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Cost-effectiveness of uncultivated field-margins and semi-natural patches in Mediterranean areas: A multi-taxa, landscape scale approach

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ABSTRACT

Careful consideration of the cost-effectiveness of wildlife-friendly practices is key to promote fit-for-purpose agro-ecological policies, but quantitative evaluations of economic costs and ecological benefits compared to other land management alternatives are scarce. We compared the cost-effectiveness of uncultivated field-margins, a widespread wildlife-friendly practice, to that of conserving large semi-natural patches at the landscape scale and over multiple seasons for six crop types in Mediterranean Israel. Increased production expenditures and revenue loss were used to assess costs. Ecological benefits were measured in terms of (1) potential biological pest-control, and (2) richness and abundance of plants, birds, butterflies, ground-dwelling and plant-associated arthropods. Field-margins increased biodiversity by 64 % compared to cultivated land and accounted for 78 % of the biodiversity recorded in semi-natural patches. The biodiversity benefits of field-margins varied across seasons and taxa. Arthropod richness in field-margins did not differ from semi-natural patches, but bird and plant richness were 42–46 % lower. Field-margins increased potential biological pest-control, but with no spillover into the fields. Field-margins were associated with revenue loss in most crop types, leading to lower cost-effectiveness compared to creating large semi-natural patches. Yet, in a few crop types which exhibited low or positive effect of field-margins on income, field-margins were more cost-effective than semi-natural patches. These results indicate that there is no one-size-fits-all agri-environmental policy. Measures need to be locally tailored (e.g. crop-specific) to maximize ecological and economic benefits at large spatial scales, while considering that in many cases setting aside contiguous areas for conservation is more cost-effective than field-scale wildlife-friendly practices.

1. Introduction

Agriculture is pivotal for meeting the rapidly increasing demand for food, fuel and fiber, but also to curb the relentless decline in biodiversity and ecological functions (Fischer et al., 2017). Agricultural production captures almost 40 % of the total global land area (Food and Agriculture Organization of the United Nations (FAO), 2015). The growing global demand for agricultural products is accelerating the conversion of remaining natural areas and driving significant intensification of agricultural practices in a way that fails to conserve biodiversity and causes irreparable damage to vital ecosystem resources (Tilman et al., 2002). Alongside changing consumption patterns and reducing food waste, there is a pressing need to increase crop production in an environmentally sustainable manner (Charles et al., 2014). One option is to promote wildlife-friendly agriculture that can complement protected areas by increasing landscape connectivity and enhancing the viability of endangered populations (Tscharntke et al., 2005), while ensuring that the ecological functions underpinning crop production and other services are maintained (Foley et al., 2011). However, there is a need to improve our understanding of how such multifunctionality can be achieved, as it is unlikely that multiple uses can be optimized everywhere (Holt et al., 2016). This raises the

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question whether promoting multifunctional landscapes is indeed better than setting aside designated areas for conservation (sparing-sharing debate; Fischer et al., 2008; Green et al., 2005).

Mounting empirical evidence demonstrates that wildlife-friendly farming practices benefit biodiversity and, more specifically, areas out-of-production such as field-margins, hedgerows and fallow-land are highly valuable (Batáry et al., 2015). Landscape features with natural and semi-natural vegetation benefit biodiversity at different scales (Benton et al., 2003). Yet their effectiveness is restricted to a subset of species that can tolerate some level of agriculture disturbance and is highly dependent on the biodiversity metric chosen and the landscape configuration (Batáry et al., 2011; Kleijn and Sutherland, 2003). Beyond their conservation benefits, landscape features with natural vegetation provide multiple ecosystem services that support crop production, such as soil fertility and biological pest-control (Holland et al., 2017). Numerous studies demonstrate these benefits, although the overall effects on agricultural production remain inconclusive (Chaplin-Kramer et al., 2011; Kovács-Hostyánszki et al., 2017). Moreover, to optimize outcomes, different ecosystem services should be used at different temporal and spatial scales. To date, however, most studies have focused on a single season, overlooking the potential effects of organism life-cycle dynamics and of the farming cycle (Bommarco et al., 2013). There is, therefore, a poor understanding of the conditions under which maintaining natural landscape elements can optimize the benefits for wildlife and farmers.

As regards the widespread adoption of wildlife-friendly practices, perhaps a more pervasive concern of farmers is the net economic costs and risks of implementing such interventions (Cordeau et al., 2011). Natural landscape features can provide different services and disservices that may trade-off against each other, making it difficult for farmers to make informed decisions about the net-effect on yield (Harrison et al., 2014). Currently, socio-economic aspects of wildlife-friendly farming are often neglected and it is not yet clear which wildlife-friendly practices are most economically effective (Wätzold and Schwerdtner, 2005). Although economic aspects have been the focus of increased attention in recent years (Pywell et al., 2015; Van Vooren et al., 2018), only a few studies have provided a quantitative analysis of the cost-effectiveness of different wildlife-friendly practices (e.g. Andrello et al., 2018). In the conservation literature, analyses of cost-effectiveness have considered effective payment policies and space-time allocation (Drechsler et al., 2016; Polasky et al., 2008), but rarely have they attempted to compare specific wildlife-friendly practices.

