richness of Heteroptera, and species richness of Heteroptera served as surrogate for species richness of Coccinellidae.

Genus and species richness of Aphididae and Coccinellidae were found to be indicators of total species richness (Table 4).

Table 3. Results of cross-taxa GLMMs testing for the relationship between the richness of surrogates and the richness of species of other taxonomical group taking into account differences between farming regimes (Dry, Irrigated). Only groups with a significant P value (<0.05, marked in bold) are shown in the table.

	Group used		Surrogate				Intercept	
Surrogate level	as Surrogate	Species level	*P*	r^2	estimate	s.e.m.	estimate	s.e.m.
Genus	Aphididae	Aphidiinae	**0,024**	0,189	0,22	0,1	-1,1	0,57
	Aphidiinae	Aphididae	**<0.001**	0,299	0,24	0,06	1,41	0,11
	Coccinellidae	Heteroptera	**<0.001**	0,255	0,15	0,04	1,57	0,14
Species	Aphididae	Aphidiinae	**0,012**	0,203	0,19	0,08	-1,04	0,51
	Aphidiinae	Aphididae	**<0.001**	0,284	0,15	0,04	1,46	0,1
	Coccinellidae	Heteroptera	**<0.001**	0,246	0,14	0,04	1,59	0,13
	Heteroptera	Coccinellidae	**0,011**	0,152	0,08	0,03	0,38	0,26

Table 4. Results of subset-taxa GLMMs testing for the relationship between the richness of surrogates and the total species richness taking into account differences between farming regimes (Dry, Irrigated). Only groups with a significant P value (<0.05, marked in bold) are shown in the table.

Surrogate	Group used	Surrogate				Intercept	
level	as Surrogate	*P*	r^2	estimate	s.e.m.	estimate	s.e.m.
Genus	Aphididae	**0,02**	0,14	0,04	0,02	1,04	0,27
	Coccinellidae	**0,003**	0,204	0,05	0,02	-0,05	0,38
Species	Aphididae	**0,03**	0,122	0,04	0,02	1,11	0,28
	Coccinellidae	**0,002**	0,216	0,06	0,02	-0,08	0,38

Partial Mantel tests showed a highly significant correlation between genera and species compositions in all groups (Table 5). In cross-taxa tests, dissimilarities in species composition of Aphidiinae correlated with those of Coccinellidae, Heteroptera and Syrphidae and dissimilarities in species composition of Coccinellidae with those of Heteroptera (Table 5).

Table 5. Partial Mantel test results checking for correlation between dissimilarities in surrogate and in species composition after partialling out for geographic distances between sampled fields. Only P<0.05 values are shown, marked in bold.

		Species											
	Group used as	Aphididae		Aphidiinae		Coccinellidae		Formicidae		Heteroptera		Syrphidae	
Surrogate level	Surrogate	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*
Order	All groups	-	-	0,17	**0,04**	-	-	-	-	-	-	-	-
Family	Heteroptera	-	-	0,19	**0,013**	0,18	**<0.001**	-	-	0,62	**<0.001**	-	-
Genus	Aphididae	0,99	**<0.001**	-	-	-	-	-	-	-	-	-	-
	Aphidiinae	-	-	0,94	**<0.001**	0,12	**0,04**	-	-	0,16	**0,032**	0,14	**0,048**
	Coccinellidae	-	-	-	-	1	**<0.001**	-	-	0,12	**0,036**	-	-
	Formicidae	-	-	-	-	-	-	0,69	**<0.001**	-	-	-	-
	Heteroptera	-	-	0,17	**0,033**	-	-	-	-	0,9	**<0.001**	-	-
	Syrphidae	-	-	0,22	**0,01**	-	-	-	-	0,14	**0,041**	0,81	**<0.001**
Species (i.e. cross-taxon)	Aphididae			-	-	-	-	-	-	-	-	-0,12	0,91
	Aphidiinae					0,12	**0,033**	-	-	0,18	**0,03**	0,15	**0,046**
	Coccinellidae							-	-	0,12	**0,032**	-	-
	Formicidae									-	-	-	-
	Heteroptera											-	-

Identification time up to species level was 36.33 hours for Aphididae and 45.37 hours for Coccinellidae. The identification of all individuals from genus to species level increased identification time by at least 15% more for Aphididae. In Coccinellidae genera identification took 20% of total identification time, while species identification took 80% approximately (authors, unpubl. data).

