



A simultaneous assessment of multiple ecosystem services and disservices in vineyards and orchards on Terceira Island, Azores

Marco Ferrante^{a,*}, Lucas Lamelas-López^a, Rui Nunes^a, Paulo Monjardino^b, David J.H. Lopes^a, António Onofre Soares^c, Gábor L. Lövei^{a,d}, Paulo A.V. Borges^a

^a Ce3C - Centre for Ecology, Evolution and Environmental Changes, Azorean Biodiversity Group, Faculty of Agricultural Sciences and Environment, University of the Azores, PT-9700-042 Angra do Heroísmo, Portugal

^b CBA - Biotechnology Centre of Azores, Faculty of Agricultural Sciences and Environment, University of the Azores, PT-9700-042 Angra do Heroísmo, Portugal

^c Centre for Ecology, Evolution and Environmental Changes and Azorean Biodiversity Group, Faculty of Sciences and Technology, University of the Azores, PT-9500-321 Ponta Delgada, Portugal

^d Department of Agroecology, Aarhus University, Flakkebjerg Research Centre, Forsøgsvej 1, DK-4200 Slagelse, Denmark

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ABSTRACT

Monitoring ecosystem processes resulting in ecosystem services (ESs) and disservices (EDs) is crucial in agricultural ecosystems. Traditionally, ESs/EDs provided by arthropods have been estimated indirectly by measuring arthropod abundance and diversity, overlooking the recognised limitations of such approach. Using a consistent methodology based on the sentinel approach, we quantified the intensity of five ecological processes leading to four ESs and two EDs in vineyards and citrus orchards on Terceira Island, Azores. We assessed herbivory rates on lettuce plants (ED), predation rates on green plasticine caterpillars by vertebrates and invertebrates (ES), the intensity of insect pollination on strawberry plants (ES), the rates of predation on wheat and dandelion seeds (ED and ES, respectively) by rodents and invertebrates, and decomposition rates using tea and rooibos leaves (ES). Herbivory rates after 2 weeks were significantly lower in vineyards (mean \pm SD; $0.5 \pm 0.6\%$) than in citrus orchards ($3.6 \pm 2.9\%$). Vertebrate predation rates in vineyards ($4.0 \pm 13.6\% \text{ d}^{-1}$) were significantly higher than in citrus orchards ($2.4 \pm 10.7\% \text{ d}^{-1}$), while no differences were observed for overall and invertebrate predation rates. Pollination efficiency in vineyards (214.5 ± 23.9 seeds/fruit) was significantly higher than in citrus orchards (162.0 ± 14.7 seeds/fruit). Seed predation rates were higher, although not significantly so, in citrus orchards ($2.0 \pm 5.8\% \text{ d}^{-1}$) than in vineyards ($0.3 \pm 0.8\% \text{ d}^{-1}$). Decomposition was significantly higher on tea than on rooibos leaves, both in vineyards (1.15 ± 0.11 g vs. 0.72 ± 0.16 g) and citrus orchards (1.34 ± 0.06 g vs. 0.78 ± 0.13 g); no differences between mass loss in the two habitats were observed. Our results demonstrated the suitability of simple, direct monitoring tools for a quantitative comparison of agricultural habitats, confirm that landscape complexity does not always support ESs, and that the same agro-ecosystem characteristics that support ESs could occasionally also favour EDs.

1. Introduction

Ecosystem services (ESs) are the outcome of ecological processes provided by natural systems (Kadykalo et al., 2020; Leemans and Groot, 2003). While the recognition of the existence and importance of ESs is not very old (Daily, 1997), nowadays it is universally accepted that they are indispensable for human societies (Clinton et al., 2018; Sutton et al., 2016). Processes leading to ESs such as biological control and pollination are particularly valuable in agro-ecosystems. The estimated global

value of natural pest control is $>$ US\$400 billion y^{-1} (Heimpel and Mills, 2017), and that of pollination ca. US\$153 billion y^{-1} (Gallai et al., 2009). Sustainable agricultural management approaches, such as integrated pest management (Ameixa et al., 2018; Barzman et al., 2015; Kogan, 1998; Noriega et al., 2018) and ecological intensification (Bommarco et al., 2013) aim at protecting and enhancing ESs. Ecosystems, however, also provide disservices (EDs) that are detrimental to agriculture and forestry activities and thus can harm humans (von Döhren and Haase, 2015). These can result from ecological processes that either do direct

* Correspondence to: Ce3C - Centre for Ecology, Evolution and Environmental Changes, Azorean Biodiversity Group, Faculty of Agricultural Sciences and Environment, University of the Azores, PT-9700-042 Angra do Heroísmo, Portugal.

E-mail address: marco.ferrante@live.it (M. Ferrante).

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harm to humans or reduce the provision of ESs, causing indirect harm (Vaz et al., 2017). The economic value of these can also be substantial. For instance, invasive species in China are responsible for an estimated economic loss of nearly US\$19 billion y^{-1} (Wan and Yang, 2016) and US \$ 120 billion y^{-1} , in the USA (Pimentel et al., 2005). Malaria, which is transmitted by *Anopheles* mosquitoes, was responsible for more than 400,000 deaths in 2018 (World Malaria Report, 2019).