From a policy perspective, there is little understanding of how different land management alternatives compare with each other. Developing subsidy policies that encourage farmers to enhance the ecological quality of the whole land or to spare land for conservation are two options that need to be carefully examined and implemented (Fischer et al., 2008). Yet, they are rarely explored from an economic perspective (Curran et al., 2016; Legras et al., 2018). Additionally, most of the knowledge accumulated to date on the effectiveness of agro-ecological practices focuses on temperate regions (Sokos et al., 2013), while the few assessments conducted within the Mediterranean region have focused on the restoration of rangeland, riparian areas, without addressing arable-farming practices (Shackelford et al., 2017). Significant intensification of crop production is expected in the Mediterranean region over the next decade (Malek et al., 2018), which could lead to both enormous changes in land systems and further decline in this essential biodiversity pool (Myers et al., 2000). Notwithstanding these threats to biodiversity, conservation actions in the Mediterranean may be extremely costly compared to other ecoregions, given that the Mediterranean region is one of the highest yielding agricultural areas globally (Naidoo and Iwamura, 2007). Hence, evidence and tools are needed to help policy-makers and farmers make informed decisions about which sustainable agricultural development options are feasible and most beneficial (Holt et al., 2016). In Israel, for example, the government only recently started to develop policies for environment-friendly farming, such as pesticide-reduction, waste treatment and minimum-tillage. Currently, the Israeli government does not promote the maintenance of non-crop habitats such as uncultivated field-margins. Consequently, farmers prefer to cultivate the entire field and clear the natural vegetation adjacent to the field to prevent potential damage to crops.

Here, we use a landscape-scale multi-season perspective to quantitatively assess the cost-effectiveness of uncultivated field-margins as compared to that of large semi-natural patches in an agricultural area designated as an ecological corridor. First, we compared biodiversity and potential biological pest control under each land management practice, by examining five different species groups selected for this purpose. Next, we identified the different costs (production cost and reduction in yield) and benefits (potential pest-control services) in each land-management practice and integrated this knowledge with the ecological benefits, to explore which land-management option is cost-effective for a diversity of crops. We hypothesized that field-margins would increase both biodiversity and pest control services, and that in heterogeneous landscapes, wider field-margins would provide more of those benefits. From an economic perspective we expected to find that field-margins would cause a small reduction in yield, which could be compensated for by the reduced expenditure on pesticide inputs, provided by the benefit of biological pest control. We also expected that sparing large semi-natural habitats would provide significantly higher biodiversity benefits compared to narrow field-margins, due to their size and the fact that they are less disturbed; but that such benefits might come at a higher financial cost, due to the high value of land in intensive cropland. Finally, we hypothesized that spatial (cropland) and temporal (seasonality) changes would affect the relative cost-effectiveness of both semi-natural patches and field-margins.

2. Materials and methods

2.1. Study site

The study was conducted in the Harod valley (northern Israel), an area of approximately 100 Km^2 of intensive agriculture. The area is located within an ecological corridor that connects several large natural areas and two major ecoregions (Lower Galilee and Shomron; see Fig. A1). The area is heavily cultivated, with arable fields, orchards, and fishponds. Most crops are managed conventionally, but minimum-tillage in wheat fields and cover-crops in orchards are common practices. Winter wheat is the most common crop (60 %), followed by a variety of irrigated vegetables crops (majority in late spring). Orchards are a mix of deciduous and evergreen fruit, nuts and olive trees. Large patches of semi-natural vegetation located within the agricultural area serve as pastureland for either cattle or sheep and goats. In the absence of subsidy policies, maintaining uncultivated field-margins within field-area is not typically practiced in this region; yet, numerous strips of semi-natural vegetation adjacent to the fields are left uncultivated, either because of limited access to these strips or because the costs of removing them are too high. These field-margins are outside the productive field-area, but are subjected to frequent soil disturbances, direct and indirect herbicide application, and high nitrogen levels due to fertilization flow from nearby agricultural areas.

2.2. Sampling design

We selected sampling transects ($n = 88$) in three habitats: cultivated land (fields and orchards), field-margins, and semi-natural patches (Table A1). The cultivated habitat transects included each of six major crops: winter wheat under both minimum and maximum tillage; two common spring crops, tomato (March–July) and watermelon (March–August); and three major orchards (almonds, olives and citrus). Arable field-size was 21.3 ± 10.9 ha (mean ± SD) and average plot size in orchards was 18.6 ± 15.4 ha (Table E1).

We mapped uncultivated field-margins in the study area (ArcMap 10.4, ESRI) based on orthophoto, and validated the maps on-site. We selected margins that were wider than 6 m. To minimize differences between fields and field-margins, 24 of 30 field-margins were selected adjacent to surveyed fields and orchards. For each field-margin, we recorded its width, the proportion of area with natural vegetation in a radius of 250 m around the transect, and land-use diversity in the radius area (Shannon-Wiener index; see Appendix B for more details in Supplementary material). For each arable-field and orchard, we mapped and calculated the percentage of uncultivated margins with semi-natural vegetation in a radius of 10 m around the plot, to test the effect of uncultivated field-margins on pest-control and economic variables (alternative measures are discussed in Appendix C in Supplementary material). We sampled large semi-natural patches used for grazing. Since grazing is very common even within protected areas in Israel, pastureland can serve as a reference to measure the level of degradation of the natural habitat. To control for the differences among fields, field-margins and semi-natural patches, in each site we recorded slope; elevation; and distances from roads, wadies (dry streams), settlements and fishponds.

2.3. Sampling methods

We surveyed five species groups (plants, birds, butterflies, ground-dwelling arthropods and plant-associated arthropods) along the agricultural season in the fall, spring and summer of 2015–2016. Plants were sampled during peak spring (early March 2016). We recorded all species in four evenly spaced $10 \times 1\,\mathrm{m}^2$ quadrats along a 100 m transect and all woody species that were present in 20 m radius around the transect. Birds were sampled using transect-count. We recorded all birds seen or heard during 10 min of walking along the 100 m transect. Sites were visited twice in the fall (September–November 2015) and four times in the spring (March–June 2016).