Discussion

Our study suggests that some higher taxa served as surrogates to assess arthropod biodiversity in agro-ecosystems. Particularly, genus richness was a good surrogate for species richness in all six studied groups. This is in accordance with several studies highlighting the usefulness of higher taxa surrogates (e.g. Williams and Gaston, 1994; Balmford et al., 1996a; Roy et al., 1996; Báldi 2003; Villaseñor et al., 2005; Biaggini et al., 2007; Anderson et al., 2011).

Farming system did not affect surrogate-species richness correlation, except for order richness in Coccinellidae and Heteroptera. However, correlations were weak as expected for such a high-level surrogate (Balmford et al., 1996a; Villaseñor et al., 2005). Furthermore, the lack of consistency between farming regimes make the order level unadvisable to use as a general surrogate (but see Biaggini et al., 2007). Family richness was found as a proper surrogate for species richness of Heteroptera, but the correlation was lower than for genus-species relationships. Therefore, if possible, the use of richness of Heteroptera genus would be preferable.

Cross-taxa surrogacy was useful only in three cases. Aphididae and Aphidiinae at genus and species level were surrogates of each other, which may be explained by their close relationship: the former are hosts of the latter (Sigsgaard, 2002; Schmidt et al., 2003). Araújo (2011) found a similar correlation between ecologically related groups: species richness of host plants and that of galling insects. Given that Aphididae depends on the plant community, and Aphidiinae in turn depends on the Aphididae, it has been found to be a good indicator of the total biodiversity of an area (Anderson et al., 2011). A significant correlation was also found between the genus richness of Coccinellidae and species richness of Heteroptera. Since both groups are not directly related, it may be that some environmental factors such as vegetation vertical structure or weed species composition into and next to the crop affect similarly to both groups.

Genus and species richness of Aphididae and Coccinellidae were good surrogates for total species richness of the studied groups. However, the strength of the relationship was low in all cases. Further, we have considered only total richness of our studied groups, which are closely related to aphids. More studies assessing overall richness of all groups should be carried out in order to determine whether these relationships are consistent.

It is remarkable that Aphididae species composition did not show any relationship with the composition of the other groups with which it maintains a close relationship (Suay-Cano et al., 2002; Schmidt et al., 2003; Freier et al., 2007; Pons et al., 2009; Dedryver et al., 2010). However, species composition of Aphidiinae was related to that of Coccinellidae, Heteroptera and Syrphidae. This could be due to the fact that all these groups are aphid predators, and the composition of aphid pest species might determine the composition of their predators in the crop, making them to be correlated as well. Groups such as Coccinellidae or Formicidae could be expected to show correlation in composition with Aphididae, as several species of ladybirds are aphid predators (Iablokoff-Khnzorian, 1982) and several ants are aphid mutualists (Sudd, 1987; Suay-Cano et al., 2002). However, we did not use just aphidophagous ladybirds neither just mutualists ants. We selected the whole group in order to assess the whole diversity. For example, ants are mutualists of aphids but they do not depend on them to a great extent (Sudd, 1987). This could be the reason why Formicidae species composition was related only with Formicidae genus composition. However, a heterogeneous group as Heteroptera had its composition correlated with several groups and levels, highlighting two possible explanations. One, that the groups we were studying were correlated in ways that we ignore. The other option is that although numbers were correlated, it does not necessary imply causation.