Quantifying and monitoring ESs and EDs is a growing field of research. The motivation behind this is the existence of multiple threats to ESs and a growing reliance on them (Carpenter et al., 2009). Additionally, global biodiversity is disappearing at a rate characteristic of a mass extinction (Dirzo et al., 2014; Sánchez-Bayo and Wyckhuys, 2019) and, unsurprisingly, this has negative consequences on many ESs (Leemans and Groot, 2003; Swiss Re Institute, 2020). These concerns culminated in the establishment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Moreover, enhancing ESs is part of the Aichi Biodiversity Targets and the Sustainable Development Goals (Mace et al., 2018; Wood et al., 2018).

Monitoring ESs and EDs is challenging. In some cases, such as soil respiration (Karhu et al., 2014), or carbon sequestration (Villa and Bernal, 2018), this is done by directly measuring a functional response without examining the organisms who are responsible for the service. More frequently, however, various proxies are used to characterise the level of ES/ED provision, most commonly the abundance and/or diversity of (presumed) ES or ED providers (Shackelford et al., 2013). This approach is prevalent in arthropod studies, where there is a long tradition of employing monitoring tools that census individuals and communities (Henderson and Southwood, 2016). Given that biodiversity maintains ecological processes that can translate to ESs (the cascade model, Potschin and Haines-Young, 2016), estimating the level of ESs using such conventional techniques is tempting, although potentially incorrect. The abundance or diversity of ES providers and the intensity of ecosystem processes do not always correlate. An apparent lack of correlation may exist because of limited spatial and temporal scales of the study because observations taken in a single place or year may underestimate the importance of individual species (Isbell et al., 2017, 2018). An actual lack of correlation can occur, depending on the species' ecological traits (Perović et al., 2018) or their functional response (e.g. Honěk et al., 2005). Moreover, antagonistic interactions within guilds are frequent and can modify the relationship between the abundance and diversity of the ES providers, leading to a disruption in the provided ESs (Aebi et al., 2011; Rusch et al., 2015). Therefore, rather than relying on proxies, adopting tools that allow a direct assessment of ESs and EDs is essential to obtain reliable estimates.

In agricultural environments, most published studies focus on a single, or few, ESs and rarely on EDs (Nieto-Romero et al., 2014; Seppelt et al., 2011). Ecosystems, however, provide multiple ESs and EDs, making synergies and trade-offs unavoidable (Bennett et al., 2009; Lee and Lautenbach, 2016). To reflect the complexity of agricultural systems we need a monitoring approach based on multiple tools that allow quantifying ecosystem processes in a consistent way. The sentinel approach, being based on standardisable, simple, and mostly low-tech tools has the potential to serve this purpose. A "sentinel" represents an element of the community (e.g. a plant, a prey) that is exposed under field conditions to record the intensity of an ecological process (e.g. herbivory, pollination, or predation). The rationale of this approach is to obtain standardised quantitative data about the intensity of a process in order to make relative comparisons between sites and treatments rather than absolute estimates of the process. This methodology allows controlling for most experimental conditions, such as the sentinel features, their density, and the exposure time; and it is suitable to obtain interpretable and comparable quantifications of natural interactions between habitats, ecosystems, or the effects of different treatments on multiple ecosystem processes. In this study, we used direct monitoring tools based on the sentinel approach to evaluate the intensity of ESs and EDs in vineyards and citrus orchards on a small Macaronesian island

(Terceira, Azores).

Oceanic island communities are characterised by low species richness, and a high share of endemic and exotic species. Taxonomic groups with a limited dispersal ability fail to colonise oceanic islands, with the result that certain functional groups may be absent (Rigal et al., 2018). Due to their isolation, oceanic islands can be considered natural laboratories and have contributed enormously to the advance of ecology (Patiño et al., 2017). Their local economies are often small, and dependent on their natural capital. In spite of this, ES studies from islands are scarce (Sieber et al., 2018).

Vineyards and citrus orchards have a long tradition on the Azores. Grapevine (*Vitis vinifera*) was introduced by the first settlers (DruMONDE-NEVES et al., 2016). The cultivation of citrus fruits, particularly oranges (*Citrus × sinensis*), began soon after (Godman, 1870); the latter became the basis of the regional economy for more than a century. Both benefit from the favourable climatic conditions and are located mostly at low elevations < 200 m asl (above sea level), near the coast and settlements, and experience similar temperature and precipitation regimes. However, there are remarkable structural and botanical differences between them. Azorean vineyards consist of small enclosures (occasionally as small as 2 m × 2 m, Fig. A1) surrounded by walls constructed from volcanic rock that protect the plants from the strong maritime winds (MadruGA et al., 2015). The surface is nearly totally covered by small-to-medium size volcanic rocks left behind by recent and shallow lava flows, and the plants are rooted in restricted spaces created by pushing away stones, and grow creeping on the rocks covering the surface. Orchards are usually mixed, including various citrus fruits, bananas, and apples, often with a dense undergrowth of grasses and weeds and surrounded by hedgerows of non-native *Pittosporum undulatum* and *Banksia integrifolia*, and endemic *Morella faya* (Fig. A2).

