



## Semi-desert fruit farms harbor more native flora than Mediterranean climate farms in central Chile

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### ABSTRACT

Understanding the factors that affect native plant communities is essential to protect floristic diversity, particularly in Mediterranean agroecosystems. The Chilean Mediterranean-climate area supports high species richness and levels of endemism, and harbors the main fruit production. We investigated whether the richness of native and non-native flora differs between two Mediterranean climate areas of Chile with contrasting rainfall levels in both cultivated and uncultivated habitats. Thirteen fruit farms under conventional management were prospected in the spring of 2015 and of 2016 by sampling in square meter quadrants (N = 3,630). A total of 191 vascular plants were found, 48.2 % of them native, 50.3 % non-native and 1.6 % not identified. Species richness was low in both areas and habitat types. However, there were more native species in uncultivated habitats in the Mediterranean-to-desert transition area than in the mesic Mediterranean area, and the contrary was observed for non-native species. Our results suggest that wetter Mediterranean climate areas are more prone to the establishment of non-native plant species.

**Keywords:** agroecosystems, exotic species, native flora, non-crop habitats, plant species richness

## Introduction

Agriculture is closely related to plant conservation worldwide. It is also one of the main factors negatively affecting biodiversity, given the conversion/destruction of natural habitat for agriculture, causing toxification from pesticides and fertilizers and generation of greenhouse gases from fossil fuel use (Chappell & LaValle 2011). Plant diversity has declined significantly on agricultural land in Europe (Waldhardt *et al.* 2003) and North America (Boutin & Jobin 1998) in recent decades. The intensification of agriculture is considered one of the main drivers of invasive plant species because of the intense levels of propagule pressure and disturbance (Chytrý *et al.* 2008; Gassó *et al.*

2012; Clotet *et al.* 2016). Agricultural fields can function as sources of weeds that invade neighboring habitats and reduce native plant diversity (Boutin *et al.* 2008).

A better understanding of the specific factors that affect native plant communities is increasingly important, considering the growing loss of biodiversity globally (Carboni *et al.* 2010). The number, cover and composition of plant species varies among agroecosystems according to farm practice, habitat type and geographic location (Boutin & Jobin 1998; Armengot *et al.* 2012). In areas within or adjacent to intensively farmed plots, herbaceous weeds are expected to predominate in species richness and abundance, given their capacity to tolerate and adapt to agricultural practices (Boutin & Jobin 1998). It is known that the establishment, dispersal and distribution of non-native

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species respond to biological factors such as competition, but also to environmental factors like precipitation and soil nutrients and to disturbances of anthropic origin (Carboni *et al.* 2010; Chen *et al.* 2016). Variation in precipitation appears to be an important predictor of plant invasion, but more research is needed to determine if precipitation favors plant invasion (Bradley *et al.* 2010; Chen *et al.* 2016). The successful establishment of non-native species in an ecosystem does not necessarily imply the reduction of richness in native species, when biotic factors are not predominating, and species richness may be promoted by environmental factors that also promote invasion (Alpert *et al.* 2000; Gilbert & Lechowicz 2005). But negative correlations between native and non-native species are expected when biotic factors like competition are important in the naturalization process (Martín-Forés *et al.* 2015).

Mediterranean climate areas hold a particularly rich and endemic flora, and therefore are important from the perspective of conservation. Areas with Mediterranean climates represent less than 5 % of the Earth's land surface, while hosting almost 20 % of vascular plants. However, these ecosystems have dense human populations and long-term development of agriculture and animal husbandry (Cowling *et al.* 1996). Agriculture, urban areas and population density are considered threats to biodiversity in the Mediterranean biome (Underwood *et al.* 2009). However, the Mediterranean basin has suffered anthropogenic landscape alterations for thousands of years, while other Mediterranean climate areas such as central Chile have suffered intensive human alterations threatening their biodiversity for a much shorter time (Martín-Forés *et al.* 2015).

High levels of species richness and endemism as well as threats to conservation of the biota in Chile are concentrated in the Mediterranean climate area, which is recognized as one of the world's biodiversity hotspots (Myers *et al.* 2000). A dramatic widespread substitution of the vegetation of Central Chile by non-native plantations and agriculture has occurred during the last decades (Moreira-Muñoz 2011). Extensive goat grazing has strongly affected the vegetation in the northern part of Mediterranean climate area (Pozo *et al.* 2006). Chilean Mediterranean climate flora has a high level of species richness relative to surface area (ca. 2,500 species in 155,000 km<sup>2</sup>) and diversified plant genera; nearly 50 % of the species are endemic to the area (Marticorena 1990). The vegetation is also diversified, with plant communities ranging from semi-desert to forest vegetation (Arroyo 1999).