Identification time can be variable and considerably reduced whether the study is focused above species level. Identifying arthropods to order level is relatively easy and can be carried out by undergraduate and master students in their final projects, thus saving costs (Schmeller et al., 2008). This would give them insight in real world ecological studies, while contributing to academic research, as occurs with bird monitoring volunteers (Bell et al., 2008). Similarly, separating Heteroptera families may be achieved by rather unexperienced workers (Cuesta-Segura pers. comm.). Identifying individuals to genus level can be carried out by laboratory technicians, researchers or parataxonomists with limited experience. Contrastingly, to reach species level, arthropods require specialized techniques that are time-consuming (Gardner et al., 2008, Qi et al., 2008), requiring experienced workers that must be paid. In many cases, taxonomists may need to mount specimens (e.g. Aphididae), extract the genitalia (e.g. Coccinellidae) and collect specific forms (castes, and/or sexuals, e.g. Formicidae) to assure proper species identification. In our study, identify all individuals from genus level to species level increased identification time by at least 15% more for Aphididae and 80% more for Coccinellidae (authors, unpubl. data). Further, qualified experience may be often reflected on taxonomist wages, increasing project budget (see Carbayo and Marques, 2011). Nonetheless, the availability of taxonomists seems to decrease nowadays. Their number is decaying fast as funding in fauna research has been drastically cut out in the last decades (Ebach et al., 2011; Valdecasas, 2011), and many of them are now on the brink of retirement without an effective replacement. All of these limitations increase the usefulness of the supra-specific level as surrogate to assess biodiversity where upper taxa properly reflect species level.

Conclusion

In summary, we show that the higher-taxa approach can be a useful method to rapidly assess arthropod biodiversity in Mediterranean agricultural landscapes, specifically in cereal pseudo-steppes and its replacement by irrigated farmlands. These results could be up-scaled to the entire Mediterranean agricultural landscape. This system can be used in a first phase of a study on biodiversity, in a context in which species identity is not necessary or in a situation of limited time and financial resources. Genus level has proved to be a particularly good surrogate both for species richness and species composition. In our study system, genus richness can be used to assess and compare relative biodiversity associated to both dry and irrigated wheat fields. In a global context, genus richness of Aphididae and Coccinellidae could be good surrogates of total species richness at least of the focus groups in Mediterranean farming areas. Our results can be useful for a time- and cost-effective assessment of biodiversity in agroecosystems, especially when expert taxonomists can not be found or paid. Arthropods require specialized techniques that are time-consuming (Gardner et al., 2008, Qi et al., 2008) but as a result of this study, the identification up to genus level of Aphididae (or Coccinellidae), allow us to know the richness of the other groups and the specific level of the group itself. This implies the saving in the identification of the other groups, a saving because the group (Aphididae or Coccinellidae) do not have to be identified to species level and the troubles of finding experts taxonomists.

Nonetheless, it should be taken into account that the surrogate correspondences found in this study are fixed to the studied groups in a specific area (Balmford et al., 1996b; Lewandowski, 2010). The effectiveness of arthropod surrogates at different time scales (months, years) would require further assessment (Favreau et al., 2006; Anderson et al., 2011). Further studies, using the same groups, should be made in order to test if our results are specific of Mediterranean agricultural areas, or if these relationships are shared with other arable landscapes. Studies including more groups that those studied here would be interesting in order to understand whole diversity patterns.

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Resumen y discusión

Los paisajes agrícolas cubren más del 40% de la superficie terrestre, y son fundamentales en la conservación de la biodiversidad (Tilman *et al*., 2002; Tscharntke *et al*., 2005). A nivel mundial se está intensificando la actividad agraria para satisfacer la demanda de la población (Green *et al*., 2005), y aunque España es uno de los países europeos que presenta una agricultura menos intensificada (Donald *et al*., 2001), también aquí se tiende a aumentar la superficie sometida a agricultura intensiva. Esta intensificación consiste en un cambio en las prácticas agrícolas orientadas a aumentar la producción, y es llevada a cabo mediante el incremento en la mecanización y aplicación de fertilizantes y biocidas, disminución de la superficie de barbecho y de los linderos, aumento del monocultivo y, sobre todo, la implantación de diferentes sistemas de regadío (Schläffer & Schmid, 1999; Benton *et al*., 2003).