To contrast the current tendency of single service studies, we quantified four ESs and two EDs, and to our knowledge, this is the first study of this kind on an oceanic island. Particularly, we assessed herbivory rates on a crop plant (ED), predation rates on green plasticine caterpillars by vertebrates and invertebrates (ES), the intensity of insect pollination for a crop plant (ES), the rates of predation on wheat and a weed seeds (ED and ES, respectively) by rodents and invertebrates, and decomposition rates of organic material (ES). We expected that the levels of herbivory, predation, and seed predation would be higher in orchards than in vineyards because of the characteristic, dense ground cover in orchards could enhance the microclimatic conditions for ground-active invertebrates (e.g., Mansion-VaquíE et al., 2017). Pollination service, instead, could be higher in vineyards than in orchards if pollinators concentrate their activity on the limited available resource, but could also be higher in orchards than vineyards because the local community of pollinators is richer in the more complex habitat. Finally, because temperature and moisture often explain most of the variation in litter decomposition (Keuskamp et al., 2013), we expected organic material decomposition rates to be higher in vineyards than in orchards, because the dark rocky surface creates higher soil temperatures, despite the similar macroclimatic conditions.

2. Material and methods

2.1. Study sites

The Azorean archipelago is a group of nine, geologically young (formed 6 million yBP) volcanic islands situated in the North Atlantic Ocean. Their climate is characterised by high humidity and precipitation (750–1700 mm annually) and relatively stable temperatures (13.8 °C in February, 22.3 °C in August) throughout the year. Their soils have a modern volcanic origin and are classified as andisols (MadruGA et al., 2015). The islands were originally covered by a dense humidity-preferring vegetation including several types of forest following elevation gradients present on all islands (ranging from sea level to 1000 m, Elias et al., 2016). Since the discovery of these islands at

the end of the 15th century, the native forests have been reduced to approximately 5% of their original area, mostly cleared for cattle grazing and agriculture (Gaspar et al., 2008). Our study was located on Terceira Island (38°37' N–38°48' N, 27°02' W–27°23' W), which is the third-largest island of the archipelago with an area of ca. 402 km², and 1021 m asl at its highest point.

In each agroecosystem, we selected three sites. All vineyards were located within the small vineyard region of Biscoitos in the northern part of the island. This region consists of ca. 20 ha of continuous volcanic rock enclosures within the homonymous village of Biscoitos where the main grape cultivar grown is “verdelho”. These enclosures are managed by a few families that historically produced wine and by the local wine cooperative. Within the enclosure, the groundcover is typically bare volcanic rock, with scarce cover of weeds. The three vineyard sites selected were 0.18 ha, 0.67 ha, and 0.92 ha in size and distant 0.2–1.2 km from each other. All orchards were mixed-fruit ones dominated by various *Citrus* spp. in and around the town of Angra do Heroísmo in the southern part of the island. The two smallest orchards (0.2 ha and 0.5 ha) were minimally managed, with trees growing at ca. 2 m from each other and with a dense grass undergrowth. The largest orchard (3.8 ha) was conventionally managed with regular fertiliser applications, while insecticide applications were avoided unless considered necessary, and trees were 3–5 m from each other. The minimum distance between orchards was 3 km. Orchards and vineyards were approximately 17 km distant from each other. To obtain comparable results, we sampled the agroecosystems when the crops were at the same phenological stage. The assessments were performed between March–May 2020 in the orchards and May–June 2020 in the vineyards, encompassing the flowering period and the peak of insect activity in each habitat (Table A1).

In each agroecosystem, we measured the intensity of five ecological processes leading to a suite of four ESs and two EDs, consistently following the sentinel approach. These included herbivory, predation on arthropods by invertebrates and vertebrates, pollination, seed predation, and decomposition.

2.2. Herbivory

Lettuce (*Lactuca sativa* cv. Lirice, Vilmorin seeds, La Méritré, France) seeds were germinated in a greenhouse nursery. After 2–3 weeks, healthy-looking small plants were transferred into 5 L pots with turf soil and watered regularly. After ca. 45 days six harvest-size potted plants per site were exposed to herbivory at no more than 2 m from a tree. Individual plants were at ~15 m from each other and watered as needed. After two weeks, all plants were collected and leaf damage on mature leaves was visually estimated following the recommendations by Johnson et al. (2016). Two plants (one each in the vineyards and the orchards) were rotting at collection time and thus were excluded from the analysis. Overall, we assessed 141 and 136 lettuce leaves from 34 plants in vineyards and orchards, respectively (6 plants x 3 sites x 2 habitats – 2 excluded plants).