Less than five percent of the regional surface of the Mediterranean climate area is part of the national system of protected areas, and their plant communities are the least represented (Luebert & Plissock 2006). Agriculture is also concentrated in the Mediterranean climate part of Chile, according to the most recent National Agricultural Census. Around 77 % of fruit farms and 90 % of vineyards are located in valleys between the Coquimbo (29° S) and Bío-Bío Regions (38.5° S), with a characteristically Mediterranean climate (INE

2007). Climate conditions in that wide latitudinal range differ from the xeric conditions in the desert-to-Mediterranean transition area in the north and the rainier conditions at more southern latitudes (Luebert & Plissock 2006).

Consideration of agricultural lands for biodiversity conservation is recognized as a "land-sharing approach" in contraposition to a land-spare one (Phalan *et al.* 2011). And although not all farmlands are suitable for that purpose, some criteria like landscape structure can guide the choice towards one or the other (Baudron & Giller 2014). Many fruit farms in Chile have large uncultivated areas (even larger than cultivated ones) under private ownership, which could contribute to biological conservation.

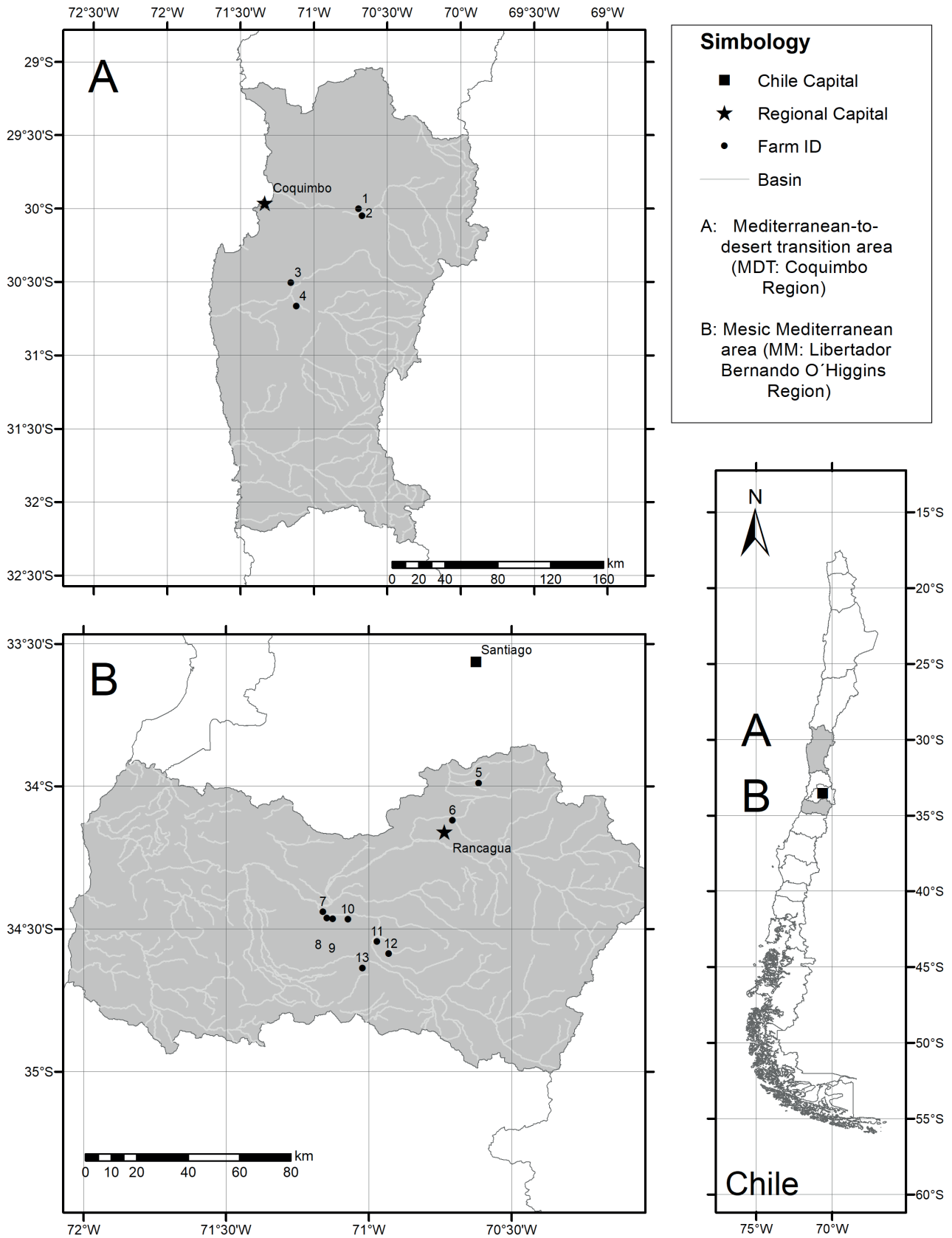
The aim of this study is to evaluate the potential contribution of fruit farms located in the Mediterranean climate of Chile to conservation of native vascular flora, and to what extent the plant community is dominated by non-native species. Specifically, we assessed the native and non-native plant species richness in fruit agroecosystems and their variation, within the farms (in cultivated *versus* uncultivated habitats), and between farms located in two different Mediterranean climate areas about 400 km apart in latitude. We assessed the interaction between native and non-native species richness in the areas and habitats. To highlight the importance of intra-farm habitats, we classified the species according to biogeographic origin, conservation status and whether they are considered weeds in Chile. We hypothesize that species richness of non-native species, mainly weeds, will be higher in cultivated habitats in both areas, while native species dominate uncultivated habitats. We also hypothesized that native species in uncultivated habitats vary between these two distant areas.