Arthropods were sampled using three methods. Butterflies were sampled using Pollard walk method (Pollard, 1977), walking 10 min along the 100 m transect on sunny days with no wind. Sites were visited twice in the fall (September–November 2015), twice in the spring (March-May 2016), and once in the early summer (June–July 2016). Ground-dwelling arthropods were sampled using dry pitfall traps in spring (April 2016), summer (June 2016) and fall (October 2016). In each site, nine dry traps of 1 L were set 5 m apart along the 100 m transect, collected after three days and taken to the lab, where they were sorted to the lowest recognizable taxonomic units (Ward and Stanley, 2004) for beetles and ants, and to genus/family/order for other taxonomic groups. Plant-associated arthropods were sampled from vegetation using 'Vortis' insect sampler (burkard.co.uk/vortis.htm) along each 100 m transect. In April 2016, arthropod suction was performed in the semi-natural patches, wheat crops, orchards and in the field-margins adjacent to these crops, and in June 2016 in tomato and watermelon fields and in the field-margins adjacent to these crops. In orchards, we sampled both the cover-crop vegetation and the trees. The samples were sorted in the lab to 18 taxonomic groups, at the order or sub-order level (Table A2). We also assessed potential biological pest-control, by classifying each taxonomic group as potential 'pests' or 'natural enemies' of agriculture if the group includes mostly insects that are known as pests or natural enemies in various local crops. Other groups were excluded from this analysis (Table A2). Detailed sampling methods are described in Appendix B in Supplementary material.

To test whether field-margins affect crop profitability, we obtained profit and loss reports and acquired additional data by conducting face-to-face interviews with the farmers. We acquired data about the management (tillage/reduced-tillage, irrigation/rain-fed), costs (including inputs, e.g. seeds, water, herbicides; labor and machinery, i.e. manpower and farm equipment), yields and revenue for a total of 47 fields and orchards. Details regarding the interviews can be found in Appendix C in Supplementary material.

2.4. Data analysis

2.4.1. Biodiversity

For each species group richness and abundance (except for plant abundance), we fitted a set of two generalized linear models (see Appendix D for full details in Supplementary material).

(1) General habitat preference models were used to determine and compare the diversity of plants, birds, butterflies and arthropods in the main habitats studied (i.e. cultivated fields and orchards, field-margins, semi-natural patches, and cover-crop in orchards for plant-associated arthropods) and throughout the season (using habitat-season interaction in the model). Landscape variables (slope; elevation; and distance from roads, wadies, settlements, and fishponds) and weather variables (temperature, wind level and cloudiness for butterflies; and time of day, namely morning/afternoon, for birds) were entered into the models, to control for their effect. For each model we then selected the best minimal model based on AICc (MuMIn R-package) (Barton, 2017; Zuur et al., 2009). We used Tukey's post-hoc analysis to compare between habitats in each season. Based on the best model estimates, we calculated mean richness/abundance in field-margins divided by mean richness/abundance in the cultivated or semi-natural patches (response ratio). We used ln (response ratio) as a measure of effect-size of field-margins compared to cultivated and semi-natural patches, following Hedges et al. (1999).

(2) Field-margins models tested the effects of field-margin properties and landscape connectivity on species diversity in field-margins. Models were run for each species group for field-margins transects only. The initial models included all landscape and weather variables selected by the habitat model and additional field-margins and landscape properties, followed by a similar model selection process. Field-margin properties included plant species richness and field-margin width. Landscape properties included proportion of area with natural vegetation and land use diversity in a radius of 250 m around the transect. We also controlled for effects of minimum-tillage on biodiversity (results of tillage models are presented in Appendix D in Supplementary material). All statistical analyses were performed using R software version 3.3.3 (R Core Team, 2017).

2.4.2. Potential biological pest-control

We measured increase or decrease of natural-enemy densities relative to pest densities (namely, natural-enemy to pest ratio) by calculating the proportion of natural-enemies relative to the total abundance of natural-enemies and pests. We analyzed enemy-pest ratio following the same protocol as biodiversity metrics (habitat model followed by field-margins model), using a quasi-binomial error distribution. In addition, for fields and orchard transects, we used ANCOVA model, with crop type as an independent variable and percentage of uncultivated field-margins as covariate, to test the effect of uncultivated field-margin percentage on enemy-pest ratio within different crops. Crop types included rain-fed wheat, irrigated wheat, watermelon, tomato, olive, almond and citrus. We separated irrigated and rain-fed wheat, to account for the effect of irrigation, since all other crops sampled were irrigated. We used elevation as an additional predictor because it was significant in the habitat model.

2.4.3. Economic costs

Field margins may affect farmers' profit through the cost side (e.g. increased inputs such as pesticides) or the revenue side (e.g. decreased yield). In order to account for both, we used two separate ANCOVA models, to test for possible effects of uncultivated margin percentages on total growing costs and total revenue (NIS; 1 USD = 3.84 NIS) per