El regadío es uno de los principales métodos utilizados para incrementar la producción. La superficie agrícola regada ha incrementado un 117% a nivel mundial en los últimos años. Aunque los sistemas de regadío representan sólo el 20% de la superficie cultivada total, producen el 40% de la producción agrícola (FAO, 2011). El agua es un recurso clave y limitante para la producción primaria, particularmente durante la sequía estival característica de climas mediterráneos (Blondel *et al*., 2010). Sin embargo, en estos ambientes el regadío modifica las condiciones ambientales naturales al mitigar de forma artificial la escasez de agua posibilitando un incremento de la producción (van der Velde *et al*., 2010). Este período de sequía estival determina importantes diferencias entre agrosistemas con clima mediterráneo y clima atlántico o continental, estableciendo acusadas diferencias en la biota asociada al ambiente agrario y la respuesta de ésta a los cambios potenciales en las prácticas y usos agrarios.

En algunas áreas mediterráneas, el regadío está modificando grandes superficies agrícolas de alto valor ecológico (p.e. Zonas Agrícolas de Alto Valor Natural; High Nature Value farming areas; Paracchini *et al*., 2008) como las dedicadas a la agricultura extensiva de secano (llamadas pseudo-estepas cerealistas; Suárez *et al*., 1997; Oñate *et al*., 2007). Estas áreas presentan unas características peculiares, que están viéndose alteradas por el cambio en el sistema de producción agrícola con efectos negativos comprobados en poblaciones de aves (Tella & Forero, 2000; Brotons *et al*., 2004; Laiolo, 2005; de Frutos & Olea, 2008). Sin embargo, su efecto sobre otros componentes de la biodiversidad agrícola (p.e. artrópodos) es todavía poco conocido (pero ver González-Estébanez *et al*., 2011 para mariposas, Pérez-Fuertes *et al*., 2015 para otros grupos de artrópodos).

Para comprobar el efecto de un cambio de una agricultura de secano a regadío en las comunidades de artrópodos, se iniciaron en el año 2007 una serie de estudios en el sureste de la provincia de León, donde coexisten diferentes sistemas agrarios, regadío y secano. En el año 2007 se seleccionaron 25 campos de trigo de secano y 12 de regadío, para realizar un muestreo puntual en el tiempo (mediados del mes de julio, antes de la cosecha), y recoger los grupos de artrópodos directamente ligados al cultivo: fitófagos (Aphididae), sus depredadores (Coccinellidae, Heteroptera, Syrphidae), parasitoides (Aphidiinae) y mutualistas (Formicidae). Se analizó la abundancia, riqueza, diversidad y composición de especies en ambos tipos de cultivos.

Los resultados muestran que el régimen agrícola (secano vs. regadío) es el factor más importante explicando las diferencias observadas en las comunidades de artrópodos estudiadas. Los cultivos de regadío mostraron una mayor abundancia (en los grupos Aphididae y Coccinellidae), riqueza (Aphididae, Aphidiinae y Coccinellidae) y diversidad (Aphidiinae, Coccinellidae y Syrphidae) que los cultivos de secano. Además, la composición de especies difirió en cultivos de regadío y secano para Coccinellidae, Formicidae y Heteroptera. La mayor diferencia entre los tipos de cultivo estudiados (y su entorno) es la diferente disponibilidad de agua presente durante los meses más secos. El hecho de realizar los estudios en el mes de julio, durante el periodo de sequía estival que se produce en el clima mediterráneo (Blondel *et al*., 2010), podría haber potenciado las diferencias en las comunidades de artrópodos.

A una escala de paisaje, el tamaño medio de las parcelas en torno al cultivo estudiado,, explicó una parte adicional de estas diferencias en abundancia y riqueza (Coccinellidae y Heteroptera), diversidad (Coccinellidae y Syrphidae) y composición (Formicidae). Esto podría deberse a que a medida que el tamaño de parcela aumenta, disminuye el efecto de los agroquímicos cerca de los bordes (Kleijn & van der Voort, 1997), mientras que al disminuir el tamaño de parcela la proporción de linderos y la heterogeneidad del paisaje aumenta (Smith *et al*., 2010). El resto de variables ambientales valoradas apenas tuvieron influencia en la comunidad de artrópodos.