## Materials and methods

### Study area

Thirteen fruit farms were prospected. Four farms are located in valleys in the Coquimbo Region (30.3° S), in the Mediterranean-to-desert transition area (MDT), while the other nine are in valleys in the O'Higgins Region (34.3° S), in the mesic Mediterranean area (MM; Fig. 1). Annual rainfall in the valleys in the Coquimbo Region is around 85 mm (average between Vicuña and Ovalle stations over the last decade (Dirección General de Aguas 2017); while annual rainfall in the valleys in the O'Higgins Region is around 500 mm (526 mm on average in Coltauco over the last decade (Dirección General de Aguas 2017). The first soil component of the farms in the Coquimbo Region is eutric leptosols or petric calcisols, associated with eutric cambisols and eutric fluvisols, respectively. The first soil component of the farms in the O'Higgins Region is petric calcisols or chromic luvisols, associated with eutric fluvisols and calcic vertisols (FAO 1998; Batjes 2005).







Farms cultivate mainly table grapes (10 of the 13 farms) and citrus fruit. The size of cultivated areas ranges between 15 and 223 ha (Median = 48 ha), and total farm areas are between 17 and 985 ha (Median = 60 ha). The farms are under conventional management with the application of fertilizers and herbicides. The most commonly applied herbicides are Glyphosate and Flumioxazim (both broad-spectrum); they are applied in late winter and spring.

### Data collection

Two intra-farm habitats were distinguished: cultivated habitats (C) and uncultivated habitats (UC). Uncultivated habitats on farms (when available) feature semi-dense shrubland and some sclerophyllous forest only in the MM zone. Different plant formations were observed and distinguished by freely available satellite imagery (Google Earth ©). Fruit crops in C habitats and plant formations on adjacent UC habitats (there were a maximum of two vegetal formations per farm) were prospected using transects (see Fig. S1 in supplementary material). Transects were used to assess species richness. Each transect was composed of ten quadrants (one square meter each) arranged in a line with a separation of 0.5 m between them. Species richness was determined based on the number of species per quadrant.

To obtain the minimum number of transect repetitions in C and UC habitats, previous study based on data collected in the majority of farms showed that a minimum of seven transects per UC habitat and five transects per C habitat were sufficient to cover the full degree of variability (Ramírez 2015). According to this result, seven transects were analyzed for each UC habitat, and 15 and 10 transects in the C habitat of the MM and MDT areas, respectively.

All individuals identified to the species level were classified according to three criteria: biogeographic origin (native, non-native, endemic), conservation status following the national classification system (RCE; *i.e.*, Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT) and Least Concern (LC)), and whether the species is considered as a weed in Chilean agroecosystems (Matthei 1995). According to Matthei (1995), weeds are plants that compete with crops directly or are harmful to people and/or other animals. The nomenclature of plants follows the on-line “Catalog of the Vascular Plants of Southern Cone Flora” by the Darwinian Botany Institute (Instituto de Botánica Darwinion 2017) and the “Catalogue of the vascular plants of Chile” for common names (Rodríguez *et al.* 2018).