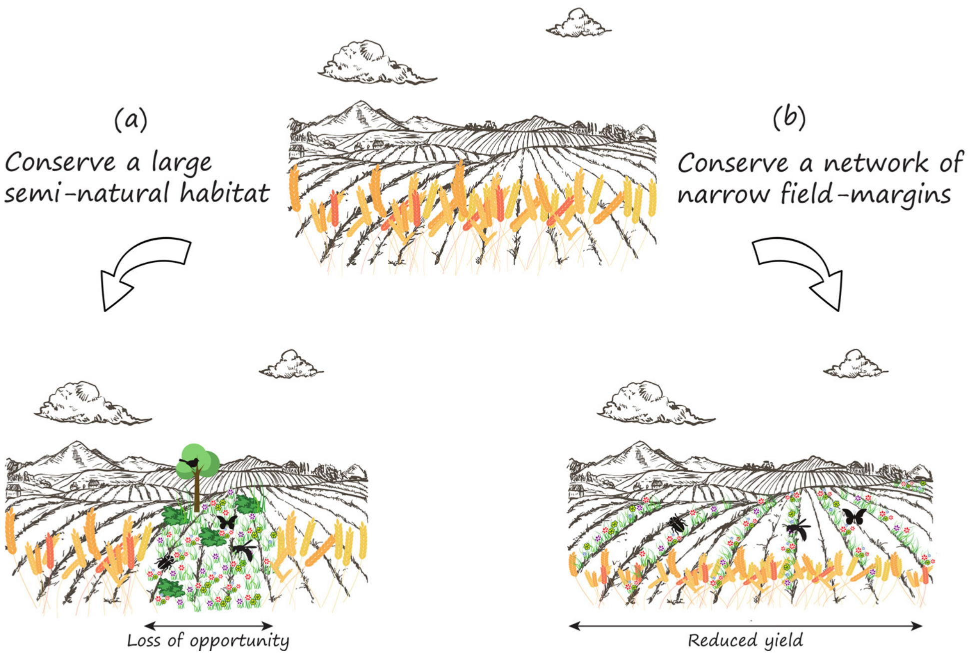

Fig. 1. Two possible actions for increasing the amount of natural habitat in the agricultural area and their effect on possible revenue loss: (a) Conserve a large semi-natural habitat causes loss of opportunity of the land converted from cultivated habitat to semi-natural habitat, but margin effect on the remaining crop production is minimal, (b) conserve a network of narrow field-margins using existing non-cultivated habitats or low-productivity land has minimal land requirements, but it can result in damages to adjacent crops and reduction in yield.

unit area (dunam = 0.1 ha) of the six crop types, as was done in the enemy-pest ratio analysis. Variance differed significantly between crop types and therefore each crop type was modeled separately. Additional predictors were plot size as fixed-effect and landowner as random effect.

2.4.4. *Cost-effectiveness of field-margins and semi-natural patches*

Cost-effectiveness measures the effectiveness of an action relative to the costs, and is used when benefits, e.g. biodiversity, cannot be expressed in monetary terms (Nunes and Van den Bergh, 2001). Cost-effectiveness does not assess whether benefits are higher or lower that the costs; rather, it is used for comparing different modes of actions. We compared cost-effectiveness of maintaining uncultivated field-margins to converting cropland to semi-natural patches (Fig. 1, see Appendix E for detailed analysis in Supplementary material). The effectiveness of field-margins and semi-natural patches was calculated based on the habitat preference models (2.4.1); we calculated the effect-size of field-margins and semi-natural patches and compared these to cultivated crops, averaged across all species groups in all seasons. We did not include benefits from potential biological pest-control (2.4.2), as field-margins were found to have no effect on natural-enemy to pest ratio.

The costs of maintaining an equal area (1 ha) of field-margins and semi-natural patches were based on the economic ANCOVA models (2.4.3). Since the revenue ANCOVA performed better in terms of statistical properties, this model's estimates were used to calculate the revenue loss (NIS ha^{-1}) associated with semi-natural patches and field-margins (Fig. 1). Converting cropland to semi-natural patches results in loss-of-opportunity and, therefore was calculated as the estimated revenue of the lost cropland (i.e., baseline-revenue at the intercept for each crop type). Maintaining uncultivated field-margins may result in damage to adjacent crop; the cost of this damage was estimated for each crop type, by calculating the revenue loss associated with increasing field-margin percentages. For each crop type we estimated the proportion of field-margins equivalent to 1 ha, according to average field properties (Appendix E in Supplementary material). We disregarded loss-of-opportunity costs of field-margins because we assumed taking additional land out of production is not necessary, as there are currently many areas out-of-production which are regularly tilled or sprayed with herbicides. Similarly, we ignored additional revenue loss for semi-natural patches because they do not significantly increase the area bordering with natural vegetation; hence, no additional damage is inflicted on the crop.

3. Results

3.1. *Biodiversity*

The diversity of plants, birds and butterflies varied between habitats, season and with the width and quality of field-margins. Average per-transect plant richness in field-margins (23.9 ± 2.2; mean ± S.E, hereafter) was significantly higher compared to cultivated habitats (7.0 ± 0.9; Fig. 2a, Table A3c) but lower compared to semi-natural patches (52.9 ± 4.2; Fig. 2b, Table A3c), and increased with field-margin's width (Table 1).

Average per-visit bird richness in cultivated habitats, field-margins and semi-natural patches was 4.4 ± 0.1, 5.3 ± 0.3 and 8.6 ± 0.3, respectively. Field-margins had higher species richness compared to cultivated habitats in spring, but not in fall (Fig. 2a, Table A3c). Compared to semi-natural patches, field-margins had significantly lower bird richness in both seasons (Fig. 2b, Table A3c). Bird richness in field-margins increased with field-margin's width (Table 1). Bird abundance in field-margins (17.7 ± 1.6) was similar to cultivated habitats (20.8 ± 2.3) in both seasons (Fig. 2d, Table A3c), and slightly yet not-significantly lower than semi-natural patches (45.2 ± 7.2) (Fig. 2e, Table A3c). Bird abundance showed seasonal effect only for field-margins ($z = 2.96$, $P < 0.01$, Table A3b), and increased with field-margin's width (Table 1).

Butterfly richness in field-margins (2.1 ± 0.1) was higher compared to cultivated habitats (1.2 ± 0.1) in fall and summer, but not in spring (Fig. 2a, Table A3c) and we did not record significant differences between field-margins and semi-natural patches in any season (2.1 ± 0.2; Fig. 2b, Table A3c). Butterfly abundance was higher in field-margins (11.1 ± 1.1) compared to cultivated habitats in all seasons (3.7 ± 0.4; Fig. 2d, Table A3c) and did not differ from semi-natural patches (11.2 ± 2.4; Fig. 2e, Table A3c). Butterfly abundance in field-margins decreased with plant richness (Table 1).