2.3. Predation

To characterise predation, we recorded attack rates on artificial caterpillars (15 mm long, 3 mm diameter) made of green plasticine (Smeedi plus, V. nr. 776609, Denmark) following Howe et al. (2009). The caterpillars were glued to a piece of bamboo and exposed on the ground along linear transects (10–25 m) at every 2 m. After 48 h, all caterpillars were collected and any attack mark left behind by predators was categorised (i.e., invertebrate, bird, mammal, Low et al., 2014). For consistency, all caterpillars were examined by the same experienced observer (MF). To account for the length of the flowering period, the assessments were run on four occasions at fortnightly intervals in the orchards and on three occasions at weekly intervals in vineyards. These periods covered the flowering and late flowering/early fruit formation in both crops. We used 150 caterpillars per habitat at each sampling

occasion (50 caterpillars x 3 sites), except for one survey in the vineyards when we used 140 caterpillars and exposed a total of 600 caterpillars in the orchards and 440 caterpillars in the vineyards. Twenty-seven caterpillars were lost (2.6%; 14 in orchards and 13 in vineyards) and were excluded from the analysis.

2.4. Pollination

Pollination service was assessed using strawberry plants (*Fragaria x ananassa* cv. San Andreas) because its flowers can be pollinated by a wide range of insects. Plants were obtained as stolons from a local supplier, planted in 5 L pots in turf soil, and kept in the greenhouse of the University of the Azores, Angra do Heroísmo campus until they started producing buds. Once each plant had five open or nearly open buds, they were exposed in the field at no more than 2 m from a tree and watered as needed. Excess buds were manually removed. In the vineyards, each plant was placed within a 50 cm x 50 cm x 50 cm wood frame. Half of the plants were covered with a white plastic mesh (1 cm x 1 cm) that did not allow pollinators to enter, while the others were covered by a 5 x 5 cm plastic mesh that protected the plants from vertebrate damage, but allowed pollinators to visit. In the citrus orchards, half of the strawberry plants were exposed without enclosure, while pollinators were excluded from the remaining plants by covering the pot with a hanging net supported by wooden sticks. Although buds were fully covered when deployed, at the time of the collection we found that several buds grew toward the light through the net. Therefore, we had no control in this habitat. In both habitats, open and pollinator-excluded plants were placed close to each other (< 2 m). At each site, we exposed three pairs of plants at 15 m from each other, for a total of 90 flowers per habitat (3 sites x 6 plants x 5 buds). After two weeks of exposure, the plants were brought back to the greenhouse and kept until fruit maturation. Ripe fruits were collected and weighed (KERN MRS 120–3, 0.001 g). Each fruit was subsequently cut in half longitudinally and the two halves were photographed against a white background using a Nikon D7200 camera with a NIKKOR 105 mm macro lens. The number of ripe seeds (i.e., seed set) was calculated using the ImageJ/Fiji software as suggested by MacInnis and Forrest (2017). Nine strawberry buds were aborted or damaged, and these were excluded from the analysis.

2.5. Seed predation

Seed predation as an ES was characterised by removal rates of seeds of a common weed, dandelion (*Taraxacum officinale*), while characterising seed predation as an ED was by measuring the removal rates of wheat (*Triticum aestivum*) seeds. Although in some cases, we noticed fragments of seeds remaining, and cannot be sure about the fate of seeds that disappeared, we considered all missing seeds as seed predation events. Seeds were offered in 15 cm x 15 cm x 6 cm or 15 cm x 15 cm x 9 cm plastic containers on whose two opposite sides a 5 cm x 7 cm opening was cut to allow seed predators to enter the box (Linabury et al., 2019). In order to separately measure removal rates by vertebrates vs. invertebrates, the opening on half of the boxes were covered with a 1 cm x 1 cm hard plastic mesh to exclude vertebrates (vertebrate exclusion treatment), while on the other half of the boxes, the openings were left open, allowing access by all seed predators. The box was covered with a lid to protect the seeds from rain and birds. Each box contained 50 seeds in a 10 x 5 pattern, fixed to the bottom with double-faced sticky tape. After arranging the seeds, sifted soil was sprinkled on the surface to allow predators to access the seeds without being stuck on the sticky tape. At each site, we set up three groups of four boxes (invertebrate access only, with either wheat or dandelion seeds; all access by all seed predators, also with wheat or dandelion seeds), arranged ad hoc at the corners of a 1 m x 1 m area. Each group was placed > 15 m from the next one at no more than 2 m from a tree. We used 36 boxes each in the orchards and vineyards, exposing a total of 1800 wheat and 1800 dandelion seeds. After 48 h, boxes were collected and the number of

missing or damaged seeds was recorded. One wheat exclusion and a single dandelion open box were damaged and these were excluded from the analysis.

2.6. Decomposition

The intensity of decomposition was measured by the tea bag test (Keuskamp et al., 2013). All bags were numbered and weighed (KERN MRS 120–3, 0.001 g). In each habitat, five pairs of tea and rooibos bags were dug into the soil ca. 10 cm deep at no more than 2 m from a tree. Each pair was placed at ~15 m from each other. After 90 days, all bags were collected, dried in an oven at 55 °C for at least 48 h, and their organic and synthetic portions were weighed separately. We calculated the organic mass (g) which had decomposed after 90 days (D) as follows:

$$D = T_0 - I_0 - T_1$$

Where T_0 is the original tea/rooibos mass, I_0 is the mass of the synthetic part of the teabags (average mass of the bag, string, and label, measured after cleaning five tea and five rooibos bags), and T_1 is the tea/rooibos mass remaining after 90 days. Two tea (in one vineyard and one orchard) and one rooibos bag (in one orchard) were severely damaged and were excluded from the analysis.