Vascular flora in farms was sampled over 21 days of fieldwork, in September 2015, in the MM area and in August 2016, in the MDT area. The difference of one month in the sampling dates between the two areas reflects the fact that the phenology of at least the same fruit crops is more advanced in the MDT area. Rainfall levels up to the sampling date were normal (*i.e.*, between average and standard

deviation of the previous ten years) in both sampling areas (Dirección General de Aguas 2017).

### Statistical analysis

To assess the difference in plant species richness, we built generalized linear mixed models (GLMM) using plant species richness per quadrant as the response variable, habitats (uncultivated *vs.* cultivated) and areas (Mediterranean-to-desert transition area *vs.* mesic Mediterranean area) as fixed effect terms, and fruit farms as the random effect term. Since richness was measured on individual quadrants within transects, the random effect was nested by transects. A top-down selection model was performed from the complete GLMM model with the Habitat-Area interaction, defined as follows:

$$\text{Richness} \sim \text{Habitat} + \text{Area} + \text{Habitat}:\text{Area} + (1 \mid \text{Farm}/\text{Transect})$$

The model selection was based on the Akaike information criterion (AIC) and model validation was based on the graphic representation of residuals (Zuur *et al.* 2009; Barbizan Sühs *et al.* 2018). We chose the Poisson error distribution (log link) for all models because it fitted the residuals better visually than the negative binomial distribution. The analyses were conducted for native and non-native plant species richness independently. All analyses were run with the software R 3.6.2 (R Development Core Team 2019) using the packages ‘*glmmADMB*’ (Skaug *et al.* 2016) for GLMMs, and ‘*gplots*’ (Warnes *et al.* 2020) for the graphic representation.

To evaluate the possible synergy or trade-off between native and non-native species, the correlation between species richness was analyzed in total and within each area. For that purpose, Pearson correlation coefficients were calculated using the packages ‘*stats*’ (R Development Core Team 2019), and ‘*ggplot2*’ (Wickham 2016) for the graphic representation.

## Results

### Flora

A total of 191 vascular plant species belonging to 62 families were found in the 3,630 quadrants on fruit farms (Tab. S1 in supplementary material). Forty-three species were present in both MDT and MM areas. The families with the largest numbers of species were Asteraceae (31 species), Poaceae (19) and Fabaceae (13). The majority of species were herbaceous plants (131), followed by shrubs (31) and trees (25). Four succulent species and one parasitic species were also found. Herbaceous plants were the most common in both C (86.3% of all species) and UC (65.7%) habitats. Eighty species (41.9%) of the flora of the two areas are considered weeds (Matthei 1995).



A total of 115 species were identified in the MDT area, 112 of which were classified to species; 66 (57.4%) are native species, 32 of them also endemic, while 46 (40.0%) are non-native species. The three other species were not classified by origin since they were identified only to genus, represented by native and non-native species in the area (Tab. S1 in supplementary material). About a third of the species in the MDT area (34.8%) were weeds (mainly non-native, five of them native) and were found mainly in C habitats (66% of the species found in C habitats vs. 20.9% of species in UC habitats). A total of 119 species were found in the MM area, 40 (33.6%) were native species (17 endemics to the Chilean Mediterranean climate flora), and 79 (66.4%) were non-native species. More than half the surveyed species in this area were weeds (57.1%; mainly non-native, five native), predominating in both habitats (83.3% of the species in C habitats and 56% in UC habitats).

Seven species (6.0%) in the MDT area are considered threatened; these are three cactus species (the 'jalajala', *Cumulopuntia sphaerica*, the 'copao', *Eulychnia acida* and the 'quisco coquimbano', *Trichocereus coquimbano* (Cactaceae)), two other dicotyledonous species (the 'carbonillo', *Cordia decandra* (Boraginaceae) and the 'palo santo' *Porlieria chilensis* (Zygophyllaceae)), and two pteridophytes (the 'palito negro', *Adiantum chilense* and the 'doradilla', *Cheilanthes mollis* (Pteridaceae)). Only one species in the MM area is considered threatened, the pteridophyte *A. chilense*.