In general, richness and abundance of ground-dwelling and plant-associated arthropods were higher in field-margins compared to cultivated areas and similar to semi-natural patches. Average per-transect ground-dwelling arthropod richness in cultivated habitats, field-margins, and semi-natural patches was 11.6 ± 0.5, 16.2 ± 0.7 and 18.3 ± 1.0, respectively. Compared to cultivated habitats, field-

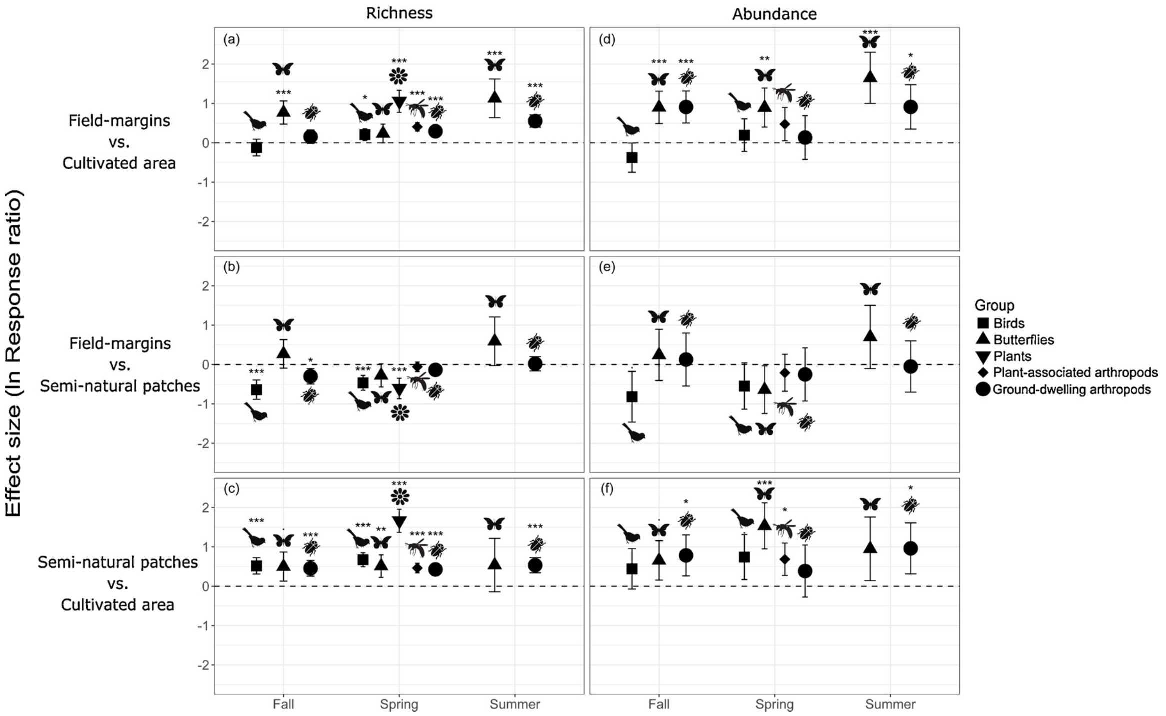

Fig. 2. Effect size of field-margins practice on richness (a,b) and abundance (c,d) compared to cultivated area and semi-natural patches; and effect-size of semi-natural patches compared to cultivated area (c,f). All figures show estimated ln(response ratio) ± 1 s.e., significance level indicates effect size ≠ 0 and is based on the multiple comparisons between habitats. Significance levels: (***) $p < 0.001$, (**) $p < 0.01$, (*) $p < 0.05$, (.) $p < 0.1$.

margins were significantly richer in spring and summer, but not in fall (Fig. 2a, Table A3c). Compared to semi-natural patches, field-margins had lower species richness in fall, while in spring and summer they had similar species richness (Fig. 2b, Table A3c). Field-margins' width had a small negative effect on species richness (Table 1). Arthropod abundance was higher in field-margins (127.3 ± 17.4) compared to cultivated habitats (66.5 ± 7.3) in both fall and summer, but not in spring (Fig. 2d, Table A3c). Arthropod abundance in field-margins was similar to semi-natural patches in all seasons (127.1 ± 12.7; Fig. 2e, Table A3c).

Average per-transect plant-associated arthropods order richness in field-margins (11.9 ± 0.3) was higher than in cultivated habitats (7.9 ± 0.3; Fig. 2a, Table A3c), and did not differ from semi-natural patches (12.5 ± 0.4; Fig. 2b, Table A3c). Average per-transect plant-associated arthropods abundance in field-margins (348.9 ± 51.3) also did not differ from semi-natural patches (301.7 ± 37.8; Fig. 2e, Table A3c). Similar to richness, it was slightly higher than cultivated habitats, yet not significantly (229.9 ± 28.2; Fig. 2d, Table A3c).

3.2. *Potential biological pest-control*

Average per-transect potential natural-enemy to pest ratio in cultivated habitats, cover-crops, field-margins and semi-natural patches was 0.12 ± 0.01, 0.15 ± 0.03, 0.23 ± 0.02 and 0.26 ± 0.03, respectively. Semi-natural patches and field-margins showed the highest enemy-pest ratio (Fig. 3, Table A3c). Enemy-pest ratio inside the plots was not affected by the proportion of uncultivated margins around the plots, and only varied among crop types. Rain-fed wheat showed the highest ratio, and multiple comparisons show significant differences for watermelons and tomatoes ($z = 4.44$, $P < 0.001$; $z = 2.99$, $P < 0.05$, respectively, Fig. A2).