2.7. Statistical analysis

All analyses were performed using the R software (R Core Team, 2020) through RStudio (R Studio Team, 2018). The effect of specific environmental factors on each ecological process was analysed using (LMMs) linear mixed models, (GLMs) generalised linear models, or (GLMMs) generalised linear mixed models (see specific paragraphs for details). Model selection was carried out by comparing Akaike Information Criterion (AIC) values (Akaike, 1998) and model validation by visually assessing the model residuals (Zuur et al., 2013).

2.7.1. Herbivory

Herbivory rates in vineyards and orchards were compared using a LMM where the % of damage on each leaf was the response, and plant ID and the site were included as random factors.

2.7.2. Predation

Overall, vertebrate, and invertebrate predation rates in vineyards and orchards during flowering and late flowering/fructification were compared using three separate GLMs with binomial distribution and logit link function, where the response was the fate (attacked/not attacked) of the individual caterpillars.

2.7.3. Pollination

To account for the lack of control in the orchards, we evaluated the effect of the investigated variables in two models. In the first model, we compared the seed sets between the two habitats considering only open cages, and included plant ID and the site as random factors. In the second model, we compared the seed sets between the two treatments (open vs. exclusion) and different vineyard sites only using a LMM with Gaussian distribution and plant ID as a random factor. In both models, the response variable was log-transformed to meet normality.

2.7.4. Seed predation

Seed predation rates were compared using a GLMM with binomial distribution and cloglog link function to account for the high frequency of zeroes. The individual fate of each seed (attacked/not attacked) was the response with seed box ID as a random factor, and the seed species and the treatment (all access vs. invertebrate only) as fixed factors in the model. We also tested the fate of each seed box (attacked/not attacked, irrespectively of the number of seeds consumed) in a GLM with binomial distribution and logit link function where the seed species and the

treatment were factors.

2.7.5. Decomposition

Mass loss in vineyards and orchards were compared using a LMM where the decomposed mass was the response, the interaction between habitat type and bag type (tea vs. rooibos) was a fixed component, and the site a random component of the model.

3. Results

3.1. Herbivory

We could not assign leaf surface loss to any particular herbivore group, but from the shape of leaf consumption and traces of mucus on plants, snails and slugs were responsible for most of the leaf loss in the citrus orchards. No similar traces were observed in the vineyards. Herbivory rates after 2 weeks were significantly higher ($p = 0.016$, LMM) in citrus orchards (mean = 3.6%, SD = 2.9%, $n = 17$) than in vineyards (mean = 0.5%, SD = 0.6%, $n = 17$).

3.2. Predation

The daily predation rates (d^{-1}) ranged between 2.2% d^{-1} and 5.5% d^{-1} in the vineyards (mean = 4.3% d^{-1} , SD = 14.1% d^{-1} , $n = 426$), and was 1.0% d^{-1} - 5.8% d^{-1} in the orchards (mean = 3.1% d^{-1} , SD = 12.0% d^{-1} , $n = 587$); these were not statistically different ($p = 0.070$, GLM). There were no significant differences ($p = 0.407$, GLM) between predation rates during (mean = 4.0% d^{-1} , SD = 13.5% d^{-1} , $n = 480$) or after flowering (mean = 3.3% d^{-1} , SD = 12.4% d^{-1} , $n = 533$). Most attacks were assigned to birds (76.7% of the total attacks), followed by invertebrates (15.1%), and rodents (8.2%). Multiple attacks by different predators on the same caterpillar were not found.

Vertebrate predation rates were significantly higher ($p = 0.037$, GLM) in vineyards (mean = 4.0% d^{-1} , SD = 13.6% d^{-1} , $n = 426$) than in citrus orchards (mean = 2.4% d^{-1} , SD = 10.7% d^{-1} , $n = 587$), but did not significantly differ during (mean = 3.3% d^{-1} , SD = 12.5% d^{-1} , $n = 480$) and after flowering (mean = 2.8% d^{-1} , SD = 11.5% d^{-1} , $n = 533$). Invertebrate predation rates were lower in the vineyards (mean = 0.4% d^{-1} , SD = 4.2% d^{-1} , $n = 426$) than in the citrus orchards (mean = 0.7% d^{-1} , SD = 5.8% d^{-1} , $n = 587$), and during (mean = 0.6% d^{-1} , SD = 5.6% d^{-1} , $n = 480$) than after flowering (mean = 0.5% d^{-1} , SD = 4.8% d^{-1} , $n = 533$); no significant differences were detected. The best models are listed in Table A2.