Para comprobar si este efecto positivo del regadío sobre las comunidades de artrópodos era producido durante un periodo mayor de tiempo (primavera y verano), se abordó un segundo estudio, en el año 2009, ampliando la ventana temporal de muestreo. Medimos la abundancia de individuos de especies de pulgones de cereales que pueden producir plagas y de sus depredadores, parasitoides y mutualistas específicos en 12 campos de trigo de secano y 6 de regadío durante gran parte del período vegetativo del trigo, del 1-V al 15-VII una vez cada 15 días (6 muestreos) Tanto el tipo de régimen agrícola (regadío vs. secano) como la fecha de muestreo condicionan la abundancia de los pulgones de los cereales y su fauna acompañante. Así, el 15-V se encontró el máximo de abundancia de Formicidae y Syrphidae en secano. El 15-VI los picos de abundancia fueron para Aphididae y Aphidiinae tanto en regadío como en secano y de Chrysopidae en regadío. El 1-VII se produjo el máximo en abundancia de Chrysopidae en secano, de Coccinellidae en secano y regadío, y de Syrphidae en regadío. En todos los grupos los mínimos de abundancia tanto en secano como en regadío se produce en las primeras y últimas fechas de los muestreos, con variaciones en función del grupo y régimen. Estas variaciones en las abundancias máximas se deben a la disponibilidad de los recursos de los que dependen cada uno de los grupos.

Los cultivos de trigo regados mantuvieron mayores abundancias a lo largo de todo el periodo de estudio que los cultivos de secano, debido a la mayor disponibilidad de agua durante los meses más secos, particularmente durante la sequía estival característica de climas mediterráneos (Blondel *et al*., 2010), junto con una mayor aplicación de nitrógeno en los campos de cultivo que parece causar que las plantas de regadío sean más vigorosas. Estas condiciones permiten más recursos y de mejor calidad frente a los herbívoros durante el período más seco. Se ha demostrado que fitófagos como los pulgones crecen más despacio y alcanzan tamaños menores cuando se alimentan de plantas sometidas a estrés hídrico (Pons & Tatchell, 1995). Por tanto, en los cultivos de trigo de regadío serían esperables mayores poblaciones de fitófagos, lo que impulsaría el crecimiento de las poblaciones del resto de fauna acompañante a través de un efecto cascada, de acuerdo a la teoría ecológica establecida y a lo encontrado en trabajos realizados con artrópodos depredadores, sus presas y parasitoides (Koricheva *et al*., 2000; Haddad *et al*., 2001; Caballero-López *et al*., 2010, 2012)

Los depredadores (Coccinellidae y Syrphidae) y parasitoides (Aphidiinae) siguieron la tendencia en abundancia de sus presas, de acuerdo a una dinámica depredador-presa (Mills, 1982; Berryman & Kindlmann, 2008). Los afidiinos, completamente dependientes de los pulgones como hospedadores, tienen una dinámica poblacional mucho más ajustada que en el caso de los depredadores. Los crisópidos adultos también muestran una dinámica ajustada a la de los pulgones, pero parece deberse a la presencia de recursos alternativos en el ecosistema.

Durante la realización de las identificaciones en los estudios anteriores observamos que una parte importante del tiempo de investigación se utilizaba en la identificación, de manera que decidimos evaluar el uso de taxones sustitutos con los datos de las muestras recogidas en el año 2007, con el objetivo de reducir el tiempo de identificación de las muestras. Los resultados indican que el uso de taxones superiores, particularmente la riqueza de géneros (Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera y Syrhpidae) puede ser un método útil para valorar de forma rápida la biodiversidad de artrópodos en paisajes agrícolas.