3.3. *Economic costs*

The revenue of irrigated wheat and watermelon crops decreased with increasing percentages of uncultivated margin (Table 2). Most other crops showed a similar, yet non-significant trend (plots with higher uncultivated margin percentages had lower revenue). In contrast, the effect of uncultivated margin percentages on citrus orchards' revenue was significantly positive and not-significantly positive for tomatoes (Table 2). Plot size mildly decreased revenue per unit-area (Table 2). Costs per unit-area were not affected by uncultivated margin percentages for any of the crop types (Table 2).

3.4. *Cost-effectiveness*

In orchards, field-margins' effect on revenue was positive or not significant, thus maintaining uncultivated field-margins was more cost-effective than sparing semi-natural patches. Unlike orchards, cost-effectiveness in arable crops was highly dependent on the revenue loss due to semi-natural vegetation bordering the field compared to loss-of-opportunity costs (Table 3). Tomatoes and rain-fed wheat were not significantly affected by field-margins resulting in the higher cost-effectiveness of field-margins in these crop types. However, field-margins had a significant, negative impact on profit in irrigated wheat and watermelon; thus, the cost-effectiveness of maintaining field-margins in these crop types is higher than for semi-natural patches.

4. Discussion

Wildlife-friendly farming programs enhance biodiversity in the agricultural landscape, but are often restricted by their effect on crop profitability which diminishes their uptake by farmers (Kleijn and Sutherland, 2003). On the other hand, sparing large semi-natural patches in the agricultural landscape may be more valuable for biodiversity conservation, but at the significant cost of taking large areas of land out of production (Green et al., 2005). Since both options compete for the same conservation resources, large-scale cost-effectiveness assessments, such as the current one, are required to effectively compare these options and optimize their implementation. Our results show that in some irrigated crops the yield-loss caused by uncultivated field-margins limits their cost-effectiveness compared to creating semi-

Table 1

Summary of best models for field-margins selected based on AICc (scaled coefficients ± Std. error t or z statistic and sig.level). Explanatory variables that were not included in the maximal model are marked as (-). Coefficients are shown only for significant variables. For models with random effects marginal R^2 are shown. Arthropod suctions model selection process did not result in any significant variables and was omitted from the table. Significance levels: (***) $p < 0.001$, (**) $p < 0.01$, (*) $p < 0.05$, (.) $p < 0.1$.

	Plant richness	Butterfly richness	Butterfly abundance	Birds richness	Birds abundance	Falling-Traps richness	Falling-Traps abundance	Natural enemy to pest ratio
Model type	Gaussian	Poisson	Negative-binomial	Poisson	Negative-binomial	Poisson	Negative-binomial	Quasi-binomial
N	30	123 samples (30 transects)	123 samples (30 transects)	163 samples (30 transects)	163 samples (30 transects)	77 samples (27 transects)	77 samples (27 transects)	30
R^2	0.28	0.05	0.32	0.46	0.20	0.58	0.11	0.21
Field-margin properties								
Width	6.8 ± 1.93 (t = 3.53) **			0.2 ± 0.04 (z = 5.01) ***	0.3 ± 0.12 (z = 2.80) **	−0.1 ± 0.03 (z = −2.26) *		
Plant richness	–	−0.1 ± 0.07 (z = −1.67) (.)	−0.3 ± 0.09 (z = −3.01) **					
Landscape properties								
Proportion of area with natural vegetation				0.1 ± 0.05 (z = 1.77) (.)				
Land use diversity								
Slope								
Elevation								−0.30 ± 0.11 (t_{28} = −2.69) *
Distance (m) from settlement								
Distance (m) from road				−0.2 ± 0.05 (z = −3.57) ***	−0.4 ± 0.11 (z = −3.50) ***			
Distance (m) from wadi				−0.3 ± 0.06 (z = −4.20) ***	−0.2 ± 0.12 (z = −1.87) (.)			
Distance (m) from fish pond								
Weather conditions								
Season spring	–		0.9 ± 0.21 (z = 4.50) ***	0.3 ± 0.09 (z = 3.48) ***	0.5 ± 0.17 (z = 2.92) **	0.7 ± 0.07 (z = 9.51) ***		–
Season summer	–			–	–	0.4 ± 0.08 (z = 4.79) ***	0.7 ± 0.21 (z = 3.21) **	–
Morning time	–	–	–	0.3 ± 0.08 (z = 3.17) **	0.4 ± 0.16 (z = 2.54) *	–	–	–
Temperature	–	0.1 ± 0.06 (z = 1.81) (.)	0.3 ± 0.09 (z = 3.60) ***	–	–	–	–	–
Wind level	–		−0.2 ± 0.09 (− = −1.67) (.)	–	–	–	–	–
Clouds	–			–	–	–	–	–

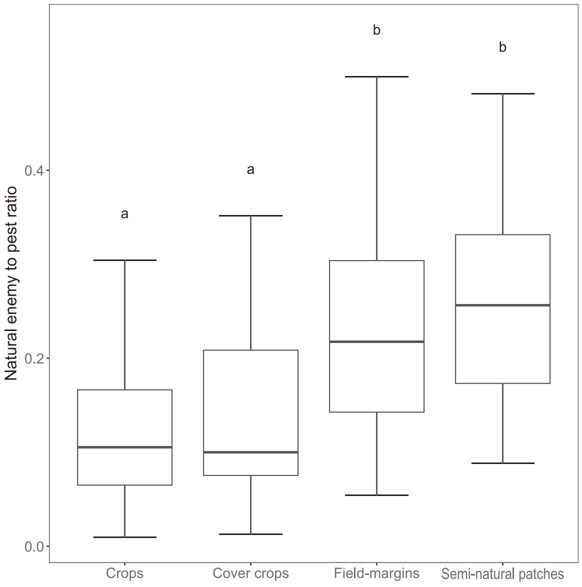

Fig. 3. Natural enemy to pest ratio in four habitats sampled. Letters denote significant statistical differences.

natural patches, while in orchards and rain-fed crops field-margins are more cost-effective. Identifying such win-win opportunities for both local farmers and biodiversity conservation is important for maximizing the benefits of wildlife-friendly farming at minimal costs (Fischer et al., 2017).