3.3. Pollination

The seed set of plants accessible to pollinators was significantly ($p = 0.004$, LMM) higher in vineyards (mean = 214.5 seeds/fruit, SD = 23.9 seeds/fruit, $n = 9$) than in citrus orchards (mean = 162.0 seeds/fruit, SD = 14.7 seeds/fruit, $n = 9$). In vineyards, there were no significant differences in the seed sets either between open and exclusion cages or between sites (Fig. 1; $p = 0.828$, LMM).

3.4. Seed predation

Seed predation was patchy and 82.9% of the seed boxes showed no signs of predator activity 48 h after settlement (Table 1). Seed predation rates were higher in citrus orchards (mean = 2.0% d^{-1} , SD = 5.8% d^{-1} , $n = 34$) than in vineyards (mean = 0.3% d^{-1} , SD = 0.8% d^{-1} , $n = 36$), and on dandelion (mean = 1.3% d^{-1} , SD = 5.1% d^{-1} , $n = 35$) than on wheat seeds (mean = 0.9% d^{-1} , SD = 2.8% d^{-1} , $n = 35$); neither habitat type nor seed species significantly affected seed predation. Seed predation on open boxes (mean = 2.2% d^{-1} , SD = 5.7% d^{-1} , $n = 35$) was higher, although non-significantly ($p = 0.065$, GLMM, Fig. 2), than on exclusion ones (mean = 0.1% d^{-1} , SD = 0.3% d^{-1} , $n = 35$).

The number of seed boxes attacked after 48 h was higher, although

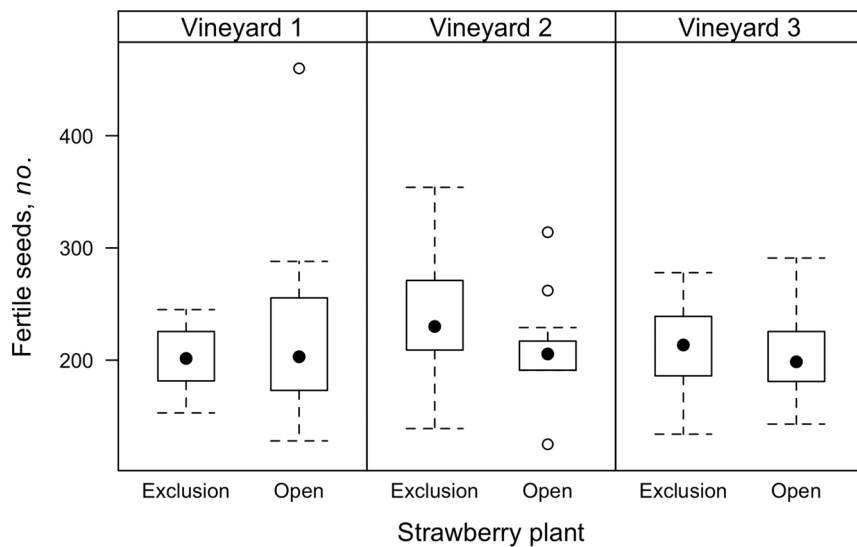


Fig. 1. Number of fertile seeds in strawberry plants accessible (open) or inaccessible to pollinators (exclusion) in vineyards. The lower and the upper side of the box indicate the upper and lower quartiles, respectively, the whiskers extend to 1.5 x the interquartile range, and the black dot corresponds to the median.

Table 1

Number of seed boxes and predation rates after 48 h for each treatment (wheat open and exclusion, dandelion open and exclusion).

Treatment	No. boxes	No. boxes with attack	Mean no. seeds removed after 48 h
Wheat seeds, open	9	6	0.1
Wheat seeds, vertebrate exclusion	8	1	1.7
<i>Taraxacum</i> seeds, open	8	5	2.7
<i>Taraxacum</i> seeds, vertebrate exclusion	9	0	0

3.5. Decomposition

On average, after 90 days tea and rooibos bags exposed in vineyards lost 63.4% and 34.9% of their original mass, respectively. The mass loss in orchards was 74.2% and 37.8%, respectively. Mass loss was significantly higher ($p < 0.001$, lsmeans) on tea than on rooibos bags, both in vineyards ($\text{mean}_{\text{tea}} = 1.15 \text{ g}$, $\text{SD}_{\text{tea}} = 0.11 \text{ g}$, $n_{\text{tea}} = 14$ vs. $\text{mean}_{\text{roo}} = 0.72 \text{ g}$, $\text{SD}_{\text{roo}} = 0.16 \text{ g}$, $n_{\text{roo}} = 15$) and in citrus orchards ($\text{mean}_{\text{tea}} = 1.34 \text{ g}$, $\text{SD}_{\text{tea}} = 0.06 \text{ g}$, $n_{\text{tea}} = 14$ vs. $\text{mean}_{\text{roo}} = 0.78 \text{ g}$, $\text{SD}_{\text{roo}} = 0.13 \text{ g}$, $n_{\text{roo}} = 14$). No significant differences were detected between the two habitats (Fig. 3).