Non-native annual and biannual herbaceous species were most frequent (in terms of number of quadrants with presence) in C habitats in both areas (Tab. 1). In order of importance the families were Poaceae (unidentified grasses), Asteraceae (the 'hierba cana', *Senecio vulgaris*), Convolvulaceae (the 'correhuela', *Convolvulus arvensis*), Fumariaceae (the 'hierba de la culebra', *Fumaria agraria*) and Brassicaceae (the 'mostacilla', *Hirschfeldia incana*). All

are considered weed species that damage crops (Matthei 1995). These species have a wide distribution range in Chile, capable of adapting to different conditions; *S. vulgaris*, *C. arvensis* and *F. agraria* are considered invasive species in the country (Fuentes *et al.* 2014). The most frequent were half introduced and half native species, including a threatened cactus species (*C. sphaerica*) in UC habitats in the MDT area. Introduced herbaceous and woody species were the most frequent in UC habitats in the MM area (Tab. 1). The 'boldo', *Peumus boldus* Molina (Lauraceae), a tree common to sclerophyllous forests, was the only native species among the ten most common species in UC transects in the MM area.

### Species richness

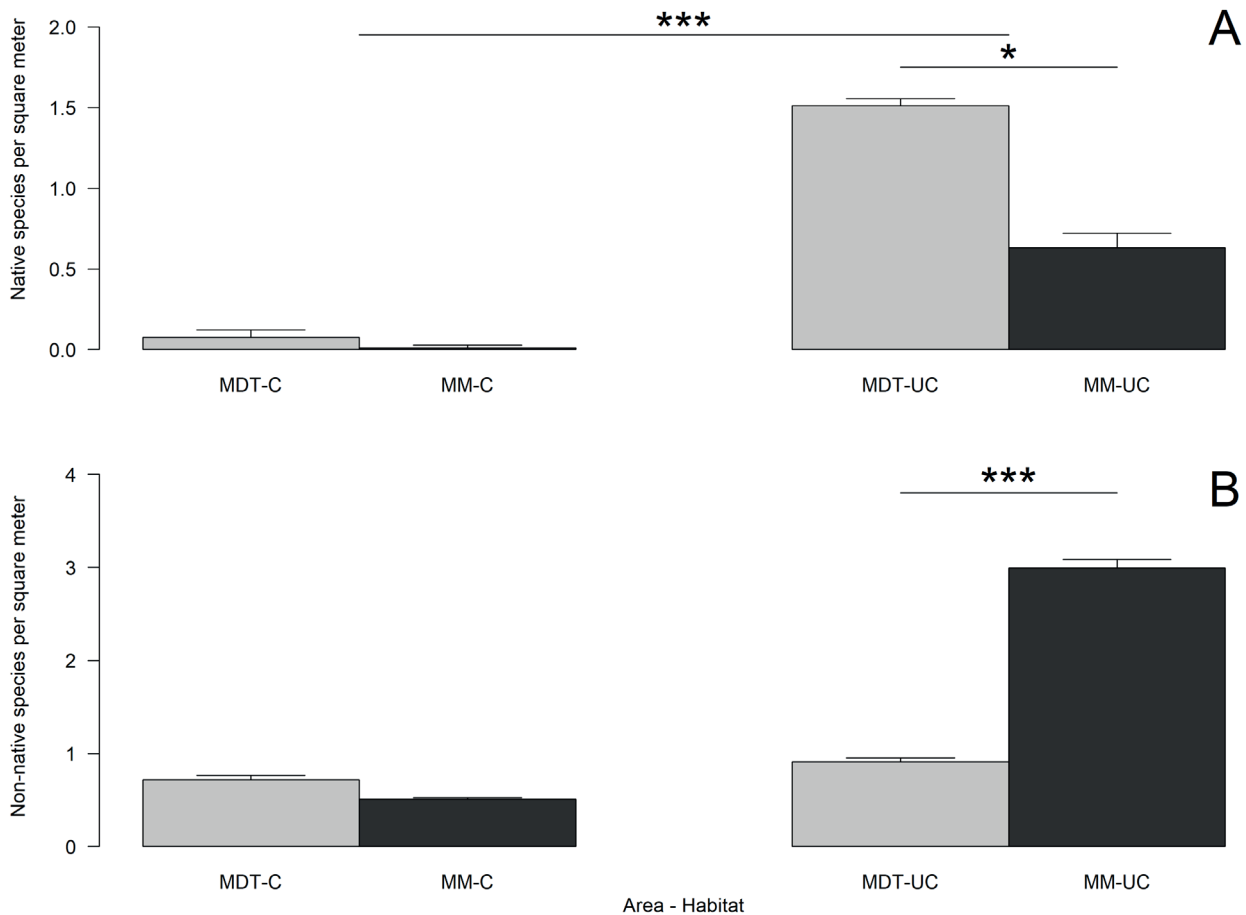
To assess the difference in native species richness, the GLMM without interaction was selected due to its lowest AIC (2745); the residuals were visually adequate (Fig. S2 in supplementary material). Native species richness was higher in the UC habitats (mean=1.13 ±0.04) than in the C habitats (mean=0.02±0.002) (estimate = 3.51, Std. Error = 0.21, z= 16.93, P<0.0001), and higher in the MDT area (mean=0.91 ±0.04) than in the MM area (mean=0.11±0.01) (estimate = -1.94, Std. Error = 0.62, z= -3.14, P<0.002). Within the UC habitats, native species richness was higher in the MDT area (mean=1.51±0.05) than in the MM area (mean=0.63±0.05) (estimate = -1.43, Std. Error = 0.65, z=-2.22, P=0.027) (Fig. 2).