4.1. *Biodiversity in field-margins and semi-natural patches*

Field-margins increased biodiversity in our study by 64 % (mean effect-size = 0.49) compared to cropland. The main beneficiaries were arthropod species. Despite field-margins' contribution to biodiversity, they maintain lower species richness than semi-natural patches (mean effect-size = −0.25, −22 %). The largest biodiversity gap exists for plants (−46 %) and birds (−42 %). Such underrepresentation of bird and plant species in wildlife-friendly farming was also reported by Phalan et al. (2011) in tropical regions; here we show it also exists in Mediterranean regions with a long history of agriculture. Although it may take time for spared patches to reach their maximal biodiversity potential, sparing land is crucial for these species groups.

Seasonality affected species' use of the different habitats, changing the relative importance of field-margins and semi-natural patches between seasons. Fields, field-margins and semi-natural patches provide important resources during the different seasons. For example, butterflies follow nectar flowers and hosts, which bloom early in spring in the semi-natural patches but persist into late summer in field-margins. In spring, field-margins can provide seeds, insects and nesting places for birds, while the ploughed fields in fall provide them with many food resources. These habitat preferences may be both season and species specific (Guyot et al., 2017). While understanding seasonal dynamics is important for better wildlife management in agricultural landscapes, it is scarcely studied. These seasonal fluctuations lead to higher ecological effectiveness of mixed solutions in agroecological ecosystems; hence, combining multiple solutions at a large spatial scale is crucial for protecting biodiversity throughout agricultural seasons.

4.2. *Effect of landscape and field-margin properties*

Richness of plants and birds increased with field-margin width and proportion of area with natural vegetation around them, emphasizing the importance of conserving wide field-margins and enlarging semi-natural patches. Contrary to plants and birds, arthropod diversity was high even in relatively narrow field-margins. This trend is consistent with previous evidence from temperate regions showing that field-margins benefit arthropod diversity even in intensive low-quality agricultural matrices (Haenke et al., 2009). Generally, field-margins properties affected biodiversity more than landscape properties. Although many studies indicate the importance of landscape in agricultural biodiversity (Chaplin-Kramer et al., 2011), our results show that wide, low-disturbance field-margins can promote biodiversity even in homogeneous and intensively cultivated landscapes. The field-margins in our research areas suffer from many disturbances, such as leakage and application of herbicides, pesticides, fertilizers and tillage; which, aside from harming biodiversity, also impose extra costs to farmers. Improving field-margin conditions, for example, by reducing

Table 2

Summary of the economic ANCOVA models. Crop type effect shows revenue and costs (NIS × 0.1 ha^{-1}; 1 USD = 3.84 NIS) of the six crop types without uncultivated margins, and the interaction terms show the effect of uncultivated margins on costs and revenue of each crop type. Significant effects ($p < 0.05$) are marked in bold.

	Revenue			Costs		
	Estimate ± SE	t-value	p-value	Estimate ± SE	t-value	p-value
Crop type (0 % uncultivated margins)						
Rain fed wheat (Intercept)	351.08 ± 45.52	7.71	< 0.001	164.14 ± 57.50	2.85	0.009
Irrigated wheat	417.47 ± 68.52	6.09	< 0.001	309.53 ± 70.10	4.42	< 0.001
Watermelon	1399.18 ± 322.64	4.34	< 0.001	206.71 ± 269.98	0.77	0.451
Tomato	3625.68 ± 363.25	9.98	< 0.001	2834.73 ± 182.66	15.52	< 0.001
Olive	2014.86 ± 502.02	4.01	< 0.001	2712.16 ± 1130.13	2.40	0.024
Almond	4970.23 ± 653.22	7.61	< 0.001	3052.65 ± 260.66	11.71	< 0.001
Citrus	3696.72 ± 229.00	16.14	< 0.001	4176.4 ± 1094.12	3.82	< 0.001
Plot size	−0.27 ± 0.12	−2.31	0.029	0.00 ± 0.14	0.01	0.990
Percent uncultivated margins x Rain fed wheat	−0.18 ± 0.63	−0.28	0.783	0.00 ± 0.76	< 0.01	0.997
Percent uncultivated margins x Irrigated wheat	**−3.79 ± 1.47**	**−2.58**	**0.016**	−0.81 ± 1.47	−0.55	0.589
Percent uncultivated margins x Watermelon	**−30.32 ± 14.04**	**−2.16**	**0.040**	9.16 ± 11.73	0.78	0.442
Percent uncultivated margins x Tomato	9.09 ± 21.89	0.42	0.681	1.20 ± 10.89	0.11	0.913
Percent uncultivated margins x Olive	−1.95 ± 9.44	−0.21	0.838	−18.76 ± 21.28	−0.88	0.386
Percent uncultivated margins x Almond	−16.87 ± 15.13	−1.11	0.275	−3.26 ± 5.96	−0.55	0.589
Percent uncultivated margins x Citrus	**147.09 ± 13.64**	**10.78**	**< 0.001**	60.69 ± 66.01	0.92	0.367
Sample size	47			46		
d.f.	26			25		
R^2 (marginal)	0.99			0.99		
R^2 (conditional)[a]	0.99			0.99		

[a] Owner random effect.