4. Discussion

Although biodiversity measures cannot always be reliably used to estimate ecological processes, the majority of the scientific studies quantify ESs provided by arthropods using proxies (Noriega et al., 2018). We demonstrated the suitability of simple, direct monitoring tools based on the sentinel approach to quantify multiple ESs and EDs in

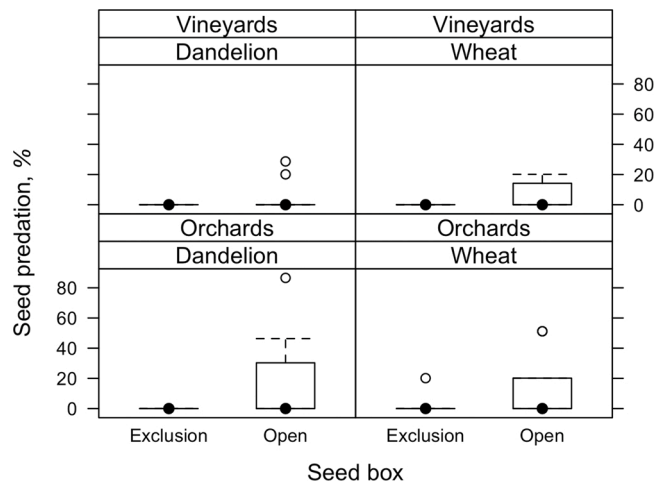


Fig. 2. Removal rates (after 48 h) of wheat and dandelion seeds in seed boxes accessible (open) or not accessible to vertebrates (exclusion) in citrus orchards and vineyards on Terceira Island. Data were transformed using the arcsine square root transformation. The lower and the upper side of the box indicate the upper and lower quartiles, respectively, the whiskers extend to 1.5x the interquartile range, and the black dot corresponds to the median.

non-significantly ($p = 0.5221$, GLM), on wheat (mean = 41.2%, SD = 50.2%, $n = 17$) than dandelion seeds (mean = 29.4%, SD = 47.0%, $n = 17$), and on the boxes with unlimited access (mean = 64.7%, SD = 49.3%, $n = 17$) than on the ones accessible only to invertebrates (mean = 5.9%, SD = 24.3%, $n = 17$; $p = 0.003$, GLM).

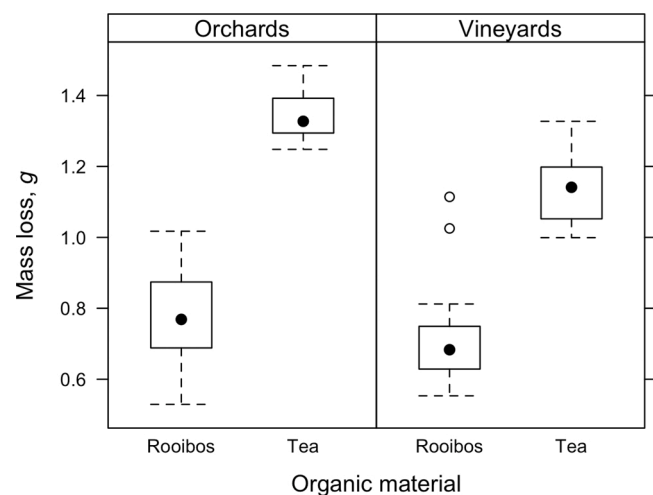


Fig. 3. Organic mass decomposed after 90 days in orchards and vineyards. The lower and the upper side of the box indicate the upper and lower quartiles, respectively, the whiskers extend to 1.5 x the interquartile range, and the black dot corresponds to the median.

two cultivated habitats. These tools can be complemented by assessing ES/ED provider abundance or diversity, but when ESs and EDs are the focus, such monitoring methodologies do not necessarily provide sufficient information.

According to our hypothesis, levels of herbivory were significantly higher in the orchards than in the vineyards, and structural differences between them could explain our results. In Terceira Island, citrus orchards are polycultural habitats with a complex horizontal and vertical structure that favours several invertebrates, some of which provide EDs such as herbivory. Slugs and snails were abundant in the dense undergrowth of the orchards, as it provides favourable microclimatic conditions. Azorean vineyards, on the contrary, form a special habitat with low plant diversity and very sparse ground cover. This characteristic makes such habitat less suitable for invertebrates, especially those with poor dispersal abilities.

Despite their remarkable structural differences, and contrarily to our hypothesis, Azorean vineyards and citrus orchards had comparable levels of overall and invertebrate predation. The overall predation rates on sentinel prey in these two agro-ecosystems were lower than the rates recorded at ground level in other temperate agro-ecosystems (Ferrante et al., 2019; González et al., 2020; Mansion-Vaquíe et al., 2017; Meyer et al., 2019). However, contrary to the above-mentioned studies where insect predators were dominant, in the Azores, attacks were mostly due to birds, while arthropod marks accounted for only 15% of the attacks. This result might reflect the low number of species and/or abundance of large predatory beetles (e.g. Carabidae and Staphylinidae), which is characteristic of oceanic islands (Borges and Hortal, 2009). Only six carabid species (of which four rare species) have been detected in Azorean orchards, and only two carabid species in vineyards (Borges et al., 2021). However, this can also be a consequence of the extinction of large-bodied native species at lower elevations (Terzopoulou et al., 2015). Nonetheless, while artificial caterpillars are suitable to monitor the activity of several predatory groups (Lövei and Ferrante, 2017), spider and parasitoid marks are only rarely recorded by this method. Therefore, the low arthropod predation rates recorded do not necessarily indicate lack of arthropod predation. The higher predation rates recorded in vineyards could have been caused by the higher contrast of the green caterpillars against the black vineyard soil, as background contrast remarkably affects the detectability of the prey (Ferrante et al., 2017).