To assess the difference in the non-native species richness, the GLMM, including the Habitat-Area interaction, was selected based on its lowest AIC (7030) and visually adequate residuals (Fig. S3 in supplementary material). Neither fixed effect was significant, but the Habitat\*Area interaction was significant (estimate = 2.25, Std. Error = 0.29, z= 7.75, P<0.0001). In the UC habitat, non-native species richness was higher in the MM area than in the MDT

**Table 1.** Biogeographic origin, weed status (yes or no), life-form, and frequency (*i.e.*, percentage of quadrants with presence) of the most frequent plant species, according to area (MDT: Mediterranean-to-desert transition area; MM: mesic Mediterranean area) and intra-farm habitat (C: cultivated; UC: uncultivated).

Area	Habitat	Species	Origin	Weed	Life-form	Frequency (%)
MDT	C	Poaceae 1	unknown	unknown	herbaceous	16
		<i>Hirschfeldia incana</i> (L.) Lagr.-Foss.	non-native	yes	herbaceous	12.4
		<i>Euphorbia serpens</i> Kunth	non-native	yes	herbaceous	11.2
		<i>Helminthotheca echioides</i> (L.) Holub	non-native	yes	herbaceous	10
	UC	Poaceae 1	unknown	unknown	herbaceous	32.4
		<i>Erodium cicutarium</i> (L.) L'Hér. ex Aiton	non-native	yes	herbaceous	29.6
		<i>Gutierrezia resinosa</i> (Hook. & Arn.) S.F. Blake	endemic	no	shrub	18.0
		<i>Cumulopuntia sphaerica</i> (C.F. Först.) E.F. Anderson	native	no	succulent	13.9
MM	C	<i>Senecio vulgaris</i> L.	non-native	yes	herbaceous	7.5
		<i>Convolvulus arvensis</i> L.	non-native	yes	herbaceous	7.4
		<i>Fumaria agraria</i> Lag.	native	yes	herbaceous	6.9
		<i>Lolium multiflorum</i> Lam.	non-native	yes	herbaceous	3.6
	UC	<i>Rubus ulmifolius</i> Schott.	non-native	yes	shrub	12.9
		<i>Eucalyptus globulus</i> Labill	non-native	no	tree	11.4
		<i>Ulmus americana</i> L.	non-native	no	tree	10.7
		<i>Poa annua</i> L.	non-native	yes	herbaceous	9.8





**Figure 2.** number of species (mean + standard error) per square meter. **A)** for native species between Mediterranean-to-desert transition area (MDT) and mesic Mediterranean area (MM), within cultivated (C) and uncultivated (UC) habitats; **B)** for non-native species between MDT and MM areas, within C and UC habitats. Three asterisks mean significance below 0.0001, and one asterisk means significance below 0.05.

area (estimate = 1.42, Std. Error = 0.39,  $z = 3.63$ ,  $P < 0.001$ ), whereas the difference was not significant in the C habitat (estimate = -0.75, Std. Error = 0.50,  $z = -1.49$ ,  $P = 0.14$ ).

Finally, the Pearson correlation coefficient between the numbers of native and non-native species quadrants was 0.152 ( $P < 0.0001$ ) for all data, and 0.07 ( $P = 0.035$ ) and 0.32 ( $P < 0.001$ ) for MDT and MM areas, respectively (Fig. 3).