No obstante, se debe tener en cuenta que las correspondencias en la sustitución están sujetas a los grupos estudiados en un área concreta (Balmford *et al*., 1996b; Lewandowski, 2010), y que la efectividad de la sustitución en diferentes escalas temporales (meses, años) puede no ser consistente (Favreau *et al*., 2006; Anderson *et al*., 2011).

Estos resultados pueden ser útiles para ahorrar tiempo y dinero en estudios de biodiversidad en agrosistemas. La identificación de todos los individuos desde el nivel de género al nivel de especies incrementó el tiempo de identificación al menos un 15% para pulgones y un 80% para coccinélidos (autores, datos no publicados). Este procedimiento se puede utilizar en una primera fase de un estudio sobre biodiversidad, en un contexto en el que la identidad de las especies no sea necesaria, o en una situación de recursos limitados, tanto económicos como temporales.

A tenor de estos resultados, resultaría interesante repetir el diseño de muestreos seguido en el año 2009 durante un mayor número de años. De esta manera se podrían analizar las variaciones interanuales en las especies dominantes, y las causas que propician que unos años se desarrollen plagas y otros no. También sería interesante realizar los muestreos en los linderos para comparar su comunidad de artrópodos con la del cultivo adyacente. Así se podría valorar la importancia de los linderos en la colonización temprana de los cultivos por parte tanto de plagas como de depredadores y su función como refugio después de cosechar el cultivo. Estos estudios nos permitirían evaluar diferentes medidas de gestión agroambiental orientadas a favorecer aquellas especies depredadoras o parasitoides de especies plagas de los cultivos.

Conclusiones

1- El tipo de sistema agrícola, secano-regadio, determina marcadas diferencias en las comunidades de artrópodos asociadas a los cultivos de trigo, causadas por diferencias en la disponibilidad de agua y productividad primaria durante el periodo estival seco característico de climas mediterráneos.

2- Los cultivos de trigo regados y rodeados de un paisaje agrícola de regadío mantienen mayor abundancia de individuos (en los grupos Aphididae y Coccinellidae), mayor riqueza de especies (Aphididae, Aphidiinae y Coccinellidae) y más diversidad de especies (Aphidiinae, Coccinellidae y Syrphidae) que los sometidos a una agricultura extensiva de secano.

3- En ambos regímenes agrícolas (regadío-secano) los depredadores (Chrysopidae, Coccinellidae y Syrphidae) y los parasitoides (Aphidiinae) de pulgones de cereales siguen las variaciones poblacionales de sus presas, coincidiendo con la clásica dinámica poblacional depredador-presa.

4- La abundancia máxima de pulgones de cereales se produce a mediados de junio en secano y regadío. Al mismo tiempo se produce el pico de Aphidiinae y Chrysopidae, y 15 días después el de Coccinellidae y Syrphidae, consistente con la teoría ecológica establecida sobre dinámicas de población para parásito-hospedador y depredador-presa.

5- La abundancia y riqueza de Formicidae es mayor en cultivos de trigo de secano. Sin embargo, el método de muestreo no es el más adecuado para este grupo, ya que no permite capturar especies edáficas estrictas.

6- La abundancia y riqueza de Coccinellidae y Heteroptera, la diversidad de Coccinellidae y Syrphidae y la composición de especies de Formicidae en cultivos de trigo (tanto de secano como de regadío) está influido por el tamaño de las parcelas de los cultivos en el paisaje de alrededor (2 x 2 km).

10- El uso de taxones superiores como sustitutos es un método útil para valorar la biodiversidad de artrópodos en ecosistemas agrícolas mediterráneos, tanto en cultivos de trigo de secano como de regadío.

11- El nivel taxonómico de género es un buen sustituto de la riqueza y la diversidad para los grupos Aphididae, Aphidiinae, Coccinellidae, Formicidae, Heteroptera y Syrphidae.

12- Los niveles taxonómicos de género y especie de las familias Aphididae y Coccinellidae son buenos sustitutos de la riqueza global de especies de artrópodos de los grupos estudiados.

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