Although on Terceira Island orchards have high abundance and species richness of pollinators, similar to those in the native forest (Picanço et al., 2017), we found higher levels of pollination in the vineyards. The non-significant differences between the seed sets in plants accessible and inaccessible to pollinators suggest that sentinel strawberry plants in this agroecosystem had high levels of self-pollination, possibly because vineyards are closer to the coast and more exposed to the strong maritime winds.

These results seem to contradict the idea that diversified agro-ecosystems (such as mixed orchards) support high levels of ES provisioning (Lichtenberg et al., 2017). However, they are consistent with the observation that landscape complexity does not always support ESs, biodiversity, and multifunctionality (Birkhofer et al., 2018).

The extremely low seed predation rates recorded, especially by invertebrates, were probably due to the fact that on Terceira Island, the peak of activity of granivorous ground beetles such as *Pseudophonus rufipes* and *Amara aenea* occur in the summer (Borges, 1995), while our study was restricted to the spring period. Nonetheless, our results are comparable to the predation rates on dandelion seeds recorded in orchards (Honěk et al., 2005) and oilseed rape fields (González et al., 2020) in the Czech Republic in spring. Surprisingly, predation rates on wheat seeds (an ED), which can be mainly attributed to rodents, was very low. These data, together with the few rodent attacks on the artificial caterpillars, suggest that rodents were not very abundant in vineyards and citrus orchards and this is consistent with camera-trap records obtained from vineyards within the same area (Lamelas-López

and Ferrante, 2021). Given the scarcity of food and the presence of predators (particularly mustelids and cats), vineyards might be unsuitable habitats for rodents (Lamelas-López and Ferrante, 2021). In habitats rich in alternative resources (fruits, stored seeds, food waste, pet food), the exposed seeds may be less attractive for rodents than in resource-poor habitats. This may have been the case for both vineyards and citrus orchards, which were located near urban areas, where abundant alternative resources could be found. Box-traps often underestimate the activity of rodents in urban areas compared to data obtained by baited camera-trap stations (Stokes, 2013). Ultimately, the similar predation rates found on wheat and dandelion seeds might indicate that the same agro-ecosystem characteristics that support ESs could also favour EDs (Campagne et al., 2018).

Contrarily to our hypothesis, we found similar decomposition levels in the two agro-ecosystems. The higher decomposition levels on green tea than on rooibos reflect their compositional difference and are consistent with other studies (Houben et al., 2018). Our records are about double of the average of ~37% and ~14% mass loss observed for tea and rooibos bags in winter wheat fields in northern France (Houben et al., 2018), and the ~63% and ~21% observed in peatlands in Canada (MacDonald et al., 2018). Collectively, these confirm the importance of temperature and precipitation in the decomposition process. However, it must be noted that tea and rooibos bag tests overlook the effect of macrofauna, and that the true decomposition levels are likely to be even higher than what we recorded.

Ours is the first study to use a consistent methodology for a complex ES/ED assessment. We showed that the same habitat characteristics can support several ESs and EDs and deduce that an effective management of agro-ecosystems should rely on evaluating multiple ESs and EDs simultaneously (Rieb et al., 2017). We contend that sentinels can be used to assess multiple ecological processes and permit a quantification of several ESs and EDs in a standardised and comparable way.

Future work must seek to assess, for all relevant ecosystem processes, the resulting ESs and EDs in a symmetrical way. In this study, we only assessed seed removal in these two contexts: as an ES (weed seeds predated) or an ED (wheat seeds predated). There could be similar two-faced assessments for several other ecosystem processes. For example, herbivory on a crop is an ED but the same on a weed could legitimately be considered an ES. Pollination is likewise a two-faced process. We need more of similar assessments to reduce the scarcity of data on EDs in most agro-ecosystems. Although this is not possible for ecosystem processes that supply only services (e.g. decomposition), a symmetrical assessment of ESs/EDs may help to determine whether specific ecosystem processes are likely to provide services or disservices.

Finally, we sound a warning that a complex assessment of ESs vs. EDs is not a simple arithmetical procedure, as primitive econometric analysis would suggest. Environmental value cannot and should not solely be measured in monetary terms (Lövei, 2015), and we need to articulate the value of ESs in more sophisticated terms. We need to move cautiously because, as stressed by Sandel (2013), there are things that money cannot buy.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authorship is by the “first-and-last-author-emphasis” (FLAE) principle. The last two authors contributed equally to the paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.agee.2022.107909](https://doi.org/10.1016/j.agee.2022.107909).

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