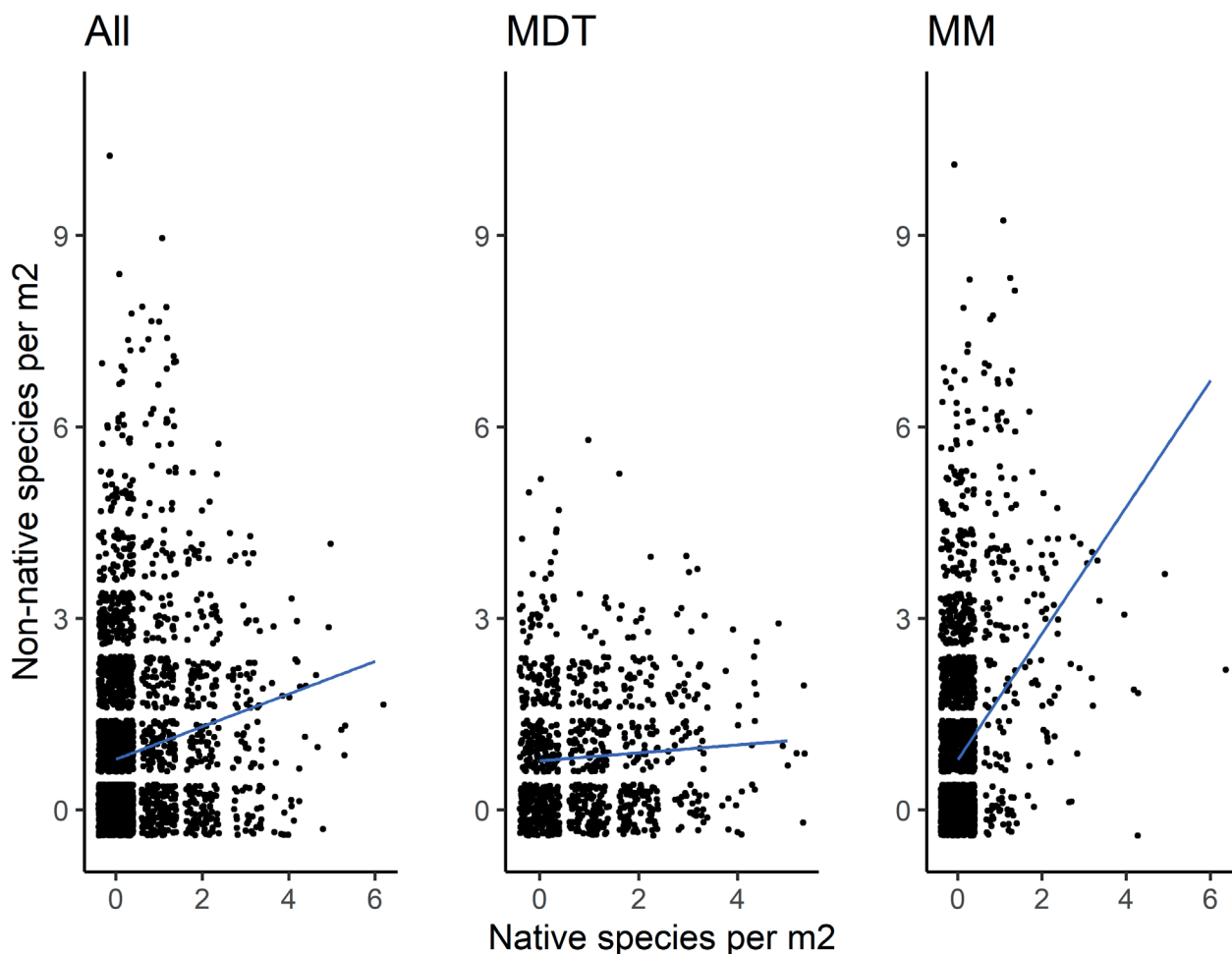
## Discussion

Our study showed that there were more native species in uncultivated habitats, and in uncultivated habitats in the Mediterranean-to-desert transition area than in comparable habitats in the mesic Mediterranean area. Species richness was generally low in both areas and habitat types, with most species considered as weeds (around 90 % non-native) in the prospected conventional fruit farms in central Chile compared to other Mediterranean-climate-type areas (e.g., Alpert *et al.* 2000).

Native flora is poorly represented in these agroecosystems under agricultural activity. A similarity analysis of the flora

on the farms and characteristic native species of a reference ecosystem (according to Luebert & Pliscoff 2006) found less than 10 % of species shared in the MM area (Arcos 2015). Non-native weed plants (*i.e.*, crop contaminants) predominate in C habitats, but also predominate in UC habitats in the MM area. Our results on average native species richness (0.02 and 1.13 species/m<sup>2</sup> in C and UC habitats, respectively) are similar to other surveys in Mediterranean climate areas of Chile within sites planted with or invaded by *Eucalyptus globulus* (Becerra *et al.* 2018). This seems to be one more indication that the native vegetation in the central valley of the Mediterranean areas of Chile has been replaced (Becerra 2016).