Table 3
Cost-effectiveness of field-margins and semi-natural patches in arable fields, sorted from the most cost-effective to the least cost-effective.

Prescription	Cost (NIS ha^{-1})	Effectiveness (ln response ratio)	Cost-effectiveness
Maintain field-margins near tomato fields	0[a]	0.495	high
Maintain field-margins near rain-fed wheat fields	419.93[a]	0.495	1.18E-03
Convert rain-fed wheat fields to natural habitat	1,232.02	0.706	5.73E-04
Convert irrigated wheat fields to natural habitat	1,615.40	0.706	4.37E-04
Convert watermelon fields to natural habitat	8,123.05	0.706	8.69E-05
Maintain field-margins near irrigated wheat fields	6,071.39	0.495	8.16E-05
Convert tomato fields to natural habitat	9,997.87	0.706	7.06E-05
Maintain field-margins near watermelon fields	142,163.20	0.495	3.49E-06

[a] Margins effect on revenue not-significantly different than zero, but positive for tomatoes and negative for rain-fed wheat.

inputs or sowing wildflowers (as it is commonly promoted elsewhere; e.g. Haenke et al., 2009), can enhance biodiversity without reducing production area while benefitting farmers, as demonstrated by our results.

4.3. Cost-effectiveness of field-margins and semi-natural patches

By increasing biodiversity, uncultivated field-margins provide environmental benefits. When such benefits are not translated to economic benefits, farmers lack the incentive to provide the socially-optimal uncultivated field-margins (Brouwer, 1999; Pretty et al., 2000). Of the seven crop types examined, only citrus orchards showed a positive effect of proportion of uncultivated field-margins on farmers' revenue, creating a win-win opportunity for farmers and biodiversity. Other orchards were not significantly affected by this ecological practice, indicating a win-no-loss situation. Pywell et al. (2015) showed that the positive effects on yield in areas out-of-production appeared after four years, so the benefits to farmers might increase over time. One of those potential benefits is biological pest control, since arthropod diversity was high in field-margins. This can benefit the farmers if it increases populations of natural enemies more than it increases pests (Bianchi et al., 2006). Our results show that field-margins maintain a natural-enemy to pest ratio equal to semi-natural patches, and higher than orchard cover-crops. A possible explanation is that field-margins are wider, receive less herbicide, and persist for a longer period as opposed to cover-crops, which are cut early in spring.

These potential benefits from pest-control were not always translated to reduction in production costs (e.g. less pesticide) or higher yields. In most irrigated field-crops, cost-effectiveness of field-margins was lower than converting production areas to semi-natural patches, as a result of relatively high revenue loss in irrigated wheat and watermelon crops. One possible explanation is that natural enemies are abundant in field-margins but do not enter the crop at a rate similar to pests (Tscharntke et al., 2016). This mechanism is partly supported by the lack of correlation between the enemy-to-pest ratio in the field and the proportion of natural vegetation around the field. Other reasons could include the use of pesticides in fields, or the low effectiveness of natural enemies. Tomato crops were the only irrigated crop in which revenue was positively affected by uncultivated field-margins, though not significantly, indicating that ecological intensification might be possible for some intensive irrigated crops and contribute to their high cost-effectiveness. Better management of field-margins to suite targeted taxa was previously shown to increase biodiversity and possibly even yield (Pywell et al., 2015, 2012). For instance, increasing floral nectar by sowing wildflowers benefits many invertebrate natural enemies (Kishinevsky et al., 2018). Promoting such practices can enhance the cost-effectiveness of field-margins to both farmers (via pest control) and biodiversity conservation.

Unlike irrigated field-crops, in extensive rain-fed wheat, the cost-effectiveness of field-margins was higher compared to semi-natural patches because there was no revenue loss caused by the uncultivated field-margins. These represent a win-no-loss situation similar to some orchards, with implications favoring the maintenance of field-margins and reduction of inputs. Furthermore, due to the low profitability of rain-fed wheat, the cost-effectiveness of creating semi-natural patches in rain-fed areas was higher than maintaining field-margins in the intensive irrigated cropland. This creates an opportunity to reduce revenue loss by diverting some of the conservation efforts to rain-fed crops. Finally, semi-natural patches in this region are grazed and generate income that we did not include in our analysis. Taking this income into account, or reducing stocking rates, would further increase the cost-effectiveness of semi-natural patches compared to field-margins.

4.4. Conclusions

Analyzing costs and benefits at a large scale for several crop types and taxa illustrates a rather complex system and shows that there is no one-size-fits-all solution. In our analysis we could not control for all benefits provided by field-margins (e.g. pollination, nutrient retention and soil erosion control). Additionally, at such scales there are many more variables affecting biodiversity and economic measures than we could control for. Nevertheless, our approach provides some general insights on the warranted solutions. First, high variation in costs among crop types and in ecological effectiveness among taxa call for mixed-solution programs; these should promote the enlargement of semi-natural patches, which are generally more cost-effective, and be supported by wildlife-friendly farming where sociological and economic conflicts are small. Furthermore, compensation schemes for farmers will be required in some cases, since benefits from ecosystem services are not translated to lower costs and do not compensate for lower yields in many crop types. In other cases, the high cost-effectiveness of field-margins allows for win-win solutions which should be promoted with knowledge and guidance to farmers at no cost and create opportunity for profit increase. These results illustrate the usefulness of cost-effectiveness analysis for tailoring optimal practices for a given agro-ecological context to maximize biodiversity conservation at minimal cost to farmers.

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Appendix A. Supplementary data

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