We found richness in both native and non-native species in cultivated habitats to be low, as expected. This may be a result of the application of broad-spectrum herbicides used in these farms. Native species richness in uncultivated habitats was higher in the Mediterranean-to-desert-area than the mesic Mediterranean area. Conversely, more non-native species were found in UC habitats in mesic Mediterranean area, which has a wetter climate. One possible explanation is the difference in annual precipitation between these



**Figure 3.** Scatter plots of correlation for native and non-native species according to areas (All data, MDT: Mediterranean-to desert transition area, and MM: mesic Mediterranean area).

areas. Annual precipitation has been identified as the most significant factor favoring non-native plant richness in other Mediterranean ecosystems in Europe and also in central Chile (Carboni *et al.* 2010; Martín-Forés *et al.* 2015). Water stress makes habitats less vulnerable to invasive non-native plant species (Alpert *et al.* 2000). Our results, in concordance with those of Martín-Forés *et al.* (2015), suggest that wetter Mediterranean-climate areas in Chile are more prone to the establishment of non-native species.

The numbers of native and non-native plant species were significantly positively correlated. This result suggests that competition is not an important factor in the establishment of non-native species (Martín-Forés *et al.* 2015), and non-native species richness might be responding to environmental factors (Gilbert & Lechowicz 2005), probably annual rainfall. Congruently, the correlation was stronger in MM area compared with MDT area, where there is more water availability.

In our study we only compared between two areas. Therefore, future studies should confirm if the vulnerability to invasion of weeds from crops is affected by rainfall, contrasting more sites or experimentally. This is particularly important in

Chile because most Chilean fruit farms are located in the part of the country with the highest levels of plant species richness and endemism, but also where flora is most threatened (Muñoz & Vianna 2012). Protected areas constitute less than 4% of the surface area in the Chilean regions with Mediterranean bioclimate compared to half of the area in Chilean Patagonia (CONAF 2017). Therefore it is recognized that efforts must go beyond protected areas for biological conservation to be effective (Simonetti *et al.* 2002). Farms in Chile are more extensive than in other agroecosystems such as Europe; a significant part of them may not be cultivated and could contribute to biological conservation. The most common non-native species in cultivated habitats are invasive species in Chile with high invasive potential (Fuentes *et al.* 2014). If annual rainfall is influencing the degree to which non-native species from adjacent crop plots can successfully establish in adjacent uncultivated areas, some agroecosystems would be more prone to invasion and consequently deserve more attention in terms of conservation.

Knowledge about the biodiversity on farms is also important for people involved in fruit production. Much of Chilean agriculture, in particular fruit production, is for



export (Muñoz *et al.* 2016). Concern has recently emerged among consumers about biodiversity in agroecosystems. As a result, the agricultural export sector must comply with the standards and requirements to reach target markets. However, producers generally know little about the biodiversity on their farms (Muñoz *et al.* 2016). In contrast, biodiversity in agroecosystems in developed countries has been well studied because of support for agro-environmental and green policies (Aviron *et al.* 2011; German Federal Environmental Agency 2014). This is not the case for developing countries, many of which are important reservoirs of plant diversity. Consequently, farmers in developing countries face increasing requirements relating to these issues in the context of more demanding markets. From the producers' perspective this represents more demands, but we consider that it is good news for biological conservation. Nonetheless, according to our results cultivated plots under conventional management are not suitable habitats for native species and are not habitats for practically any plant. The majority of the quadrants surveyed in cultivated habitats had no plants (61.4 % of quadrants in C habitats and 4.9 % in UC habitats) because of herbicide applications. Therefore, restoration with native species or any effort for conservation should be undertaken in uncultivated areas within farms.

In this study we found low and not homogeneously distributed species richness in both areas and habitat types in fruit farms. There were more native species in uncultivated habitats in the Mediterranean-to-desert transition area than in the mesic Mediterranean area, and the contrary was observed for non-native species. Native and non-native plant species were positively correlated, suggesting that competition is not a relevant factor, and non-native species richness may respond to environmental factors such as annual rainfall. This study is an initial contribution to understanding the underlying patterns of native plant assemblages in agroecosystems in this Mediterranean climate hotspot.

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